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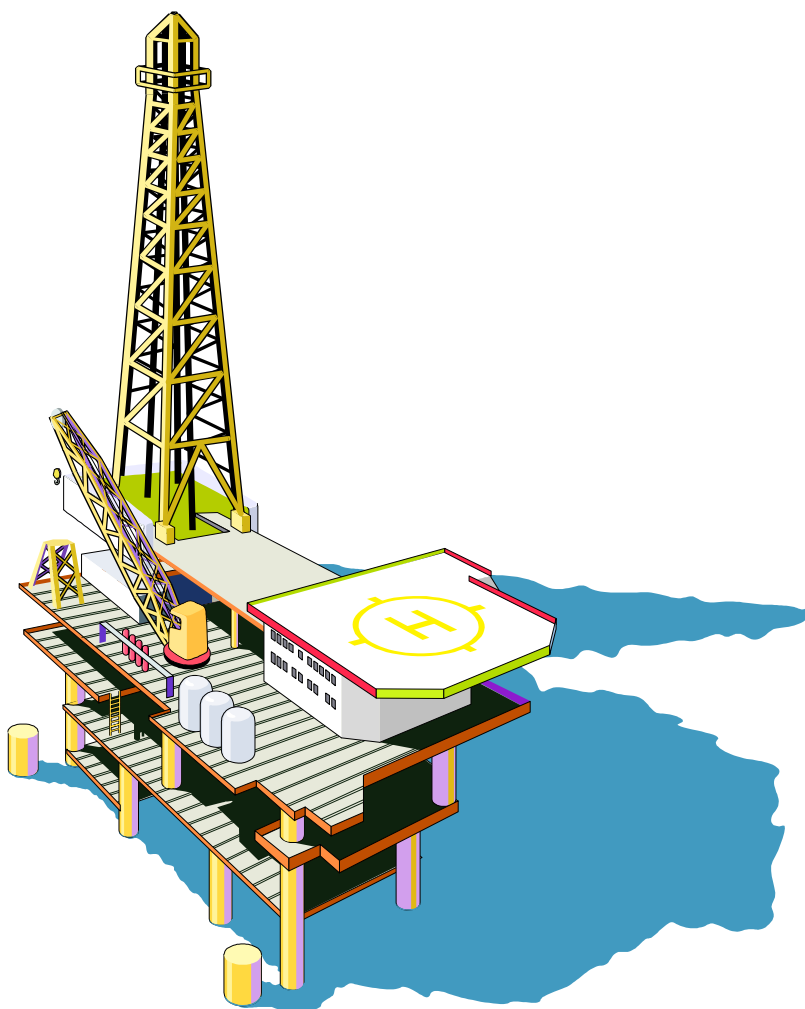
Environmental Assessment of Proposed Effluent Limitations Guidelines and Standards for Synthetic-Based Drilling Fluids and other Non-Aqueous Drilling Fluids in the Oil and Gas Extraction Point Source Category

ENVIRONMENTAL ASSESSMENT
OF
PROPOSED EFFLUENT LIMITATIONS GUIDELINES AND
STANDARDS FOR SYNTHETIC-BASED DRILLING FLUIDS AND
OTHER NON-AQUEOUS DRILLING FLUIDS IN THE
OIL AND GAS EXTRACTION POINT SOURCE CATEGORY

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Office of Science and Technology
Engineering and Analysis Division
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EXHIBITS

EXECUTIVE SUMMARY

A.   Background

This environmental assessment consists of an evaluation of the ecological and indirect human health impacts for the discharge of cuttings contaminated with synthetic-based drilling fluids (SBFs) with respect to discharges to water. In addition, this document describes the environmental characteristics of SBF drilling wastes (e.g., toxicity, bioaccumulation, biodegradation), the types of anticipated impacts, and the pollutant modeling results for water column concentrations, pore water concentrations, and human health effects via consumption of affected seafood. This document does not consider the potential non-water quality environmental effects associated with the proposed rule.

The geographic areas considered under this rule are those where EPA knows SBFs are currently used and those where EPA projects SBFs will be used as a result of the SBF Effluent Guidelines. This includes the Gulf of Mexico, offshore California, and Cook Inlet, Alaska. It is these three geographic areas where EPA projects that pollutant loadings will change as a result of the proposed rule and are included in the various environmental impact analyses of this environmental assessment.

EPA considered two regulatory options for the SBF rule: a discharge option and a zero discharge option. While discharge of SBF-cuttings would be allowed under the discharge option, discharge of SBFs not associated with drill cuttings would not be allowed. Since zero discharge of neat SBFs is also current industry practice due to the value of SBFs recovered and reused, it has no incremental environmental impact.

In the zero discharge option, both the SBF-cuttings as well as neat SBF would be prohibited from discharge. Because the zero discharge option results in the absence of discharged pollutants, the environmental assessment analyses did not require calculations to demonstrate zero environmental impacts.

For the purposes of this environmental assessment, EPA projected that the only material effect that the discharge option of the proposed SBF regulation would have on the SBF-cuttings wastestream would be to reduce the amount of synthetic base fluid on the drill cuttings from 11% to 7%. This reduction is based on the performance of the current shale shaker technology (11% base fluid retention), and the proposed BAT technology (7% base fluid retention). The model BAT technology consists of a vibrating centrifuge which recovers additional SBF from the SBF-cuttings. For the purpose of this environmental assessment, EPA does not project that the other proposed limitations, such as the stock base fluid limitations, would materially affect the discharge.

Thus, under the discharge option, the amount of pollutant discharge is reduced but the types of pollutants are not affected. Also, EPA projects that the number of wells using SBF will increase. In the Gulf of Mexico, EPA projects that under current requirements 113 SBF wells annually will be drilled in the Gulf of Mexico, while under the proposed SBF Effluent Guidelines 136 SBF wells will be drilled annually. Since all of the analyses, except for exposure by way of shrimp consumption, are on a site specific basis, the number of wells discharging does not affect the conclusions of this environmental assessment. Only the quantity and types of pollutants discharged at a particular site affect the conclusions (except shrimp consumption analysis).

In offshore California and Cook Inlet, Alaska, SBFs are not used under current requirements but EPA projects that the wells currently drilled with OBFs will convert to SBFs as a result of the SBF Effluent Guidelines. To show the effect of the model BAT technology, however, this environmental assessment determines "current technology" impacts in offshore California and Cook Inlet as if the wells projected to convert to SBF currently discharge SBF-cuttings at 11% base fluid retention. This is compared to the SBF-cuttings discharges projected to occur at 7% base fluid retention as a result of the proposed SBF rule.

The amount of pollutants discharged and impacting the receiving water depends on the efficiency of the solids control equipment, here expressed as either 11% or 7% retention on cuttings, and the volume of cuttings generated from drilling a given well or well interval. The volume of cuttings generated while drilling the SBF intervals of a well depends on the type of well (development or production) and the water depth. According to analyses of the model wells provided by industry representatives, wells drilled in less than 1,000 feet of water are estimated to generate 565 barrels of cuttings for a development well and 1,184 barrels of cuttings for an exploratory well. Wells drilled in water greater than 1,000 feet deep are estimated to generate 855 barrels of cuttings for a development well, and 1,901 cuttings for an exploratory well. These values assume 7.5 percent washout, based on the rule of thumb reported by industry representatives of 5 to 10 percent washout when drilling with SBF. Washout, that is, the caving in or sluffing off of the well bore, increases hole volume and increases the amount of cuttings generated when drilling a well.

EPA has adopted the Minerals Management Service (MMS) and industry categorization of drilling wells according to type of drilling operation, i.e., exploratory or development, and water depth. Deep water wells are defined as wells that are drilled in water greater than 1,000 feet deep whereas shallow water wells are drilled in water less than 1,000 feet deep. Using other federal and state government agency data, EPA determined the number of wells drilled annually using SBFs, OBFs, and water-based drilling fluids (WBFs).

B.   Water Quality Assessment

EPA based the methodologies for assessing both surface water and pore water quality impacts of SBF-cuttings on the methodologies used to assess the discharge of water-based fluids and cuttings (WBF-cuttings) for the offshore effluent limitations guidelines (ELG). In the current SBF-cuttings discharge impact analysis, surface water quality assessments rely on modeling data presented in a study of the post-discharge transport behavior of oil and solids from oil-based fluids cuttings (OBF-cuttings). Due to the similar hydrophobic and physical properties between SBFs and OBFs, EPA assumes that dispersion behavior of SBF-cuttings is similar to that of OBF-cuttings.

In general, the methodology consists of modeling incremental water column and pore water concentrations and comparing them to Federal water quality criteria/toxic values for marine acute, marine chronic, and human health protection. Additionally, EPA used the proposed sediment guidelines for protection of benthic organisms to assess potential impacts from a group of select metals in pore water. Note that all of these comparisons are performed only for those pollutants for which EPA has numeric criteria. Those pollutants include priority and nonconventional pollutants associated with the drilling fluid barite and with contamination by formation (crude) oil, but do *not* include synthetic base fluids themselves.

Surface Water Quality

Results of the water quality analyses for the Gulf of Mexico, offshore California, and Cook Inlet show that there are no exceedances of Federal water quality criteria in either the current technology (11% retention) or discharge option (7% retention) scenarios.

Pore Water Quality

EPA calculated sediment pollutant levels based on the assumption of a uniform distribution of the mass loadings of pollutants from model operations into a defined area of impact.

To assess the pore water quality impacts of the discharge of SBF-cuttings on the benthic environment, EPA projected the pollutant concentrations in the pore water for the model wells under the two discharge scenarios at the edge of a 100-meter mixing zone. EPA then compared these projected pore water concentrations of pollutants from the SBF-cuttings to Federal water quality criteria to determine the number of exceedances and the magnitude of each exceedance. Exhibit ES-1 presents a summary of the pore water quality analyses where exceedances are expressed as multiplied factors of the Federal water quality criteria. Compared to current technology, the projected number and magnitude of water quality criteria exceedances decreases under the discharge option.

An additional method for assessing potential benthic impacts of certain metals is EPA's proposed sediment guidelines for the protection of benthic organisms. These proposed guidelines are based on an equilibrium partitioning (EqP) approach to determine guidelines based on "numerical concentrations for individual chemicals that are applicable across the range of sediments encountered in practice." The EqP sediment guidelines (ESG) for the six metals -- copper, cadmium, nickel, lead, silver, and zinc -- account for the additive toxicity effects of these metals. For this environmental assessment, the measured interstitial water [i.e., pore water] concentrations of the metals are compared to water quality criteria final chronic values (FCVs). The sum of the interstitial water concentration:FCV ratios for the six metals is calculated for each of the model wells. The guideline is met if this sum is less than or equal to one.

In the Gulf of Mexico, all four model wells fail to meet the sediment guidelines using the current technology, with concentration:FCV ratios ranging from 1.2 to 3.9 for the six-metal composite (see Table ES-1). Under the discharge option, the development model wells meet the guideline. While the exploratory model wells do not meet the guideline under the discharge option, the projected pollutant pore water concentrations are 43 percent lower compared to those projected for the current industry practice. For Cook Inlet, Alaska and offshore California, the deep and shallow development model wells pass the guidelines using both the current technology and the discharge option technology. EPA does not anticipate that exploratory wells will be drilled in Cook Inlet and offshore California.

C. Human Health Effects

This portion of the environmental analysis presents the human health-related risks and risk reductions (benefits) of current technology and the discharge and zero discharge regulatory options. EPA based the health risks and benefits analysis on human exposure to carcinogenic and noncarcinogenic contaminants through consumption of affected seafood; specifically, recreationally-caught finfish and commercially-caught shrimp. EPA used seafood consumption and lifetime exposure duration assumptions to estimate risks and benefits under the current technology (11% retention) and discharge option (7% retention) scenarios for the three geographic areas where the quantities of SBF-cuttings discharged will be affected by this rule. The analysis is performed only for those contaminants for which bioconcentration factors, oral reference doses (RfDs), or oral slope factors for carcinogenic risks have been established. Thus, the analysis considers contaminants associated with the drilling fluid barite and with contamination by formation (crude) oil, but does not consider the synthetic base compounds themselves.

In order to derive the risks due to consumption of contaminated seafood, EPA first determined the concentration of contaminants in finfish and shrimp tissues. Finfish tissue contamination is affected by the level of contamination of water column, whereas, shrimp tissue contamination is dependent on the level of contamination of sediment pore water.

Exhibit ES-1. Summary of Pore Water Quality Analyses (a, b)
[Exceedance Factor Over Federal Water Quality Criteria (c)]

Discharge Region	Pollutant	Shallow Water				Deep Water			
		Development		Exploratory		Development		Exploratory	
		Current Tech-nology	Discharge Option	Current Tech-nology	Discharge Option	Current Tech-nology	Discharge Option	Current Tech-nology	Discharge Option
Gulf of Mexico	Arsenic	1.3	-- (d)	2.7	--	1.9	1.1	4.3	2.5
	Chromium	--	--	1.7	--	1.3	--	2.8	1.6
	Mercury	--	--	--	--	--	--	1.2	--
	Lead	--	--	--	--	--	--	1.5	--
	Nickel	--	--	--	--	--	--	1.2	--
	Metals Composite (e)	1.1	--	2.3	1.3	1.7	--	3.7	2.1
Cook Inlet, Alaska	Arsenic	--	--	NA (f)	NA	NA	NA	NA	NA
	Metals Composite (e)	--	--	NA	NA	NA	NA	NA	NA
Offshore California	Arsenic	--	--	NA	NA	1.2	--	NA	NA
	Metals Composite (e)	--	--	NA	NA	1.1	--	NA	NA

(a)   Subsequent to finalization of the analyses contained in this document, EPA published revised water quality criteria (63 FR 68354, December 10, 1998). The following changes affect this Environmental Assessment water quality analyses and will be reflected in the final rule: arsenic human health criterion is deleted; copper acute criterion is raised to 4.8 ug/l and copper chronic criterion is raised to 3.1 ug/l; mercury chronic criterion is raised to 0.94 ug/l and mercury human health is reduced to 0.051 ug/l; and phenol human health criterion is deleted. Appendix B contains the December 1998 criteria recommendations and an analysis of how the water quality assessment would change using these revised criteria. **In summary, with the new criteria, the arsenic and mercury exceedances are eliminated.**
(b)   There would be no exceedances for any pollutants with the zero discharge option.
(c)   Values refer to the exceedance factor for the projected pollutant concentration compared to the Federal water quality criteria; a value of 1.0, for example, indicates a pollutant concentration equal to the water quality criteria.
(d)   -- indicates that no exceedances are predicted.
(e)   Metals composite includes cadmium, copper, lead, nickel, silver, and zinc.
(f)   NA indicates that type of model well does not currently exist or is not projected for that geographic region.

Recreational Finfish Fisheries

Exposure of recreational finfish to drilling fluid contaminants occurs through the uptake of dissolved pollutants found in the water column. Instead of using the water column pollutant concentrations at the edge of the mixing zone (as for the water quality analyses), EPA calculates an average water column concentration of each pollutant for the area *within* a 100-m radius of the discharge. For the exposure of finfish within the 100-m mixing zone, the effective exposure

concentration is the exposure concentration adjusted by the volumetric proportion of the total water column that contains the discharge plume. The effective exposure concentration of each pollutant is multiplied by the exposure proportion and by a pollutant-specific bioconcentration factor (BCF) to yield the tissue concentration of each pollutant in finfish on a mg/kg basis.

The concentration of pollutants in finfish tissue is used to calculate the risk of noncarcinogenic and carcinogenic (arsenic only) risk from ingestion of recreationally-caught fish. For this analysis, the 99th percentile intake rate of 177 g/day (uncooked basis) is used as the exposure for high-end seafood consumers in the general adult population (SAIC, 1998). This analysis is a worst case scenario because the seafood consumed is assumed to consist only of contaminated finfish.

For noncarcinogenic risk evaluation, the tissue pollutant concentration (mg/kg) is multiplied by the consumption rate (mg/kg/day) for a 70 kg individual. This value is compared to the oral reference dose (RfD) to determine the hazard quotient for each pollutant. If the hazard quotient is less than or equal to one, toxic effects are considered unlikely to occur.

To calculate the carcinogenic risks, the slope factor as provided by the EPA Integrated Risk Information System database (IRIS) is used to estimate the lifetime excess cancer risk that could occur from ingestion of contaminated seafood. For this analysis, only arsenic has a slope factor available for estimation of the lifetime excess cancer risk. For purposes of this assessment, EPA considers a risk level of 1×10^{-6} to be acceptable.

Exhibit ES-2 presents a summary of the health risks from ingestion of recreationally-caught finfish from around SBF-cuttings discharges under current technology and the discharge option. Although current practice in Cook Inlet, Alaska and offshore California is zero discharge of SBF-cuttings, the current technology analysis is presented for comparison purposes. Numerically, the hazard quotients and lifetime excess cancer risks decrease by 31 percent under the discharge option as compared to current technology. However, in both current technology and discharge option scenarios, the hazard quotients are several orders of magnitude less than 1, so toxic effects are not predicted to occur. Also, the lifetime excess cancer risks for both current technology and discharge option are less than 10^{-6} and are, therefore, considered by EPA acceptable for either of these scenarios.

Commercial Shrimp Fisheries

EPA based projected shrimp tissue concentrations of pollutants from SBF discharges on the uptake of pollutants from sediment pore water. The pore water pollutant concentrations are based on the assumption of even distribution of the total annual SBF discharge over an area of impact surrounding the model well.

Exhibit ES-2. Summary of Finfish Health Risks

Pollutant	Gulf of Mexico		Cook Inlet, Alaska		Offshore California	
	Current Technology	Discharge Option	Current Technology	Discharge Option	Current Technology	Discharge Option
99th Percentile Hazard Quotient (a, b)						
Naphthalene	3.85e-05	2.67e-05	3.91e-05	2.71e-05	3.72e-06	2.58e-06
Fluorene	7.39e-07	5.12e-07	7.50e-07	5.20e-07	7.14e-08	4.95e-07
Phenol	3.60e-13	3.60e-13	3.66e-13	3.66e-13	3.48e-14	3.48e-14
Cadmium	1.86e-06	1.29e-06	1.88e-06	1.31e-06	1.79e-07	1.24e-07
Mercury	7.90e-06	5.50e-06	8.02e-06	5.59e-06	7.63e-07	5.32e-07
Antimony	3.41e-06	2.37e-06	3.46e-06	2.40e-06	3.30e-07	2.29e-07
Arsenic	1.25e-06	8.65e-07	1.27e-06	8.77e-07	1.21e-07	8.35e-08
Chromium	1.04e-05	7.23e-06	1.06e-05	7.33e-06	1.01e-06	6.98e-07
Nickel	3.27e-07	2.27e-07	3.32e-07	2.30e-07	3.16e-08	2.19e-08
Selenium	2.53e-07	1.75e-07	2.57e-07	1.78e-07	2.45e-08	1.69e-08
Silver	1.68e-08	1.16e-08	1.70e-08	1.18e-08	1.62e-09	1.12e-09
Thallium	4.17e-04	2.89e-04	4.23e-04	2.93e-04	4.03e-05	2.79e-05
Zinc	3.09e-08	2.14e-08	3.13e-08	2.17e-08	2.98e-09	2.07e-09
Lifetime Excess Cancer Risk (c, d)						
Arsenic 30-yr exposure 70-yr exposure	2.41e-10 5.61e-10	1.67e-10 3.89e-10	2.44e-10 5.70e-10	1.69e-10 3.95e-10	2.32e-11 5.42e-12	1.61e-11 3.76e-12

(a)   Only pollutants for which there is an oral RfD are presented in this summary table.
(b)   None of the hazard quotients exceed 1. Therefore, toxic effects are not predicted to occur.
(c)   Only pollutants for which there is a slope factor are presented in this summary table.
(d)   The lifetime excess cancer risks are less than 10^{-6} and are, therefore, acceptable.

        To calculate the noncarcinogenic and carcinogenic health risks for commercial shrimp, the methodology is the same as that used for recreational finfish. However, instead of calculating an effective exposure concentration that describes the portion of the water affected within the mixing zone, the exposure is adjusted by the amount of the total commercial shrimp catch affected. This is estimated by prorating the total potential exposure (total catch) by the portion of the total shrimp catch affected by the well type being analyzed. The shrimp catch is assumed to occur evenly over the area occupied by the species harvested. Only shallow water model wells are used in this assessment due to the limited shrimp harvesting that occurs in water depths greater than 1,000 feet. Health risks for commercial shrimp were not performed for the Cook Inlet, Alaska geographic area because shrimp are not harvested commercially in that area.

Exhibit ES-3 presents a summary of the health risks from ingestion of commercially-caught shrimp. For both current technology and discharge option, the hazard quotients are several orders of magnitude less than 1, so toxic effects are not predicted to occur under either scenario. Also, all of the lifetime excess cancer risks for both current technology and discharge option are less than 10^{-6} and are, therefore, acceptable under either scenario.

D.   Toxicity

EPA has reviewed information concerning the determination of toxicity to the receiving environment of SBFs and SBF base fluids. This information includes data generated for toxicity requirements imposed on North Sea operators as well as experimental testing conducted by the oil and gas industry in the United States. Because the synthetic base fluids are water insoluble and the SBFs do not disperse in water as water-based drilling fluids (WBFs) do, but rather tend to sink to the bottom with little dispersion, most research has focused on determining toxicity in the sedimentary phase as opposed to the aqueous phase.

SBFs have routinely been tested using an aqueous phase test to measure toxicity of the suspended particulate phase (SPP) (the SPP toxicity test) and found to have low toxicity. However, recently presented data from an interlaboratory variability study indicates that the SPP toxicity results are highly variable when applied to SBFs, with a coefficient of variation of 65.1 percent. Variability reportedly depended on such things as mixing times and the shape and size of the SPP preparation containers.

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

Although there are data available on the toxicity of both SBFs and SBF base fluids from the North Sea and United States, the information is insufficient to draw meaningful conclusions other than broad generalizations. Also, little is known about the influence of organics in the sediment on the toxicity of these fluids, be it a natural or a formulated sediment. However, with the limited data, several assumption can be made.

(1)   North Sea amphipods appear to be less sensitive to synthetic base fluids than those amphipods currently used in US testing.

Exhibit ES-3. Summary of Shrimp Health Risks

| Pollutant | Gulf of Mexico | | | | Offshore California | |
| | Development | | Exploratory | | | |
	Current Technology	Discharge Option	Current Technology	Discharge Option	Current Technology	Discharge Option
99th Percentile Hazard Quotient (a)						
Naphthalene	4.71e-06	5.83e-05	5.44e-06	6.51e-06	2.08e-08	1.19e-08
Fluorene	4.64e-08	5.70e-08	5.35e-08	6.43e-08	2.05e-10	1.17e-10
Phenol	5.28e-12	6.53e-12	6.12e-12	7.32e-12	2.34e-14	1.34e-14
Cadmium	2.59e-06	3.19e-06	3.00e-06	3.60e-06	1.15e-08	6.54e-09
Mercury	1.10e-05	1.36e-05	1.28e-07	1.54e-05	4.89e-08	2.79e-08
Antimony	4.78e-06	5.91e-06	5.52e-06	6.62e-06	2.11e-08	1.21e-08
Arsenic	1.74e-06	2.16e-06	2.02e-06	2.42e-06	7.70e-09	4.42e-09
Chromium	1.46e-05	1.80e-05	1.69e-05	2.02e-05	6.44e-08	3.68e-08
Nickel	4.57e-07	5.64e-07	5.28e-07	6.34e-07	2.02e-09	1.16e-09
Selenium	3.54e-07	4.35e-07	4.10e-07	4.92e-07	1.56e-09	8.92e-10
Silver	2.34e-08	2.89e-08	2.72e-08	3.25e-08	1.04e-10	5.93e-11
Thallium	5.83e-04	7.21e-04	6.77e-04	8.09e-04	2.58e-06	1.48e-06
Zinc	4.32e-08	5.33e-08	4.99e-08	6.01e-08	1.91e-10	1.09e-10
Lifetime Excess Cancer Risk (b)						
Arsenic 30-yr exposure	3.36e-10	4.16e-10	3.89e-10	4.67e-10	1.49e-12	8.52e-13
70-yr exposure	7.84e-10	9.70e-10	9.08e-10	1.09e-10	3.47e-12	1.99e-12

(a)   Only pollutants for which there is an oral RfD are presented in this summary table.
(b)   Only pollutants for which there is a slope factor are presented in this summary table.

(2)   When comparing SBFs and OBFs, base fluid toxicity appears to show greater discriminatory power than does drilling fluid toxicity.
(3)   Discriminatory power seems to be diminished with the use of formulated sediments.
(4)   Mysid SPP testing does not seem to give meaningful results for SBFs.

    Because data are limited, EPA and industry are continuing to gather information on sediment toxicity through ongoing research. Industry is currently evaluating sediment test methods, using formulated sediments and species sensitivities. EPA is beginning research on the toxicity of synthetic base fluids and the factors that influence the toxicity of SBFs (as well as the

biodegradation and bioaccumulation of synthetic base fluids). The goal of this EPA research is to restore discriminatory power to discern the differences in toxicity between diesel oil, mineral oil, and synthetic base fluids. Because the current, examined amphipod test species are not indicating sufficient discriminatory power, EPA may further consider using other test organisms, such as polychaetes.

E.   Bioaccumulation

EPA reviewed several studies on the bioaccumulation potential of synthetic base fluids. The available information is scant, comprising only a few studies on octanol:water partition coefficients (P_{ow}) and two on tissue uptake in experimental exposures [only one of which derived a bioconcentration factor (BCF)]. The P_{ow} represents the ratio of a material present in the oil phase, i.e., in octanol versus the water phase. The P_{ow} generally increases as a molecule becomes less polar (more hydrocarbon-like). The available information on the bioaccumulation potential of synthetic base fluids covers only three types of synthetics: an ester (one studies), internal olefins (IO; three studies), and poly alpha olefins (PAO; four studies). One study included a low toxicity mineral oil (LTMO) for comparative purposes. This limitation with respect to the types of synthetic base fluids tested is partially mitigated by the fact that these materials represent the more common base fluids currently in use in drilling operations.

For PAOs, the log P_{ow}s reported were >10, 11.9, 14.9, 15.4, and 15.7 in the four studies reviewed. The three studies of IOs that were reviewed reported log P_{ow}s of 8.57 and >9. The ester was reported to have a log P_{ow} of 1.69 in the one report in which it was tested. A log P_{ow} of 15.4 was reported for an LTMO. The only BCF reported was calculated for IOs; a value of 5.4 was determined. In 30-day exposures of mud minnows (*Fundulus grandis*) to water equilibrated with a PAO- or LTMO-coated cuttings, only the LTMO was reported to produce adverse effects and tissue uptake/occurrence. Growth retardation was observed for the LTMO and LTMO was observed at detectable levels in 50% of the muscle tissue samples examined (12 of 24) and most (19 of 24) of the gut samples examined. The PAO was not found at detectable levels in any of the muscle tissue samples and occurred in only one of twenty-four gut samples examined.

These limited data suggest that synthetic base fluids do not pose a serious bioaccumulation potential. Despite this general conclusion, existing data cannot be considered sufficiently extensive to be conclusive. This caution is specifically appropriate given the wide variety of chemical characteristics resulting from marketing different formulations of synthetic fluids (i.e., carbon chain length or degree of unsaturation within a fluid type, or mixtures of different fluid types). Additional data should be obtained both for the purpose of confirming what is known about existing fluids and to ensure completeness and currency with new product development.

F.   Biodegradation

EPA reviewed studies regarding the biodegradability of synthetic base fluids deposited on offshore marine sediments. In addition, EPA compared the various methods used to predict SBF biodegradation. Method variations include: calculation of biochemical oxygen demand in inoculated freshwater aqueous media versus uninoculated seawater aqueous media; determination of product (gases) evolved versus the concentration of synthetic base fluid remaining at periodic test intervals; varying initial concentrations of test material; aqueous versus sediment matrices; and within sediment matrices, layering versus mixed sediment protocols.

In the field, the mechanisms observed from the deposition of SBF contaminated drill cuttings involve the initial smothering of the benthic community followed by organic enrichment of the sediment due to adherent drilling fluids. Organic enrichment causes oxygen depletion due to the biodegradation of the discharged synthetic base fluids. This biodegradation results in predominantly anoxic conditions in the sediment, with limited aerobic degradation processes occurring at the sediment:water column interface. Therefore, the biodegradation of deposited drilling fluid will be an anaerobic process to a large degree. Standardized tests that utilize aqueous media, while readily available and easily performed, may not adequately mimic the environment in which the released synthetic base fluid is likely to be found and degraded. As a result, alternative test methods have been developed that more closely simulate seabed conditions.

The result of this review is that the current state of knowledge for these materials is as follows:

(a)   All synthetic fluids have high theoretical oxygen demands (ThODs) and are likely to produce a substantial sediment oxygen demand when discharged in the amounts typical of offshore drilling operations.

(b)   Existing aqueous phase laboratory test protocols are incomparable and results are highly variable. Sedimentary phase tests are less variable in their results, although experimental differences between the "simulated seabed" and "solid phase" protocols have resulted in variations between test results.

(c)   There is disagreement among the scientific community as to whether slow or rapid degradation of synthetic base fluids is preferable with respect to limiting environmental damage and hastening recovery of benthic communities. Materials which biodegrade quickly will deplete oxygen more rapidly than more slowly degrading materials. However, rapid biodegradation also reduces the exposure period of aquatic organisms to materials which may bioaccumulate or have toxic effects. EPA believes that rapid degradation is preferable because seafloor recovery has been correlated with disappearance of the SBF base fluid.

(d)   Limited field data suggest these materials will be substantially degraded on a time scale of one to a few years; however, the distribution and fate of these materials is not extensively documented, especially as applicable to the Gulf of Mexico where only three field studies have been conducted.

The limited data from field studies suggest that organic enrichment of the sediment is a dominant impact of SBF-cuttings discharges. Biodegradability of these materials is therefore an important factor in assessing their potential environmental fate and effects.

Each of the existing biodegradation test methods has advantages and disadvantages. The seabed simulations better represent field conditions, but they are expensive and have limited market availability. The standard aqueous test methods are not relevant to field conditions, but are more rapid, more widely available, and less expensive. The solid phase test combines the benefits of these two extremes: it mimics receiving water (sediment) conditions, is reproducible, and can be made simplistic enough to perform at moderate expense.

G.   Seabed Surveys

EPA reviewed and summarized seabed surveys conducted at sites where cuttings contaminated with SBFs (SBF-cuttings) have been discharged. Since more surveys have been performed and more detailed information has been collected at sites where WBFs (exclusively) have been discharged, results from the WBF sites is also presented as a comparison. While the technical performance of SBFs is comparable to that of OBFs, and EPA is projecting that SBFs may be used as a replacement to OBFs more so than as a replacement of WBFs, as far as environmental effects of discharge are concerned EPA believes that SBFs are more comparable to WBFs. Also, WBFs are currently allowed for discharge in certain offshore and coastal areas, while OBFs (and OBF-cuttings) are not. For these reasons, EPA sees it fitting to compare the environmental effects of SBF-cuttings discharge with those of WBF and WBF-cuttings discharge.

The reviewed seabed surveys measured either sediment or biologic effects from discharges of either WBFs or SBFs. Specifically, indicators of drilling fluid impact of seabed sediments are determined by measuring drilling fluid tracer concentrations (as either barium or SBF base fluid) in the sediment at varying distances from the drill site in an attempt to determine fluid dispersion and range of potential impact. Another class of impacts frequently measured are benthic community effects. The purpose of these studies is to assess potential drilling fluid affects such as increased metals and/or anoxia on biota.

There is very little information upon which to base any broad conclusions about the potential extent of impacts from the discharge of SBF-cuttings. It appears that biological impacts may range from as little as 50 m to as much as 500 m shortly after discharges cease to as much as 200 m a year later. Ester SBFs appear to be more readily biodegraded in North Sea studies than an ether SBF; the Gulf of Mexico study suggests PAOs also are less biodegradable than esters. Also, although esters appear to be readily biodegraded, one study indicates the persistence of uncharacterized "minor" impacts on benthos after synthetic-based fluid levels have fallen to reference levels. These limited data, however, are not entirely adequate as a basis for any reliable projections concerning the potential nature and extent of impacts from discharges of SBFs. However, the reported adverse benthic community impacts are expected, given the basic SBF and marine sediment chemistry, the level of nutrient enrichment from these materials, and the ensuing development of benthic anoxia. The extent and duration of these impacts are much more speculative. Severe effects seem likely within 200 m of the discharge; impacts as far as 500 m have been demonstrated. The initiation of benthic recovery seems likely within a year, although it also seems unlikely that it will be complete within one year. And the relative impacts of the various types of SBFs is speculative given the limited marine sediment applicability of available laboratory methods for assessing toxicity and biodegradability and the paucity of field data for laboratory versus field correlations.

1. INTRODUCTION

This document presents the analyses and results of the environmental assessment for the proposed rule for the wastestream of synthetic-based drilling fluids (SBFs) and other non-aqueous drilling fluids, and cuttings contaminated with these drilling fluids. The environmental assessment consists of an evaluation of the ecological and indirect human health impacts for each proposed regulatory option with respect to discharges to water. This document describes the environmental characteristics of SBF drilling wastes (e.g., toxicity, bioaccumulation, biodegradation), the types of anticipated impacts, and the pollutant modeling results for water column concentrations, pore water concentrations, and human health effects via consumption of affected seafood. This document does not consider the potential non-water quality environmental effects associated with the proposed rule.

Since about 1990, the oil and gas extraction industry has developed many new oleaginous (oil-like) base materials from which to formulate high performance drilling fluids. A general class of these are called "synthetic" materials. This class of substances include vegetable esters, poly alpha olefins, internal olefins, linear alpha olefins, synthetic paraffins, ethers, linear alkyl benzenes, and others. Other, nonsynthetic oleaginous materials have also been developed for this purpose, such as the enhanced mineral oils and non-synthetic paraffins. Industry developed these synthetic and non-synthetic oleaginous materials as the base fluid to provide the drilling performance characteristics of traditional oil-based fluids (OBFs) based on diesel and mineral oil, but with lower environmental impact and greater worker safety. These environmental and safety characteristics have been achieved through lower toxicity, elimination of polynuclear aromatic hydrocarbons (PAHs), faster biodegradability, lower bioaccumulation potential, and, in some drilling situations, less drilling waste volume. In this document, the synthetic or other new oleaginous base fluids will be referred to collectively as synthetic base fluids. The drilling fluids formulated from them will be referred to collectively as SBFs.

As SBFs came into commercial use, EPA determined that the current drilling discharge monitoring methods, which were developed to control the discharge of water-based fluids (WBFs), did not appropriately control the discharge of these new drilling fluids. Because WBFs disperse in water, oil contamination of WBFs with formation oil or other sources can be measured by the static sheen test. Many soluble or water-accommodated toxic components of the WBFs will disperse in the aqueous phase and be detected by the suspended particulate phase (SPP) toxicity test. With SBFs, which are highly hydrophobic and do not disperse in water but instead sink as a mass, formation oil contamination has been shown to be less detectable by the

static sheen test. Similarly, the potential toxicity of the discharge to the benthos is not apparent in the current SPP toxicity test.

EPA has, therefore, sought to identify methods to control the discharge of cuttings associated with SBFs (SBF-cuttings) in a way that reflects the appropriate level of technology. One way to do this is through stock limitations on the base fluids from which the drilling fluids are formulated. This would ensure that the substitution of synthetic and other oleaginous base fluids for traditional mineral and diesel oils reflects the appropriate level of technology. In other words, EPA wants to ensure that only the SBFs formulated from the "best" base fluids are allowed for discharge. Parameters that distinguish the various base fluids are the polynuclear aromatic hydrocarbon (PAH) content, sediment toxicity, rate of biodegradation, and potential for bioaccumulation.

EPA also thinks that the SBF-cuttings should be controlled with other limitations, such as a limitation on the toxicity of the SBF at the point of discharge and a limitation on the mass or concentration of SBFs discharged with the drill cuttings. The latter type of limitation would take advantage of the solids separation efficiencies achievable with SBFs, and consequently minimize the discharge of organic and toxic components.

In addition to the discharge option described above, EPA is also considering a zero discharge option for SBF-cuttings. EPA would select zero discharge as the preferred option if the controls in the discharge option proved to be inadequate or inappropriate.

EPA has determined the water quality and human health impacts of each of the two regulatory options (i.e., discharge and zero discharge) based on changes in the discharge of SBF wastes, and on the number of wells projected to use SBFs. Under the discharge option, wells drilled using SBFs will be allowed to discharge SBF-cuttings. Due to the proposed limitations, less SBF would be retained on the cuttings and so less SBF would be discharged per well than is currently practiced in the Gulf of Mexico. In addition, under the discharge option, EPA will control the toxicity, PAH content, and biodegradation rate of the base fluids used in SBFs. For wells currently using OBFs for drilling, EPA projects that under the discharge option, a portion of these wells will convert to SBF usage and will discharge SBF-cuttings. These wells comprise a fraction of the OBF wells drilled in the Gulf of Mexico and all of the OBF wells drilled in offshore California and Cook Inlet, Alaska.

The effect of the zero discharge option would be to eliminate the discharge of SBF-cuttings into ambient waters by those wells currently drilled with SBFs. However, EPA believes another

effect of zero discharge would be that many of the wells currently using SBFs would convert to OBFs.

This environmental assessment presents background information and several types of characterizations and assessments concerning the discharge of SBFs and SBF-cuttings, including:

- A description of the regulatory options considered for the proposed rule (Chapter 2).

- A characterization of the industry, including the geographic areas and the population affected by the proposed rule (Chapter 3).

- Wastestream characterizations in terms of SBFs and SBF-cuttings (Chapter 3).

- Characterization of the affected environment, including the receiving water and fisheries (Chapter 3).

- Water quality compliance assessments for SBF-cuttings discharges to receiving waters and comparison of receiving water pollutant concentrations (water column and interstitial (pore) water) projected from surface water dispersion modeling to Federal numeric water quality standards (Chapter 4).

- A carcinogenic and non-carcinogenic risk assessment for SBF-cuttings for high-rate seafood consumption, based on seafood contamination levels projected from modeling (Chapter 5).

- A summary and comparison of the aquatic toxicity test results conducted to date on SBFs (Chapter 6).

- A summary and comparison of bioaccumulation study results conducted to date on SBFs (Chapter 7).

- A summary and comparison of biodegradation study results conducted to date on SBFs (Chapter 8).

- A summary and comparison of seabed survey results conducted to date on SBF discharges to assess benthic impacts (Chapter 9).

The pollutant concentrations in water and seafood tissue are based solely on analysis of discharges from this one particular wastestream under different regulatory options. That is, the analyses do not consider background pollutant concentrations or pollutant loadings from other potential discharges.

2. DESCRIPTION OF REGULATORY OPTIONS

This environmental assessment determines impacts for the discharge of wastes associated with synthetic-based drilling fluids (SBFs) under current industry practice and the two regulatory options considered by EPA for the SBF rule: a discharge option and a zero discharge option.

The discharge option controls the stock base fluid through limitations on PAH content, sediment toxicity, and biodegradation rate. At the point of discharge, the discharge option controls sheen, formation oil content, and retention of SBF on the cuttings. The discharge option also maintains current requirements of stock limitations on barite of mercury and cadmium, and the diesel oil discharge prohibition.

While discharge of SBF-cuttings would be allowed under the discharge option, discharge of SBFs not associated with drill cuttings would not be allowed. Since zero discharge of neat SBFs is current industry practice due to the value of the SBFs recovered, this option has no incremental environmental impact. For this portion of the wastestream, therefore, an environmental assessment was not conducted.

Under the zero discharge option, neat SBFs (not associated with drill cuttings) as well as SBF-cuttings would be prohibited from discharge. Because the zero discharge option results in the absence of discharged pollutants, the environmental assessment analyses did not require calculations to demonstrate zero environmental impacts.

EPA determined that the only major effect that the discharge option would have on the characterization of the SBF-cuttings currently discharged would be to reduce the retention of the SBF on the cuttings from 11% base fluid to 7% base fluid. This means that for the purpose of this environmental assessment, base fluid selection, formation oil contaminant level, and sheen forming characteristics would not be materially affected in moving from current practice to the discharge option.

Current industry practice for managing and treating SBF-cuttings before discharge is to send the cuttings through solids separation equipment that separates the drill cuttings from the drilling fluid. The drilling fluid is recovered and reused. The drill cuttings are considered waste and are discharged under permit requirements. The solids separation equipment consist of primary and secondary shale shakers and occasionally a centrifuge. Based on industry data, the efficiency of current solids separation equipment results in a long term average of 11% (by

weight) retention of SBF base fluid on cuttings (EPA, 1999). "Retention" is defined as the percentage of base fluid remaining on the wet cuttings (on a weight/weight basis). It is determined using an industry standard test in which the cuttings sample is heated, the liquid is separated from the solids, and the weight percent liquid in the original sample is calculated.

The technology basis for the discharge option is an add-on, vibrating centrifuge to current solids separation equipment. Based on performance data, the long term average retention for the add-on technology is 7% by weight (EPA, 1999). The 7% retention value is used as the basis for determining the amount of SBF discharged on cuttings in the discharge option, and consequently, the amount of pollutants discharged.

The different SBF retention values, 11% for current technology and 7% for the discharge option, represent different amounts of SBF discharged into the receiving water. For the water quality analyses (Chapter 4) and the human health impact assessments (Chapter 5), the impacts under the discharge option (7% retention) and under current technology (11% retention) were determined.

Also, EPA projects that the discharge option would encourage operators to convert wells currently drilled with oil-based drilling fluid (OBF) to SBF. Thus, EPA projects that in the Gulf of Mexico, while 113 wells annually are currently projected to drill with SBF, after the rule an additional 23 wells, for a total of 136 would drill with SBF. Therefore, the analyses of this environmental assessment assume that in the Gulf of Mexico, the current practice is 113 wells discharging at 11% base fluid retention on cuttings and the discharge option would give 136 wells drilled annually and discharging cuttings at 7% retention.

In offshore California and Cook Inlet, Alaska, no SBF wells are currently drilled. EPA projects that the 12 OBF wells in California and the one OBF well in Cook Inlet will convert to SBF as a result of this rule. Therefore, in the discharge option, 12 SBF wells would be drilled annually in California, one SBF well would be drilled annually in Cook Inlet and these wells would discharge the SBF-cuttings at 7% base fluid retention. Even though these wells currently use OBF and do not discharge, in order to compare with current technology, this environmental assessment also calculates the impacts that would occur if these California and Cook Inlet wells used SBF and discharged at 11% retention.

Current regulations establish the geographic areas where drilling wastes may be discharged: offshore subcategory waters beyond 3 miles from the shoreline and, in Alaska, offshore waters with no 3-mile restriction. The SBF effluent guidelines would be applicable only where drilling wastes are currently allowed for discharge. The only coastal subcategory waters

where drilling wastes may be discharged is in Cook Inlet, Alaska. In total, there are three areas where current guidelines allow drilling wastes to be discharged and drilling is active: offshore Gulf of Mexico, offshore California, and Cook Inlet, Alaska. Because these are the only geographic areas where EPA projects pollutant loadings to change as a result of the proposed rule, they are the only areas considered in the environmental assessment.

3. CHARACTERIZATION

3.1 Industry Characterization

The geographic areas where drilling wastes are allowed to be discharged are: the offshore subcategory waters of the Atlantic, Gulf of Mexico, and Pacific coasts beyond 3 miles from shore; all of the offshore subcategory waters of Alaska, which has no 3 mile discharge restriction; and the coastal subcategory waters of Cook Inlet, Alaska. Within these discharge areas, drilling is currently active in three places: (i) the Gulf of Mexico (GOM), (ii) offshore southern California; and (iii) Cook Inlet, Alaska. Offshore subcategory waters of Alaska has active drilling and effluent guidelines allows discharge. However, drilling wastes are not currently discharged in the Alaska offshore waters.

Among these three areas, the vast majority of drilling activity occurs in the GOM, where 1,302 wells were drilled in 1997. This activity compares to 28 wells drilled in California and 7 wells drilled in Cook Inlet in 1997. In the GOM, over the last few years, there has been a high growth in the number of wells drilled in the deepwater, defined by the Minerals Management Service (MMS) as water greater than 1,000 feet deep. For example, in 1995, 84 wells were drilled in the deepwater, comprising 8.6 percent of all GOM wells drilled that year. By 1997, that number increased to 173 wells drilled and comprised over 13 percent of all GOM wells drilled. This increased activity in deepwater increases the usefulness of SBFs. Operators drilling in deepwater cite the potential for riser disconnect in floating drill ships, which favors SBF over OBF; higher daily drilling cost that more easily justifies use of more expensive SBFs over WBFs; and the greater distance to barge drilling wastes that may not be discharged (i.e., OBFs).

EPA has adopted the MMS categorization of drilling wells according to type of drilling operation, i.e., exploratory or development, and water depth. Deep water wells are wells that are drilled in water depths greater than 1,000 feet whereas shallow water wells are drilled in water less than 1,000 feet. Using information gathered from industry, EPA projected the number of wells drilled annually using SBFs, WBFs, and OBFs (EPA, 1999). Table 3-1 presents a summary of the wells drilled with OBFs and SBFs as used in the analyses for the environmental assessment. For the water quality and human health impact analyses, EPA projected that under the discharge option, certain wells currently using OBFs would switch to SBF usage (EPA, 1999). In the Gulf of Mexico, EPA projected that 20% of the wells drilled with OBF, all of which are located in shallow water, would convert to SBF. In Cook Inlet, Alaska and offshore California, EPA projected that all OBF wells would convert to SBF.

Exhibit 3-1. Estimated Number of Wells Drilled Annually By Drilling Fluid

Type of Well	Shallow Water (<1,000 ft)		Deep Water (>1,000 ft)		Total Wells
	Develop.	Explor.	Develop.	Explor.	
Gulf of Mexico					
Baseline All Wells (a)	645	358	48	76	1,127
Baseline SBF Wells	13	7	36	57	113
Discharge Option SBF Wells	28 (b)	15	36(c)	57	136
Zero Discharge Option SBF Wells	0	0	36	57	93
Offshore California (d)					
Baseline All Wells	11	0	15	0	26
Baseline OBF Wells	1	0	11	0	12
Discharge Option SBF Wells	1	0	11	0	12
Coastal Cook Inlet, Alaska (d)					
Baseline All Wells	7	1	0	0	8
Baseline OBF Wells	1	0	0	0	1
Discharge Option SBF Wells	1	0	0	0	1

(a) While this table lists total number of wells, the only wells included in the analysis are those affected by this rule: SBF wells or wells converting from OBF to SBF in discharge option or converting from SBF to OBF in zero discharge option.
(b) EPA assumes that 95 percent of GOM shallow water development wells of this analysis are existing sources, and 5 percent are new sources (equals one new source well).
(c) EPA assumes that 50 percent of GOM deep water development wells of this analysis are existing sources, and 50 percent are new sources (equals 18 new source wells).
(d) EPA assumes all offshore California and Cook Inlet, Alaska, wells are existing sources, and in discharge option all OBF wells convert to SBF wells.
Source: EPA, 1999

3.2   Wastestream Characterization

The American Petroleum Institute (API) provided EPA with characteristic well data in terms of well diameters and well section depths for model wells. From this, EPA calculated the volumes of waste generated (EPA, 1999). As in the MMS data, API information distinguishes wells into four categories: shallow water development, shallow water exploratory, deep water development, and deep water exploratory.

Drill cuttings are produced continuously at the bottom of the hole at a rate proportionate to the advancement of the drill bit. These drill cuttings are carried to the surface by the drilling fluid, where the cuttings are separated from the drilling fluid by the solids control system. The drilling fluid is then sent back down hole, provided it still has characteristics to meet technical requirements. Various sizes of drill cuttings are separated by the solids separations equipment. It is necessary to remove both the fines (small sized cuttings) and the large sand- and gravel-sized cuttings from the drilling fluid stream to maintain the required flow properties.

Because of cost, SBFs, used or unused, are considered a valuable commodity by the industry and not a waste. It is industry practice to continuously reuse the SBF while drilling a well interval, and at the end of the well, to ship the remaining SBF back to shore for refurbishment and reuse. Compared to WBFs, SBFs are relatively easy to separate from the drill cuttings because the drill cuttings do not disperse in the drilling fluid to the same extent.   With WBF, due to dispersion of the drill cuttings, drilling fluid components often need to be added to maintain the required drilling fluid properties. These additions are often in excess of what the drilling system can accommodate. The excess "dilution volume" of WBF is discharged. This excess dilution volume does not occur with SBF. For these reasons, SBF is only discharged as a contaminant of the drill cuttings wastestream. It is not discharged as neat drilling fluid (drilling fluid not associated with cuttings).

The top of the well is normally drilled with a WBF. As the well becomes deeper, the performance requirements of the drilling fluid increase, and the operator may, at some point, decide that the drilling fluid system should be changed to either a traditional OBF using diesel oil or mineral oil, or an SBF. The system, including the drill string and the solids separation equipment, must be changed entirely from the WBF to the SBF (or OBF) system, because the two drilling fluid systems do not function as a blended system. Thus, the entire system is either a water dispersible drilling fluid or a water non-dispersible drilling fluid (such as an SBF). The decision to change the system from a WBF water dispersible system to an OBF or SBF water non-dispersible system depends on many factors including:

- the operational considerations, i.e. rig type (risk of riser disconnects with floating drilling rigs), rig equipment, distance from support facilities,
- the relative drilling performance of one type fluid compared to another, e.g., rate of penetration, well angle, hole size/casing program options, horizontal deviation,
- the presence of geologic conditions that favor a particular fluid type or performance characteristic, e.g., formation stability/sensitivity, formation pore pressure vs. fracture gradient, potential for gas hydrate formation,
- drilling fluid cost - base cost plus daily operating cost,

- drilling operation cost - rig cost plus logistic and operation support, and
- drilling waste disposal cost.

Industry has commented that while the right combination of factors that favor the use of SBF can occur in any area, they most frequently occur with "deep water" operations. This is due to the fact that these operations are higher cost and can therefore better justify the higher initial cost of SBF use.

The volume of cuttings generated while drilling the SBF intervals of a well depends on the type of well (development or production) and the water depth. According to analyses of the model wells provided by industry representatives, wells drilled in less than 1,000 feet of water are estimated to generate 565 barrels of cuttings for a development well and 1,184 barrels of cuttings for an exploratory well. Wells drilled in water greater than 1,000 feet deep are estimated to generate 855 barrels of cuttings for a development well, and 1,901 cuttings for an exploratory well (see Exhibit 3-2). These values assume 7.5 percent washout, based on the rule of thumb reported by industry representatives of 5 to 10 percent washout when drilling with SBF. Washout is caving in or sluffing off of the well bore. Washout, therefore, increases hole volume and increases the amount of cuttings generated when drilling a well. Assuming no washout, the values above become, respectively, 526, 1,101, 795, and 1,768, barrels of dry cuttings.

The drill cuttings range in size from large particles on the order of a centimeter in size to small particles a fraction of a millimeter in size, called fines. As the drilling fluid returns from downhole laden with drill cuttings, it normally is first passed through primary shale shakers which remove the largest cuttings, ranging in size of approximately 1 to 5 millimeters. The drilling fluid may then be passed over secondary shale shakers to remove smaller drill cuttings. Finally, a portion or all of the drilling fluid may be passed through a centrifuge or other shale shaker with a very fine mesh screen, for the purpose of removing the fines. It is important to remove fines from the drilling fluid in order to maintain the desired flow properties of the active drilling fluid system. Thus, the cuttings wastestream usually consists of larger cuttings from a primary shale shaker, smaller cuttings from a secondary shale shaker, and fines from a fine mesh shaker or centrifuge.

Before being discharged, the larger cuttings are sometimes sent through an additional separation device in order to recover additional drilling fluid.

The recovery of SBF from the cuttings serves two purposes. The first is to deliver drilling fluid for reintroduction to the active drilling fluid system and the second is to minimize the discharge of SBF. The recovery of drilling fluid from the cuttings is a conflicting concern,

Exhibit 3-2. Volume of SBF-Cuttings Generated Per Model Well

Parameter	Shallow Water (<1,000 ft)		Deep Water (≥1,000 ft)	
	Development	Exploratory	Development	Exploratory
Calculated SBF Interval Volume (bbls)	526	1,101	795	1,768
SBF Interval Volume Plus 7.5% Washout (bbls)	565	1,184	855	1,901
Amount of Dry Cuttings Generated Per Interval Volume (lbs)	514,150	1,077,440	778,050	1,729,910

Source: EPA, 1999

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

Drill cuttings are typically discharged continuously during drilling, as they are separated from the drilling fluid in the solids separation equipment. The drill cuttings will also carry a residual amount of adherent drilling fluid. Total suspended solids (TSS) makes up the bulk of the pollutant loadings, and is comprised of two components: the drill cuttings themselves, and the solids in the adhered drilling fluid (see Exhibit 3-3). The drill cuttings are primarily small bits of stone, clay, shale, and sand. The source of the solids in the drilling fluid is primarily the barite weighting agent, and clays that are added to modify the viscosity.   Because the quantity of TSS is so high and consists of mainly large particles that settle quickly, discharge of SBF drill cuttings can cause benthic smothering and/or sediment grain size alteration resulting in potential damage to invertebrate populations and benthic community structure.

Additionally, environmental impacts can be caused by toxic, conventional, and nonconventional pollutants adhering to the solids. The adhered SBF drilling fluid is mainly composed, on a volumetric basis, of the synthetic material, or more broadly speaking, oleaginous

Exhibit 3-3. Model Well Characteristics

Parameter	Shallow Water (<1,000 ft)		Deep Water (≥1,000 ft)	
	Development	**Exploratory**	**Development**	**Exploratory**
Amount of Cuttings (lbs) (= TSS associated with drill cuttings)	514,150	1,077,440	778,050	1,729,910
Amount of Solids as Barite (lbs) (=TSS associated with drilling fluid) @11% retention @7% retention	51,818 29,661	108,588 62,158	78,414 44,886	174,346 99,799
Amount of Synthetic Base Fluid Associated with Adhering Drilling Fluid (lbs) @11% retention @7% retention	73,834 42,287	154,724 88,616	111,730 63,992	248,420 142,279
Amount of Crude at 0.2% (vol.) Contamination (lbs) @11% retention @7% retention	228 131	478 478	345 198	767 440

Source: EPA, 1999

material. The oleaginous material may be toxic or bioaccumulate, and it may contain priority pollutants such as polynuclear aromatic hydrocarbons (PAHs). This oleaginous material may cause hypoxia (reduction in oxygen) or anoxia in the immediate sediment, depending on bottom currents, temperature, and rate of biodegradation. Oleaginous materials which biodegrade quickly will deplete oxygen more rapidly than more slowly degrading materials. EPA, however, believes that rapid biodegradation is environmentally preferable to persistence despite the increased risk of anoxia which accompanies fast biodegradation. This is because recolonization of the area impacted by the discharge of SBF-cuttings or OBF-cuttings has been correlated with the disappearance of the base fluid in the sediment, and does not seem to be correlated with anoxic effects that may result while the base fluid is disappearing. In studies conducted in the North Sea, base fluids that biodegrade faster have been found to disappear more quickly, and recolonization at these sites has been more rapid (Daan et al., 1996 and Schaanning, 1995).

As a component of the drilling fluid, the barite weighting agent is also discharged as a contaminant of the drill cuttings. Barite is a mineral principally composed of barium sulfate, and it is known to generally have trace contaminants of several toxic heavy metals such as mercury, cadmium, arsenic, chromium, copper, lead, nickel, and zinc. EPA developed a profile of metals concentrations in drilling fluids formulated with barite as part of the Offshore Effluent

Limitations Guidelines rulemaking effort. As a result of the Offshore Effluent Limitations Guidelines, stock barite must meet the maximum limitations of cadmium of 3 mg/l and for mercury of 1 mg/l. Exhibit 3-4 lists the concentrations of the pollutants associated with barite.

Formation oil is another contaminant of drilling fluids. Together with the synthetic oil, formation oil contributes to the total oil concentration found in drilling fluids. EPA estimates that a model SBF wastestream will contain 0.2% by volume formation oil (EPA, 1999). EPA obtained the concentrations for both priority and non-conventional organic pollutants from analytical data presented in the Offshore Subcategory Oil and Gas Development Document for Gulf of Mexico diesel (EPA, 1993). Thus, EPA used diesel oil as an estimate for formation oil in terms of pollutant content. Exhibit 3-5 lists the concentrations of organic pollutants found in SBF drilling fluid contaminated with formation oil.

Exhibit 3-4. Heavy Metal Concentrations in Barite

Pollutant	Average Concentration of Pollutants in Barite (mg/kg)	Reference
Priority Pollutants, Metals		
Cadmium	1.1	Offshore Development
Mercury	0.1	Document, Table XI-6
Antimony	5.7	(EPA, 1993)
Arsenic	7.1	
Beryllium	0.7	
Chromium	240.0	
Copper	18.7	
Lead	35.1	
Nickel	13.5	
Selenium	1.1	
Silver	0.7	
Thallium	1.2	
Zinc	200.5	
Non-Conventional Metals		
Aluminum	9,069.9	Offshore Development
Barium	120,000	Document, Table IX-6,
Iron	15,344.3	except barium, which was
Tin	14.6	estimated (EPA, 1993)
Titanium	87.5	

Exhibit 3-5. Formation Oil Characteristics

Pollutant	Average Concentration of Pollutants in SBF Contaminated with Formation Oil		Reference
	mg pollutant/ ml formation oil	lbs/bbl of SBF (a)	
Priority Pollutant Organics			
Naphthalene	1.43	0.0010052	lbs/bbl pollutant conc.
Fluorene	0.78	0.0005483	calculated from Offshore
Phenanthrene	1.85	0.0013004	Dev. Doc., Table VII-9
Phenol (μg/g)	6	7.22E-08	(EPA, 1993)
Non-Conventional Pollutants			
Alkylated benzenes	8.05	0.0056587	
Alkylated naphthalenes	75.68	0.0531987	
Alkylated fluorenes	9.11	0.0064038	
Alkylated phenanthrenes	11.51	0.0080909	
Alkylated phenols (μg/g)	52.9	0.0000006	
Total biphenyls	14.96	0.0105160	
Total dibenzothiophenes (μg/g)	760	0.0000092	

(a)   Assumes 0.2% contamination from formation oil using diesel as an estimate of pollutant content.

3.3   Receiving Water Characterization

3.3.1 *Gulf of Mexico*

The Gulf of Mexico is a semi-enclosed sea that can be subdivided into four physiographic regions: the continental shelf, the continental slope and associated canyons, the Yucatan Strait, and the Straits of Florida. Physical oceanography is dominated by the clockwise flow of the Loop Current that enters the Gulf through the Yucatan Strait and exits through the Straits of Florida. The average position of the northern part of the Loop Current is close to 26°N and the mean eastern side of the Loop Current is west of the 2000 m isobath offshore Florida (MMS,1989). The most northerly position occurs on the slope just south of Mobile, Alabama. The Loop sheds large eddies (diameters of 300 to 400 km, averaging 234 km) that last for periods ranging from 4 to 12 months (MMS, 1989; 1991). The vertical extent of these eddies ranges to over 1,000 m.

Surface temperatures are nearly isothermal during summer (29°-30°C), but show strong, horizontal temperature gradients in winter ranging from 25°C at the core of the Loop current to 14-15°C over the northern coastal areas. Salinities range from a low of 20 ppt during periods of high freshwater inflow from the Mississippi River to a high of 29-32 ppt during periods of low

freshwater inflow. The thermocline also migrates due to seasonal influences. The thermocline depth is approximately 45 m during summer and ranges from between 30 m to 60 m during winter.

Current speeds reported at a depth of 100 m from a mooring buoy located at the 1000 m isobath off Louisiana averaged 13.4 cm/s for a period of November to September (MMS, 1989). MMS (1988) reports an average current speed of 17.2 cm/s for December to April at a depth of 35 m in about 400 m water depth near Green Canyon off Louisiana. MMS (1988) also reports an average current speed of 13.6 cm/s at 55 m depth in 100 m water depth (near West Flower Garden Bank, south of Louisiana/Texas border) and an average of 19.8 cm/s at 63 m depth in 280 m water depth (East Breaks vicinity, south of Galveston, Texas) .

Most drilling activity in the Gulf of Mexico occurs in the Central and Western planning areas for MMS, generally offshore Louisiana and Texas.

3.3.2 *Cook Inlet, Alaska*

Cook Inlet is located on the northwest edge of the Gulf of Alaska in southcentral Alaska. It is a large tidal estuary that is approximately 330 km long increasing in width from 36 km in the north to 83 km in the south. The upper inlet has water depths of 30 m to 60 m and has extensive tidal marshes and mud flats along the western and northern margins. At the East and West Forelands, where the upper inlet is divided from the lower inlet, water depths increase to over 130 m in deeper channels. In Lower Cook Inlet water depths range from 30 m to 40 m below the forelands to over 180 m at the entrance to the inlet.

The circulation pattern of Lower Cook Inlet is a complex pattern influenced by large tidal ranges, bathymetry, surface wind patterns, Coriolis effect, water density structure, and shoreline configuration. Surface circulation in the lower inlet appears to follow a generally counter-clockwise pattern near the mouth of the inlet as clear oceanic waters are met by more turbid water flowing south through the inlet (Dames & Moore, 1978).

Cook Inlet currents are dominated by tidal currents and large-scale, local or regional meterological events (EPA Region 10, 1984). Tidal currents range from 10 to 50 cm/sec. Above the tidal currents, the Kenai Current and western surface outflows affect Cook Inlet circulation. Houghton et al., 1981 measured flood tides ranging from 77 cm/sec to 51 cm/sec for depths ranging from 14 m to 52 m and ebb tide ranging from 103 cm/sec to 41 cm/sec for the same depths at one point in Cook Inlet.

Salinity in Cook Inlet varies seasonally due to variations in fresh water inflow. During summer (May through September) river discharges decrease the salinity of the upper Inlet. During winter, intrusion by more saline oceanic waters increase salinity throughout the Inlet. At the mouth of the Inlet salinity value remain nearly constant at 32 ppt. As a result of circulation patterns, salinity on the eastern side of Lower Cook Inlet tends to be higher than the western side.

Cook Inlet is characterized by large quantities of glacial sediments washed into the upper inlet from seven major glacier-fed rivers. Sediment inflow from glacial sources is seasonal with larger amounts of glacially-derived sediment occurring in summer months. In upper Cook Inlet, clay- and silt-sized particles are kept in suspension by tidal currents. The bulk of this fine sediment is transported down the west side of the inlet and deposited in the Aleutian Trench beyond Kodiak Island. Extreme ranges of sediments vary from 1 to 2 mg/l at the mouth of Cook Inlet to over 2,000 mg/l in Knit Arm (Dames & Moore, 1978).

3.3.3 *Offshore California*

The Southern California Bight is the area of the California coastline from Point Conception in the north to San Diego in the south. Currently, it is the only area with oil and gas activity in the offshore California discharge region. The area has three principle features: (i) a narrow continental shelf ranging in width between 3 km and 10 km; (ii) distinct basins with depths to 1 km; and (iii) a number of islands.

Circulation on the shelf of southern California is not well defined (MMS, 1991). The offshore flow is generally a counter-clockwise flow from the shelf and slope area north of Point Conception past the channel islands and then eastward where it intersects the shelf at a point not precisely determined.

The major surface currents offshore California are the California Current (mean speed about 15 cm/sec) that flows generally southward and affects areas further offshore and the Davidson Current (speeds up to 15-30 cm/sec) that flows northward closer to the shore. The Davidson Current mainly occurs in areas where oil and gas leases occur offshore California (MMS, 1985).

3.4   Recreational and Commercial Fisheries

3.4.1 *Gulf of Mexico*

Recreational Finfish

In the Gulf of Mexico, 1,818 people participated in 16,319 recreational fishing trips (excluding Texas). In Texas 266,500 man-hours of sport-boat fishing were reported for the Exclusive Economic Zone in 1991 (NMFS, 1997). Data from the National Marine Fisheries Service (NMFS) Fisheries Statistics Survey are presented in Exhibit 3-6 for recreational fish catch in Gulf of Mexico states, excluding Texas. Texas data are maintained by the state and not reported to NMFS.

Commercial Shrimp

Gulf of Mexico commercial shrimp fisheries include mainly brown, pink, white, and northern shrimp. According to NMFS (1997), the commercial shrimp landings in the Gulf of Mexico represented 72% and 70% of the total US landings by weight in 1995 and 1996, respectively with 219.8 million and 218.6 million pounds of shrimp landed each year. The value of these shrimp represented 77% and 79% of the total US shrimp landings by weight for those respective years at $437 million and $401 million. The commercial shrimp landings for Gulf of Mexico states is presented in Exhibit 3-7.

As presented in the offshore Environmental Assessment (Avanti Corporation, 1993), the state reporting the landing does not necessarily represent the state in which the shrimp were caught. EPA has used the catch:landings ratios used in the offshore assessment to adjust the landings figures by factors of 123% for Louisiana and 85% for Texas. Also, as developed for the offshore analysis, the total catch is adjusted to calculate the portion caught in areas potentially affected by SBF discharges, i.e., beyond 3 miles from shore. These calculations are presented in Appendix A.

3.4.2 *Cook Inlet, Alaska*

Recreational Finfish

Cook Inlet area waters provided over 50% of the total (saltwater and freshwater) sportfishing days in Alaska in 1992 with an estimated 375,993 saltwater recreational fishing days

Exhibit 3-6. Gulf of Mexico Recreational Fisheries Catch (pounds)

State	1995	1996	Average
W. Florida	17,570,384	14,610,412	16,090,398
Alabama	3,801,411	2,950,265	3,375,838
Mississippi	849,152	1,143,668	996,410
Louisiana	3,136,809	2,035,401	2,586,105
Total	25,357,756	20,739,746	23,048,751

Source: NMFS, 1998

Exhibit 3-7. Gulf of Mexico Commercial Shrimp Catch (pounds)

Shrimp Species	Florida	Mississippi	Alabama	Louisiana	Texas	Total	Total Texas and Louisiana
Brown							
1995	1,234,564	10,782,239	11,156,659	45,023,758	56,108,138	124,305,358	101,131,896
1996	664,345	8,187,562	9,101,653	51,420,060	50,584,072	119,957,692	102,004,132
Average	949,455	9,484,901	10,129,156	48,221,909	53,346,105	122,131,525	101,568,014
Northern							
1995	17,192	–	82,732	–	1,584	101,508	1,584
1996	–	–	12,081	–	–	12,081	0
Average	17,192	–	47,407	–	1,584	57,587	1,584
Pink							
1995	18,069,106	130,102	3,557,597	4,768	830,226	22,591,799	834,994
1996	23,753,839	165,568	4,433,053	108,095	23,065,104	30,525,659	2,173,199
Average	20,911,473	147,835	3,995,325	56,432	1,447,665	26,558,729	1,504,097
White							
1995	1,169,910	4,299,183	3,088,084	50,752,795	16,582,811	75,892,783	67,335,606
1996	949,053	1,927,839	1,392,376	29,368,900	21,619,926	55,258,094	50,988,826
Average	1,059,482	3,113,511	2,240,230	40,060,848	19,101,369	65,575,439	59,162,216
Other Marine							
1995	1,175,400	–	–	–	930,837	2,106,237	930,837
1996	1,224,820	–	–	–	1,433,385	2,658,205	1,433,385
Average	1,200,110	–	–	–	1,182,111	2,382,221	1,182,111

Source: NMFS, 1998

recorded (Mills, 1993). Most of the recreational fishing in the inlet is for halibut and chinook salmon.

Commercial Shrimp

There has been no commercial shrimping in Cook Inlet since January 1, 1997. The Alaska Board of Fisheries mandated closures for Inner Cook Inlet (Kachemak Bay) in 1988 and Outer Cook Inlet since January 1997 (Beverage, 1998). These closures were due to insufficient information on the biology and stock status of the coonstriped shrimp, which was the primary species sought by Alaskan commercial shrimpers. There is no information that indicates that these closures will be lifted in the near future.

3.4.3 Offshore California

Recreational Finfish

In southern California an estimated 958 people participated in 3,519 fishing trips in 1996 (NMFS, 1997). The finfish catch reported for 1995 and 1996 were 4,771,722 pounds and 3,191,205 pounds, respectively (NMFS, 1997).

Commercial Shrimp

Commercial shrimping occurs in the same general location as oil and gas activities. Primary species caught in offshore California waters are ridgeback and spot prawns. These two species accounted for 5 percent of all the 1997 shrimp landings in California. There were 450,189 lbs of spot prawn and 385,931 lbs of ridgeback prawns landed in Southern California ports in 1997 (CA DFG, 1998). Shrimping for ridgeback and spot prawns occurs in water depth between 50 fathoms and 200 fathoms and outside state waters.

The CA Department of Fish and Game (CA DFG) records shrimp catch data in 6- by 10-mile blocks. By identifying the blocks that are within the species' depth range and outside state waters, shrimp catch can be expressed on a pounds per square mile basis. The depths were taken from NOAA nautical charts and catch blocks were taken from Southern California Fisheries Charts, provided by CA DFG. There were 44, 10-by-6 mile blocks that were identified as having the 50- to 200-fathom depth range and existing outside state waters. From these blocks, a shrimping area of 264,000 square miles was determined. Using the total pounds of ridgeback and spot prawns reported in southern ports, a catch rate of 3.17 pounds of shrimp per square mile is used in this analysis.

4. WATER QUALITY ASSESSMENT

4.1   Introduction

EPA based the methodologies for assessing both surface and pore water quality impacts from the discharge of SBF-cuttings on the methodologies used to assess the discharge of water-based fluids (WBFs) and associated cuttings (WBF-cuttings) for the offshore effluent limitations guidelines (ELG). The methodology for the offshore guidelines is presented in Avanti Corporation, 1993. However, there are several major differences in the analyses, most notably the absence of bulk drilling fluid discharges in the SBF guidelines. In the offshore ELG, these bulk discharges were a major wastestream and numerous existing drilling fluid characterization and transport studies were used as sources of data for the water quality assessment. In the current SBF-cuttings discharge impact analysis, surface water quality assessments rely on modeling data presented in a study (Brandsma, 1996) of the post-discharge transport behavior of oil and solids from cuttings contaminated with oil-based fluids (OBF-cuttings). Due to the similar hydrophobic and physical properties between SBFs and OBFs, EPA assumes that dispersion behavior of SBF-cuttings is similar to that of OBF-cuttings.

In addition, the offshore ELG only examined impacts in the Gulf of Mexico. For the SBF guidelines, EPA considered the impacts in offshore California and Cook Inlet, Alaska separately from the Gulf of Mexico. Although the analysis methodology does not change between regions, data used to conduct the water quality assessment contains certain assumptions specific to each region, for example, current speed.

For the pore water quality assessment, the absence of bulk drilling fluid discharges greatly affects the annual pollutant loadings. EPA applied the same methodology used for the offshore ELG in assessing the effects of SBF-cuttings discharges on pore water quality for the current industry practice and the discharge option.

The analyses in this chapter are conservative due to the assumption that discharged pollutants immediately leach into the water column or into the pore water. In the water column, total organic pollutant discharge concentrations are assumed to represent the soluble concentration. Metals are assumed to leach immediately into the water column at pollutant-specific amounts determined for mean seawater pH (as derived in Avanti Corporation, 1993; Appendix C). In the pore water, pollutant-specific partition coefficients are used for organic pollutants (from EPA's IRIS) to determine soluble concentrations. The mean seawater leach factors are used for metals in the same manner as used for the water column concentrations. For

both organic pollutants and metals, the total leached concentration is assumed to be immediately available in the pore water.

In general, the methodology consists of modeling incremental water column and pore water concentrations and comparing them to EPA water quality criteria/toxic values for marine acute, marine chronic, and human health protection. Additionally, EPA used the proposed sediment guidelines for protection of benthic organisms to assess potential impacts from a group of select metals in pore water (EPA, 1998b). Note that all of these comparisons are performed only for those pollutants for which EPA has numeric criteria. Those pollutants include priority and nonconventional pollutants associated with the drilling fluid barite and with contamination by formation (crude) oil, but do *not* include synthetic base fluids themselves. Potential impacts from synthetic base fluid compounds are described in Chapters 6 through 9 of this document.

4.2   Surface Water

To help evaluate the relative water quality impacts of the current industry practice and regulatory options, EPA estimates the water column concentration of pollutants present in SBF drilling discharges under regulatory discharge options and compares them to Federal water quality criteria/toxic values. This comparative analysis applies only to those pollutants for which EPA has published numeric criteria, as presented in Exhibit 4-1.[1] Note that there are no criteria for the synthetic-based fluid compounds themselves.

In order to determine the water column pollutant concentrations, EPA used data regarding the transport of discharged drill solids and corresponding oil concentration in the water column. The study was performed by Brandsma (1996) and the data are published in the April 1996 E&P Forum Summary Report No. 2.61/202. Because of the extensive North Sea use of oil-based drilling fluids (OBF) and discharge of OBF-cuttings, the E&P Forum sponsored the research project to evaluate the modeled dispersement of treated versus untreated OBF-cuttings. Following is a description of the Brandsma (1996) study from that E&P report.

Brandsma modeled the discharge of nine treatments of cuttings obtained from a North Sea drilling platform to obtain: (1) a maximum deposition density (g/m^2) of cuttings and oil; (2)

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[1]   Subsequent to finalization of the analyses contained in this chapter, EPA published revised water quality criteria (63 FR 68354, December 10, 1998). The following changes affect this Environmental Assessment water quality analyses and will be reflected in the final rule: arsenic human health criterion is deleted; copper acute criterion is raised to 4.8 ug/l and copper chronic criterion is raised to 3.1 ug/l; mercury chronic criterion is raised to 0.94 ug/l and mercury human health is reduced to 0.051 ug/l; and phenol human health criterion is deleted. Appendix B contains the December 1998 criteria recommendations and an analysis of how the water quality assessment would change using these revised criteria.

water column concentrations of suspended solids and oil; (3) the maximum thickness (cm) of cuttings deposited on the seabed; and (4) the seabed area (ha) that would achieve a 100 ppm oil content threshold in the upper 4 cm or 10 cm of the sediment.

Exhibit 4-1. Federal Water Quality Criteria

Pollutant	Marine Acute Criteria (µg/l)	Marine Chronic Criteria (µg/l)	Human Health Criteria (µg/l) (a)
Antimony			4,300
Arsenic	69	36	0.14
Cadmium	42	9.3	
Chromium (VI)	1,100	50	
Copper	2.4	2.4	
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
Zinc	90	81	

(a)   Human health criteria for consumption of organisms only; risk factor of 10^{-6} for carcinogens.
Source: Tabulation of water quality criteria, EPA Health and Ecological Criteria Division, February 1997. See footnote 1 (page 4-2) and Appendix B for information on criteria revision as of December 10, 1998.

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

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

The Offshore Operators Committee (OOC) drilling and production discharge model was used to simulate the concentrations and deposition of discharged cuttings. The OOC model utilized a mixture of 12 profile size classes of mud and cuttings particles (with adsorbed oil) and water. All other discharge conditions were fixed. All discharges simulated a 68.5-hour discharge of 152 m^3 of cuttings from a 0.3 m diameter pipe shunted to a depth of 15.2 m below

mean sea level. This cuttings volume is the volume expected from a single well section of OBF-cuttings. Results presented are based on these 152 m^3 model efforts, however, results are scaled up to a 300 m^3 volume which was later determined by the project steering committee to be more representative of actual OBF-cuttings volumes generated using OBFs (representing two well sections).

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

Water column results were determined at a radial distance of 1000 m downstream. For untreated and centrifuged OBF-cuttings, projected water column oil concentrations at 1000 m were below maximum North Sea background levels at all four sites; all other treatments resulted in projected 1000 m oil concentrations that exceeded maximum background levels (except through treatment at the Haltenbanken site). The explanation for this apparent conundrum is that while treatments other than centrifugation also reduce oil content (from an untreated level of 15.8% [w/w] to a range of 0.3% to 5.1%), these treatments also generate cuttings with finer particle sizes. Thus, according to the model, the untreated and centrifuged OBF-cuttings would not reach the 1000 m mark to the same extent that the treated OBF-cuttings would because the finer particles created by the treatment have lower settling velocities and are transported farther in the water column (Brandsma, 1996).

Although Brandsma (1996) does not present oil concentration data for a radial distance of 100 m (the edge of the mixing zone established for U.S. offshore discharges by Clean Water Act Section 403, Ocean Discharge Criteria, as codified at 40 CFR 125 Subpart M), the study does present data on suspended solids and oil concentration as a function of transport time. Using current speeds representative of each geographic area (Gulf of Mexico; Cook Inlet, Alaska; and offshore California) and the transport times reported by Brandsma, EPA derived the corresponding oil concentrations and dilutions at 100 m. For example, assuming a mean current speed of 15 cm/s as representative of the Gulf of Mexico, a transport time of approximately 11 minutes is derived as the time required for the plume to reach 100 m (100 m/0.15 m/sec). From graphical analysis of the data presented in Figure 2 of Brandsma's 1996 study (provided in Appendix C), the oil concentration can be determined for selected transport times. Based on the mean initial oil concentration of the 9 cuttings cases presented in the study (5.5% in water-washed cuttings), the dilutions achieved can be estimated for a selected time (i.e., distance) in the following manner. The 5.5% (w/w) oil content converts to 55 g oil/kg wet cuttings. Based on a reported mean OBF-cuttings density of 2.050 kg wet cuttings/l, the initial oil concentration of 112,750 mg oil/l (55 g/kg x 2.050 kg/l) is used to determine the dilutions achieved. For the Gulf

of Mexico example, the oil concentration at 11 minutes of 3.2 mg/l is used to calculate a 35,234-fold dilution (112,750 mg/3.2 mg) at 11 minutes. As described above, 11 minutes represents the estimated time at which the plume would reach the edge of the mixing zone at 100 meters.

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

Exhibit 4-2 summarizes the water quality analyses for Gulf of Mexico, Cook Inlet, Alaska, and offshore California water column pollutant concentrations at 100 m from SBF-cuttings discharges. The results show that no exceedances of any Federal or state water quality criteria or standards are expected using current technology or the discharge option.

Exhibit 4-2. Summary of Water Column Water Quality Analyses

Discharge Region	Shallow Water				Deep Water			
	Development		Exploratory		Development		Exploratory	
	Current Technology	Discharge Option	Current Technology	Discharge Option	Current Technology	Discharge Option	Current Technology	Discharge Option
Gulf of Mexico	-- (b)	--	--	--	--	--	--	--
California	--	--	NA (c)	NA	--	--	NA	NA
Cook Inlet, Alaska	--	–	NA	NA	NA	NA	NA	NA

(a)   Current technology equals the Gulf of Mexico current industry practice of SBF-cuttings treatment to 11% SBF retention on cuttings.
(b)   -- indicates no exceedances of Federal or state water quality criteria or standards from any of the discharged pollutants.
(c)   NA = Not applicable; For Cook Inlet, Alaska and offshore California, EPA does not anticipate any exploratory drilling to occur. In addition, EPA does not consider any of the drilling activity in Cook Inlet, Alaska to be in deep water (> 1,000 ft).

4.2.1 *Gulf of Mexico*

Exhibits 4-3 and 4-4 compare the projected pollutant concentrations for Gulf of Mexico discharges of SBFs with the Federal water quality criteria under the discharge scenarios for the current technology and the discharge option. For this analysis, and all subsequent water quality and pore water quality analyses in this report, the zero discharge option is not presented in tabular form. Because no drilling wastes are discharged under the zero discharge option, there are no water quality criteria concerns to assess.

The water column pollutant concentrations for all four model wells (deep water exploratory, deep water development, shallow water exploratory, and shallow water development) are the same within each discharge scenario. This occurs because only the total discharge volume for each of the model wells varies, not the discharge rate or individual pollutant concentrations. The reader should also note that in the exhibits that follow, only the most stringent water quality criterion is listed for each pollutant. Any exceedances of water quality criteria are detailed in the footnotes of each table.

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

4.2.2 *Cook Inlet, Alaska*

EPA compared pollutant concentrations resulting from the discharge of SBF-cuttings in Cook Inlet, Alaska to both Federal criteria and state water quality standards because the discharges occur in state waters. The Alaska standard for "toxic and other deleterious organic and inorganic substances" states that "individual substances may not exceed criteria in EPA, Quality Criteria for Water, or, if those do not exist, may not exceed the Primary Maximum Contaminant Levels of the Alaska Drinking Water Standards (18 AAC 80)." The Alaska standards for waters classified as marine waters for growth and propagation of fish, shellfish, and other aquatic life, and wildlife are presented in Exhibit 4-5.

Exhibit 4-3. Water Column Pollutant Concentrations - Gulf of Mexico, Current Technology

Pollutant	Pollutant Conc. in Effluent (mg/l) (a)	Trace Metal Leach Factor (b)	Water Column Conc. at 100 m (mg/l) (c)	Federal Water Quality Criteria (mg/l) (d)	Federal Criteria Exceedance Factor (e)
Naphthalene	1.1700		3.32e-05		
Fluorene	0.6382		1.81e-05	1.40e+01	
Phenanthrene	1.5136		4.30e-05		
Phenol	0.0001		2.39e-09	4.60e+03	
Cadmium	0.1707	0.1100	5.33e-07	9.30e-03	
Mercury	0.0155	0.0180	7.93e-09	2.50e-05	
Antimony	0.8843			4.30e+00	
Arsenic	1.1015	0.0050	1.56e-07	1.40e-04	
Beryllium	0.1086				
Chromium	37.2331	0.0340	3.59e-05	5.00e-02	
Copper	2.9011	0.0063	5.19e-07	2.40e-03	
Lead	5.4453	0.0200	3.09e-06	8.10e-03	
Nickel	2.0944	0.0430	2.56e-06	8.20e-03	
Selenium	0.1707			7.10e-02	
Silver	0.1086			1.90e-03	
Thallium	0.1862			6.30e-03	
Zinc	31.1051	0.0041	3.92e-06	8.10e-02	
Aluminum	1,407.0				
Barium	18,616.5	0.0021	1.11e-03		
Iron	2,380.5	0.1300	8.78e-03		
Tin	2.2650				
Titanium	13.5746				
Alkylated benzenes	6.5861		1.87e-04		
Alkylated naphthalenes	61.9177		1.76e-03		
Alkylated fluorenes	7.4534		2.12e-04		
Alkylated phenanthrenes	9.4169		2.67e-04		
Alkylated phenols	0.0007		2.10e-08		
Total biphenyls	12.2395		3.47e-04		
Total dibenzothiophenes	0.0107		3.02e-07		

(a)   See section 3.2 for effluent pollutant concentrations.

(b)   Source: Offshore Environmental Assessment (Avanti, 1993); assumed to be 1 unless otherwise listed.

(c)   Water column pollutant conc. = (avg. poll. conc. x leach factor)/dilutions (35,234 dilutions).

(d)   Most stringent criterion shown on this table representing marine acute, marine chronic, and human health (fish consumption) criteria (see Exhibit 4-1); there are no Federal water quality criteria for specific SBF compounds.

(e)   No Federal water quality criteria are exceeded.

Exhibit 4-4. Water Column Pollutant Concentrations - Gulf of Mexico, Discharge Option

Pollutant	Pollutant Conc. in Effluent (mg/l) (a)	Trace Metal Leach Factor (b)	Water Column Conc. at 100 m (mg/l) (c)	Federal Water Quality Criteria (mg/l) (d)	Federal Criteria Exceedance Factor (e)
Naphthalene	0.811		2.30e-05		
Fluorene	0.442		1.26e-05	1.40e+01	
Phenanthrene	1.049		2.98e-05		
Phenol	0.0001		1.66e-09	4.60e+03	
Cadmium	0.118	0.1100	3.69e-07	9.30e-03	
Mercury	0.0108	0.0180	5.49e-09	2.50e-05	
Antimony	0.613			4.30e+00	
Arsenic	0.763	0.0050	1.08e-07	1.40e-04	
Beryllium	0.0750				
Chromium	25.80	0.0340	2.49e-05	5.00e-02	
Copper	2.011	0.0063	3.59e-07	2.40e-03	
Lead	3.774	0.0200	2.14e-06	8.10e-03	
Nickel	1.452	0.0430	1.77e-06	8.20e-03	
Selenium	0.118			7.10e-02	
Silver	0.0750			1.90e-03	
Thallium	0.129			6.30e-03	
Zinc	21.56	0.0041	2.51e-06	8.10e-02	
Aluminum	975.2				
Barium	12,902	0.0021	7.69e-04		
Iron	1,650	0.1300	6.09e-03		
Tin	1.570				
Titanium	9.408				
Alkylated benzenes	4.566		1.30e-04		
Alkylated naphthalenes	42.93		1.22e-03		
Alkylated fluorenes	5.167		1.47e-04		
Alkylated phenanthrenes	6.529		1.85e-04		
Alkylated phenols	0.0005		1.46e-08		
Total biphenyls	8.486		2.41e-04		
Total dibenzothiophenes	0.0074		2.10e-07		

(a)   See section 3.2 for effluent pollutant concentrations.

(b)   Source: Offshore Environmental Assessment (Avanti, 1993); assumed to be 1 unless otherwise listed.

(c)   Water column pollutant conc. = (avg. poll. conc. x leach factor)/dilutions (35,234 dilutions).

(d)   Most stringent criterion shown on this table representing marine acute, marine chronic, and human health (fish consumption) criteria (see Exhibit 4-1); there are no Federal water quality criteria for specific SBF compounds.

(e)   No Federal water quality criteria are exceeded.

Exhibit 4-5. Alaska State Water Quality Standards

Pollutant	Standard (mg/l)
Antimony	6.00E-03
Barium	2.00E+00
Beryllium	4.00E-03
Chromium	1.00E-01
Nickel	1.00E-01
Selenium	5.00E-02
Thallium	2.00E-03

EPA determined the dilutions for assessment of compliance with water quality criteria and standards using the same methodology as for the Gulf of Mexico analysis. A current speed of 40 cm/sec was used (EPA Region 10, 1984), resulting in a transport time of 4.2 minutes to reach the edge of the 100-meter mixing zone. The midpoint oil concentration from Brandsma (1996) at 4 minutes is 28 mg/l. This concentration is a 4,027-fold dilution from the initial discharge concentration of oil (112,750 mg/l).

The current operating practice in Cook Inlet, Alaska is zero discharge of SBF-cuttings. However, for the purpose of comparison with the discharge option, an analysis of the current technology (11% SBF retention on cuttings) is presented in Exhibit 4-6 for Cook Inlet, Alaska. For the discharge option, Exhibit 4-7 presents the water column concentrations of pollutants at 100 meters from the discharge point and compares them to Federal water quality criteria and Alaska state standards. Under the current technology and the discharge option, there are no exceedances of the Federal criteria or state numerical standards in Cook Inlet, Alaska.

4.2.3 *Offshore California*

EPA compared pollutant concentrations resulting from the discharge of SBF-cuttings in offshore California waters to Federal water quality criteria to determine compliance with these guidelines. EPA determined the dilutions for assessment of compliance with water quality standards using the same methodology as for the Gulf of Mexico analysis. A current speed of 30 cm/sec was used (MMS, 1985), resulting in a transport time of 5.5 minutes to reach the edge of the 100-meter mixing zone. The midpoint oil concentration from Brandsma (1996) at 5 minutes is 20 mg/l. This concentration is a 5,638-fold dilution from the initial discharge concentration of oil (112,750 mg/l).

Exhibit 4-6. Water Column Pollutant Concentrations - Cook Inlet, Alaska, Current Technology

Pollutant	Pollutant Conc. in Effluent (mg/l) (a)	Trace Metal Leach Factor (b)	Water Column Conc. at 100 m (mg/l) (c)	Federal Water Quality Criteria (mg/l) (d)	State Water Quality Standards (mg/l)	Criteria/ Standards Exceed. Factor (e)
Naphthalene	1.1700		2.91e-04			
Fluorene	0.6382		1.58e-04	1.40e+01		
Phenanthrene	1.5136		3.76e-04			
Phenol	0.0001		2.09e-08	4.60e+03		
Cadmium	0.1707	0.1100	4.66e-06	9.30e-03		
Mercury	0.0155	0.0180	6.93e-08	2.50e-05		
Antimony	0.8843		2.20e-04	4.30e+00	6.00e-03	
Arsenic	1.1015	0.0050	1.37e-06	1.40e-04	5.00e-01	
Beryllium	0.1086		2.70e-05		4.00e-03	
Chromium	37.2331	0.0340	3.14e-04	5.00e-02	1.00e-01	
Copper	2.9011	0.0063	4.54e-06	2.40e-03		
Lead	5.4453	0.0200	2.70e-05	8.10e-03		
Nickel	2.0944	0.0430	2.24e-05	8.20e-03	1.00e-01	
Selenium	0.1707		4.24e-05	7.10e-02	5.00e-02	
Silver	0.1086		2.70e-05	1.90e-03		
Thallium	0.1862		4.62e-05	6.30e-03	2.00e-03	
Zinc	31.1051	0.0041	3.17e-05	8.10e-02		
Aluminum	1,407.0					
Barium	18,616.5	0.0021	9.71e-03		2.00e+00	
Iron	2,380.5	0.1300	7.68e-02			
Tin	2.2650		5.62e-04			
Titanium	13.5746		3.37e-03			
Alkylated benzenes	6.5861		1.64e-03			
Alkylated naphthalenes	61.9177		1.54e-02			
Alkylated fluorenes	7.4534		1.85e-03			
Alkylated phenanthrenes	9.4169		2.34e-03			
Alkylated phenols	0.0007		1.84e-07			
Total biphenyls	12.2395		3.04e-03			
Total dibenzothiophenes	0.0107		2.64e-06			

(a)   See section 3.2 for effluent pollutant concentrations.
(b)   Source: Offshore Environmental Assessment (Avanti, 1993); assumed to be 1 unless otherwise listed.
(c)   Water column pollutant conc. = (avg. poll. conc. x leach factor)/dilutions (4,027 dilutions).
(d)   Most stringent criterion shown on this table representing marine acute, marine chronic, and human health (fish consumption) criteria (see Exhibit 4-1); there are no Federal water quality criteria for specific SBF compounds.
(e)   No Federal water quality criteria or state standards are exceeded.

Exhibit 4-7. Water Column Pollutant Concentrations - Cook Inlet, Alaska, Discharge Option

Pollutant	Poll. Conc. in Effluent (mg/l) (a)	Trace Metal Leach Factor (b)	Water Column Conc. at 100 m (mg/l) (c)	Federal Water Quality Criteria (mg/l) (d)	State Water Quality Standards (mg/l)	Criteria/ Standards Exceed. Factor (e)
Naphthalene	0.811		2.01e-04			
Fluorene	0.442		1.10e-04	1.40e+01		
Phenanthrene	1.049		2.61e-04			
Phenol	0.0001		1.45e-08	4.60e+03		
Cadmium	0.118	0.1100	3.23e-06	9.30e-03		
Mercury	0.0108	0.0180	4.81e-08	2.50e-05		
Antimony	0.613		1.52e-04	4.30e+00	6.00e-03	
Arsenic	0.763	0.0050	9.48e-07	1.40e-04	5.00e-01	
Beryllium	0.075		1.87e-05		4.00e-03	
Chromium	25.80	0.0340	2.18e-04	5.00e-02	1.00e-01	
Copper	2.011	0.0063	3.15e-06	2.40e-03		
Lead	3.774	0.0200	1.87e-05	8.10e-03		
Nickel	1.452	0.0430	1.55e-05	8.20e-03	1.00e-01	
Selenium	0.118		2.94e-05	7.10e-02	5.00e-02	
Silver	0.075		1.87e-05	1.90e-03		
Thallium	0.129		3.20e-05	6.30e-03	2.00e-03	
Zinc	21.56	0.0041	2.19e-05	8.10e-02		
Aluminum	975.2					
Barium	12,902	0.0021	6.73e-03		2.00e+00	
Iron	1,650	0.1300	5.33e-02			
Tin	1.570		3.90e-04			
Titanium	9.408		2.34e-03			
Alkylated benzenes	4.566		1.13e-03			
Alkylated naphthalenes	42.93		1.07e-02			
Alkylated fluorenes	5.167		1.28e-03			
Alkylated phenanthrenes	6.529		1.62e-03			
Alkylated phenols	0.0005		1.28e-07			
Total biphenyls	8.486		2.11e-03			
Total dibenzothiophenes	0.0074		1.83e-06			

(a)   See section 3.2 for effluent pollutant concentrations.

(b)   Source: Offshore Environmental Assessment (Avanti, 1993); assumed to be 1 unless otherwise listed.

(c)   Water column pollutant conc. = (avg. poll. conc. x leach factor)/dilutions (4,027 dilutions).

(d)   Most stringent criterion shown on this table representing marine acute, marine chronic, and human health (fish consumption) criteria (see Exhibit 4-1); there are no Federal water quality criteria for specific SBF compounds.

(e)   No Federal water quality criteria or state standards are exceeded.

The current practice in offshore California is zero discharge of SBF-cuttings. However, for the purpose of comparison with the discharge option, an analysis of the current technology (11% SBF retention on cuttings) is presented in Exhibit 4-8 for offshore California. For the discharge option, Exhibit 4-9 presents the water column concentrations of pollutants at 100 meters from the discharge point and compares them to Federal water quality criteria. Under both current technology and the discharge option, there are no exceedances of the Federal water quality criteria in offshore California.

4.3 Sediment Pore Water Quality

EPA calculated sediment pollutant levels based on the assumption of a uniform distribution of the annual mass loadings of pollutants from model operations into a defined area of impact. Using the derived sediment pollutant concentrations, EPA assessed sediment pore water quality. A summary of the pore water quality analyses for discharges of SBF-cuttings in the Gulf of Mexico, Cook Inlet, Alaska, and offshore California is presented in Exhibit 4-10.

4.3.1 *Gulf of Mexico*

To assess the pore water quality impacts of the discharge of SBF-cuttings on the benthic environment, EPA determined the pollutant concentrations in the pore water for each model well and each discharge scenario at the edge of the 100-meter mixing zone. EPA then compared these projected pore water concentrations of pollutants from the SBF-cuttings to Federal water quality criteria to determine the number of exceedances and the magnitude of each exceedance. Following is a detailed explanation of the methodology used to assess pore water quality.

The pore water quality analysis of the offshore Effluent Limitations Guidelines characterized sediment pollutants through a number of field surveys of both exploratory and development operations. These surveys predominantly measured sediment barium content, which was considered the best marker for assessing transport and fate of the particulate fraction of water-based drilling fluids. In this current environmental assessment, EPA again assessed field surveys but the sediment concentration of synthetic base fluid was considered the most reliable marker of SBF-cuttings transport. EPA compiled sediment synthetic base fluid concentration data from 5 surveys of 11 wells. Ten wells were drilled in the North Sea and one in the Gulf of Mexico. If the survey data did not include data for a 100-m sampling location, EPA linearly extrapolated the existing data points to 100 m. A summary of the 100-m sediment synthetic base fluid concentrations is presented in Exhibit 4-11. For three of the wells listed in the summary, data for two different sampling transects are included. Because concentrations were averaged over different transects per well, that is, not consistently down current, the

Exhibit 4-8. Water Column Pollutant Concentrations - Offshore California, Current Technology

Pollutant	Pollutant Conc. in Effluent (mg/l) (a)	Trace Metal Leach Factor (b)	Water Column Conc. at 100 m (mg/l) (c)	Federal Water Quality Criteria (mg/l) (d)	Federal Criteria Exceedance Factor (e)
Naphthalene	1.1700		2.08e-04		
Fluorene	0.6382		1.13e-04	1.40e+01	
Phenanthrene	1.5136		2.68e-04		
Phenol	0.0001		1.48e-08	4.60e+03	
Cadmium	0.1707	0.1100	3.33e-06	9.30e-03	
Mercury	0.0155	0.0180	4.95e-08	2.50e-05	
Antimony	0.8843		1.57e-04	4.30e+00	
Arsenic	1.1015	0.0050	9.77e-07	1.40e-04	
Beryllium	0.1086		1.93e-05		
Chromium	37.2331	0.0340	2.25e-04	5.00e-02	
Copper	2.9011	0.0063	3.24e-06	2.40e-03	
Lead	5.4453	0.0200	1.93e-05	8.10e-03	
Nickel	2.0944	0.0430	1.60e-05	8.20e-03	
Selenium	0.1707		3.03e-05	7.10e-02	
Silver	0.1086		1.93e-05	1.90e-03	
Thallium	0.1862		3.30e-05	6.30e-03	
Zinc	31.1051	0.0041	2.26e-05	8.10e-02	
Aluminum	1,407.0				
Barium	18,616.5	0.0021	6.93e-03		
Iron	2,380.5	0.1300	5.49e-02		
Tin	2.2650		4.02e-04		
Titanium	13.5746		2.41e-03		
Alkylated benzenes	6.5861		1.17e-03		
Alkylated naphthalenes	61.9177		1.10e-02		
Alkylated fluorenes	7.4534		1.32e-03		
Alkylated phenanthrenes	9.4169		1.67e-03		
Alkylated phenols	0.0007		1.31e-07		
Total biphenyls	12.2395		2.17e-03		
Total dibenzothiophenes	0.0107		1.89e-06		

(a)   See section 3.2 for effluent pollutant concentrations.

(b)   Source: Offshore Environmental Assessment (Avanti, 1993); assumed to be 1 unless otherwise listed.

(c)   Water column pollutant conc. = (avg. poll. conc. x leach factor)/dilutions (5,638 dilutions).

(d)   Most stringent criterion shown on this table representing marine acute, marine chronic, and human health (fish consumption) criteria (see Exhibit 4-1); there are no Federal water quality criteria for specific SBF compounds.

(e)   No Federal water quality criteria are exceeded.

Exhibit 4-9. Water Column Pollutant Concentrations - Offshore California, Discharge Option

Pollutant	Pollutant Conc. in Effluent (mg/l) (a)	Trace Metal Leach Factor (b)	Water Column Conc. at 100 m (mg/l); (c)	Federal Water Quality Criteria (mg/l) (d)	Federal Criteria Exceedance Factor (e)
Naphthalene	0.811		1.44e-04		
Fluorene	0.442		7.85e-05	1.40e+01	
Phenanthrene	1.049		1.86e-04		
Phenol	0.0001		1.03e-08	4.60e+03	
Cadmium	0.118	0.1100	2.10e-05	9.30e-03	
Mercury	0.0108	0.0180	1.91e-06	2.50e-05	
Antimony	0.613		1.09e-04	4.30e+00	
Arsenic	0.763	0.0050	1.35e-04	1.40e-04	
Beryllium	0.075		1.33e-05		
Chromium	25.80	0.0340	4.58e-03	5.00e-02	
Copper	2.011	0.0063	3.57e-04	2.40e-03	
Lead	3.774	0.0200	6.69e-04	8.10e-03	
Nickel	1.452	0.0430	2.57e-04	8.20e-03	
Selenium	0.118		2.09e-05	7.10e-02	
Silver	0.075		1.33e-05	1.90e-03	
Thallium	0.129		2.29e-05	6.30e-03	
Zinc	21.56	0.0041	3.82e-03	8.10e-02	
Aluminum	975.2				
Barium	12,902	0.0021	4.81e-03		
Iron	1,650	0.1300	3.80e-02		
Tin	1.570		2.79e-04		
Titanium	9.408		1.67e-03		
Alkylated benzenes	4.566		8.10e-04		
Alkylated naphthalenes	42.93		7.61e-03		
Alkylated fluorenes	5.167		9.17e-04		
Alkylated phenanthrenes	6.529		1.16e-03		
Alkylated phenols	0.0005		9.12e-08		
Total biphenyls	8.486		1.51e-03		
Total dibenzothiophenes	0.0074		1.31e-06		

(a)   See section 3.2 for effluent pollutant concentrations.
(b)   Source: Offshore Environmental Assessment (Avanti, 1993).
(c)   Water column pollutant conc. = (avg. poll. conc. x leach factor)/dilutions (5,638 dilutions).
(d)   Most stringent criterion shown on this table representing marine acute, marine chronic, and human health (fish consumption) criteria (see Exhibit 4-1); there are no Federal water quality criteria for specific SBF compounds.
(e)   No Federal water quality criteria are exceeded.

Exhibit 4-10. Summary of Pore Water Quality Analyses - Factors by Which Criteria are Exceeded

Discharge Region	Pollutant	Shallow Water (a)				Deep Water (a)			
		Development		Exploratory		Development		Exploratory	
		Current Tech-nology	Discharge Option	Current Tech-nology	Discharge Option	Current Tech-nology	Discharge Option	Current Tech-nology	Discharge Option
Gulf of Mexico	Arsenic	1.3	-- (b)	2.7	--	1.9	1.1	4.3	2.5
	Chromium	--	--	1.7	--	1.3	--	2.8	1.6
	Mercury	--	--	--	--	--	--	1.2	--
	Lead	--	--	--	--	--	--	1.5	--
	Nickel	--	--	--	--	--	--	1.2	--
Cook Inlet, Alaska	Arsenic	--	--	NA (c)	NA	NA	NA	NA	NA
Offshore California	Arsenic	--	--	NA	NA	1.2	--	NA	NA

(a)   There would be no exceedances for any pollutants with the zero discharge option.
(b)   -- indicates that no exceedances are predicted.
(c)   NA indicates that type of model well does not currently exist or is not projected for that geographic region.

resultant synthetic base fluid concentration represents the average concentration found at any given point 100 m around a well as opposed to the maximum (i.e., down current) concentration. Given the reported depths and discharge volumes of the studies, the calculated average concentration most closely represents current practice for a Gulf of Mexico shallow water exploratory model well.

In order to determine SBF-cuttings pollutant concentrations for other model well types, EPA assumed that the relative concentrations or proportions between the base fluid and other pollutants as found in the SBF are maintained after discharge and transport. Therefore, to project the sediment concentration of each pollutant, EPA multiplied the ratio of each pollutant to the synthetic base fluid by the average 100-m base fluid concentration (13,892 mg synthetic/kg for the shallow water exploratory model well; see Exhibit 4-11). For each model well, this factor is further adjusted to account for the varying total amount of oil (synthetic plus formation oil) discharged. For example, EPA determined that the shallow development well would discharge only 47.7% of the oil as the shallow exploratory well. Therefore, the sediment pollutant concentrations for the shallow development well are 47.7% of those for the shallow exploratory well. For the deep wells (using the shallow water exploratory well as 100%), these factors are 160.5% and 72.2% for exploratory and development well pollutants, respectively.

Exhibit 4-11. Summary of Synthetic Base Fluid Concentrations at 100 Meters

Data Source	Study Site/Location	Depth (m)	Base Fluid Type	Conc. at 100 m (mg/kg) (a)
Candler et al., 1995	MPI-895; Gulf of Mexico	39	PAO	90,105
Daan et al., 1996	K14-13; North Sea	30	Ester	522.1
Smith and May,1991 in Schaanning, 1995	Ula 7/12-9; North Sea	67	Ester	46,400
Baake et al., 1992 in Schaanning, 1995	Gyda 2/1-9; North Sea	--	Ether	1,418
Gjøs, 1995a in Vik et al., 1996a	Tordis Well; North Sea	181 - 218	PAO	15,090
Gjøs. 1995b in Vik et al., 1996a	Loke Well; North Sea	76 - 81	Ester	145.8
	Sleipner A Well; North Sea	76 - 81	Ester	62; 622
	Sleipner Ø Well; North Sea	--	Ester	3,850
Gjøs, 1992 & 1993 in Vik et al., 1996a	Gyda 2/1-9; North Sea	70	Ether	420; 200
Larsen, 1995 in Vik et al., 1996a	Ula 2/7-29; North Sea	67	Acetal	24,833; 10,000
Feldstedt, 1991 in Vik et al., 1996a	Ula 7/12-A6	67	Acetal	815
Average concentration at 100 meters (represents a Gulf of Mexico shallow water exploratory model well)				13,892
Average concentration at 100 meters (excluding the 2 shallowest discharges; represents Cook Inlet, Alaska and offshore California shallow water exploratory model well)				8,655

(a)   More than one value per well represents values from different sampling transects.

These sediment pollutant concentrations are converted into pore water concentrations. For metals, the mean seawater leach factors of trace metals in barite are used. For organic pollutants, partition coefficients are used to project pore water concentrations. Partition coefficients estimate the ratio of sediment to pore water concentration as the product of the fraction of organic carbon (f_{oc}) and the octanol-water partition coefficient (K_{ow}). For sediments, the K_{ow} = the partition coefficient for organic particle carbon (K_{oc}). Therefore, $K_{sed} = f_{oc} * K_{oc}$. Both the f_{oc} and K_{oc} used for this analysis are presented in Exhibit 4-12 and are based on the offshore environmental analysis (Avanti Corporation, 1993). The leach factors and partition coefficients are summarized in Exhibit 4-12. The sediment concentration multiplied by the pollutant specific leach factor or inverse of the partition coefficient results in the amount of pollutant available in the pore water. To calculate the interstitial (pore water) concentration of each pollutant, the available pollutant sediment concentration is multiplied by the dry weight of sediment in a 1m x 1m x 0.05m unit volume and divided by the volume of water per unit volume of sediment. Based on the offshore Environmental Assessment, the dry weight of sediment equals 35.5 kg and the volume of pore water approximated from a dry sediment specific weight of 2 g/ml is 32.5 l (Avanti Corporation, 1993).

The calculated pore water concentrations of pollutants are then compared to their respective EPA marine water quality criteria to determine the nature and magnitude of any projected water quality exceedances. Exhibits 4-13 through 4-20 present the pore water quality analyses and comparisons to the EPA water quality criteria for Gulf of Mexico discharges from wells using the current and discharge option technologies.

4.3.2   *Cook Inlet, Alaska and Offshore California*

To assess the pore water quality impacts for Cook Inlet, Alaska and offshore California, EPA again used the synthetic base fluid concentrations presented in Exhibit 4-11 to estimate the concentration of synthetic fluids at 100 meters from the discharge. Due to the increased energy and depth of Cook Inlet and offshore California, two of the studies in Exhibit 4-11 were eliminated from the calculation of the average synthetic base fluid concentration at 100 meters. Both of the eliminated studies included discharges in less than 40 meters total water depth (Candler et al., 1995 and Daan et al., 1996).

Exhibit 4-12. Trace Metal Leach Factors and Organic Pollutant Partition Coefficients

Trace Metal	Mean Seawater Leach Factor		
Cadmium	0.11		
Mercury	0.018		
Arsenic	0.005		
Chromium	0.034		
Copper	0.0063		
Lead	0.02		
Nickel	0.043		
Zinc	0.0041		
Barium	0.0021		
Iron	0.13		
Organic Pollutant	K_{oc}	f_{oc}	**1/Partition Coefficient**
Naphthalene	1,995	0.63%	0.0796
Fluorene	3,900	0.63%	0.0407
Phenanthrene	14,000	0.63%	0.0113
Phenol	14	0.63%	11.34

Source: Offshore Environmental Assessment (Avanti Corporation, 1993).

Exhibit 4-13. Pore Water Pollutant Concentrations - Gulf of Mexico Deep Water Development Model Well, Current Technology

Pollutant	Poll. Conc. in Sediment at 100 m (mg/kg) (a)	Partition Coefficient^-1 or Leach Factor	Pore Water Conc. (mg/l) (b)	Federal Water Quality Criteria (mg/l) (c)	Federal Criteria Exceedance Factor (d)
Naphthalene	0.0529	0.0795	4.59e-03		
Fluorene	0.0289	0.0407	1.28e-03	1.40e+01	
Phenanthrene	0.0684	0.0113	8.45e-04		
Phenol	3.80e-06	11.338	4.71e-05	4.60e+03	
Cadmium	0.0077	0.1100	9.28e-04	9.30e-03	
Mercury	0.0007	0.0180	1.38e-05	2.50e-05	
Antimony	0.0400			4.30e+00	
Arsenic	0.0498	0.0050	2.72e-04	1.40e-04	1.9
Beryllium	0.0049				
Chromium	1.6844	0.0340	6.26e-02	5.00e-02	1.3
Copper	0.1312	0.0063	9.03e-04	2.40e-03	
Lead	0.2463	0.0200	5.38e-03	8.10e-03	
Nickel	0.0947	0.0430	4.45e-03	8.20e-03	
Selenium	0.0077			7.10e-02	
Silver	0.0049			1.90e-03	
Thallium	0.0084			6.30e-03	
Zinc	1.4072	0.0041	6.30e-03	8.10e-02	
Aluminum	63.6558				
Barium	842.203	0.0021	1.93e+00		
Iron	107.6918	0.1300	1.53e+01		
Tin	0.1025				
Titanium	0.6141				
Alkylated benzenes	0.2978				
Alkylated naphthalenes	2.7998				
Alkylated fluorenes	0.3370				
Alkylated phenanthrenes	0.4258				
Alkylated phenols	0.0000				
Total biphenyls	0.5534				
Total dibenzothiophenes	0.0005				

(a)   Pollutant concentration in sediment calculation shown in Appendix D.

(b)   Pore water conc. = Poll. Conc. in Sediment * Partition Coeff^{-1} or Leach Factor * 35.5 kg sediment/32.5 l pore water

(c)   Most stringent criterion shown on this table representing marine acute, marine chronic, and human health (fish consumption) criteria (see Exhibit 4-1); there are no Federal water quality criteria for specific SBF compounds.

(d)   Pore water pollutant concentration exceeds the water quality criteria for arsenic (human health) by a factor of 1.9 and chromium (marine chronic) by a factor of 1.3.

Exhibit 4-14. Pore Water Pollutant Concentrations - Gulf of Mexico Deep Water Exploratory Model Well, Current Technology

Pollutant	Poll. Conc. in Sediment at 100 m (mg/kg) (a)	Partition Coefficient^-1 or Leach Factor	Pore Water Conc. (mg/l) (b)	Federal Water Quality Criteria (mg/l) (c)	Federal Criteria Exceedance Factor (d)
Naphthalene	0.1177	0.0795	1.02e-02		
Fluorene	0.0642	0.0407	2.85e-03	1.40e+01	
Phenanthrene	0.1523	0.0113	1.88e-03		
Phenol	8.46e-06	11.338	1.05e-04	4.60e+03	
Cadmium	0.0172	0.1100	2.06e-03	9.30e-03	
Mercury	0.0016	0.0180	3.07e-05	2.50e-05	1.2
Antimony	0.0890			4.30e+00	
Arsenic	0.1108	0.0050	6.05e-04	1.40e-04	4.3
Beryllium	0.0109				
Chromium	3.7453	0.0340	1.39e-01	5.00e-02	2.8
Copper	0.2918	0.0063	2.01e-03	2.40e-03	
Lead	0.5478	0.0200	1.20e-02	8.10e-03	1.5
Nickel	0.2107	0.0430	9.90e-03	8.20e-03	1.2
Selenium	0.0172			7.10e-02	
Silver	0.0109			1.90e-03	
Thallium	0.0187			6.30e-03	
Zinc	3.1289	0.0041	1.40e-02	8.10e-02	
Aluminum	141.5403				
Barium	1,872.659	0.0021	4.30e+00		
Iron	239.4554	0.1300	3.40e+01		
Tin	0.2278				
Titanium	1.3655				
Alkylated benzenes	0.6625				
Alkylated naphthalenes	6.2284				
Alkylated fluorenes	0.7497				
Alkylated phenanthrenes	0.9473				
Alkylated phenols	0.0001				
Total biphenyls	1.2312				
Total dibenzothiophenes	0.0011				

(a)   Pollutant concentration in sediment calculation shown in Appendix D.

(b)   Pore water conc. = Poll. Conc. in Sediment * Partition Coeff^{-1} or Leach Factor * 35.5 kg sediment/32.5 l pore water

(c)   Most stringent criterion shown on this table representing marine acute, marine chronic, and human health (fish consumption) criteria (see Exhibit 4-1); there are no Federal water quality criteria for specific SBF compounds.

(d)   Pore water pollutant concentration exceeds the water quality criteria for mercury (marine chronic) by a factor of 1.2, arsenic (human health) by a factor of 4.3, chromium (marine chronic) by a factor of 2.8, lead (marine chronic) by a factor of 1.5, and nickel (marine chronic) by a factor of 1.2.

Exhibit 4-15. Pore Water Pollutant Concentrations - Gulf of Mexico Shallow Water Development Model Well, Current Technology

Pollutant	Poll. Conc. in Sediment at 100 m (mg/kg) (a)	Partition Coefficient^-1 or Leach Factor	Pore Water Conc. (mg/l) (b)	Federal Water Quality Criteria (mg/l) (c)	Federal Criteria Exceedance Factor (d)
Naphthalene	0.0350	0.0795	3.04e-03		
Fluorene	0.0191	0.0407	8.49e-04	1.40e+01	
Phenanthrene	0.0453	0.0113	5.59e-04		
Phenol	2.52e-06	11.338	3.12e-05	4.60e+03	
Cadmium	0.0051	0.1100	6.13e-04	9.30e-03	
Mercury	0.0005	0.0180	9.12e-06	2.50e-05	
Antimony	0.0264			4.30e+00	
Arsenic	0.0329	0.0050	1.80e-04	1.40e-04	1.3
Beryllium	0.0032				
Chromium	1.1131	0.0340	4.13e-02	5.00e-02	
Copper	0.0867	0.0063	5.97e-04	2.40e-03	
Lead	0.1628	0.0200	3.56e-03	8.10e-03	
Nickel	0.0626	0.0430	2.94e-03	8.20e-03	
Selenium	0.0051			7.10e-02	
Silver	0.0032			1.90e-03	
Thallium	0.0056			6.30e-03	
Zinc	0.9299	0.0041	4.16e-03	8.10e-02	
Aluminum	42.0670				
Barium	556.571	0.0021	1.28e+00		
Iron	71.1682	0.1300	1.01e+01		
Tin	0.0677				
Titanium	0.4058				
Alkylated benzenes	0.1970				
Alkylated naphthalenes	1.8523				
Alkylated fluorenes	0.2230				
Alkylated phenanthrenes	0.2817				
Alkylated phenols	0.0000				
Total biphenyls	0.3662				
Total dibenzothiophenes	0.0003				

(a)   Pollutant concentration in sediment calculation shown in Appendix D.
(b)   Pore water conc. = Poll. Conc. in Sediment * Partition Coeff[-1] or Leach Factor * 35.5 kg sediment/32.5 l pore water
(c)   Most stringent criterion shown on this table representing marine acute, marine chronic, and human health (fish consumption) criteria (see Exhibit 4-1); there are no Federal water quality criteria for specific SBF compounds.
(d)   Pore water pollutant concentration exceeds the water quality criterion for arsenic (human health) by a factor of 1.3.

Exhibit 4-16. Pore Water Pollutant Concentrations - Gulf of Mexico Shallow Water Exploratory Model Well, Current Technology

Pollutant	Poll. Conc. in Sediment at 100 m (mg/kg) (a)	Partition Coefficient^-1 or Leach Factor	Pore Water Conc. (mg/l) (b)	Federal Water Quality Criteria (mg/l) (c)	Federal Criteria Exceedance Factor (d)
Naphthalene	0.0732	0.0795	6.36e-03		
Fluorene	0.0399	0.0407	1.78e-03	1.40e+01	
Phenanthrene	0.0947	0.0113	1.17e-03		
Phenol	5.26e-06	11.338	6.52e-05	4.60e+03	
Cadmium	0.0107	0.1100	1.28e-03	9.30e-03	
Mercury	0.0010	0.0180	1.91e-05	2.50e-05	
Antimony	0.0554			4.30e+00	
Arsenic	0.0690	0.0050	3.77e-04	1.40e-04	2.7
Beryllium	0.0068				
Chromium	2.3326	0.0340	8.66e-02	5.00e-02	1.7
Copper	0.1818	0.0063	1.25e-03	2.40e-03	
Lead	0.3411	0.0200	7.45e-03	8.10e-03	
Nickel	0.1312	0.0430	6.16e-03	8.20e-03	
Selenium	0.0107			7.10e-02	
Silver	0.0068			1.90e-03	
Thallium	0.0117			6.30e-03	
Zinc	1.9487	0.0041	8.73e-03	8.10e-02	
Aluminum	88.1537				
Barium	1,166.324	0.0021	2.68e+00		
Iron	149.1369	0.1300	2.12e+01		
Tin	0.1419				
Titanium	0.8504				
Alkylated benzenes	0.4123				
Alkylated naphthalenes	3.8760				
Alkylated fluorenes	0.4666				
Alkylated phenanthrenes	0.5895				
Alkylated phenols	0.0000				
Total biphenyls	0.7662				
Total dibenzothiophenes	0.0007				

(a)   Pollutant concentration in sediment calculation shown in Appendix D.

(b)   Pore water conc. = Poll. Conc. in Sediment * Partition Coeff^{-1} or Leach Factor * 35.5 kg sediment/32.5 l pore water

(c)   Most stringent criterion shown on this table representing marine acute, marine chronic, and human health (fish consumption) criteria (see Exhibit 4-1); there are no Federal water quality criteria for specific SBF compounds.

(d)   Pore water pollutant concentration exceeds water quality criteria for arsenic (human health) by a factor of 2.7 and chromium (marine chronic) by a factor of 1.7.

Exhibit 4-17. Pore Water Pollutant Concentrations - Gulf of Mexico Deep Water Development Model Well, Discharge Option

Pollutant	Poll. Conc. in Sediment at 100 m (mg/kg) (a)	Partition Coefficient^-1 or Leach Factor	Pore Water Conc. (mg/l) (b)	Federal Water Quality Criteria (mg/l) (c)	Federal Criteria Exceedance Factor (d)
Naphthalene	0.0303	0.0795	2.63e-03		
Fluorene	0.0165	0.0407	7.35e-04	1.40e+01	
Phenanthrene	0.0392	0.0113	4.84e-04		
Phenol	2.18e-06	11.338	2.70e-05	4.60e+03	
Cadmium	0.0044	0.1100	5.31e-04	9.30e-03	
Mercury	0.0004	0.0180	7.90e-06	2.50e-05	
Antimony	0.0229			4.30e+00	
Arsenic	0.0285	0.0050	1.56e-04	1.40e-04	1.1
Beryllium	0.0028				
Chromium	0.9641	0.0340	3.58e-02	5.00e-02	
Copper	0.0751	0.0063	5.17e-04	2.40e-03	
Lead	0.1410	0.0200	3.08e-03	8.10e-03	
Nickel	0.0542	0.0430	2.55e-03	8.20e-03	
Selenium	0.0044			7.10e-02	
Silver	0.0028			1.90e-03	
Thallium	0.0048			6.30e-03	
Zinc	0.8054	0.0041	3.61e-03	8.10e-02	
Aluminum	36.4354				
Barium	482.062	0.0021	1.11e+00		
Iron	61.6409	0.1300	8.75e+00		
Tin	0.0587				
Titanium	0.3515				
Alkylated benzenes	0.1707				
Alkylated naphthalenes	1.6045				
Alkylated fluorenes	0.1931				
Alkylated phenanthrenes	0.2440				
Alkylated phenols	0.0000				
Total biphenyls	0.3172				
Total dibenzothiophenes	0.0003				

(a)   Pollutant concentration in sediment calculation shown in Appendix D.

(b)   Pore water conc. = Poll. Conc. in Sediment * Partition Coeff^{-1} or Leach Factor * 35.5 kg sediment/32.5 l pore water

(c)   Most stringent criterion shown on this table representing marine acute, marine chronic, and human health (fish consumption) criteria (see Exhibit 4-1); there are no Federal water quality criteria for specific SBF compounds.

(d)   Pore water pollutant concentrations exceed the water quality criterion for arsenic (human health) by a factor of 1.1.

Exhibit 4-18. Pore Water Pollutant Concentrations - Gulf of Mexico Deep Water Exploratory Model Well, Discharge Option

Pollutant	Poll. Conc. in Sediment at 100 m (mg/kg) (a)	Partition Coefficient^-1 or Leach Factor	Pore Water Conc. (mg/l) (b)	Federal Water Quality Criteria (mg/l) (c)	Federal Criteria Exceedance Factor (d)
Naphthalene	0.0674	0.0795	5.85e-03		
Fluorene	0.0368	0.0407	1.63e-03	1.40e+01	
Phenanthrene	0.0872	0.0113	1.08e-03		
Phenol	4.84e-06	11.338	6.00e-05	4.60e+03	
Cadmium	0.0098	0.1100	1.18e-03	9.30e-03	
Mercury	0.0009	0.0180	1.76e-05	2.50e-05	
Antimony	0.0509			4.30e+00	
Arsenic	0.0634	0.0050	3.46e-04	1.40e-04	2.5
Beryllium	0.0063				
Chromium	2.1437	0.0340	7.96e-02	5.00e-02	1.6
Copper	0.1670	0.0063	1.15e-03	2.40e-03	
Lead	0.3135	0.0200	6.85e-03	8.10e-03	
Nickel	0.1206	0.0430	5.66e-03	8.20e-03	
Selenium	0.0098			7.10e-02	
Silver	0.0063			1.90e-03	
Thallium	0.0107			6.30e-03	
Zinc	1.7909	0.0041	8.02e-03	8.10e-02	
Aluminum	81.0149				
Barium	1,071.874	0.0021	2.46e+00		
Iron	137.0596	0.1300	1.95e+01		
Tin	0.1304				
Titanium	0.7816				
Alkylated benzenes	0.3793				
Alkylated naphthalenes	3.5663				
Alkylated fluorenes	0.4293				
Alkylated phenanthrenes	0.5424				
Alkylated phenols	0.0000				
Total biphenyls	0.7050				
Total dibenzothiophenes	0.0006				

(a)   Pollutant concentration in sediment calculation shown in Appendix D.

(b)   Pore water conc. = Poll. Conc. in Sediment * Partition Coeff^{-1} or Leach Factor * 35.5 kg sediment/32.5 l pore water

(c)   Most stringent criterion shown on this table representing marine acute, marine chronic, and human health (fish consumption) criteria (see Exhibit 4-1); there are no Federal water quality criteria for specific SBF compounds.

(d)   Pore water pollutant concentrations exceed the water quality criteria for arsenic (human health) by a factor of 2.5 and chromium (marine chronic) by a factor of 1.6.

Exhibit 4-19. Pore Water Pollutant Concentrations - Gulf of Mexico Shallow Water Development Model Well, Discharge Option

Pollutant	Poll. Conc. in Sediment at 100 m (mg/kg) (a)	Partition Coefficient^-1 or Leach Factor	Pore Water Conc. (mg/l) (b)	Federal Water Quality Criteria (mg/l) (c)	Federal Criteria Exceedance Factor (d)
Naphthalene	0.0201	0.0795	1.74e-03		
Fluorene	0.0109	0.0407	4.87e-04	1.40e+01	
Phenanthrene	0.0260	0.0113	3.20e-04		
Phenol	1.44e-06	11.338	1.79e-05	4.60e+03	
Cadmium	0.0029	0.1100	3.51e-04	9.30e-03	
Mercury	0.0003	0.0180	5.22e-06	2.50e-05	
Antimony	0.0151			4.30e+00	
Arsenic	0.0188	0.0050	1.03e-04	1.40e-04	
Beryllium	0.0019				
Chromium	0.6371	0.0340	2.37e-02	5.00e-02	
Copper	0.0496	0.0063	3.42e-04	2.40e-03	
Lead	0.0932	0.0200	2.04e-03	8.10e-03	
Nickel	0.0358	0.0430	1.68e-03	8.20e-03	
Selenium	0.0029			7.10e-02	
Silver	0.0019			1.90e-03	
Thallium	0.0032			6.30e-03	
Zinc	0.5323	0.0041	2.38e-03	8.10e-02	
Aluminum	24.0779				
Barium	318.565	0.0021	7.31e-01		
Iron	40.7346	0.1300	5.78e+00		
Tin	0.0388				
Titanium	0.2323				
Alkylated benzenes	0.1129				
Alkylated naphthalenes	1.0618				
Alkylated fluorenes	0.1278				
Alkylated phenanthrenes	0.1615				
Alkylated phenols	0.0000				
Total biphenyls	0.2099				
Total dibenzothiophenes	0.0002				

(a)   Pollutant concentration in sediment calculation shown in Appendix D.

(b)   Pore water conc. = Poll. Conc. in Sediment * Partition Coeff^{-1} or Leach Factor * 35.5 kg sediment/32.5 l pore water

(c)   Most stringent criterion shown on this table representing marine acute, marine chronic, and human health (fish consumption) criteria (see Exhibit 4-1); there are no Federal water quality criteria for specific SBF compounds.

(d)   No Federal water quality criteria are exceeded.

Exhibit 4-20. Pore Water Pollutant Concentrations - Gulf of Mexico Shallow Water Exploratory Model Well, Discharge Option

Pollutant	Poll. Conc. in Sediment at 100 m (mg/kg) (a)	Partition Coefficient^-1 or Leach Factor	Pore Water Conc. (mg/l) (b)	Federal Water Quality Criteria (mg/l) (c)	Federal Criteria Exceedance Factor (d)
Naphthalene	0.0419	0.0795	3.64e-03		
Fluorene	0.0229	0.0407	1.02e-03	1.40e+01	
Phenanthrene	0.0542	0.0113	6.69e-04		
Phenol	3.01e-06	11.338	3.73e-05	4.60e+03	
Cadmium	0.0061	0.1100	7.35e-04	9.30e-03	
Mercury	0.0006	0.0180	1.09e-05	2.50e-05	
Antimony	0.0317			4.30e+00	
Arsenic	0.0395	0.0050	2.16e-04	1.40e-04	
Beryllium	0.0039				
Chromium	1.3352	0.0340	4.96e-02	5.00e-02	
Copper	0.1040	0.0063	7.16e-04	2.40e-03	
Lead	0.1953	0.0200	4.27e-03	8.10e-03	
Nickel	0.0751	0.0430	3.53e-03	8.20e-03	
Selenium	0.0061			7.10e-02	
Silver	0.0039			1.90e-03	
Thallium	0.0067			6.30e-03	
Zinc	1.1154	0.0041	5.00e-03	8.10e-02	
Aluminum	50.4577				
Barium	667.584	0.0021	1.53e+00		
Iron	85.3634	0.1300	1.21e+01		
Tin	0.0812				
Titanium	0.4868				
Alkylated benzenes	0.2360				
Alkylated naphthalenes	2.2188				
Alkylated fluorenes	0.2671				
Alkylated phenanthrenes	0.3374				
Alkylated phenols	0.0000				
Total biphenyls	0.4386				
Total dibenzothiophenes	0.0004				

(a)   Pollutant concentration in sediment calculation shown in Appendix D.

(b)   Pore water conc. = Poll. Conc. in Sediment * Partition Coeff^{-1} or Leach Factor * 35.5 kg sediment/32.5 l pore water

(c)   Most stringent criterion shown on this table representing marine acute, marine chronic, and human health (fish consumption) criteria (see Exhibit 4-1); there are no Federal water quality criteria for specific SBF compounds.

(d)   No Federal water quality criteria are exceeded.

The resulting average base fluid concentration at 100 m (8,655 mg/kg) is used to calculate the pore water concentrations of individual pollutants in synthetic fluids for a shallow water exploratory model well. As for the Gulf of Mexico analysis, the concentration of base fluid at 100 meters is multiplied by the proportion of total oil discharged relative to a shallow exploratory well to calculate the other model well type pollutant concentrations. These resulting concentration at 100 meters for each pollutant is multiplied by the pollutant-specific leach factor for metals or divided by the partition coefficient for organic pollutants to derive pore water pollutant concentrations.

EPA projects that only development wells will be drilled in both Cook Inlet, Alaska (shallow only) and offshore California (both shallow and deep). EPA does not project the drilling of any exploratory wells in these areas, and for this reason model results concerning exploratory wells are not shown. Although operators in Cook Inlet, Alaska and offshore California currently cannot discharge SBF-cuttings, EPA presents pore water pollutant concentrations for these areas based on the current treatment technology (11% retention on cuttings) for the purpose of comparison with the discharge option results. The pore water pollutant concentrations for the current technology and discharge option are compared to Federal water quality criteria and Alaska state standards in Exhibits 4-21 through 4-24.

Exhibit 4-21. Pore Water Pollutant Concentrations - California Deep Water Development Model Well, Current Technology

Pollutant	Poll. Conc. in Sediment at 100 m (mg/kg) (a)	Partition Coefficient^-1 or Leach Factor	Pore Water Conc. (mg/l)	Federal Water Quality Criteria (mg/l) (b)	Federal Criteria Exceedance Factor (c)
Naphthalene	0.0330	0.0795	2.86e-03		
Fluorene	0.0180	0.0407	7.99e-04	1.40e+01	
Phenanthrene	0.0426	0.0113	5.26e-04		
Phenol	2.37e-06	11.338	2.93e-05	4.60e+03	
Cadmium	0.0048	0.1100	5.78e-04	9.30e-03	
Mercury	0.0004	0.0180	8.60e-06	2.50e-05	
Antimony	0.0249			4.30e+00	
Arsenic	0.0310	0.0050	1.70e-04	1.40e-04	1.2
Beryllium	0.0031				
Chromium	1.0494	0.0340	3.90e-02	5.00e-02	
Copper	0.0818	0.0063	5.63e-04	2.40e-03	
Lead	0.1535	0.0200	3.35e-03	8.10e-03	
Nickel	0.0590	0.0430	2.77e-03	8.20e-03	
Selenium	0.0048			7.10e-02	
Silver	0.0031			1.90e-03	
Thallium	0.0052			6.30e-03	
Zinc	0.8767	0.0041	3.93e-03	8.10e-02	
Aluminum	39.6583				
Barium	524.702	0.0021	1.20e+00		
Iron	67.0932	0.1300	9.53e+00		
Tin	0.0638				
Titanium	0.3826				
Alkylated benzenes	0.1855				
Alkylated naphthalenes	1.7443				
Alkylated fluorenes	0.2100				
Alkylated phenanthrenes	0.2653				
Alkylated phenols	0.0000				
Total biphenyls	0.3448				
Total dibenzothiophenes	0.0003				

(a)   Pollutant concentration in sediment calculation shown in Appendix D.
(b)   Most stringent criterion shown on this table representing marine acute, marine chronic, and human health (fish consumption) criteria (see Exhibit 4-1); there are no Federal water quality criteria for specific SBF compounds.
(c)   Pore water pollutant concentration exceeds the water quality criterion for arsenic (human health) by a factor of 1.2.

Exhibit 4-22. Pore Water Pollutant Concentrations - Cook Inlet, Alaska and Offshore California Shallow Water Development Model Well, Current Technology

Pollutant	Poll. Conc. in Sediment at 100 m (mg/kg) (a)	Partition Coefficient^-1 or Leach Factor	Pore Water Conc. (mg/l) (b)	Federal Water Quality Criteria (mg/l) (c)	Alaska State Standards (mg/l)	Criteria/ Standards Exceedance Factor (d)
Naphthalene	0.0218	0.0795	1.89e-03			
Fluorene	0.0119	0.0407	5.29e-04	1.40e+01		
Phenanthrene	0.0282	0.0113	3.48e-04			
Phenol	1.57e-06	11.338	1.94e-05	4.60e+03		
Cadmium	0.0032	0.1100	3.82e-04	9.30e-03		
Mercury	0.0003	0.0180	5.68e-06	2.50e-05		
Antimony	0.0165			4.30e+00	6.00e-03	
Arsenic	0.0205	0.0050	1.12e-04	1.40e-04	5.00e-01	
Beryllium	0.0020				4.00e-03	
Chromium	0.6935	0.0340	2.58e-02	5.00e-02	1.00e-01	
Copper	0.0540	0.0063	3.72e-04	2.40e-03		
Lead	0.1014	0.0200	2.22e-03	8.10e-03		
Nickel	0.0390	0.0430	1.82e-03	8.20e-03	1.00e-01	
Selenium	0.0032			7.10e-02	5.00e-02	
Silver	0.0020			1.90e-03		
Thallium	0.0035			6.30e-03	2.00e-03	
Zinc	0.5794	0.0041	2.60e-03	8.10e-02		
Aluminum	26.2082					
Barium	346.750	0.0021	7.95e-01		2.00e+00	
Iron	44.3386	0.1300	6.30e+00			
Tin	0.0422					
Titanium	0.2528					
Alkylated benzenes	0.1227					
Alkylated naphthalenes	1.1540					
Alkylated fluorenes	0.1389					
Alkylated phenanthrenes	0.1755					
Alkylated phenols	0.0000					
Total biphenyls	0.2281					
Total dibenzothiophenes	0.0002					

(a) Pollutant concentration in sediment calculation shown in Appendix D.

(b) Pore water conc. = Poll. Conc. in Sediment * Partition Coeff^{-1} or Leach Factor * 35.5 kg sediment/32.5 l pore water

(c) Most stringent criterion shown on this table representing marine acute, marine chronic, and human health (fish consumption) criteria (see Exhibit 4-1); there are no Federal water quality criteria for specific SBF compounds.

(d) No Federal water quality criteria or state standards are exceeded.

Exhibit 4-23. Pore Water Pollutant Concentrations - California Deep Water Development Model Well, Discharge Option

Pollutant	Poll. Conc. in Sediment at 100 m (mg/kg) (a)	Partition Coefficient^-1 or Leach Factor	Pore Water Conc. (mg/l) (b)	Federal Water Quality Criteria (mg/l) (c)	Federal Criteria Exceedance Factor (d)
Naphthalene	0.0189	0.0795	1.64e-03		
Fluorene	0.0103	0.0407	4.58e-04	1.40e+01	
Phenanthrene	0.0244	0.0113	3.02e-04		
Phenol	1.36e-06	11.338	1.68e-05	4.60e+03	
Cadmium	0.0028	0.1100	3.31e-04	9.30e-03	
Mercury	0.0003	0.0180	4.92e-06	2.50e-05	
Antimony	0.0143			4.30e+00	
Arsenic	0.0178	0.0050	9.70e-05	1.40e-04	
Beryllium	0.0018				
Chromium	0.6007	0.0340	2.23e-02	5.00e-02	
Copper	0.0468	0.0063	3.22e-04	2.40e-03	
Lead	0.0878	0.0200	1.92e-03	8.10e-03	
Nickel	0.0338	0.0430	1.59e-03	8.20e-03	
Selenium	0.0028			7.10e-02	
Silver	0.0018			1.90e-03	
Thallium	0.0030			6.30e-03	
Zinc	0.5018	0.0041	2.25e-03	8.10e-02	
Aluminum	22.700				
Barium	300.33	0.0021	6.89e-01		
Iron	38.403	0.1300	5.45e+00		
Tin	0.0365				
Titanium	0.2190				
Alkylated benzenes	0.1063				
Alkylated naphthalenes	0.9996				
Alkylated fluorenes	0.1203				
Alkylated phenanthrenes	0.1520				
Alkylated phenols	0.0000				
Total biphenyls	0.1976				
Total dibenzothiophenes	0.0002				

(a)   Pollutant concentration in sediment calculation shown in Appendix D.

(b)   Pore water conc. = Poll. Conc. in Sediment * Partition Coeff^{-1} or Leach Factor * 35.5 kg sediment/32.5 l pore water

(c)   Most stringent criterion shown on this table representing marine acute, marine chronic, and human health (fish consumption) criteria (see Exhibit 4-1); there are no Federal water quality criteria for specific SBF compounds.

(d)   No Federal water quality criteria are exceeded.

Exhibit 4-24. Pore Water Pollutant Concentrations - Cook Inlet, Alaska and Offshore California Shallow Water Development Model Well, Discharge Option

Pollutant	Poll. Conc. in Sediment at 100 m (mg/kg) (a)	Partition Coefficient^-1 or Leach Factor	Pore Water Conc. (mg/l) (b)	Federal Water Quality Criteria (mg/l) (c)	Alaska State Standards (mg/l)	Criteria/ Standards Exceedance Factor (d)
Naphthalene	0.0125	0.0795	1.09e-03			
Fluorene	0.0068	0.0407	3.03e-04	1.40e+01		
Phenanthrene	0.0162	0.0113	2.00e-04			
Phenol	8.98e-07	11.338	1.11e-05	4.60e+03		
Cadmium	0.0018	0.1100	2.19e-04	9.30e-03		
Mercury	0.0002	0.0180	3.25e-06	2.50e-05		
Antimony	0.0094			4.30e+00	6.00e-03	
Arsenic	0.0117	0.0050	6.41e-05	1.40e-04	5.00e-01	
Beryllium	0.0012				4.00e-03	
Chromium	0.3969	0.0340	1.47e-02	5.00e-02	1.00e-01	
Copper	0.0309	0.0063	2.13e-04	2.40e-03		
Lead	0.0581	0.0200	1.27e-03	8.10e-03		
Nickel	0.0223	0.0430	1.05e-03	8.20e-03	1.00e-01	
Selenium	0.0018			7.10e-02	5.00e-02	
Silver	0.0012			1.90e-03		
Thallium	0.0020			6.30e-03	2.00e-03	
Zinc	0.3316	0.0041	1.49e-03	8.10e-02		
Aluminum	15.0008					
Barium	198.470	0.0021	4.55e-01		2.00e+00	
Iron	25.3781	0.1300	3.60e+00			
Tin	0.0241					
Titanium	0.1447					
Alkylated benzenes	0.0704					
Alkylated naphthalenes	0.6615					
Alkylated fluorenes	0.0796					
Alkylated phenanthrenes	0.1006					
Alkylated phenols	0.0000					
Total biphenyls	0.1308					
Total dibenzothiophenes	0.0001					

(a)   Pollutant concentration in sediment calculation shown in Appendix D.

(b)   Pore water conc. = Poll. Conc. in Sediment * Partition Coeff^{-1} or Leach Factor * 35.5 kg sediment/32.5 l pore water

(c)   Most stringent criterion shown on this table representing marine acute, marine chronic, and human health (fish consumption) criteria (see Exhibit 4-1); there are no Federal water quality criteria for specific SBF compounds.

(d)   No Federal water quality criteria or state standards are exceeded.

4.4   Sediment Guidelines for the Protection of Benthic Organisms

An additional method for assessing potential benthic impacts of certain metals is EPA's proposed sediment guidelines for the protection of benthic organisms (EPA, 1998b). These proposed guidelines are based on an equilibrium partitioning (EqP) approach to determine guidelines based on "numerical concentrations for individual chemicals that are applicable across the range of sediments encountered in practice." The EqP sediment guidelines (ESG) for the six metals copper, cadmium, nickel, lead, silver, and zinc account for the additive toxicity effects of these metals. They are derived by two procedures: (a) by comparing the sum of the metal's molar concentrations, measured as simultaneously extracted metal (SEM), to the molar concentration of acid volatile sulfide (AVS) in sediments:

$$\sum_i [SEM] \leq [AVS]$$

or (b) by comparing the measured interstitial water [i.e., pore water] concentrations of the metals to water quality criteria final chronic values (FCVs):

$$\sum_i [M_{i,d}]/[FCV_{i,d}] \leq 1$$

for the ith metal with a total dissolved concentration ($M_{i,d}$). Meeting one or both of these conditions indicates that benthic organisms should be acceptably protected.

For this environmental analysis, the second (interstitial water guideline) method is used to assess potential impacts. The pore water concentrations presented in section 4.3 are used for the following analyses. The sum of the interstitial water concentration:FCV ratios for the six metals is calculated for each of the model wells. Exhibits 4-25 and 4-26 present the ESG analysis for Gulf of Mexico wells for current technology and the discharge option, respectively. Exhibit 4-27 presents the analysis for Cook Inlet, Alaska and offshore California model wells.

All model wells in the Gulf of Mexico fail to meet the sediment guidelines using the current technology, with concentration:FCV ratios ranging from 1.2 to 3.9. Under the discharge option, the development model wells meet the guideline. The exploratory model wells do not meet the guideline, but the projected pollutant pore water concentrations are 43 percent lower compared to those projected for the current industry practice. For Cook Inlet, Alaska and offshore California, the deep and shallow development model wells pass the guidelines using both the current technology and the discharge option technology.

Exhibit 4-25. Sediment Guidelines Analysis - Gulf of Mexico, Current Technology

Metal	Pore Water Conc. At 100 m (µg/l) (a)	FCV (µg/l) (b)	Conc./FCV (c)
Deep Water Development Model Well			
Cadmium	0.928	9.3	0.0998
Copper	0.903	2.4	0.376
Lead	5.38	8.1	0.664
Nickel	4.45	8.2	0.543
Silver	-	-	-
Zinc	6.30	81	0.0778
		Sum =	1.8
Deep Water Exploration Model Well			
Cadmium	2.06	9.3	0.221
Copper	2.01	2.4	0.837
Lead	11.97	8.1	1.48
Nickel	9.89	8.2	1.21
Silver	-	-	-
Zinc	14.0	81	0.170
		Sum =	3.9
Shallow Water Development Model Well			
Cadmium	0.613	9.3	0.0659
Copper	0.597	2.4	0.249
Lead	3.56	8.1	0.439
Nickel	2.94	8.2	0.358
Silver	-	-	-
Zinc	4.16	81	0.0513
		Sum =	1.7
Shallow Water Exploratory Model Well			
Cadmium	1.28	9.3	0.138
Copper	1.25	2.4	0.521
Lead	7.45	8.1	0.920
Nickel	6.16	8.2	0.752
Silver	-	-	-
Zinc	8.73	81	0.108
		Sum =	2.4

(a) Pore water concentration calculated in Exhibits 4-13 through 4-16.
(b) FCV = final chronic value = marine chronic water quality criterion.
(c) The guideline is met if the sum of Conc./FCV is ≤1. All Gulf of Mexico model wells exceed the sediment guidelines using the current practice. See Appendix A for revised FCVs and analysis of changes to this assessment due to the revisions. See footnote 1, page 4-2.

Exhibit 4-26. Sediment Guidelines Analysis - Gulf of Mexico, Discharge Option

Metal	Pore Water Conc. At 100 m (µg/l) (a)	FCV (µg/l) (b)	Conc./FCV (c)
Deep Water Development Model Well			
Cadmium	0.531	9.3	0.0571
Copper	0.517	2.4	0.215
Lead	3.08	8.1	0.380
Nickel	2.55	8.2	0.311
Silver	-	-	-
Zinc	3.61	81	0.0446
		Sum =	1.0
Deep Water Exploratory Model Well			
Cadmium	1.18	9.3	0.127
Copper	1.15	2.4	0.479
Lead	6.85	8.1	0.846
Nickel	5.66	8.2	0.690
Silver	-	-	-
Zinc	8.02	81	0.0990
		Sum =	2.2
Shallow Water Development Model Well			
Cadmium	0.351	9.3	0.0377
Copper	0.342	2.4	0.143
Lead	2.04	8.1	0.252
Nickel	1.68	8.2	0.205
Silver	-	-	-
Zinc	2.38	81	0.0294
		Sum =	0.67
Shallow Water Exploratory Model Well			
Cadmium	0.735	9.3	0.0790
Copper	0.716	2.4	0.298
Lead	4.27	8.1	0.527
Nickel	3.53	8.2	0.430
Silver	-	-	-
Zinc	4.99	81	0.0616
		Sum =	1.4

(a)   Pore water concentration calculated in Exhibits 4-17 through 4-20.

(b)   FCV = final chronic value = marine chronic water quality criterion.

(c)   The guideline is met if the sum of Conc./FCV is ≤ 1. The Gulf of Mexico exploratory model wells exceed the sediment guidelines under the discharge option.   See Appendix A for revised FCVs and analysis of changes to this assessment due to the revisions. See footnote 1, page 4-2.

Exhibit 4-27. Sediment Guidelines Analysis - Cook Inlet, Alaska and Offshore California

Metal	Pore Water Conc. At 100 m (µg/l) (a)	FCV (µg/l) (b)	Conc./FCV
Deep Water Development Model Well, Current Technology			
Cadmium	0.578	9.3	0.0622
Copper	0.563	2.4	0.234
Lead	3.35	8.1	0.413
Nickel	2.77	8.2	0.338
Silver	-	-	-
Zinc	3.93	81	0.0485
		Sum =	1.1
Deep Water Development Model Well, Discharge Option			
Cadmium	0.331	9.3	0.0356
Copper	0.322	2.4	0.134
Lead	1.92	8.1	0.237
Nickel	1.59	8.2	0.194
Silver	-	-	-
Zinc	2.25	81	0.0278
		Sum =	0.63
Shallow Water Development Model Well, Current Technology			
Cadmium	0.382	9.3	0.0411
Copper	0.372	2.4	0.155
Lead	2.22	8.1	0.274
Nickel	1.83	8.2	0.223
Silver	-	-	-
Zinc	2.59	81	0.32
		Sum =	0.73
Shallow Water Development Model Well, Discharge Option			
Cadmium	0.219	9.3	0.0235
Copper	0.213	2.4	0.0887
Lead	1.27	8.1	0.157
Nickel	1.05	8.2	0.128
Silver	-	-	-
Zinc	1.48	81	0.0183
		Sum =	0.42

(a)   Pore water concentration calculated in Exhibits 4-21 through and 4-24.
(b)   FCV = final chronic value = marine chronic water quality criterion.
(c)   The guideline is met if the sum of Conc./FCV is ≤ 1. The Cook Inlet, Alaska and offshore California development model wells meet the sediment guidelines under the discharge option. See Appendix A for revised FCVs and analysis of changes to this assessment due to the revisions. See footnote 1, page 4-2.

5. HUMAN HEALTH RISKS

5.1   Introduction

This portion of the environmental analysis presents the human health-related risks and risk reductions (benefits) of current technology and the discharge and zero discharge regulatory options. EPA based the health risks and benefits analysis on human exposure to carcinogenic and noncarcinogenic contaminants through consumption of affected seafood; specifically, recreationally-caught finfish and commercially-caught shrimp. EPA used seafood consumption and lifetime exposure duration assumptions to estimate risks and benefits under each of the discharge scenarios for the three geographic regions where the discharge of SBF-cuttings will be affected by this rule. The analysis is performed for those contaminants for which bioconcentration factors, oral reference doses (RfDs), or oral slope factors for carcinogenic risks have been established. Thus, the analysis considers contaminants associated with the drilling fluid barite and with contamination by formation (crude) oil, but does not consider the synthetic base compounds themselves.

5.2   Recreational Fisheries Tissue Concentrations

Exposure of recreational finfish to drilling fluid contaminants occurs through the uptake of dissolved pollutants found in the water column. Instead of using the water column pollutant concentrations at the edge of the mixing zone (as for the water quality analyses), EPA calculates an average water column concentration of each pollutant for the area *within* a 100-m radius of the discharge. As described in Chapter 4, Brandsma's 1996 study was used to determine base fluid concentrations at specified distances from a discharge point. Also as presented in Chapter 4, Brandsma does not provide concentrations as a function of distance, but rather as a function of time. Therefore, to calculate an average concentration within 100 m, the time required for transport to the edge of the mixing zone was calculated as the quotient of the distance to the edge of the mixing zone and the current speed (100 meters/current speed, in m/sec). Based on this transport time, equal time intervals (and therefore radial distances) were chosen to create a series of base fluid concentrations at varying radii across the total radius of the mixing zone. These concentrations were used to calculate the dilutions achieved at these distances using the method described in Chapter 4 (section 4.2). The average dilution for the area within 100 meters was derived from these estimated dilutions between the discharge point and the 100-meter boundary. The base fluid concentrations from Brandsma (1996), the calculated dilutions, and the average dilutions used are presented below in the discussions for each geographic region.

The average dilution available within 100 m is used to determine the ambient bioavailable concentrations of pollutants associated with the SBF within the effluent plume by multiplying the average number of dilutions by the respective initial pollutant concentrations. For metals, these pollutant concentrations are further adjusted by leach factors to account for the amount of the metal dissolved, and therefore, bioavailable. These dissolved metals remain in the part of the plume that is diluted in the water column instead of settling to the seafloor with the larger solids. This resulting exposure concentration of SBF pollutants characterizes only the area within the discharge plume. Within the mixing zone, however, the water column also contains "uncontaminated" waters. Thus, for the exposure of finfish within the 100-m mixing zone, the effective exposure concentration is the exposure concentration adjusted by the volumetric proportion of the total water column that contains the discharge plume. This volumetric proportion represents the proportion of time that exposure would occur assuming the fish have an equal probability of being present (and therefore exposed) anywhere in the entire cylinder that makes up the mixing zone. This proportion is determined in the following manner:

exposure proportion = discharge plume volume/water column volume
= discharge rate (m^3/min) * t_T (time to reach 100 m; min)/$\pi r^2 h$

where:

discharge rate = 25.1 m^3/day (= 0.0175 m^3/min)
t_T = 100 m/current speed (m/sec)
r = 100 m
h = depth affected by the plume, which = fall velocity * t_T;
where fall velocity = 0.015 m/sec (Delvigne, 1996).

The effective exposure concentration of each pollutant is multiplied by this exposure proportion and by a pollutant-specific bioconcentration factor (BCF) to yield the tissue concentration of each pollutant in finfish on a mg/kg basis. Pollutant-specific BCFs used for this analysis are presented in Exhibit 5-1. These calculated tissue concentrations represent a potential upper estimate of contamination for fish contained within a 100-m radius of a discharge of SBF-cuttings. The following sections provide the geographic region-specific input parameters for the tissue concentration calculations. The calculations and resulting finfish tissue pollutant concentrations are presented in Appendix E.

5.2.1 *Gulf of Mexico*

The transport time for discharges in the Gulf of Mexico is based on a 15 cm/sec current speed (MMS, 1989), resulting in an 11 minute estimation for the plume to reach 100 meters. The time intervals used for the average dilutions within the mixing zone and the extracted base fluid concentration data from Brandsma (1996) are presented in Exhibit 5-2. The tissue concentrations

are presented in Appendix E, Exhibits E-1 and E-2 for the current technology and discharge option, respectively.

Exhibit 5-1. Pollutant-Specific Bioconcentration Factors

Pollutant	BCF (l/kg) (a)
Naphthalene	426
Fluorene	30
Phenanthrene	2,630
Phenol	1.4
Cadmium	64
Mercury	5,500
Antimony	1
Arsenic	44
Beryllium	19
Chromium	16
Copper	36
Lead	49
Nickel	47
Selenium	4.8
Silver	0.5
Thallium	116
Zinc	47
Aluminum	231

(a)   There are no BCFs for specific SBF compounds.
Source: Offshore Environmental Assessment (Avanti, 1993)

Exhibit 5-2. Calculation of Average Dilutions within Gulf of Mexico Mixing Zone

Time (t; min.)	1	3	5	7	9	11	Avg.
Base fluid concentration @ t (mg/l)	73	32	20	10	9	3.2	
Initial base fluid content in cuttings (mg/l)	112,750						
Calculated Dilutions	1,545	3,523	5,638	11,275	12,528	35,234	11,624

Source: Derived from Figure 2, Brandsma (1996); see Appendix C.

5.2.2   *Cook Inlet, Alaska*

The transport time for discharges in Cook Inlet, Alaska is based on a 40 cm/sec current speed (EPA Region 10, 1984), resulting in a 4.2 minute estimation for the plume to reach 100 meters. The time intervals used to calculate the average dilutions within the mixing zone and the extracted OBF concentration data from Brandsma (1996) are presented in Exhibit 5-3.

Exhibit 5-3. Calculation of Average Dilutions within Cook Inlet, Alaska and Offshore California Mixing Zones

Time (t; min.)	1	2	3	4	5	Avg.
Base fluid concentration @ t (mg/l)	73	45.5	32	28	20	
Initial base fluid concentration in cuttings (mg/l)	112,750					
Calculated Dilutions	1,545	2,478	3,523	4,027	5,638	
Alaska (4.2 minutes)						2,893
California (5.5 minutes)						3,442

Source: Derived from Figure 2, Brandsma (1996); see Appendix B.

The calculations for determining the finfish tissue concentrations including the calculations of the proportion of the plume impacting Cook Inlet, Alaska mixing zones are presented in Appendix E, Exhibits E-3 and E-4 for the current technology and the discharge option, respectively. Although current practice in Cook Inlet, Alaska is zero discharge of SBF-cuttings, the analysis of current technology is presented for comparison with the discharge option.

5.2.3   *Offshore California*

The transport time for discharges offshore California is based on a 30 cm/sec current speed (MMS, 1985), resulting in a 5.5 minute estimation for the plume to reach 100 meters. The time intervals used to calculate the average dilutions within the mixing zone and the extracted base fluid concentration data from Brandsma (1996) are presented in Exhibit 5-3, above.

The calculations for determining the finfish tissue concentrations including the calculations of the proportion of the plume impacting offshore California mixing zones are presented in Appendix E, Exhibits E-5 and E-6 for current technology and the discharge option,

respectively. Although current practice in offshore California is zero discharge of SBF-cuttings, the analysis of current technology is presented for the purpose of comparison with the discharge option.

5.3   Commercial Fisheries Shrimp Tissue Concentrations

EPA based projected shrimp tissue concentrations of pollutants from SBF discharges on the uptake of pollutants from sediment pore water. The pore water pollutant concentrations are based on the assumption of even distribution of the total annual SBF discharge over an area of impact surrounding the model well. The area of impact was determined using the 11-well synthetic fluid sediment concentration data described in section 4.3.1. For each distance from the well, the corresponding sediment concentrations of synthetic base fluids were averaged and plotted (see Exhibit 5-4).

Based on a log:log regression of these data, the distances to various concentrations of synthetic base fluids were determined (i.e., order of magnitude sediment concentrations ranging from 1 mg/kg to 100,000 mg/kg). A study by Berge (1996) observed the environmental effects (faunal changes) of treated OBF-cuttings on a natural seabed. Based upon the analyses provided in Berge (1996), a no effect threshold was set at 100 mg/kg. The radial distance to that sediment concentration (772 m as determined in Exhibit 5-4) results in an associated impact area of 1.9 km^2, which is used for the analyses presented in this section.

While Berge indicates the usage of a 1,000 mg/kg threshold can be determined from data in the study, the analyses are confounded by the statistical necessity of combining the data set into low and high synthetic base fluid content groupings for the analyses. The low synthetic base fluid content group was composed of cuttings treatments that resulted in residual base fluid levels of 150 mg/kg and 990 mg/kg. Thus, Berge also offers that the no effect concentration found in the experiments ranged from 150 ppm to 1,000 ppm of base fluid in sediment. For this analyses, therefore, a no effect threshold of 100 mg/kg is used.

In order to calculate the discharge pollutant distribution over the 1.9 km^2 impact area, the following assumptions that were applicable in the Environmental Assessment for the offshore effluent guidelines are used for this current SBF assessment (Avanti Corporation, 1993):

- •   Sediment depth affected = 5 cm
- •   Unit volume sediment affected = 0.05 m^3
- •   Density of sediment = 710 kg/m^3
- •   Mass of unit volume sediment = 35.5 kg
- •   Volume of water in unit volume of sediment = 32.5 liters

- Impact radius = 772 m; impact area = 1.9 km^2
- Sediment mass = (impact area * sed. depth * sediment density) =
  1.9 x 10^6 m^2 * 0.05 m * 710 kg/m^3 = 6.745e+07 kg
- Average pollutant concentration (mg poll. / kg sed.) = poll. loadings / sed. mass
- Shrimp tissue concentration = (avg. poll. conc.) * (leach factor or partition coeff.$^{-1}$) *
  35.5 kg sediment/32.5 l water * (BCF) * (% lipids).

The above assumptions are used to calculate the average pollutant concentrations in pore water at any point within the well impact area. The calculations of these sediment pollutant concentrations for Gulf of Mexico SBF-cuttings discharges are presented in Appendix F. To obtain the pollutant concentrations in shrimp tissue, the pore water concentration is multiplied by a pollutant-specific BCF, and is adjusted for a shrimp lipid content of 1.1% (Avanti Corporation, 1993). The bioconcentration factors used in the current analysis are listed in Exhibit 5-1. The following sections (5.3.1 through 5.3.3) present the input parameters for calculating the shrimp tissue pollutant concentration for each of the geographic areas (Gulf of Mexico, Cook Inlet, Alaska, and offshore California) using the current technology (11% retention on cuttings) or the discharge option (7% retention on cuttings). The shrimp tissue concentrations do not serve as endpoints for this analysis, but rather are used for estimating the health risks presented in section 5.5 of this chapter.

5.3.1   *Gulf of Mexico*

The concentrations of pollutants in shrimp tissue are presented in Appendix G, Exhibits G-1 through G-4 for Gulf of Mexico model wells using current technology and the discharge option. Only shallow water wells are considered for shrimp impact analysis because shrimp are harvested mainly from waters potentially affected by drilling discharges from shallow water development and exploratory model wells.

5.3.2   *Cook Inlet, Alaska*

Shrimp harvesting by trawling or pot fishing is prohibited in Cook Inlet, Alaska by the Alaska Board of Fisheries due to inadequate information regarding the biology and stock status of shrimp in Cook Inlet waters (Beverage, 1998). Emergency Orders (AK Rule 2-S-H-11-96 and AK Rule 5 AAC 31.390; AK Dept. of Fish & Game, 1998) were issued for Inner Cook Inlet and Outer Cook Inlet in 1996 and 1997, respectively. A previous rule prohibiting shrimp harvesting in Inner Cook Inlet dates back to 1988. There is currently no evidence that these orders will be lifted in the near future. Therefore, human health effects from exposure to commercial shrimp harvests were not analyzed for Cook Inlet, Alaska SBF-cuttings discharges.

Exhibit 5-4. Arithmetically-Averaged Concentration Data
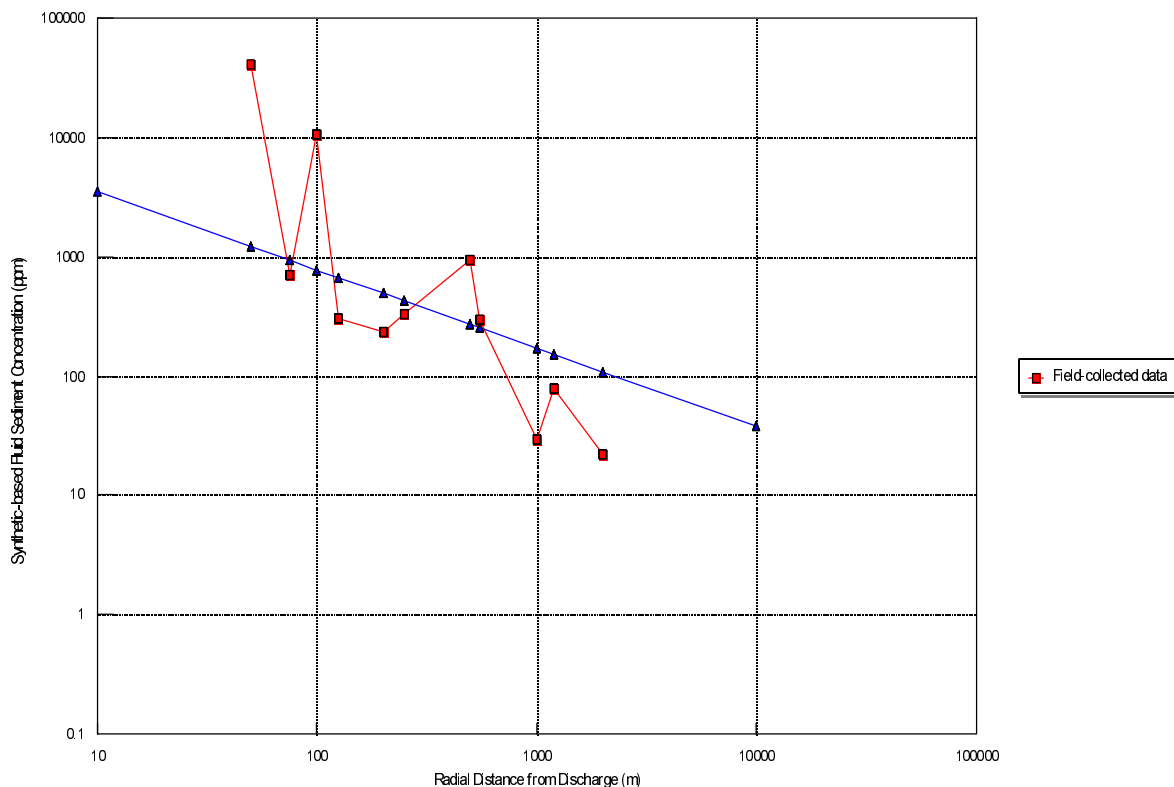
Regression Output:		Regression Equation:	x (m)	y (mg/l)	Impact
X Coefficient(s)	-1.5267	y=1.5267*x+14.7567	(distance)	(conc.)	Area
Std Err of Coef:	0.350		8	100,000	0.0002
Constant:	14.7567		38	10,000	0.004
Std Err of Y Est:	1.350		171	1,000	0.1
R Squared:	0.679		772	100	1.9
No. of observations:	11		3,490	10	38
Degrees of freedom:	9		15,768	1	781

5.3.3 *Offshore California*

The concentrations of pollutants in shrimp tissue are presented in Appendix G, Exhibits G-5 and G-6 for offshore California model wells using the current technology and discharge option, respectively. Only shallow water development model wells are considered for shrimp impact analysis because shrimp are harvested mainly from waters potentially affected by shallow water wells and there are no exploration wells in offshore California. The calculations of the sediment pollutant concentrations for offshore California SBF-cuttings discharges are presented in Appendix F.

5.4   Noncarcinogenic and Carcinogenic Risk - Recreational Fisheries

The concentration of pollutants in finfish tissue is used to calculate the risk of noncarcinogenic and carcinogenic (arsenic only) risk from ingestion of recreationally-caught fish. For this analysis, the 99th percentile intake rate of 177 g/day (uncooked basis) is used as the exposure for high-end seafood consumers in the general adult population (SAIC, 1998). This analysis is a worst case scenario because the seafood consumed is assumed to consist only of contaminated finfish.

For noncarcinogenic risk evaluation, the tissue pollutant concentration (mg/kg) is multiplied by the consumption rate (mg/kg/day) for a 70 kg individual. This value is compared to the oral reference dose (RfD) to determine the hazard quotient (HQ) for each pollutant in accordance with the following equations:

$$HQ = CDI / RfD$$

where

$$HQ = \text{hazard quotient (unitless)}$$
$$CDI = \text{chronic daily intake (mg/kg/day)}$$
$$RfD = \text{reference dose (mg/kg/day)}$$

and

$$CDI = (IR * TPC) / BW$$

where

$$IR = \text{intake rate (0.177 kg/day)}$$
$$TPC = \text{tissue pollutant concentration (mg/kg)}$$
$$BW = \text{body weight (70 kg)}$$

The RfD is based on the assumption that thresholds exist for certain toxic effects to occur. These thresholds are estimates of a daily exposure to humans that is likely to be without an appreciable risk of deleterious effects during a lifetime. Therefore, if the hazard quotient is less than or equal to one, toxic effects are considered unlikely to occur. The oral RfDs used in this analysis are from EPA's Integrated Risk Information System (IRIS) database (EPA, 1998c) and are summarized in Exhibit 5-5. For those pollutants without a published oral RfD, no hazard quotient is calculated.

Exhibit 5-5. Oral Reference Doses and Slope Factors

Pollutant	Oral RfD (mg/kg-day)	Slope Factor (mg/kg-day)$^{-1}$ (a)
Napththalene	2.00e-02	NA
Fluorene	4.00e-02	NA
Phenol	6.00e-01	NA
Cadmium	1.00e-03	NA
Mercury	3.00e-04	NA
Antimony	4.00e-04	NA
Arsenic	3.00e-04	1.50e+00
Chromium	3.00e-03	NA
Nickel	2.00e-02	NA
Selenium	5.00e-03	NA
Silver	5.00e-03	NA
Thallium	8.00e-05	NA
Zinc	3.00e-01	NA
Barium	7.00e-02	NA

(a)   NA indicates that a slope factor is not available for that pollutant; there are no slope factors for specific SBF compounds.

Source: EPA, 1998b; Integrated Risk Information System (IRIS).

To calculate the carcinogenic risks, the slope factor as provided by IRIS is used to estimate the lifetime excess cancer risk that could occur from ingestion of contaminated seafood. The cancer risks are calculated in accordance with the following equations:

$$CR = CDI * SF$$

where

CR   = cancer risk (unitless)
CDI   = chronic daily intake (mg/kg/day)
SF   = slope factor (mg/kg/day)$^{-1}$

and

$$CDI = (IR * TPC * EF * ED) / (BW * AT)$$

where

IR   = intake rate (0.177 kg/day)
TPC   = tissue pollutant concentration (mg/kg)
EF   = exposure frequency (365 days/yr)
ED   = exposure duration (two exposure durations considered in this analysis: 30 years and 70 years)

       BW   = body weight (70 kg)
       AT   = averaging time (70 year lifetime * 365 days/yr)

For this analysis, only arsenic has a slope factor available for estimation of the lifetime excess cancer risk. The risk calculations for arsenic are performed considering a 30-year exposure period and a 70-year exposure period. For the purposes of this analysis, a risk level of 1 x 10^{-6} is considered to be acceptable.

        Exhibit 5-6 presents a summary of the health risks from ingestion of recreationally-caught finfish from around SBF-cuttings discharges under current technology and the discharge option. Although current practice in Cook Inlet, Alaska and offshore California is zero discharge of SBF-cuttings, the current technology analysis is presented for comparison purposes. None of the hazard quotients exceed 1. Therefore, toxic effects are not predicted to occur. Also all of the lifetime excess cancer risks are less than 10^{-6} and are, therefore, acceptable.

5.4.1   *Gulf of Mexico*

        The noncarcinogenic and carcinogenic health risks for Gulf of Mexico recreational fisheries are presented in Exhibits 5-7 and 5-8 for current technology and the discharge option, respectively. Based on the 99th percentile consumption rate, the hazard quotients for noncarcinogenic risks and the lifetime excess cancer risk estimates for carcinogens (arsenic) are well below the acceptable risk levels adopted by the Agency for this analysis.

5.4.2   *Cook Inlet, Alaska*

        The noncarcinogenic and carcinogenic health risks for Cook Inlet, Alaska recreational fisheries are presented in Exhibits 5-9 and 5-10 for the current technology and the discharge option, respectively. Although current practice in Cook Inlet, Alaska is zero discharge of SBF-cuttings, the current technology analysis is presented for comparison purposes. Based on the 99th percentile consumption rate, the hazard quotients for noncarcinogenic risks and the lifetime excess cancer risk estimate for carcinogens (arsenic) are well below the acceptable risk levels adopted by the Agency for this analysis.

Exhibit 5-6. Summary of Finfish Health Risks

Pollutant	Gulf of Mexico		Cook Inlet, Alaska		Offshore California	
	Current Technology	Discharge Option	Current Technology	Discharge Option	Current Technology	Discharge Option
99th Percentile Hazard Quotient (a, b)						
Naphthalene	3.85e-05	2.67e-05	3.91e-05	2.71e-05	3.72e-06	2.58e-06
Fluorene	7.39e-07	5.12e-07	7.50e-07	5.20e-07	7.14e-08	4.95e-07
Phenol	3.60e-13	3.60e-13	3.66e-13	3.66e-13	3.48e-14	3.48e-14
Cadmium	1.86e-06	1.29e-06	1.88e-06	1.31e-06	1.79e-07	1.24e-07
Mercury	7.90e-06	5.50e-06	8.02e-06	5.59e-06	7.63e-07	5.32e-07
Antimony	3.41e-06	2.37e-06	3.46e-06	2.40e-06	3.30e-07	2.29e-07
Arsenic	1.25e-06	8.65e-07	1.27e-06	8.77e-07	1.21e-07	8.35e-08
Chromium	1.04e-05	7.23e-06	1.06e-05	7.33e-06	1.01e-06	6.98e-07
Nickel	3.27e-07	2.27e-07	3.32e-07	2.30e-07	3.16e-08	2.19e-08
Selenium	2.53e-07	1.75e-07	2.57e-07	1.78e-07	2.45e-08	1.69e-08
Silver	1.68e-08	1.16e-08	1.70e-08	1.18e-08	1.62e-09	1.12e-09
Thallium	4.17e-04	2.89e-04	4.23e-04	2.93e-04	4.03e-05	2.79e-05
Zinc	3.09e-08	2.14e-08	3.13e-08	2.17e-08	2.98e-09	2.07e-09
Lifetime Excess Cancer Risk (c, d)						

Arsenic
  30-yr exposure
  70-yr exposure
	2.41e-10
	5.61e-10
		1.67e-10
		3.89e-10
			2.44e-10
			5.70e-10
				1.69e-10
				3.95e-10
					2.32e-11
					5.42e-12
						1.61e-11
						3.76e-12

(a)   Only pollutants for which there is an oral RfD are presented in this summary table.
(b)   None of the hazard quotients exceed 1. Therefore, toxic effects are not predicted to occur.
(c)   Only pollutants for which there is a slope factor are presented in this summary table.
(d)   The lifetime excess cancer risks are less than 10^{-6} and are, therefore, acceptable.

Exhibit 5-7. Recreational Finfish Health Risks - Gulf of Mexico, Current Technology

Pollutant	(A) Fish Tissue Concentration (mg/kg)	(B) 99th %ile Intake (mg/kg-day)	(C) Oral RfD (mg/kg-day) (a)	(D) 99th %ile Hazard Quotient (b)	(E) Slope Factor (mg/kg-day)-1	(F) Lifetime Excess Cancer Risk (c)
Noncarcinogenic Risks					**Carcingenic Risk - Arsenic Only:**	
Naphthalene	3.04e-04	7.70e-07	2.00e-02	3.85e-05		
Fluorene	1.17e-05	2.96e-08	4.00e-02	7.39e-07		
Phenanthrene	2.43e-03	6.15e-06	NA			
Phenol	8.55e-11	2.16e-13	6.00e-01	3.60e-13		
Cadmium	7.34e-07	1.86e-09	1.00e-03	1.86e-06		
Mercury	9.37e-07	2.37e-09	3.00e-04	7.90e-06		
Antimony	5.40e-07	1.37e-09	4.00e-04	3.41e-06		
Arsenic	1.48e-07	3.74e-10	3.00e-04	1.25e-06	30 yr: 1.50e+00	2.41e-10
Beryllium	1.26e-06	3.19e-09	NA		70 yr: 1.50e+00	5.61e-10
Chromium	1.24e-05	3.13e-08	3.00e-03	1.04e-05		
Copper	4.02e-07	1.02e-09	NA			
Lead	3.26e-06	8.24e-09	NA			
Nickel	2.59e-06	6.54e-09	2.00e-02	3.27e-07		
Selenium	5.01e-07	1.27e-09	5.00e-03	2.53e-07		
Silver	3.32e-08	8.39e-11	5.00e-03	1.68e-08		
Thallium	1.32e-05	3.34e-08	8.00e-05	4.17e-04		
Zinc	3.66e-06	9.26e-09	3.00e-01	3.09e-08		
Aluminum	1.99e-01	5.02e-04	NA			
Barium	0.00e+00	0.00e+00	7.00e-02	0.00e+00		
Iron	0.00e+00	0.00e+00	NA			
Tin	0.00e+00	0.00e+00	NA			
Titanium	0.00e+00	0.00e+00	NA			

(a)   NA indicates that an oral RfD is not available; RfDs are not available for specific SBF compounds.
(b)   None of the hazard quotients exceed 1. Therefore, toxic effects are not predicted to occur.
(c)   The lifetime excess cancer risks are less than 10^{-6} and are, therefore, acceptable.

Table Calculations:
    B =   A * 0.177 (kg/day) / 70 kg
    D =   B / C
    F =   B * 30 yrs (or 70 yrs) / 70 (lifetime in yrs) * E

Exhibit 5-8. Recreational Finfish Health Risks - Gulf of Mexico, Discharge Option

Pollutant	(A) Fish Tissue Concentration (mg/kg)	(B) 99th %ile Intake (mg/kg-day)	(C) Oral RfD (mg/kg-day) (a)	(D) 99th %ile Hazard Quotient (b)	(E) Slope Factor (mg/kg-day)-1	(F) Lifetime Excess Cancer Risk (c)
Noncarcinogenic Risks					**Carcingenic Risk - Arsenic Only:**	
Naphthalene	2.11e-04	5.34e-07	2.00e-02	2.67e-05		
Fluorene	8.11e-06	2.05e-08	4.00e-02	5.12e-07		
Phenanthrene	1.69e-03	4.26e-06	NA			
Phenol	8.55e-11	2.16e-13	6.00e-01	3.60e-13		
Cadmium	5.09e-07	1.29e-09	1.00e-03	1.29e-06		
Mercury	6.53e-07	1.65e-09	3.00e-04	5.50e-06		
Antimony	3.74e-07	9.46e-10	4.00e-04	2.37e-06		
Arsenic	1.03e-07	2.59e-10	3.00e-04	8.65e-07	30 yr: 1.50e+00	1.67e-10
Beryllium	8.74e-07	2.21e-09	NA		70 yr: 1.50e+00	3.89e-10
Chromium	8.57e-06	2.17e-08	3.00e-03	7.23e-06		
Copper	2.79e-07	7.04e-10	NA			
Lead	2.26e-06	5.71e-09	NA			
Nickel	1.79e-06	4.53e-09	2.00e-02	2.27e-07		
Selenium	3.47e-07	8.77e-10	5.00e-03	1.75e-07		
Silver	2.30e-08	5.82e-11	5.00e-03	1.16e-08		
Thallium	9.14e-06	2.31e-08	8.00e-05	2.89e-04		
Zinc	2.54e-06	6.42e-09	3.00e-01	2.14e-08		
Aluminum	1.38e-01	3.48e-04	NA			
Barium	0.00e+00	0.00e+00	7.00e-02	0.00e+00		
Iron	0.00e+00	0.00e+00	NA			
Tin	0.00e+00	0.00e+00	NA			
Titanium	0.00e+00	0.00e+00	NA			

(a)   NA indicates that an oral RfD is not available; RfDs are not available for specific SBF compounds.
(b)   None of the hazard quotients exceed 1. Therefore, toxic effects are not predicted to occur.
(c)   The lifetime excess cancer risks are less than 10^{-6} and are, therefore, acceptable.

Table Calculations:
        B =   A * 0.177 (kg/day) / 70 kg
        D =   B / C
        F =   B * 30 yrs (or 70 yrs) / 70 (lifetime in yrs) * E

Exhibit 5-9. Recreational Finfish Health Risks - Cook Inlet, Alaska, Current Technology

Pollutant	(A) Fish Tissue Concentration (mg/kg)	(B) 99th %ile Intake (mg/kg-day)	(C) Oral RfD (mg/kg-day) (a)	(D) 99th %ile Hazard Quotient (b)	(E) Slope Factor (mg/kg-day)-1	(F) Lifetime Excess Cancer Risk (c)
Noncarcinogenic Risks					**Carcingenic Risk - Arsenic Only:**	
Naphthalene	3.09e-04	7.81e-07	2.00e-02	3.91e-05		
Fluorene	1.19e-05	3.00e-08	4.00e-02	7.50e-07		
Phenanthrene	2.47e-03	6.24e-06	NA			
Phenol	8.68e-11	2.19e-13	6.00e-01	3.66e-13		
Cadmium	7.45e-07	1.88e-09	1.00e-03	1.88e-06		
Mercury	9.51e-07	2.40e-09	3.00e-04	8.02e-06		
Antimony	5.48e-07	1.39e-09	4.00e-04	3.46e-06		
Arsenic	1.50e-07	3.80e-10	3.00e-04	1.27e-06	30 yr: 1.50e+00	2.44e-10
Beryllium	1.28e-06	3.23e-09	NA		70 yr: 1.50e+00	5.70e-10
Chromium	1.26e-05	3.17e-08	3.00e-03	1.06e-05		
Copper	4.08e-07	1.03e-09	NA			
Lead	3.31e-06	8.36e-09	NA			
Nickel	2.62e-06	6.63e-09	2.00e-02	3.32e-07		
Selenium	5.08e-07	1.28e-09	5.00e-03	2.57e-07		
Silver	3.37e-08	8.51e-11	5.00e-03	1.70e-08		
Thallium	1.34e-05	3.38e-08	8.00e-05	4.23e-04		
Zinc	3.72e-06	9.39e-09	3.00e-01	3.13e-08		
Aluminum	2.01e-01	5.09e-04	NA			
Barium	0.00e+00	0.00e+00	7.00e-02	0.00e+00		
Iron	0.00e+00	0.00e+00	NA			
Tin	0.00e+00	0.00e+00	NA			
Titanium	0.00e+00	0.00e+00	NA			

(a)   NA indicates that an oral RfD is not available; RfDs are not available for specific SBF compounds.
(b)   None of the hazard quotients exceed 1. Therefore, toxic effects are not predicted to occur.
(c)   The lifetime excess cancer risks are less than 10^{-6} and are, therefore, acceptable.

Table Calculations:
    B =   A * 0.177 (kg/day) / 70 kg
    D =   B / C
    F =   B * 30 yrs (or 70 yrs) / 70 (lifetime in yrs) * E

Exhibit 5-10. Recreational Finfish Health Risks - Cook Inlet, Alaska, Discharge Option

Pollutant	(A) Fish Tissue Concentration (mg/kg)	(B) 99th %ile Intake (mg/kg-day)	(C) Oral RfD (mg/kg-day) (a)	(D) 99th %ile Hazard Quotient (b)	(E) Slope Factor (mg/kg-day)-1	(F) Lifetime Excess Cancer Risk (c)
Noncarcinogenic Risks					**Carcingenic Risk - Arsenic Only:**	
Naphthalene	2.14e-04	5.41e-07	2.00e-02	2.71e-05		
Fluorene	8.23e-06	2.08e-08	4.00e-02	5.20e-07		
Phenanthrene	1.71e-03	4.32e-06	NA			
Phenol	8.68e-11	2.19e-13	6.00e-01	3.66e-13		
Cadmium	5.16e-07	1.31e-09	1.00e-03	1.31e-06		
Mercury	6.63e-07	1.68e-09	3.00e-04	5.59e-06		
Antimony	3.80e-07	9.60e-10	4.00e-04	2.40e-06		
Arsenic	1.04e-07	2.63e-10	3.00e-04	8.77e-07	30 yr: 1.50e+00	1.69e-10
Beryllium	8.87e-07	2.24e-09	NA		70 yr: 1.50e+00	3.95e-10
Chromium	8.70e-06	2.20e-08	3.00e-03	7.33e-06		
Copper	2.83e-07	7.15e-10	NA			
Lead	2.29e-06	5.80e-09	NA			
Nickel	1.82e-06	4.60e-09	2.00e-02	2.30e-07		
Selenium	3.52e-07	8.90e-10	5.00e-03	1.78e-07		
Silver	2.33e-08	5.90e-11	5.00e-03	1.18e-08		
Thallium	9.27e-06	2.34e-08	8.00e-05	2.93e-04		
Zinc	2.57e-06	6.51e-09	3.00e-01	2.17e-08		
Aluminum	1.40e-01	3.53e-04	NA			
Barium	0.00e+00	0.00e+00	7.00e-02	0.00e+00		
Iron	0.00e+00	0.00e+00	NA			
Tin	0.00e+00	0.00e+00	NA			
Titanium	0.00e+00	0.00e+00	NA			

(a)   NA indicates that an oral RfD is not available; RfDs are not available for specific SBF compounds.
(b)   None of the hazard quotients exceed 1. Therefore, toxic effects are not predicted to occur.
(c)   The lifetime excess cancer risks are less than 10^{-6} and are, therefore, acceptable.

Table Calculations:
    B =   A * 0.177 (kg/day) / 70 kg
    D =   B / C
    F =   B * 30 yrs (or 70 yrs) / 70 (lifetime in yrs) * E

5.4.3 *Offshore California*

The noncarcinogenic and carcinogenic health risks for offshore California recreational fisheries are presented in Exhibits 5-11 and 5-12 for current technology and the discharge option, respectively. Although current practice in offshore California is zero discharge of SBF-cuttings, the current technology analysis is presented for comparison purposes. Based on the 99th percentile consumption rate, the hazard quotients for noncarcinogenic risks and the lifetime excess cancer risk estimate for carcinogens (arsenic) are well below the acceptable risk levels adopted by the Agency for this analysis.

5.5   Noncarcinogenic and Carcinogenic Risk - Commercial Shrimp

To calculate the noncarcinogenic and carcinogenic health risks for commercial shrimp, the methodology is the same as that used for recreational finfish. However, instead of calculating an effective exposure concentration that describes the portion of the water affected within the mixing zone, the exposure is adjusted by the amount of the total commercial shrimp catch affected. This is estimated by prorating the total potential exposure (total catch) by the portion of the total shrimp catch affected by the well type being analyzed. The shrimp catch is assumed to occur evenly over the area occupied by the species harvested. As calculated for the offshore effluent guidelines Environmental Assessment, the total catch is divided by the populated area to yield a catch density in lbs/mi^2 (Avanti Corporation, 1993). This catch density is multiplied by the area affected for each model well under current technology and the discharge option (number of wells * $1.9 \ km^2$) and divided by the total catch to calculate a percent of the catch affected by the SBF-cuttings discharge. Only shallow water model wells are used in this assessment due to the limited shrimp harvesting that occurs in water depths greater than 1,000 feet.

Exhibit 5-13 presents a summary of the health risks from ingestion of commercially-caught shrimp. None of the hazard quotients exceed 1. Therefore, toxic effects are not predicted to occur. Also all of the lifetime excess cancer risks are less than 10^{-6} and are, therefore, acceptable.

Exhibit 5-11. Recreational Finfish Health Risks - Offshore California, Current Technology

Pollutant	(A) Fish Tissue Concentration (mg/kg)	(B) 99th %ile Intake (mg/kg-day)	(C) Oral RfD (mg/kg-day) (a)	(D) 99th %ile Hazard Quotient (b)	(E) Slope Factor (mg/kg-day)-1	(F) Lifetime Excess Cancer Risk (c)
Noncarcinogenic Risks					**Carcinogenic Risk - Arsenic Only:**	
Naphthalene	2.94e-05	7.44e-08	2.00e-02	3.72e-06		
Fluorene	1.13e-06	2.86e-09	4.00e-02	7.14e-08		
Phenanthrene	2.35e-04	5.94e-07	NA			
Phenol	8.26e-12	2.09e-14	6.00e-01	3.48e-14		
Cadmium	7.09e-08	1.79e-10	1.00e-03	1.79e-07		
Mercury	9.06e-08	2.29e-10	3.00e-04	7.63e-07		
Antimony	5.22e-08	1.32e-10	4.00e-04	3.30e-07		
Arsenic	1.43e-08	3.62e-11	3.00e-04	1.21e-07	30 yr: 1.50e+00	2.32e-11
Beryllium	1.22e-07	3.08e-10	NA		70 yr: 1.50e+00	5.42e-12
Chromium	1.20e-06	3.02e-09	3.00e-03	1.01e-06		
Copper	3.88e-08	9.82e-11	NA			
Lead	3.15e-07	7.96e-10	NA			
Nickel	2.50e-07	6.32e-10	2.00e-02	3.16e-08		
Selenium	4.84e-08	1.22e-10	5.00e-03	2.45e-08		
Silver	3.20e-09	8.10e-12	5.00e-03	1.62e-09		
Thallium	1.27e-06	3.22e-09	8.00e-05	4.03e-05		
Zinc	3.54e-07	8.94e-10	3.00e-01	2.98e-09		
Aluminum	1.92e-02	4.85e-05	NA			
Barium	0.00e+00	0.00e+00	7.00e-02	0.00e+00		
Iron	0.00e+00	0.00e+00	NA			
Tin	0.00e+00	0.00e+00	NA			
Titanium	0.00e+00	0.00e+00	NA			

(a)   NA indicates that an oral RfD is not available; RfDs are not available for specific SBF compounds.
(b)   None of the hazard quotients exceed 1. Therefore, toxic effects are not predicted to occur.
(c)   The lifetime excess cancer risks are less than 10^{-6} and are, therefore, acceptable.

Table Calculations:
    B =   A * 0.177 (kg/day) / 70 kg
    D =   B / C
    F =   B * 30 yrs (or 70 yrs) / 70 (lifetime in yrs) * E

Exhibit 5-12. Recreational Finfish Health Risks - Offshore California, Discharge Option

Pollutant	(A) Fish Tissue Concentration (mg/kg)	(B) 99th %ile Intake (mg/kg-day)	(C) Oral RfD (mg/kg-day) (a)	(D) 99th %ile Hazard Quotient (b)	(E) Slope Factor (mg/kg-day)-1	(F) Lifetime Excess Cancer Risk (c)
Noncarcinogenic Risks					**Carcinogenic Risk - Arsenic Only:**	
Naphthalene	2.04e-05	5.16e-08	2.00e-02	2.58e-06		
Fluorene	7.83e-07	1.98e-09	4.00e-02	4.95e-07		
Phenanthrene	1.63e-04	4.12e-07	NA			
Phenol	8.26e-12	2.09e-14	6.00e-01	3.48e-14		
Cadmium	4.91e-08	1.24e-10	1.00e-03	1.24e-07		
Mercury	6.31e-08	1.60e-10	3.00e-04	5.32e-07		
Antimony	3.62e-08	9.14e-11	4.00e-04	2.29e-07		
Arsenic	9.91e-09	2.51e-11	3.00e-04	8.35e-08	30 yr: 1.50e+00	1.61e-11
Beryllium	8.44e-08	2.13e-10	NA		70 yr: 1.50e+00	3.76e-12
Chromium	8.28e-07	2.09e-09	3.00e-03	6.98e-07		
Copper	2.69e-08	6.80e-11	NA			
Lead	2.18e-07	5.52e-10	NA			
Nickel	1.73e-07	4.38e-10	2.00e-02	2.19e-08		
Selenium	3.35e-08	8.47e-11	5.00e-03	1.69e-08		
Silver	2.22e-09	5.62e-12	5.00e-03	1.12e-09		
Thallium	8.83e-07	2.23e-09	8.00e-05	2.79e-05		
Zinc	2.45e-07	6.20e-10	3.00e-01	2.07e-09		
Aluminum	1.33e-02	3.36e-05	NA			
Barium	0.00e+00	0.00e+00	7.00e-02	0.00e+00		
Iron	0.00e+00	0.00e+00	NA			
Tin	0.00e+00	0.00e+00	NA			
Titanium	0.00e+00	0.00e+00	NA			

(a) NA indicates that an oral RfD is not available; RfDs are not available for specific SBF compounds.
(b) None of the hazard quotients exceed 1. Therefore, toxic effects are not predicted to occur.
(c) The lifetime excess cancer risks are less than 10^{-6} and are, therefore, acceptable.

Table Calculations:
        B =   A * 0.177 (kg/day) / 70 kg
        D =   B / C
        F =   B * 30 yrs (or 70 yrs) / 70 (lifetime in yrs) * E

Exhibit 5-13. Summary of Shrimp Health Risks

Pollutant	Gulf of Mexico				Offshore California	
	Development		Exploratory			
	Current Technology	Discharge Option	Current Technology	Discharge Option	Current Technology	Discharge Option
99th Percentile Hazard Quotient (a)						
Naphthalene	4.71e-06	5.83e-05	5.44e-06	6.51e-06	2.08e-08	1.19e-08
Fluorene	4.64e-08	5.70e-08	5.35e-08	6.43e-08	2.05e-10	1.17e-10
Phenol	5.28e-12	6.53e-12	6.12e-12	7.32e-12	2.34e-14	1.34e-14
Cadmium	2.59e-06	3.19e-06	3.00e-06	3.60e-06	1.15e-08	6.54e-09
Mercury	1.10e-05	1.36e-05	1.28e-07	1.54e-05	4.89e-08	2.79e-08
Antimony	4.78e-06	5.91e-06	5.52e-06	6.62e-06	2.11e-08	1.21e-08
Arsenic	1.74e-06	2.16e-06	2.02e-06	2.42e-06	7.70e-09	4.42e-09
Chromium	1.46e-05	1.80e-05	1.69e-05	2.02e-05	6.44e-08	3.68e-08
Nickel	4.57e-07	5.64e-07	5.28e-07	6.34e-07	2.02e-09	1.16e-09
Selenium	3.54e-07	4.35e-07	4.10e-07	4.92e-07	1.56e-09	8.92e-10
Silver	2.34e-08	2.89e-08	2.72e-08	3.25e-08	1.04e-10	5.93e-11
Thallium	5.83e-04	7.21e-04	6.77e-04	8.09e-04	2.58e-06	1.48e-06
Zinc	4.32e-08	5.33e-08	4.99e-08	6.01e-08	1.91e-10	1.09e-10
Lifetime Excess Cancer Risk (b)						
Arsenic 30-yr exposure 70-yr exposure	3.36e-10 7.84e-10	4.16e-10 9.70e-10	3.89e-10 9.08e-10	4.67e-10 1.09e-10	1.49e-12 3.47e-12	8.52e-13 1.99e-12

(a)   Only pollutants for which there is an oral RfD are presented in this summary table.
(b)   Only pollutants for which there is a slope factor are presented in this summary table.

5.5.1 *Gulf of Mexico*

Under the current technology scenario, there are 13 development wells (12 existing and 1 new source) and 7 existing exploratory wells in Gulf of Mexico shallow waters (< 1,000 ft). Under the discharge option, there are 28 (27 existing and 1 new source) development wells and 15 exploratory wells in Gulf of Mexico shallow waters. The catch impacted in the Gulf of Mexico is calculated in Exhibit 5-14.

Exhibit 5-14. Calculation of Shrimp Catch Impacted in the Gulf of Mexico

	Current Technology		Discharge Option	
	Development	**Exploratory**	**Development**	**Exploratory**
Number of Wells	13	7	28	15
Area Impacted (km^2) (1.9 km^2/well)	24.7	13.3	53.2	28.5
Catch Rate (lbs/mi^2) (a)	11,443			
Total Catch Affected (lbs)	65,856	35,461	141,843	75,987
Total Catch (lbs)	172,474,211			
% of Total Catch Affected	0.038%	0.021%	0.082%	0.044%

(a)   The catch rate calculation is presented in Appendix A.

These percentages of catch affected are used to adjust the intake calculations assuming that individuals would consume seafood from the entire Gulf harvest and exposure would be proportional to the amount of the total catch affected. The estimated noncarcinogenic and carcinogenic risks are presented in Exhibits 5-15 through 5-18 for Gulf of Mexico commercial shrimp affected by the current technology and the discharge option. Based on the 99th percentile consumption rate of 177 g/day, the hazard quotients for noncarcinogenic risks and the lifetime excess cancer risk estimate for carcinogens (arsenic) are well below the acceptable risk levels adopted by the Agency for this analysis.

5.5.2 *Cook Inlet, Alaska*

As presented in Section 5.3.2, shrimp harvesting by trawling or pot fishing is prohibited in Cook Inlet, Alaska by the Alaska Board of Fisheries due to inadequate information regarding the biology and stock status of shrimp in Cook Inlet waters (Beverage, 1998). Therefore, human health effects from exposure to commercial shrimp harvests were not analyzed for Cook Inlet, Alaska SBF-cuttings discharges.

Exhibit 5-15. Commercial Shrimp Health Risks - Gulf of Mexico, Shallow Water Development Model Well, Current Technology

Pollutant	(A) Shrimp Tissue Concentration (mg/kg)	(B) 99th %ile Intake (mg/kg-day)	(C) Oral RfD (mg/kg-day) (a)	(D) 99th %ile Hazard Quotient (b)	(E) Slope Factor (mg/kg-day)-1	(F) Lifetime Excess Cancer Risk (c)
Noncarcinogenic Risks					**Carcinogenic Risk - Arsenic Only:**	
Naphthalene	9.80e-02	9.42e-08	2.00e-02	4.71e-06		
Fluorene	1.93e-03	1.85e-09	4.00e-02	4.64e-08		
Phenanthrene	1.11e-01	1.07e-07	NA			
Phenol	3.30e-06	3.17e-12	6.00e-01	5.28e-12		
Cadmium	2.70e-03	2.59e-09	1.00e-03	2.59e-06		
Mercury	3.45e-03	3.31e-09	3.00e-04	1.10e-05		
Antimony	1.99e-03	1.91e+09	4.00e-04	4.78e-06		
Arsenic	5.44e-04	5.23e-10	3.00e-04	1.74e-06	30 yr: 1.50e+00	3.36e-10
Beryllium	4.63e-03	4.45e+09	NA		70 yr: 1.50e+00	7.84e-10
Chromium	4.55e-02	4.37e-08	3.00e-03	1.46e-05		
Copper	1.48e-03	1.42e-09	NA			
Lead	1.20e-02	1.15e-08	NA			
Nickel	9.51e-03	9.14e-09	2.00e-02	4.57e-07		
Selenium	1.84e-03	1.77e-09	5.00e-03	3.54e-07		
Silver	1.22e-04	1.17e-10	5.00e-03	2.34e-08		
Thallium	4.85e-02	4.66e-08	8.00e-05	5.83e-04		
Zinc	1.35e-02	1.30e-08	3.00e-01	4.32e-08		
Aluminum	7.30e+02	7.01e-04	NA			
Barium	0.00e+00	0.00e+00	7.00e-02	0.00e+00		
Iron	0.00e+00	0.00e+00	NA			
Tin	0.00e+00	0.00e+00	NA			
Titanium	0.00e+00	0.00e+00	NA			

(a)   NA indicates that an oral RfD is not available; RfDs are not available for specific SBF compounds.
(b)   None of the hazard quotients exceed 1. Therefore, toxic effects are not predicted to occur.
(c)   The lifetime excess cancer risks are less than 10^{-6} and are, therefore, acceptable.

Table Calculations:
B =   A * (0.177 (kg/day) * % of catch affected) / 70 kg
D =   B / C
F =   B * 30 yrs (or 70 yrs) / 70 (lifetime in yrs) * E

Exhibit 5-16. Commercial Shrimp Health Risks - Gulf of Mexico, Shallow Water Development Model Well, Discharge Option

Pollutant	(A) Shrimp Tissue Concentration (mg/kg)	(B) 99th %ile Intake (mg/kg-day)	(C) Oral RfD (mg/kg-day) (a)	(D) 99th %ile Hazard Quotient (b)	(E) Slope Factor (mg/kg-day)-1	(F) Lifetime Excess Cancer Risk (c)
Noncarcinogenic Risks					**Carcinogenic Risk - Arsenic Only:**	
Naphthalene	5.62e-01	1.17e-06	2.00e-02	5.83e-05		
Fluorene	1.10e-03	2.28e-09	4.00e-02	5.70e-08		
Phenanthrene	6.38e-02	1.32e-07	NA			
Phenol	1.89e-06	3.92e-12	6.00e-01	6.53e-12		
Cadmium	1.54e-03	3.19e-09	1.00e-03	3.19e-06		
Mercury	1.97e-03	4.08e-09	3.00e-04	1.36e-05		
Antimony	1.40e-03	2.36e-09	4.00e-04	5.91e-06		
Arsenic	3.12e-04	6.47e-10	3.00e-04	2.16e-06	30 yr: 1.50e+00	4.16e-10
Beryllium	2.65e-03	5.49e-09	NA		70 yr: 1.50e+00	9.70e-10
Chromium	2.60e-02	5.39e-08	3.00e-03	1.80e-05		
Copper	8.46e-04	1.75e-09	NA			
Lead	6.86e-03	1.42e-08	NA			
Nickel	5.44e-03	1.13e-08	2.00e-02	5.64e-07		
Selenium	1.05e-03	2.18e-09	5.00e-03	4.35e-07		
Silver	6.98e-05	1.45e-10	5.00e-03	2.89e-08		
Thallium	2.78e-02	5.76e-08	8.00e-05	7.21e-04		
Zinc	7.71e-03	1.60e-08	3.00e-01	5.33e-08		
Aluminum	4.18e+02	8.67e-04	NA			
Barium	0.00e+00	0.00e+00	7.00e-02	0.00e+00		
Iron	0.00e+00	0.00e+00	NA			
Tin	0.00e+00	0.00e+00	NA			
Titanium	0.00e+00	0.00e+00	NA			

(a)   NA indicates that an oral RfD is not available; RfDs are not available for specific SBF compounds.
(b)   None of the hazard quotients exceed 1. Therefore, toxic effects are not predicted to occur.
(c)   The lifetime excess cancer risks are less than 10^{-6} and are, therefore, acceptable.

Table Calculations:
    B =   A * (0.177 (kg/day) * % of catch affected) / 70 kg
    D =   B / C
    F =   B * 30 yrs (or 70 yrs) / 70 (lifetime in yrs) * E

Exhibit 5-17. Commercial Shrimp Health Risks - Gulf of Mexico, Shallow Water Exploratory Model Well, Current Technology

Pollutant	(A) Shrimp Tissue Concentration (mg/kg)	(B) 99th %ile Intake (mg/kg-day)	(C) Oral RfD (mg/kg-day) (a)	(D) 99th %ile Hazard Quotient (b)	(E) Slope Factor (mg/kg-day)-1	(F) Lifetime Excess Cancer Risk (c)
Noncarcinogenic Risks					**Carcinogenic Risk - Arsenic Only:**	
Naphthalene	2.05e-01	1.09e-07	2.00e-02	5.44e-06		
Fluorene	4.03e-03	2.14e-09	4.00e-02	5.35e-08		
Phenanthrene	2.33e-01	1.24e-07	NA			
Phenol	6.91e-06	3.67e-12	6.00e-01	6.12e-12		
Cadmium	5.65e-03	3.00e-09	1.00e-03	3.00e-06		
Mercury	7.23e-03	3.84e-09	3.00e-04	1.28e-05		
Antimony	4.16e-03	2.21e-09	4.00e-04	5.52e-06		
Arsenic	1.14e-03	6.05e-10	3.00e-04	2.02e-06	30 yr: 1.50e+00	3.89e-10
Beryllium	9.71e-03	5.16e-09	NA		70 yr: 1.50e+00	9.08e-10
Chromium	9.53e-02	5.06e-08	3.00e-03	1.69e-05		
Copper	3.10e-03	1.65e-09	NA			
Lead	2.51e-02	1.33e-08	NA			
Nickel	1.99e-02	1.06e-08	2.00e-02	5.28e-07		
Selenium	3.86e-03	2.05e-09	5.00e-03	4.10e-07		
Silver	2.56e-04	1.36e-10	5.00e-03	2.72e-08		
Thallium	1.02e-01	5.42e-08	8.00e-05	6.77e-04		
Zinc	2.82e-02	1.50e-08	3.00e-01	4.99e-08		
Aluminum	1.53e+02	8.12e-05	NA			
Barium	0.00e+00	0.00e+00	7.00e-02	0.00e+00		
Iron	0.00e+00	0.00e+00	NA			
Tin	0.00e+00	0.00e+00	NA			
Titanium	0.00e+00	0.00e+00	NA			

(a)   NA indicates that an oral RfD is not available; RfDs are not available for specific SBF compounds.
(b)   None of the hazard quotients exceed 1. Therefore, toxic effects are not predicted to occur.
(c)   The lifetime excess cancer risks are less than 10^{-6} and are, therefore, acceptable.

Table Calculations:
$\quad$ B =   A * (0.177 (kg/day) * % of catch affected) / 70 kg
$\quad$ D =   B / C
$\quad$ F =   B * 30 yrs (or 70 yrs) / 70 (lifetime in yrs) * E

Exhibit 5-18. Commercial Shrimp Health Risks - Gulf of Mexico, Shallow Water Exploratory Model Well, Discharge Option

Pollutant	(A) Fish Tissue Concentration (mg/kg)	(B) 99th %ile Intake (mg/kg-day)	(C) Oral RfD (mg/kg-day) (a)	(D) 99th %ile Hazard Quotient (b)	(E) Slope Factor (mg/kg-day)-1	(F) Lifetime Excess Cancer Risk (c)
Noncarcinogenic Risks					**Carcinogenic Risk - Arsenic Only:**	
Naphthalene	1.17e-01	1.30e-07	2.00e-02	6.51e-06		
Fluorene	2.31e-03	2.57e-09	4.00e-02	6.43e-08		
Phenanthrene	1.33e-01	1.48e-07	NA			
Phenol	3.95e-06	4.39e-12	6.00e-01	7.32e-12		
Cadmium	3.24e-03	3.60e-09	1.00e-03	3.60e-06		
Mercury	4.14e-03	4.61e-09	3.00e-04	1.54e-05		
Antimony	2.38e-03	2.65e-09	4.00e-04	6.62e-06		
Arsenic	6.53e-04	7.27e-10	3.00e-04	2.42e-06	30 yr: 1.50e+00	4.67e-10
Beryllium	5.56e-03	6.19e-09	NA		70 yr: 1.50e+00	1.09e-09
Chromium	5.46e-02	6.07e-08	3.00e-03	2.02e-05		
Copper	1.77e-03	1.97e-09	NA			
Lead	1.44e-02	1.60e-08	NA			
Nickel	1.14e-02	1.27e-08	2.00e-02	6.34e-07		
Selenium	2.21e-03	2.46e-09	5.00e-03	4.92e-07		
Silver	1.46e-04	1.62e-10	5.00e-03	3.25e-08		
Thallium	5.82e-02	6.48e-08	8.00e-05	8.09e-04		
Zinc	1.62e-02	1.80e-08	3.00e-01	6.01e-08		
Aluminum	8.76e+02	9.75e-04	NA			
Barium	0.00e+00	0.00e+00	7.00e-02	0.00e+00		
Iron	0.00e+00	0.00e+00	NA			
Tin	0.00e+00	0.00e+00	NA			
Titanium	0.00e+00	0.00e+00	NA			

(a)   NA indicates that an oral RfD is not available; RfDs are not available for specific SBF compounds.

(b)   None of the hazard quotients exceed 1. Therefore, toxic effects are not predicted to occur.

(c)   The lifetime excess cancer risks are less than 10^{-6} and are, therefore, acceptable.

Table Calculations:

B =   A * (0.177 (kg/day) * % of catch affected) / 70 kg

D =   B / C

F =   B * 30 yrs (or 70 yrs) / 70 (lifetime in yrs) * E

5.5.3 *Offshore California*

EPA projects that there is one shallow water development model well using SBFs in offshore California. The shrimp catch impacted offshore California is calculated in the following manner:

impact area per well:	1.9 km^2
number of wells:	1 development well
area impacted:	1.9 km^2
total catch:	836,120 lbs
lbs caught/mi^2:	3.17 lbs/mi^2
catch affected:	1.403 lbs
% catch affected:	0.000168%

This percentage of the catch affected is used to adjust the intake calculations assuming that individuals would consume seafood harvested from the entire offshore California shrimp harvesting area and exposure would be proportional to the amount of the total catch affected. The estimated noncarcinogenic and carcinogenic risks are presented in Exhibits 5-19 and 5-20 for the current technology and discharge option. Although the current practice offshore California is zero discharge of SBF-cuttings, the current technology analysis based on 11% retention on cuttings is presented for comparison purposes. Based on the 99th percentile consumption rate, the hazard quotient for noncarcinogenic risks and the lifetime excess cancer risk estimate for carcinogens are both well below the acceptable risk levels adopted by the Agency for this analysis.

Exhibit 5-19. Commercial Shrimp Health Risks - Offshore California, Shallow Water Development Model Well, Current Technology

Pollutant	(A) Shrimp Tissue Concentration (mg/kg)	(B) 99th %ile Intake (mg/kg-day)	(C) Oral RfD (mg/kg-day) (a)	(D) 99th %ile Hazard Quotient (b)	(E) Slope Factor (mg/kg-day)-1	(F) Lifetime Excess Cancer Risk (c)
Noncarcinogenic Risks					**Carcinogenic Risk - Arsenic Only:**	
Naphthalene	9.80e-02	4.16e-10	2.00e-02	2.08e-08		
Fluorene	1.93e-03	8.20e-12	4.00e-02	2.05e-10		
Phenanthrene	1.11e-01	4.72e-10	NA			
Phenol	3.30e-06	1.40e-14	6.00e-01	2.34e-14		
Cadmium	2.70e-03	1.15e-11	1.00e-03	1.15e-08		
Mercury	3.45e-03	1.47e-11	3.00e-04	4.89e-08		
Antimony	1.90e-03	8.45e-12	4.00e-04	2.11e-08		
Arsenic	5.44e-04	2.31e-12	3.00e-04	7.70e-09	30 yr: 1.50e+00	1.49e-12
Beryllium	4.63e-03	1.97e-11	NA		70 yr: 1.50e+00	3.47e-12
Chromium	4.55e-02	1.93e-10	3.00e-03	6.44e-08		
Copper	1.48e-03	6.29e-12	NA			
Lead	1.20e-02	5.10e-11	NA			
Nickel	9.51e-03	4.04e-11	2.00e-02	2.02e-09		
Selenium	1.84e-03	7.82e-12	5.00e-03	1.56e-09		
Silver	1.22e-04	5.18e-13	5.00e-03	1.04e-10		
Thallium	4.85e-02	2.06e-10	8.00e-05	2.58e-06		
Zinc	1.35e-02	5.73e-11	3.00e-01	1.91e-10		
Aluminum	7.30e+02	3.10e-06	NA			
Barium	0.00e+00	0.00e+00	7.00e-02	0.00e+00		
Iron	0.00e+00	0.00e+00	NA			
Tin	0.00e+00	0.00e+00	NA			
Titanium	0.00e+00	0.00e+00	NA			

(a)   NA indicates that an oral RfD is not available; RfDs are not available for specific SBF compounds.
(b)   None of the hazard quotients exceed 1. Therefore, toxic effects are not predicted to occur.
(c)   The lifetime excess cancer risks are less than 10^{-6} and are, therefore, acceptable.

Table Calculations:
        B =   A * (0.177 (kg/day) * % of catch affected) / 70 kg
        D =   B / C
        F =   B * 30 yrs (or 70 yrs) / 70 (lifetime in yrs) * E

Exhibit 5-20. Commercial Shrimp Health Risks - Offshore California, Shallow Water Development Model Well, Discharge Option

Pollutant	(A) Shrimp Tissue Concentration (mg/kg)	(B) 99th %ile Intake (mg/kg-day)	(C) Oral RfD (mg/kg-day) (a)	(D) 99th %ile Hazard Quotient (b)	(E) Slope Factor (mg/kg-day)-1	(F) Lifetime Exces Cancer Risk (c)
Noncarcinogenic Risks					**Carcinogenic Risk - Arsenic Only:**	
Naphthalene	5.62e-02	2.39e-10	2.00e-02	1.19e-08		
Fluorene	1.10e-03	4.67e-12	4.00e-02	1.17e-10		
Phenanthrene	6.38e-02	2.71e-10	NA			
Phenol	1.89e-06	8.03e-15	6.00e-01	1.34e-14		
Cadmium	1.54e-03	6.54e-12	1.00e-03	6.54e-09		
Mercury	1.97e-03	8.37e-12	3.00e-04	2.79e-08		
Antimony	1.14e-03	4.84e-12	4.00e-04	1.21e-08		
Arsenic	3.12e-04	1.33e-12	3.00e-04	4.42e-09	30 yr: 1.50e+00	8.52e-12
Beryllium	2.65e-03	1.13e-11	NA		70 yr: 1.50e+00	1.99e-12
Chromium	2.60e-02	1.10e-10	3.00e-03	3.68e-08		
Copper	8.46e-04	3.59e-12	NA			
Lead	6.86e-03	2.91e-11	NA			
Nickel	5.44e-03	2.31e-11	2.00e-02	1.16e-09		
Selenium	1.05e-03	4.46e-12	5.00e-03	8.92e-10		
Silver	6.98e-05	2.97e-13	5.00e-03	5.93e-11		
Thallium	2.78e-02	1.18e-10	8.00e-05	1.48e-06		
Zinc	7.71e-03	3.28e-11	3.00e-01	1.09e-10		
Aluminum	4.18e+02	1.78e-06	NA			
Barium	0.00e+00	0.00e+00	7.00e-02	0.00e+00		
Iron	0.00e+00	0.00e+00	NA			
Tin	0.00e+00	0.00e+00	NA			
Titanium	0.00e+00	0.00e+00	NA			

(a)   NA indicates that an oral RfD is not available; RfDs are not available for specific SBF compounds.
(b)   None of the hazard quotients exceed 1. Therefore, toxic effects are not predicted to occur.
(c)   The lifetime excess cancer risks are less than 10^{-6} and are, therefore, acceptable.

Table Calculations:
     B =   A * (0.177 (kg/day) * % of catch affected) / 70 kg
     D =   B / C
     F =   B * 30 yrs (or 70 yrs) / 70 (lifetime in yrs) * E

6. TOXICITY

6.1   Introduction

This chapter presents the information that EPA has reviewed concerning the determination of toxicity to the receiving environment of various synthetic base fluids and the formulated synthetic-based drilling fluids (SBFs). This information includes data generated for toxicity requirements imposed on North Sea operators as well as experimental testing conducted by the oil and gas industry in the United States. Because the synthetic base fluids are water insoluble and the SBFs do not disperse in water as water-based drilling fluids (WBFs) do, but rather tend to sink to the bottom with little dispersion, most research has focused on determining toxicity in the sedimentary phase as opposed to the aqueous phase.

Since1984, EPA has used an aqueous phase toxicity test to demonstrate compliance with NPDES permits for the discharge of drilling fluids and drill cuttings. This aqueous phase test measures toxicity of the suspended particulate phase (SPP), and is often called the SPP toxicity test (see "Drilling Fluid Toxicity Test" 40 CFR 435, Subpart A, Appendix 2). SBFs have routinely been tested using the SPP toxicity test and found to have low toxicity (Candler et al., 1997). Rabke et al. 1998a, have recently presented data from an interlaboratory variability study indicating that the SPP toxicity results are highly variable when applied to SBFs, with a coefficient of variation of 65.1 percent. Variability reportedly depended on such things as mixing times and the shape and size of the SPP preparation containers. As part of the coastal effluent guidelines effort, published in December 1996, EPA identified the problems with applying the SPP toxicity test to SBFs due to the insolubility of the SBFs in water. (EPA, 1996).

North Sea testing protocols require monitoring the toxicity of fluids using a marine algae (*Skeletonema costatum*), a marine copepod (*Arcartia tonsa*), and a sediment worker (*Corophium volutator* or *Abra alba*). The algae and copepod tests are performed in the aqueous phase, whereas the sediment worker test uses a sedimentary phase. Again, because the SBFs are hydrophobic and do not disperse or dissolve in the aqueous phase, the algae and copepod tests are only considered appropriate for the water soluble fraction of the SBFs, while the sediment worker test is considered appropriate for the insoluble fraction of the SBFs (Vik et al., 1996a). As with the aqueous phase algae and copepod tests, the SPP toxicity test mentioned above is only relevant to the water soluble fraction of the SBFs (Candler et al., 1997).

Both industry and EPA have identified the need for more appropriate toxicity test methods for assessing the relative toxicities of various SBFs. EPA has recently begun a research project to determine the toxicity of synthetic and other oleaginous (oily) base fluids, and

influences of drilling fluid formulation and crude oil contamination on SBF toxicity. Results from this research are not yet available. Industry has sponsored and continues to sponsor research to evaluate and develop test procedures, with the goal of identifying an appropriate toxicity test method for SBFs as measured at the point of discharge. The toxicity data on SBFs and SBF base fluids that EPA was able to collect is summarized in Exhibit 6-1. The individual studies are summarized below.

6.2   Summaries of Identified Articles Containing Toxicity Information

The following two papers presented essentially the same data on *Ampelisca abdita* and *Corophuim volutator*. However, Still and Candler (1997) presented additional data not included by Candler et al., 1997. Therefore, we have included a summary of both papers.

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

The authors reported the results of a study sponsored by M-I Drilling Fluids. The study evaluated the use of the ASTM sediment toxicity test method E1367-92 for determining the toxicity base fluids used for SBFs and OBFs. The base fluids tested were a diesel oil (DO), an enhanced mineral oil (EMO), linear paraffin (LP), an internal olefin (IO) and a polyalphaolefin (PAO). The tests were conducted with two marine amphipods, *Ampelisca abdita* and *Corophium volutator*. The tests were conducted in two phases: 1) whole fluid was used to determine the range of toxicity to *A. abdita* and 2) base fluid was used in definitive tests to determine 10-day LC50 values for both test species. Chemical analyses for Total Petroleum Hydrocarbons (TPH) were used to determine actual exposure concentrations of the highest concentration of each test. For Phase 1 of the study, the amphipods were exposed to two concentrations (5,000 and 10,000 mg whole fluid/kg dry sediment). Ranking for toxicity, from most toxic to least toxic, at 5000 mg/kg sediment was: DO and EMO (zero percent survival in both tests), PAO (11 % survival), IO (32% survival), and LP (44% survival). Rankings at the 10,000 mg/kg sediment level, from most to least toxic, was: DO and EMO (O% survival), LP (8% survival), PAO (11% survival), and IO (25% survival). For Phase 2, the amphipods were exposed to definitive concentrations of a DO, EMO, IO and PAO. The toxicity ranking of the SBFs and OBFs were based on 10-day LC50 values. Those LC50 values, presented in decreasing toxicity (increasing LC50 values) for *A. abdita* tests were: EMO with an LC50 value of 557 mg/kg of sediment, DO with an LC50 value of 879 mg/kg, IO with an LC50 value of 3,121 mg/kg, and PAO with an LC50 value of 10,690 mg/kg. The LC50 values for *C. volutator* were: DO (840 g/kg), EMO (7,146 mg/kg), IO (>30,000 mg/kg), and PAO (>30,000 mg/kg). The authors stated that the study proved that the ASTM E1367-92 test methods and both of the test species can be used as screening tool for use with synthetic base fluids.

Exhibit 6-1. Reported Toxicities of Synthetic-Based Fluids (LC50s)

	Ampelisca abdita	*Leptocheirus plumulosus*	*Rhepoxynius abronius*	*Corophium volutator*	*Abra alba*	*Skeletonema costatum*	*Acartia tonsa*	*Fundulus grandis*
BASE FLUID - Natural Sediment								
Diesel Candler, 1997 Rabke, 1998b Still, 1997	879 mg/kg 1.0 ml/kg 0.7 ml/kg	 850 mg/kg	 24 mg/kg	840 mg/kg				
EMO Candler, 1997 Still, 1997	557 mg/kg	 251 mg/kg	 239 mg/kg	7146 mg/kg				
IO Candler, 1997 Rabke, 1998b Vik, 1996 Still, 1997	3121 mg/kg 4.0 ml/kg 3.0 ml/kg	 3.7 ml/kg 2,944 mg/kg	 299 mg/kg	>30,000mg/kg 7,100 mg/l	300 mg/l	2,050 mg/l	>10,000 mg/l	
PAO Candler, 1997 Rabke, 1998b Vik, 1996 Still, 1997	10,690 mg/kg 13.4 ml/kg 12.5 ml/kg	 9,636 mg/kg	 975 mg/kg	>30,000mg/kg 12.0 ml/kg 3.0 ml/kg	 7,900 mg/l	 3,900 mg/l	 >50,000 mg/l	
Ester Vik, 1996a					>100,000 mg/l	60,000 mg/l	50,000 mg/l	
Acetal Vik, 1996a					549 mg/l	>100,000 mg/l	>100,000 mg/l	
LAO Vik, 1996a					1,021 mg/l	>10,000 mg/l	>10,000 mg/l	
BASE FLUID - Formulated Sediment								
Diesel Rabke, 1998b		1.0 ml/kg 0.7 ml/kg						

Exhibit 6-1. Reported Toxicities of Synthetic-Based Fluids (LC50s; continued)

	Ampelisca abdita	*Leptocheirus plumulosus*	*Rhepoxynius abronius*	*Corophium volutator*	*Abra alba*	*Skeletonema costatum*	*Acartia tonsa*	*Fundulus grandis*
WHOLE FLUID - Natural Sediment								
Diesel Rabke, 1998b	1.5 ml/kg	9.4 ml/kg						
IO Rabke, 1998b Friedheim et al., 1996	1.5 ml/kg	2.3 ml/kg		7,131 mg/kg	303 mg/kg			
PAO Rabke, 1998 Jones, 1991 Friedheim et al., 1996 Vik, 1996a	3.7 ml/kg	36.5 ml/kg		>10,000 mg/kg >10,000 mg/l	572 mg/kg 7,000 mg/l	82,400 mg/l	>50,000 mg/l	>8.4% TPH
Ester Vik, 1996a							34,000- 145,000 mg/l	>50,000 mg/l
LAO Friedheim et al., 1996				1,268 mg/kg	277 mg/kg			
WHOLE FLUID - Formulated Sediment								
Diesel Rabke, 1998b		2.9 ml/kg 1.7 ml/kg 0.7 ml/kg 1.3 ml/kg						
IO Rabke, 1998b Hood, 1997	3.6 ml/kg	2.5 ml/kg 2.7 ml/kg 10.5 ml/kg 2,279 mg/kg 4,498 mg/kg 2,245 mg/kg 1,200 mg/kg 943 mg/kg						

Exhibit 6-1. Reported Toxicities of Synthetic-Based Fluids (LC50s; continued)

	Ampelisca abdita	*Leptocheirus plumulosus*	*Rhepoxynius abronius*	*Corophium volutator*	*Abra alba*	*Skeletonema costatum*	*Acartia tonsa*	*Fundulus grandis*
PAO Rabke, 1998b		<2.5 ml/kg						
WHOLE FLUID -No Sediment								
	Mysidopsis bahia							
IO Rabke, 1998a Hood, 1997	221,436 - >1,000,000 ppm (SPP) 56,500 - >1,000,000 ppm (SSP)							

Still, I. and J. Candler. 1997. Benthic Toxicity Testing of Oil-Based and Synthetic-Based Drilling Fluids. Eighth International Symposium on Toxicity Assessment. Perth, Western Australia. 25-30 May 1997.

A two phase sediment toxicity study was conducted to examine the applicability of established sediment toxicity test methods for synthetic base fluids and SBFs. During Phase I, the marine amphipod *Ampelisca abdita* was tested with one drilling fluid formulation dosed individually with the following five base fluids: a diesel oil (DO), an enhanced mineral oil (EMO), a linear paraffin (LP), an internal olefin (IO) and a polyalphaolefin (PAO). Testing during Phase I served as rangefinders, with test concentrations of 5,000 and 10,000 mg drilling fluid/kg dry sediment.   Enhanced mineral oil and diesel were the most toxic for both concentrations. The toxicity ranking (most toxic to least toxic) for the SBFs at 5,000 mg/kg were PAO, IO and LP. The toxicity ranking (most toxic to least toxic) for the SBFs at 10,000 mg/kg were LP, PAO, and IO. For Phase II, definitive sediment toxicity tests were conducted. LC50 values were determined for EMO, DO, IO and PAO base fluids, using four marine amphipods: *Ampelisca abdita*, *Corophium volutator*, *Rhepoxynius abronius*, and *Leptocheirus plumulosus*. For *Ampelisca abdita*, the toxicity ranking (most toxic to least toxic) and corresponding LC50 values were: EMO (557 mg/kg); DO (879 mg/kg); IO (3,121 mg/kg); and PAO (10,680 mg/kg). For *Corophium volutator,* the toxicity ranking (most toxic to least toxic) and corresponding LC50 values were: DO (840 mg/kg); EMO (7,146 mg/kg); IO (>30,000 mg/kg); and PAO (>30,000 mg/kg). For *Rhepoxynius abronius* the toxicity ranking (most toxic to least toxic) and corresponding LC50 values were: DO (24 mg/kg); EMO (239 mg/kg); IO (299 mg/kg); and PAO (975 mg/kg). For *Leptocheirus plumulosus,* the toxicity ranking (most toxic to least toxic) and corresponding LC50 values were: EMO (251 mg/kg); DO (850 mg/kg); IO (2,944 mg/kg); and PAO (9,636 mg/kg). These results were ranked against the UK Offshore Chemical Notification Scheme (OCNS), which includes sediment testing as well as biodegradation and bioaccumulation in the ranking procedure. Using the OCNS classification, the results of this study ranked the based fluids, from most toxic to least toxic, as: diesel, enhanced mineral oil, IO and PAO.

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

The authors conducted an interlaboratory variability study with six different laboratories using the SPP toxicity test with a synthetic-based drilling fluid (SBF). The purpose was to determine the variability associated with this test method when applied to SBFs. A subsample of an internal olefin SBF was shipped to the individual laboratories where the SPP test was conducted. Results were reported in ppm (vol:vol) of SPP and ranged from 221,436 to >1,000,000 ppm. The coefficient of variation was 65.1 %.

Rabke, S. and J. Candler. 1998b. Development of Acute Benthic Toxicity Testing for Monitoring Synthetic-Based Muds Discharged Offshore. Presented at IBC Conference on Minimizing the Environmental Effects of Offshore Drilling, Houston Texas, February 9, 1998.

The authors used the ASTM E1367-92 method to determine the toxicity of synthetic-based drilling fluids (SBFs) and oil-based drilling fluids (OBFs) to the marine amphipods *Ampelisca abdita* and *Leptocheirus plumulosus*. The authors examined the variability of the test, including variability due to test organisms. The authors used formulated sediments in place of natural sediments to evaluate their use in marine sediment testing. However, concurrent tests were conducted using natural sediment as a control. The test species were exposed to varying concentrations of diesel oil (DO), polyalphaolefin (PAO) and internal olefin (IO). The authors concluded that using formulated sediments and whole fluids decreased the usefulness of the test method as a screening tool; PAO synthetic-based drilling fluids appeared to be as toxic as diesel in the whole fluid/formulated sediment test; and formulated sediment gave acceptable control survival although it reduced the discriminatory power of the tests. The results of the study are presented in Exhibit 6-1.

Jones, F.V., J.H. Rushing and M.A. Churan. 1991. The Chronic Toxicity of Mineral Oil-Wet and Synthetic-Wet Cuttings on an Estuarine Fish, Fundulus grandis*. SPE 23497.*

The authors determined the toxic effects of cuttings associated with a mineral oil-based drilling fluid (OBF-cuttings) and a poly alpha oelfin (PAO) synthetic-based drilling fluid (PAO-SBF-cuttings) to an estuarine fish, the mud minnow, *Fundulus grandis*. Unaltered cuttings were dried and crumbled to a uniform state and divided in half. The cuttings were then hot rolled with the appropriate amounts of each drilling fluid to obtain concentrations of 1%, 5%, and 8.4% oil on wet cuttings, based on retort measurements. Before distributing the fish in test containers, the fish were anesthetized with 2.5 ppt quinaldine, then measured for weight and length. The fish were allowed to recover in fresh seawater before placement in test containers. Contaminated cuttings were layered (approximately 3.8 cm thick) into tanks, then covered with seawater. Each tank received seawater flow at a rate of 28.5 ml/2 minute intervals. The fish were exposed for a total of 30 days. Fish were randomly removed from each tank on Day 15 for length and weight measurements. The authors also sacrificed the fish for bioaccumulation measurements; no data were provided in this paper. (However, see Chapter 7 for a discussion of Rushing et al., 1991, a companion paper containing procedural details.) At Day 30 the remaining fish were measured for weight and length. The authors concluded that neither the mineral oil-based nor synthetic-based drilling fluids affected growth of the fish based on percentage growth. However, the overall growth of the control and 5% PAO-SBF cuttings-exposed fish at Day 15 and Day 30 were significantly greater than fish exposed to all other treatments.

Vik, E.A., S. Dempsey, B. Nesgard. 1996a. Evaluation of Available Test Results from Environmental Studies of Synthetic Based Drilling Muds. OLF Project, Acceptance Criteria for Drilling Fluids. Aquateam Report No. 96-010.

The authors provided a summary for tests conducted with unused base fluids and whole SBFs. However, the authors did not cite sources for the data, leaving one to assume the work was conducted by their laboratory. The authors state that the North Sea test organisms were a marine algae (*Skeletonema costatum*), a marine copepod (*Acartia tonsa*), and a sediment worker (*Corophium volutator*, or *Abra alba*). The authors consider that algae and copepods are relevant for the water soluble fraction tests and sediment workers are relevant for testing the non-soluble fraction. The authors further state that the algae has been the most sensitive of three species in controlling the toxicity of discharged fluids.

Montgomery, R. 1998. Memorandum to J. Daly, EPA, Regarding Draft API Sediment Toxicity Protocol for Use With Synthetic-Based Drilling Fluids. December 11, 1998. Plus attachments.

Work for this report is in progress, therefore detailed data will not be presented here. However, there are trends that appear worth reporting. API is sponsoring a research study to evaluate the appropriateness of sediment toxicity tests with *Leptocheirus plumulosus, Ampelisca abdita,* and *Mysidopsis bahia* as applied to SBFs and OBFs. The API research is also evaluating the MICROTOX test. Phase 1 of the study compared rangefinding results with whole fluids mixed in formulated sediments. Trends indicated sediment toxicity of the synthetic-based fluids did not differ much (i.e., by a factor of <2X) when compared to sediment toxicity of an OBF based on diesel oil. Phase 2 was conducted with the same species and whole fluids mixed in natural sediments. The trend was that sediment toxicity of the SBFs was slightly less (i.e., by a factor of 2-3X) when compared to sediment toxicity of OBFs. Another trend is the loss of discriminatory power between sediment toxicity of OBFs and SBFs. Results of the tests with natural sediments appeared to have better discriminatory power over the results of tests with formulated sediments. Both industry and EPA are currently investigating methods to discriminate sediment toxicity of SBFs and OBFs.

Hood, C. 1997. Unpublished Data Received By J. Daly (U.S. EPA) July 9,1997 from C. Hood, Baker Hughes INTEQ.

Unpublished data was provided by Ms. Cheryl Hood of Baker Hughes INTEQ, on the toxicity of four synthetic-based drilling fluids (SBFs) to the mysid, *Mysidopsis bahia* and the amphipod, *Leptocheirus plumulosus*. The 96-h LC50 for the mysids ranged from 14,600 to >500,000 ppm SPP and the 10-d LC50 for the amphipod ranged from 943 to 4498 mg SBF/kg dry sediment.

6.3   Summary

Although there are data available on the toxicity of both SBFs and base fluids from the North Sea and United States, the information is insufficient to draw meaningful conclusions other than broad generalizations. Also, little is known about the influence of the organics in either natural sediments or formulated sediments on the toxicity of these fluids. However, with the limited data, several assumptions can be made.

(1)   North Sea amphipods appear to be less sensitive to synthetic base fluids than those amphipods currently used in US testing.

(2)   Synthetic base fluid toxicity appears to show greater discriminatory power versus diesel toxicity than does SBFs toxicity.

(3)   Discriminatory power seems to be diminished with the use of formulated sediments.

(4)   Mysid SPP testing does not appear to be a relevant test method for these fluids.

Because data are limited, EPA and industry are continuing to gather information on sediment toxicity through ongoing research. Industry is currently evaluating sediment test methods, using formulated sediments and species sensitivities. EPA is beginning research on the toxicity of synthetic base fluids and the factors that influence the toxicity of these synthetic base fluids (as well as the biodegradation and bioaccumulation of synthetic base fluids). The goal of EPA research is to restore discriminatory power to discern the differences in toxicity between diesel oil, mineral oil, and synthetic base fluids. Because the current, examined amphipod test species are not indicating sufficient discriminatory power, EPA may further consider using other test organisms, such as polychaetes.

7. BIOACCUMULATION

7.1 Introduction

One factor to be considered in assessing the potential environmental impacts of discharged drilling fluids and drill cuttings is their potential for bioaccumulation. This chapter presents the information that EPA has gathered concerning the bioaccumulation of oleaginous base fluids, including the synthetic base fluids and mineral oil.

The information that EPA identified was provided by oil and gas operators and by oilfield chemical (drilling mud) suppliers. Much of this information is in the public domain. However, only a minimal amount can be found in peer reviewed publications. Most of the available information has been developed by mud suppliers to provide information to government regulators to assess the acceptability of these materials for discharge into the marine environment.

7.2 Summary of Data

The available information on the bioaccumulation potential of synthetic base fluids is scant, comprising only a few studies on octanol:water partition coefficients (P_{ow}) and two on tissue uptake in experimental exposures [only one of which derived a bioconcentration factor (BCF)]. The P_{ow} represents the ratio of a material that dissolves or disperses in octanol (the oil phase) versus water. The P_{ow} generally increases as a molecule becomes less polar (more hydrocarbon-like). The available information on the bioaccumulation potential of synthetic base fluids covers only three types of synthetics: an ester (one studies), internal olefins (IO; three studies), and poly alpha olefins (PAO; four studies). One study included a low toxicity mineral oil (LTMO) for comparative purposes. This limitation with respect to the types of synthetic base fluids tested is partially mitigated by the fact that these materials represent the more common of synthetic base fluid types currently in use in drilling operations.

These limited data suggest that synthetic base fluids do not pose a serious bioaccumulation potential. Despite this general conclusion, existing data cannot be considered sufficiently extensive to be conclusive. This caution is specifically appropriate given the wide variety of chemical characteristics resulting from marketing different formulations of synthetic fluids (i.e., carbon chain length or degree of unsaturation within a fluid type, or mixtures of different fluid types). Additional data should be obtained both for the purpose of confirming what is known about existing fluids and to ensure completeness and currency with new product development.

The data that EPA identified concerning the bioaccumulation potential of synthetic base fluids are summarized in Exhibit 7-1. Nine reports provided original information. This information consisted of P_{ow} data (based on calculated or experimental data), dispersibility data, or subchronic exposure of test organisms to yield data for calculating BCFs or assessing uptake. log P_{ow} values less than three or greater than seven would indicate that a test material is not likely to bioaccumulate (Zavallos et al., 1996).

For PAOs, the log P_{ow}s reported were >10, 11.9, 14.9, 15.4, and 15.7 in the four studies reviewed. The three studies of IOs that were reviewed reported log P_{ow}s of 8.57 and >9. The ester was reported to have a log P_{ow} of 1.69 in the one report in which it was tested. A log P_{ow} of 15.4 was reported for an LTMO. The only BCF reported was calculated for IOs; a value of 5.4 l/kg was determined. In 30-day exposures of mud minnows (*Fundulus grandis*) to water equilibrated with a PAO- or LTMO-coated cuttings, only the LTMO was reported to produce adverse effects and tissue uptake/occurrence. Growth retardation was observed for the LTMO and LTMO was observed at detectable levels in 50% of the muscle tissue samples examined (12 of 24) and most (19 of 24) of the gut samples examined. The PAO was not found at detectable levels in any of the muscle tissue samples and occurred in only one of twenty-four gut samples examined.

7.3 Summaries of Identified Reports Containing Bioaccumulation Information

Friedheim, J.E. et al. 1991. An Environmentally Superior Replacement for Mineral-Oil Drilling Fluids. SPE 23062. Presented at the Offshore Europe Conference, Aberdeen, September 3-6, 1991.

Bioaccumulation studies were conducted on both the PAO-base fluid and the PAO-based SBF. The calculated octanol/water partition coefficient for the PAO gives a log P_{ow} of 15.4. The authors concluded the PAO was not expected to bioaccumulate in aquatic species for a variety of reasons. The authors base their projection on data that indicate gill uptake of xenobiotics increases with increasing lipophilicity up to about a log P_{ow} of 7, beyond which there exists an inverse relationship between lipophilicity and bioconcentration. Thus, these authors believe that there appears to be a cut-off point in water solubility (or lack thereof) beyond which compounds cannot move past the aqueous diffusion layer present at the water/gill interface; a similar scenario accounts for a decreased absorption of hydrophobic chemicals in fish intestine. Therefore, Friedheim et al. concluded the physico-chemical properties of the PAO (i.e., low water solubility) would prohibit it from passing freely into aquatic species and bioaccumulating. PAOs are highly lipid soluble, and thus Friedheim et al. believe they are likely to be absorbed into the organic fraction of the sediment or onto suspended organic solids in the aquatic environment. These authors postulate that the PAO either would not be bioavailable (due to

Exhibit 7-1. Bioaccumulation Data for Synthetic Fluids and Mineral Oil Muds

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

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

sequestration by the sediment) or would not be able to pass through the gill (or intestine) due to the molecular size of the "suspended particle," (which is likely referring to the adsorption of the PAO to the suspended organic solids to which the authors referred earlier).

Leuterman, A.J.J. 1991. Environmental Considerations in M-I Product Development Novasol/Novadril. M-I Drilling Fluids Co., January 15, 1991.

Although Novasol [a PAO] is highly lipid soluble, with a calculated octanol/water partition coefficient (log P) of >10.0, it was not expected by this author to bioaccumulate in aquatic species. Leuterman presented several reasons he considered well-documented. These reasons include the following:

1. High molecular weight, low water soluble polymers are thought not to pass biological membranes due to molecular volume considerations.

2. Highly lipophilic chemicals in aquatic systems are likely to absorb and partition into the organic fraction, in this case the organic fractions of the drilling fluid. In this arrangement the chemical constituent would not be bioavailable for absorption due to sequestration in the drilling fluid and cuttings or would not be able to pass through the gill or intestine, if ingested, due to the molecular size of the chemical constituent.

3. Gill uptake of xenobiotics increases with increasing lipophilicity up to about log P of 7. Beyond this level there exists an inverse relationship between lipophilicity and bioconcentration. Toxicokinetically this reduction apparently results from a decrease in the magnitude of the uptake rate constant. There appears to exist a cut-off point in the water solubility, i.e., the lack of, beyond which compounds cannot move past an aqueous diffusion layer present at the water/gill interface. A similar scenario accounts for decreased absorption of hydrophobic chemicals in fish intestines. Since transport into biological membranes requires, in most cases, that the xenobiotic be available in a dissolved form, the physico-chemical properties of Novasol, i.e., low water solubility, would prevent its passage into aquatic species and thence bioaccumulate.

4. If the base fluid did pass into the aquatic species, aquatic animals have the ability to metabolize xenobiotics through various enzyme systems located primarily in the intestine and liver. Once metabolized, these metabolites are normally of a more water soluble form, i.e., hydroxylated products, and are eliminated from the organism and not accumulated.

To confirm the expected low bioavailability of Novasol, M-I conducted a thirty (30) day bioaccumulation test using the mud minnow *Fundulus grandis*. This author states that preliminary results of this test reveal no detectable amount of the material, or its degradation products, in the tissue or organs of the test animals. In fact, the test animals showed no ill effect, no deformities and no reduced growth rates. No data are provided, however.

Friedheim, J.E. and R.M. Panternuehl. 1993. Superior Performance With Minimal Environmental Impact: A Novel Nonaqueous Drilling Fluid. SPE/IADC 25753. presented at the SPE/IADC Drilling Conference, Amsterdam, February 23-25, 1993.

Both an octanol/water partition coefficient determination and actual laboratory testing with fish were discussed to describe the potential for bioaccumulation of the PAO system. The authors cite earlier reports (Friedheim et al. 1991), in which the partition coefficient (log P_{ow}) for the PAO is 15.4. This high value along with the large molecular weight of the material led the authors to conclude the PAO should not accumulate in aquatic life. These arguments are based on knowledge of gill uptake of xenobiotics and absorption of hydrophobic chemicals in intestines of fish. The authors' conclusion is that the physico-chemical properties of the PAO would prohibit it from passing freely into aquatic species and bioaccumulating. Also, previous laboratory bioaccumulation test results (Rushing et al., 1991) using *Fundulus grandis* (mud minnow) were cited to support the arguments presented above.

Schaanning, M.T. 1995a. Evaluation of Overall Marine Impact of the Novadril Mud Systems. NIVA Report 0-95018.

The ICI Brixham Laboratory estimated that log Pow = 14.9-15.7 for a PAO product coded AB-5243-SO. This product was, however, composed of 65% of a synthetic hydrocarbon having a chain length of 22 carbon atoms (C22), 20% C32, and 15% C42 and C52 oligomers, neither of which were predominant components of the Novasol I and Novasol II base fluids. Measured coefficients of polyalphaolefins (oligomer composition not specified) exceeded the upper limit of 8.0 that could be determined by the applied HPLC-method.

Information on concentrations of Novasol PAO's in animal tissues from exposed organisms, as noted by these authors, is rather scarce. The authors discuss a few results of a recent study of fish sampled at a North Sea Novadril II well site that were cited in M-I information dated January, 1995. No taste or smell was found in any of the fish sampled. Neither did the concentration of Novasol exceed the detection limit of 0.1 mg.kg-1 in any of the fish samples analyzed. No information was provided by the authors as to where, when and how sampling was performed or how many and which species were analyzed. The authors also present that analyses of commercial fish species captured at the drilling sites is obviously of great public interest. Because of the lack of control on exposure of the analyzed individuals to the test chemical, however, a field study showing neither smell, taste nor detectable concentrations, was not considered to yield evidence that the chemical has a low potential for bioaccumulation. Results of Rushing et al. (1991) were also discussed in this report.

Growcock, F.B., S.L. Andrews and T.P. Frederick. 1994. Physicochemical Properties of Synthetic Drilling Fluids. IADC/SPE 27450. Presented at the IADC/SPE Drilling Conference, Dallas, Texas, February 15-18, 1994.

The dispersibility (aqueous phase partitioning) of synthetic fluids in seawater was tested. The dispersibility test consists of shaking equal volumes of seawater and synthetic fluid for 10 seconds followed by a 10 minute equilibration prior to sampling the seawater phase for organic carbon analysis. The test gave the following trend among various synthetic base fluids:

Ester>Di-Ether>>Detergent Alkylate>PAO>LTMO.

This trend was considered by the authors as qualitatively consistent with the trend in the octanol/water partition coefficient, P_{ow}, which ranges from log P_{ow} = 1.69 for the ester to log P_{ow} = 15.4 for the PAO and the LTMO (no data or sources cited). The authors concluded that it is possible for a significant portion of the ester, and perhaps other synthetics as well, to disperse in seawater.

Færevik, I. Undated. Discharges and regulations of synthetic drilling fluids on the Norwegian Continental Shelf and summary of results from ecotoxicological testing and field surveys. Norwegian Pollution Control Authority.

Laboratory testing shows that many of the chemicals in synthetic drilling fluids have a potential for bioaccumulation. Specifically the olefin base fluids show log P_{ow} values well above 7.0. The ester base fluids are unlikely to bioaccumulate, but several of the additives in ester based drilling fluids show log P_{ow} values above 5.0. The molecular weight for both base fluids and additives in synthetic drilling fluids are typically below 600.

The author asserts that existing bioaccumulation tests are not relevant for surface active substances that are commonly present in synthetic drilling fluids. Rather, bioaccumulation should be expressed as the distribution between sediment and water (the sediment:water partition coefficient, log P_{sw}), not as now by the octanol and water coefficient (log P_{ow}). The author states that the potential for bioaccumulation is overestimated due to inadequate methods of calculation.

Because these fluids have such low aqueous solubilities, a concern has been noted that P_{ow} data are less relevant than, perhaps, P_{sw} data. This would provide some measure of the potential for long-term leaching of these materials into sediment pore water with their subsequent availability to benthic infauna and epifauna. This concern is valid, and these data may be worth pursuing because the standard P_{ow} and P_{sw} protocols appear adequate to evaluate these fluids and are relatively brief and inexpensive procedures. Also, standard experimental protocols for

measuring uptake in test species are available and would be useful for testing a subset of materials for which log P_{ow} or P_{sw} determinations have been performed to confirm bioaccumulation potentials projected from P_{ow} or P_{sw} data.

Environment & Resource Technology. 1994a. Bioaccumulation Potential of ISO-TEQ Base Fluid. ERT 94/209. Prepared for Baker Hughes INTEQ.

The bioaccumulation potential of ISO-TEQ base fluid, an internal olefin of chain length from 16 to 18 carbon atoms (C16-C18), was evaluated. The bioaccumulation potential was estimated by measuring the log octanol-water partition coefficient by HPLC following OECD 117 guidelines. Under the standard conditions described in the report, no elution of the test substance occurred during a period of 6.5 hours. To enhance the elution of the test substance, it was re-examined using 2-propanol:water. The absence of detectable HPLC peaks with the standard system indicated that the log P_{ow} value for ISO-TEQ base fluid was greater than the value for the most lipophilic calibration standard, suggesting that the value would be greater than 9.

Environment & Resource Technology. 1994b. Bioconcentration Assessment Report, Assessment of the bioconcentration factor (BCF) of ISO-TEQ base fluid in the blue mussel Mytilus edulis*. ERT 94/061. Prepared for Baker Hughes INTEQ.*

The study was conducted in accordance with an SOP written to conform with OECD guidelines 305 A-E for the determination of bioconcentration or bioaccumulation of chemicals from the aqueous phase. Specimens of the blue mussel *Mytilus edulis* were exposed to saturated aqueous concentrations of ISO-TEQ base fluid (a predominantly C16-C18 internal olefin) under flow-through conditions for ten days, and subsequently allowed to depurate in clean seawater for a further 20 days. BCF values were calculated from uptake and depuration rates or each compound group separately. The bioconcentration factors (BCF) were calculated from

- the ratio of tissue (lipid) concentration to water concentration of the major components of the fluid at equilibrium (10 days), or if a steady-state was not achieved,

- the ratio of the uptake to depuration rate constants, calculated as defined in the SOP.

The test met all validity criteria, with the exception of exposure concentration control, which varied more than specified as a consequence of the very low saturation concentrations of the test substance components. The variation was not, however, of a magnitude sufficient to significantly affect the estimated low BCF values. ISO-TEQ exhibited high rates of uptake and depuration, with no detectable tissue residue. The equilibrium log BCF values (lipid weight basis) for the test substances were estimated to be 5.37 for the C16 compounds and 5.38 for the

C18 compounds. After cessation of exposure, the test animals depurated their tissues to concentrations of test compound to < 1 ug.g-1 (0.03% of peak value). Log BCF values were approximately half the probable log P_{ow} values (>8).

Jones, F.V., Rushing, J.H., and M.A. Churan. 1991. The Chronic Toxicity of Mineral Oil-Wet and Synthetic Liquid-Wet Cuttings on and Estuarine Fish, Fundulus grandis. *SPE 23497. Presented at the First International Conference on Health, Safety and Environment, The Hague, The Netherlands, November 10-14, 1991.*

Mud minnows (*Fundulus grandis*) were held in tanks of synthetic seawater (i.e., formulated from a mixture of salts and substances that mimic natural seawater). Drilling fluids were prepared using a 80/20 ratio of mineral oil/water for a 7.4 pounds per gallon (ppg) drilling fluid (MOBF) and a 70/30 ratio of PAO/water for an 11.0 ppg drilling fluid (PAO-SBF). Both drilling fluids were then hot-rolled for 16 hours at 66ºC. Each drilling fluid was added to a container of dried cuttings, hand-mixed, and hot-rolled for another 24 hours at 66ºC. Laboratory bioaccumulation tests showed that the presence of cuttings soaked in an 11.0 ppg 70/30 PAO-SBF system did not affect the growth rate of this species. Rather, they showed equal or better weight gain and size increase as compared to the control samples. Conversely, test runs using MOBF-soaked cuttings showed a retarded growth rate with respect to the control. The authors also offered that fish cultured with the mineral oil had to spend a large portion of their energy removing this hydrocarbon from their blood stream, and that this energy drain may have caused the lower observed growth in those fish in the MOBF tanks.

Zevallos, M.A., J. Candler, J.H. Wood and L.M. Reuter. 1996. Synthetic-Based Fluids Enhance Environmental and Drilling Performance in Deepwater Locations. SPE 35329. Presented at the SPE International Petroleum Conference & Exhibition of Mexico, Villahermosa, Tabasco, Mexico, March 5-7, 1996.

Measurement of bioaccumulation of synthetic fluids can be estimated using the N-octanol/water partition coefficient (P_{ow}). P_{ow} values less than three or greater than seven would indicate that the test material will not bioaccumulate. Both the 11.19 P_{ow} for PAO and 8.57 P_{ow} for IO indicate these synthetic materials would not bioaccumulate. Ranked by their P_{ow} values, IOs have a greater potential than PAOs to bioaccumulate.

Davies, J.M., D.R. Bedborough, R.A.A. Blackman, J.M. Addy, J.F. Appelbee, W.C. Grogan, J.G. Parker and A. Whitehead. 1989. The Environmental Effect of Oil-based Mud Drilling in the North Sea. <u>In</u>: Drilling Wastes, F.R. Engelhardt, J.P Ray and A.H. Gillam (eds). Elsevier Applied Science, New York. Pp. 59-89

During 1985 and 1986, fish were caught from three areas in the North Sea close to oil and gas exploration and production platforms and from areas outside the influence of drilling activity as reference (control) samples. These operations had drilled many wells using OBM, including both diesel oil- and mineral oil-based OBMs. Fish were tasted by a trained panel to determine the presence of any oily taint in the flesh. A fish was deemed to be oil tainted if more than half the panel detected an oily taint. Among cod, haddock, tusk, and dabs caught between 0.40 and 9.3 km from oil platforms, only for dabs caught between 0.55 km and 0.86 km did more than half the panel detect an oily taint.

Rushing, J.H., M.A. Churan, and F.V. Jones. 1991. Bioaccumulation from Mineral Oil-Wet and Synthetic Liquid-Wet Cuttings in an Estuarine Fish, Fundulus grandis. *SPE 23497. Presented at the First International Conference on Health, Safety and Environment, The Hague, The Netherlands, November 10-14, 1991.*

The authors report an experimental study on uptake of low aromatic mineral oil (LTMO) and Novasol PAO in tissue and gut samples from mud minnows (*Fundulus grandis*) exposed for 30 days to water equilibrated with contaminated cuttings at nominal concentrations of 1%, 5%, and 8.4% base fluid (i.e., PAO or mineral oil). Gut samples represented carefully excised internal organs and connecting structures from the mouth to the anus. Muscle tissue samples were prepared from fish whose heads, tails, skin, and viscera were removed, thus including finer bones in these samples. Samples from each of the three dosings were taken seven times during the course of the exposure (Days 3, 7, 10, 15, 20, 25, and 30) and again after a 4-day depuration period.

Among fish exposed to SBM-coated cuttings, analysis of fish tissue and organs using GC/MS measured no uptake of PAO in samples of fish tissue, and an accumulation of PAO was observed in only one of 24 gut samples. By contrast, fish exposed to LTMO cuttings showed accumulations of mineral oil in 19 of 24 fish gut samples and detectable amounts of mineral oil components in 12 of the 24 tissue samples analyzed. Both mineral oil and olefins were shown present in the water of the aquaria throughout the exposure period.

The authors concluded that the contrast between the mineral oil and the polyalphaolefins was a result of restricted uptake of the larger olefin molecules across gill and digestive structures. The authors further assert that the high molecular weight and the structure of PAOs is a key factor in limiting the amount of uptake by fish. Since PAOs are a complex, high molecular

weight molecule, fish could not uptake the material through its gill structure. One sampling showed a low amount of PAO in the gut analysis. It is possible this material was in the intestinal tract of the fish and had not passed through the fish when sampled.

8. BIODEGRADATION

8.1 Introduction

A number of different and contrasting test methods have been used to predict the biodegradability of synthetic base fluids deposited on offshore marine sediments. These method variations have included: calculation of biochemical oxygen demand in inoculated freshwater aqueous media versus uninoculated seawater aqueous media; determination of product (gases) evolved versus the concentration of synthetic base fluid remaining at periodic test intervals; varying initial concentrations of test material; aqueous versus sediment matrices; and within sediment matrices, layering versus mixed sediment protocols.

In the field, the mechanisms observed from the deposition of SBF contaminated drill cuttings involve the initial smothering of the benthic community followed by organic enrichment of the sediment due to adherent drilling fluids. Organic enrichment causes oxygen depletion due to the biodegradation of the discharged synthetic base fluids. This biodegradation results in predominantly anoxic conditions in the sediment, with limited aerobic degradation processes occurring at the sediment:water column interface. Therefore, the biodegradation of deposited drilling fluid will be an anaerobic process to a large degree. Standardized tests that utilize aqueous media, while readily available and easily performed, may not adequately mimic the environment in which the released synthetic base fluid is likely to be found and degraded. As a result, alternative test methods have been developed that more closely simulate seabed conditions. One method uses a deposition of synthetic base fluid on marine sediment and measuring degradation in a sediment matrix. Another method uses anaerobic conditions in aqueous media (Vik et al., 1996b; Limia, 1996; Munro, 1997).

8.2 Biodegradation Test Methods

A variety of test methods, each with characteristic limitations and qualifications, has been used to assess the biodegradation of test materials. Slater et al. (1995) present a descriptive comparison of the technical details of the Organization for Economic Co-operation and Development (OECD) 301-series test protocols, the Biochemical Oxygen Demand for Insoluble Substance (BODIS) protocols, and seabed simulation test protocols.

The OECD 301-series tests are all aqueous freshwater tests that use an activated sewage sludge inoculum. As an example of 301 protocols, the OECD 301D "Clean Bottle" test protocol is briefly summarized in Exhibit 8-1. The 301A through 301F tests vary in the analytical endpoint used to quantify oxygen demand, the concentration range of the test substance, and their

design suitability among poorly soluble, volatile, or adsorbing test substances. The drawbacks of using these tests for synthetic base fluids are: the insolubility of synthetic base fluids in aqueous media, the use of a freshwater matrix, the use of an aqueous matrix for the test, and the aerobic nature of the test.

Exhibit 8-1. OECD 301D: 28-Day Closed Bottle Test

A solution of test substance (e.g., synthetic base fluid) is prepared in a mineral medium consisting of stock solutions of a) KH_2PO_4, K_2HPO_4, $Na_2HPO_4 \cdot 2H_2O$, NH_4Cl; b) $CaCl_2$; c) $MgSO_4 \cdot 7H_2O$; and d) $FeCl_3 \cdot 6H_2O$. The test solution is poured into test bottles and inoculated with a small number of micro-organisms derived from the secondary effluent of a domestic sewage treatment plant (or laboratory-scale unit) or surface water. A parallel series of bottles containing inoculated blank medium is prepared for reference measurements of oxygen uptake by the inoculum. The closed test bottles are incubated in the dark at constant temperature for 28 days. Dissolved oxygen measurements are taken via Winkler titration or oxygen electrode at time zero and weekly intervals; more frequent intervals require more bottles. The percent degradation of the test substance is calculated as the ratio of the biochemical oxygen demand of the test substance (in mg O_2 uptake per mg test substance) and the theoretical oxygen demand (or less accurately, the chemical oxygen demand) of the test substance.

The OECD 306 methods change the matrix from a freshwater matrix to a seawater matrix, and allow for two analytical variants. In one analytical variant, the incubation period increases from 28 days to 60 days. The biggest difference between the OECD freshwater and seawater tests is the presence of an activated sludge inoculum in freshwater tests versus the absence of an inoculum in the seawater tests, which relies on endogenous marine microorganisms for degradative capacity.

Two International Standards Organization (ISO) protocols, one for freshwater (BODIS/FW) and one for seawater (BODIS/SW), also have been used to assess biodegradability of insoluble test materials. The same characteristics as discussed for the OECD 301 methods regarding the presence/absence of a sludge inoculum apply to these ISO protocols: the freshwater test uses inoculum but the seawater test does not. Likewise, freshwater and seawater respirometric methods, which rely on analytically different endpoints, can be characterized as similar to the 301-series tests. An ISO protocol for assessing freshwater anaerobic biodegradability is available (see Exhibit 8-2 for a brief description). The protocol may more accurately assess real-world conditions for a large portion of discharged synthetic base fluids. However, although this protocol provides a quantification of anaerobic biodegradation, it still relies on an aqueous freshwater matrix.

> **Exhibit 8-2. ISO 11734: "Water Quality--Evaluation of the "Ultimate" Anaerobic Biodegradability of Organic Compounds in Digested Sludge--Method by Measurement of the Biogas Production"**
>
> A test compound (e.g., synthetic base fluid) is added to a dilution medium at an organic carbon concentration of 20 mg/l to 100 mg/l. The dilution medium is a solution of the following constituents: KH_2PO_4, $Na_2HPO_4 \cdot 12H_2O$, NH_4Cl, $CaCl_2 \cdot 2H_2O$, $MgCl_2 \cdot 6H_2O$, $FeCl_2 \cdot 4H_2O$, $Na_2S \cdot 9H_2O$, resazurin (oxygen indicator), stock solution of trace elements, and de-oxygenated water. Under anaerobic conditions, the test solution is inoculated with washed digested sludge containing very low amounts of inorganic carbon, then incubated in sealed vessels in the dark at constant temperature for 60 days.
>
> As a result of anaerobic degradation, carbon dioxide and methane evolve in the headspace above the test solution, and the amount of dissolved carbon dioxide, hydrogen carbonate, or carbonate in the solution increases. The amount of microbiologically produced carbon in the head space gas is calculated from the measured increase in head space pressure as applied to the gas law equation (PV=nRT). The amount of inorganic carbon produced in the solution is measured, and is added to the amount of head space carbon to determine the total carbon produced in excess over blank values. The percentage biodegradation is calculated as the total carbon produced relative to the initial carbon in the test compound.
>
> The progress of biodegradation can be charted by intermediate measurements of head space pressure. A graph of pressure versus time should show an initial lag phase followed by a period of steadily increasing pressure, ending with a plateau phase indicating the cessation of gas production. Significant deviations from this course may indicate that the test should be prolonged or repeated.

To address the issue of aqueous versus sediment matrices, two non-standard test protocols have been developed. One, the "NIVA" protocol (Norwegian Institute for Water Research; Schaanning, 1994), which is commonly referred to as the "simulated seabed study," relies on layering of test material on the surface of the test sediment. The other is the "SOAEFD" test protocol (Scottish Office, Agriculture Environment and Fisheries Department; Munro et al., 1997b), which is commonly referred to as the "solid phase test," mixes the test material into the test sediment prior to incubation (see Exhibits 8-3 and 8-4 for brief descriptions of the NIVA and SOAEFD protocols). These laboratory protocols, to date, have assessed biodegradability of synthetic fluids at experimental sediment levels (NIVA = 700 mg/kg to 18,000 mg/kg; SOAEFD = 100 mg/kg to 5,400 mg/kg) that are below or at the lower end of the range of sediment concentrations of synthetic fluids measured in the field at two drill sites in the North Sea (up to 4,700 mg/kg and up to 100,000 mg/kg) and one drill site in the Gulf of Mexico (up to 134,000 mg/kg, or 13.4 percent).

Exhibit 8-3. NIVA Protocol for Simulated Seabed Biodegradation Study

NIVA protocols have evolved since 1990, and intend to more accurately represent offshore seabed conditions for biodegradation. The test consists of a series of chambers containing clean sediment, covered with 15 cm of seawater drawn from a depth of 60 m from the Oslofjord and pumped through the experimental chambers. On Day 0, a thin layer of drill cuttings (1-2 mm) is created by adding a slurry to the chamber water and allowing particulates and solids to settle. Tests run for as long as 160 days.

Based on the measured amounts of fluid at Day 0 and the last day of the test, the percentage decrease is calculated. Rates are adjusted for the loss of drilling fluid due to seawater flow by using Ba concentrations as an indicator for test substance lost due to seawater flow-through. NIVA has found that first-order kinetics describe the loss of drilling fluid over time according to

$$C_t = C_0 \times 10^{-kt}$$

where C_t = test substance concentration at time t (in days), C_0 = the concentration at $t = 0$, k is the decay constant, and t is the time in days.

Exhibit 8-4. SOAEFD Protocol for Solid-Phase Test System for Degradation of Synthetic Base Fluid

A synthetic base fluid is homogeneously mixed at specific concentrations with prepared marine sediment and maintained in a trough of flowing sea water for 120 days. Base fluid is added at concentrations of 100 ppm, 500 ppm, and 5,000 ppm to represent historical measurements of mineral-oil-based cuttings piles at distances from the platform of 1,000 m to 3,000 m, 200 m to 1,000 m, and 200 m, respectively. The concentrations of added base fluid are determined empirically prior to the experiment as µg TOC per g of dry sediment.

At set times, triplicate jars are removed for chemical analysis of the base fluid. The concentration of the base fluid remaining is determined by solvent extraction followed by gas chromatography with flame ionization detection. Base fluid concentrations (in ppm) are graphed as a function of time; results are compared in terms of how closely the data follow first order reaction kinetics, as expressed by the equation:

$$A_t = A_0 e^{-kt}$$

where A_0 is the concentration of the substance at time $t = 0$, A_t is the concentration at time t, k is the rate constant for the reaction and e is the log to the base e.

Three additional analyses are conducted to further characterize the course of biological activity throughout the experiment: the oxidation-reduction (redox) profiles of the test sediments as compared with clean sediment; the number of culturable bacteria from sediments; and the number of bacteria capable of growth on the test fluid as the sole carbon source (the Sheen-screen). The sediment redox profiles, expressed in mV, measure the level of oxygenation of the sediment at varying depths, indicating the local concentration of organic matter. Trends in redox measurements are charted by depth and over time, for temporal and spacial comparisons between test sediments and clean sediment. Throughout the experiment, samples are taken at the sediment surface and at a depth of 4 mm to measure the number of "culturable" aerobic and anaerobic bacteria. The Sheen-screen measures the number of aerobic and facultative anaerobic bacteria per gram of wet sediment capable of growth on the synthetic base fluid as the sole carbon source. It is an indicator for the biodegradation potential of a base fluid in the sediment used. The conditions for the Sheen-screen are aerobic and thus, growth of obligate anaerobes is not provided for and test conditions do not accurately mimic real world conditions for discharged synthetic drilling fluids.

Aerobic test conditions have been summarized by Vik et al. (1996b) and are presented in Exhibit 8-5; a summary of laboratory and field biodegradation assessment procedures were summarized by Vik at al. (1996b) and are presented in Exhibit 8-6.

8.3   Biodegradability Results

Two overarching concerns in any presentation of data on biodegradation of synthetic base fluids are the incompatibility of test results obtained using different protocols and the high variability routinely encountered within a given protocol. These two factors mitigate against the utility of the data in any comparative sense. Additionally, the differences in fresh- versus saltwater media, aerobic versus anaerobic media, and aqueous versus sediment matrices render the applicability of most of the reported tests as extremely limited. Sedimentary phase tests are more comparable to the actual conditions in which these materials will be found and provide more consistent results than aqueous phase tests.

8.3.1 *Aqueous Phase Tests*

Exhibit 8-7 presents a ranking of aerobic biodegradation test results for an acetal synthetic fluid using OECD 301B (FW), 301D (FW), 306 (SW), BODIS (FW), and BODIS (SW) protocols at two concentrations of added test material. Given the substantial differences in experimental design and protocols, results of 28-day tests expectantly show a wide range in results, from 5% degradation to 86% degradation. Degradation was, as expected for a system subject to saturation kinetics, more extensive for any given protocol at the lower test concentrations (although with one exception). Few other comparisons are meaningful. For example, seawater tests show less degradation than freshwater tests. Thus, BODIS seawater tests show less degradation (8% and 19.5% at 40 mg/l and 10 mg/l, respectively) than BODIS freshwater tests (50% and 86% at 40 mg/l and 10 mg/l, respectively). Similarly, the OECD 306 seawater test at all concentrations shows less degradation compared to either the OECD 301B or 301D freshwater tests at the same test concentration. However, the freshwater tests all use an activated sewage sludge inoculum of microorganisms, whereas the seawater tests are endogenous levels of microorganisms, with no exogenous addition of microbial degraders. Because the initial degradative capacity of the two types of media are not comparable, no valid quantitative comparisons are possible.

Within laboratory variability also is high for these tests. Exhibit 8-8 presents BODIS aerobic freshwater and seawater results at one laboratory for two synthetic fluids (an ester and an acetal). The pooled, average relative standard deviation (RSD) for four freshwater tests of each

Exhibit 8-5. Summary of Aquatic Phase Aerobic Laboratory Biodegradation Test Conditions and Their Suitability for Poorly Soluble, Volatile, and Surface Active Compounds

OECD Guidelines/ ISO Procedures (a)	Analytical Method	Suitability for compounds which are:			Concen-tration of Test Substance	Ino-culum	Test Duration (days)	Test Medium
		Poorly Soluble (b)	Volatile	Adsor-bing (b)				
OECD 301A - DOC Die-Away	Dissolved organic carbon (DOC)	-	-	+/-	10-40 mg DOC/l	+	28	FW
OECD 301B - CO_2 Evolution Test	CO_2 evolution	+	-	+	10-20 mg DOC/l	+	28	FW
OECD 301C - MITI (l) Test	Oxygen consumption	+	+/-	+	100 mg/l	+	28	FW
OECD 301D - Closed Bottle Test	Dissolved oxygen	+/-	+	+	2-5 mg/l	+	28	FW
OECD 301E - Modified OECD Screening Test	Dissolved organic carbon	-	-	+/-	10-40 mg DOC/l	+	28	FW
OECD 301F - Manometric Respirometry Test	Oxygen consumption	+	+/-	+	50-100 mg ThOD/l	+	28	FW
OECD 308 - Biodegradability in seawater - Shake Flask Test - Closed Bottle Test	Dissolved organic carbon Dissolved oxygen	- +/-	- +	+/- +	5-40 mg DOC/l 2-10 mg/l	- -	60 28	SW
ISO-procedure: BOD-test for insoluble substances (BODIS)	Dissolved oxygen	+	-	+/-	100 mg ThOD/l (c)	+	28	FW
Modified Seawater BODIS Test	Dissolved oxygen	+	-	+/-	100 mg ThOD/l (c)	-	28	SW
Respirometric methods	Respirometric: CO_2-production O_2-consumption in headspace	+	+/-	+	100 mg ThOD/l (and lower) (c)			SW/FW

Abbreviations: ThOD = Theoretical oxygen demand; BOD = biochemical oxygen demand
(c)   OECD (1993); ISO (1990)
(d)   Characteristics of synthetic base fluids
(e)   Corresponds to ~ 30 mg/l test substance of drilling fluids
Source: Vik et al., 1996b

Exhibit 8-6. Summary of Test Procedures Used in the Biodegradation Testing of Synthetic-Based Drilling Fluids

Factors influencing test results	Aqueous Phase Tests			Sedimentary Phase Studies		Seabed Surveys		
	Aerobic		Anaerobic					
	Seawater (a)	Fresh-water	Fresh-water	NIVA "Seabed Simulation"	SOAEFD "Solid Phase"	Norwegian sector	Dutch sector	Gulf of Mexico
Test Substance	**Base fluid or Synthetic Fluid**	**Base fluid or Synthetic Fluid**	**Base fluid or Synthetic Fluid**	**Cuttings**	**Base fluid**	**Cuttings**	**Cuttings**	**Cuttings**
Physical test conditions: Temperature ºC	15-20	15-25	37	7-12	7-12	7-12	7-12	7-12
Availability of oxygen	Good	Good	None	Lower dependent on test concentration	Very low	Very low	Very low	Very low
Nutrient availability	Good	Good	Good	May be limiting	May be limiting	May be limiting	May be limiting	May be limiting
Test concentration	2-40 mg/l	0.5-40 mg/l	50 mg/l	700-18000 mg/kg	100, 500, 5000 mg/kg	up to 100,000 mg/kg	up to 4700 mg/kg	up to 134,000 mg/kg
Depth of mud layer	Not applicable	Not applicable	Not applicable	1-2 mm	Mixed into the sediment	0-20+ cm	0-20+ cm	0-20+ cm
Migration of test substance	Not applicable	Not applicable	Not applicable	Possible	Very low	Very probable	Extensive	Extensive
Inoculum: Quantity/density	Low	Generally high	High	Fairly low	Fairly low	Fairly low	Fairly low	Fairly low
Variability	High	Lower than seawater	Lower than seawater	High	High	High	High	High
Acclimation	None	None	None	Some	Some	Some	Some	Some
Source	Seawater	Activated sludge	Activated sludge	Seawater and mixed sediments (b)	Seawater and mixed sediments	Seawater and natural benthic fauna	Seawater and natural benthic fauna	Seawater and natural benthic fauna
Renewal	None	None	None	Possible	Possible	Very likely	Very likely	Very likely

Exhibit 8-6. Summary of Test Procedures Used in the Biodegradation Testing of Synthetic-Based Drilling Fluids (continued)

Factors influencing test results	Aqueous Phase Tests			Sedimentary Phase Studies		Seabed Surveys		
	Aerobic		Anaerobic					
	Seawater (a)	Fresh-water	Fresh-water	NIVA "Seabed Simulation"	SOAEFD "Solid Phase"	Norwegian sector	Dutch sector	Gulf of Mexico
Test Substance	**Base fluid or Synthetic Fluid**	**Base fluid or Synthetic Fluid**	**Base fluid or Synthetic Fluid**	**Cuttings**	**Base fluid**	**Cuttings**	**Cuttings**	**Cuttings**
Sampling/analyses: Sampling depth	Not relevant	Not relevant	Not relevant	1-2 cm	8.6 cm (c)	1 cm	10 cm	up to 1 m
Chemical analyses	Oxygen demand/CO_2	Oxygen demand/CO_2	CO_2	Presence of base fluid/DO/pH/redox	Presence of base fluid/DO/redox	Presence of base fluid	Presence of base fluid	Presence of base fluid
Macrofaunal analyses	None	None	None	Mortality on surface (d)	None	Abundance and diversity	Abundance and diversity	Abundance and diversity
Microbial analyses	No	No	No	Yes	Yes			
Relevance of test to real environment	Aerobic degradation only	Not relevant	Not relevant	Relevant, but test concentrations are lower; question anaerobic condition simulation and test substance migration	Relevant; dosing more stable but misses layering as in situ	Relevant. Difficult to obtain representative samples and compatible results from one year to another	Relevant. Difficult to obtain representative samples and compatible results from one year to another	Relevant. Difficult to obtain representative samples and compatible results from one year to another

(a)   No standard marine test presently exists and a large variety of methods have been used.
(b)   In the latest NIVA test, natural benthic fauna were sieved out, then returned.
(c)   NIVA are presently trying an alternative procedure using undisturbed sediments to keep the macro-fauna alive.
(d)   Comprises the entire test container contents.
DO = dissolved oxygen
Adapted from Vik et al., 1996b

Exhibit 8-7. Ranking of Aqueous Phase Biodegradation Methods and Test Results

No.	Test Method	Test Concentration	% Biodegradation
1	BODIS Freshwater	10 mg/l	86
2	OECD 301 B Freshwater	10 mg/l	78.6
4	OECD 301 B Freshwater	20 mg/l	62.8
5	BODIS Freshwater	40 mg/l	50
6	OECD 306 Seawater	0.5 mg/l	35
3	OECD 301 D Freshwater	0.5 mg/l	73
7	OECD 301 D Freshwater	2.5 mg/l	21
8	BODIS Seawater	10 mg/l	19.5
9	OECD 306 Seawater	10 mg/l	9.4
10	BODIS Seawater	40 mg/l	8
11	OECD 306 Seawater	2 - 2.5 mg/l	5

Source: Slater et al. (1995)

Exhibit 8-8. Average Percentage Biodegradation Using BODIS Seawater and Freshwater Procedures for an Ester and Acetal

Base fluid	Seawater tests					Freshwater tests				
	Test # (a)	Biodeg. (%)	s.d. (%) (b)	Relative s.d. (%) (c)	n	Test # (a)	Biodeg. (%)	s.d. (%) (b)	Relative s.d. (%) (c)	n
Ester	1	41	8.1	18	5	1	68	3.1	5	4
	2	32	2.9	9	5	2	94	11.2	12	4
	3	29	7.1	24	5	3	94	9.9	11	7
	4	34	3.7	11	5	4	99	1.9	2	10
	5	57	5.2	9	5					
	6	59	5.0	8	5					
	Pooled average	42	12.9	31	30	Pooled average	92	12.9	14	25
Acetal	1	9	2.2	24	5	1	58	10.7	18	4
	2	5	1.2	24	5	2	69	9.1	13	5
	3	9	1.8	20	5	3	75	12.0	16	7
	4	11	2.8	25	5	4	95	4.9	5	10
	5	37	4.7	13	5					
	6	12	7.1	59	5					
	Pooled average	14	11.2	80	30	Pooled average	79	16.5	21	26

(a)   # = number of parallels
(b)   s.d. = standard deviation
(c)   relative s.d. = defined as (s.d./biodeg) x 100%
Source: Vik et al. (1996b)

base fluid was 14% for the ester (n=25) and 21% for the acetal (n=26). For six seawater tests, however, the RSD increased to 31% (n=30) and 80% (n=30), respectively for the ester and acetal.

Anaerobic results, although more relevant to the potential impacts of synthetic base fluids in marine receiving waters, show even greater variability for many types of synthetic base fluids (Exhibit 8-9). For example, fatty acid esters or alcohols showed significant anaerobic degradation potential, with degradation ranging from 79% to 89% with RSDs of less than 25%. However, degradation rates ranged from -1.5% to 48% for 13 mineral oils and 8 other synthetic fluids. Furthermore, RSDs were much higher, with a <u>minimum</u> RSD of 80% and all others well in excess of 100%.

8.3.2 *Sedimentary Phase Tests*

Schaanning (1994; 1995; 1996a; and 1996b) reported on a series of studies using the NIVA methods (Exhibit 8-3) to compare the biodegradation rates (half-life) of ester, IO, LO,PAO and ether base and based fluids. The results from the studies indicated the following degradation rates esters>LO>IO>PAO>ethers. The half-lifes reported were esters ranged from 16 to 22 days, LO half-life reported was 51days, IO half-life reported was 73 days, PAO ranged from 43 to 207 days, and the ethers ranged from 254 to 536 days.

Vik et al. (1996b) compare the results of two sedimentary phase protocols (NIVA and SOAEFD) for ester-type synthetic fluids (Exhibit 8-10). An ester-type synthetic base fluid was degraded 46% and 97% at 28 days and 160 days, respectively, in the NIVA protocol, with a calculated half-life of 31 days. The SOAEFD protocol for a similar synthetic base fluid resulted in 97% degradation at 28 days with no further measured degradation at 60 days, giving a calculated half-life of 12 days. Experimental differences, as discussed earlier, are substantial enough that any comparison is not very meaningful. Vik et al. (1996b) also report results of the NIVA protocol (see Exhibit 8-10) across a variety of synthetic fluids and mineral oil. Their results indicate the ester and LAO fluids (respective half-lives of 31 and 43 days) degrade more rapidly than the PAO, acetal, and mineral oil (half-lives ranging from 199 - 207 days). This general trend was also observed in the solid phase tests, at least for the lower test concentrations.

Limia (1997) reports solid phase degradation data for a series of test substances that included an ester, acetal, PAO, IO, LAO, n-paraffin, and mineral oil. Results suggested relative degradation rates were dependent on initial concentrations. At the highest concentration (5,000

Exhibit 8-9. Anaerobic Biodegradability of Test Chemicals Examined in the ECETOC Screening Test (a)

Test Chemical	Test Duration (days)	Degradation in the ECETOC test (% of organic carbon)		
		Net gas Production	Net DIC (b) Production	Extent of Ultimate Degradation (c)
fatty acid ester I	35	63.3	19.2	82.5±13.9
fatty acid ester II	35	61.2	22.5	83.7±13.1
Oleyl alcohol	84	61.1	27.5	88.6±14.8
2-Ethyl hexanol	84	57.3	21.5	78.8±21.4
Mineral oil A	35	0.7	3.2	3.9±11.0
Mineral oil B	28	4.3	1.1	5.4±8.2
Mineral oil C	28	3.8	2.0	5.8±6.7
Di-octyl ether	42	8.8	3.5	12.3±10.8
Di-hexadecyl ether	42	-0.6	1.9	1.4±12.5
linear $\propto$-olefin ($C_{16/18}$)	84	22.3	0.1	22.4±19.5
linear $\propto$-olefin (C_{14})	98	40.5	7.8	48.3±15.5
Polyalphaolefin I	70	4.4	10.0	14.4±20.3
Polyalphaolefin II	50	-1.6	2.2	0.6±16.2
Alkylbenzene	50	0.9	-2.4	-1.5±12.2
Acetal-derivative	70	3.7	8.9	12.6±19.2

(a)   ECETOC = European Centre for Ecotoxicology and Toxicology of Chemicals
(b)   DIC = Dissolved Inorganic Carbon
(c)   Value reported is mean value (from 5 replicates) and its 95%-confidence interval
Source: Steber et al. (1995)

mg/kg) the ester, LAO, and acetal all showed substantial degradation (25 - 50%; ester>acetal>LAO) after 120 days, whereas all other base fluids tested showed little degradation. At 500 mg/kg, degradation of the ester was nearly 60%, whereas all of the other base fluids degraded much less. At 100 mg/kg, only the ester, LAO, IO, and n-paraffin all degraded substantially (>75%), whereas the other test materials (mineral oil, PAO, and acetal) did not show more than 35% degradation. Similarly, Munro et al. (1998) reported degradation rates using the SOAEFD method that were highly concentration dependent as well as sediment dependent. The half-life for all compounds tested (olive oil, mineral oil, ester, and PAO-LAO blend) increased with concentration and from mud to sand.

Exhibit 8-10. Percentage Biodegradation of Base Fluids in Drilling Fluids Measured by Various Test Methods

Drilling Fluid/Base Fluid Tested	% Biodegradation Measured by Sedimentary Phase Test Methods					
	NIVA's Seabed Simulation Studies (layered using drilling fluid)			SOAEDF's Solid-Phase Sediment Test (base fluid/sand mixture)		
	160-day	28-day	Half-life (days) (a)	60-day	28-day	Half-life (days)
An ester	97	46	16, 20, 22	67[b], 97[c], 98 (d) 98, 78, 25 (e)	97	37 (b), 12 (c), 10 (d)
A mineral oil	44	23	399	16, 10, -4 (e)		
A PAO	43	11	43, 127, 207	-11, 4, 8 (e)		
An acetal	39	12	200	20, 0, 10 (e)		
An IO			73	60, 10, -2 (e)		
An LAO	93	38	43	70, 23, 5 (e)		
An LO			51			
An ether			254, 392, 536			

(a) Values from Schaanning (1994, 1995, 1996a & 1996b)
(b) Mixed in mud substrate; Munro et al. (1997)
(c) Substrate not specified in Vik et al. (1996)
(d) Mixed in sand substrate; Munro et al. (1997)
(e) Three values presented are day 56 values at 100 mg/kg, 500 mg/kg, and 5,000 mg/kg sediment substrates, respectively; Munro et al. (1997)
Source: Adapted from Vik et al. (1996b)

8.4   Discussion and Conclusions

The result of this review is that the current state of knowledge for these materials is as follows:

• All synthetic fluids have high theoretical oxygen demands (ThODs) and are likely to produce a substantial sediment oxygen demand when discharged in the amounts typical of offshore drilling operations.

• Existing aqueous phase laboratory test protocols are incomparable and results are highly variable. Sedimentary phase tests are less variable in their results, although experimental differences between the "simulated seabed" and "solid phase" protocols have resulted in variations between test results.

- There is disagreement among the scientific community as to whether slow or rapid degradation of synthetic base fluids is preferable with respect to limiting environmental damage and hastening recovery of benthic communities. Materials which biodegrade quickly will deplete oxygen more rapidly than more slowly degrading materials. However, rapid biodegradation also reduces the exposure period of aquatic organisms to materials which may bioaccumulate or have toxic effects.

- Limited field data suggest these materials will be substantially degraded on a time scale of one to a few years; however, the distribution and fate of these materials is not extensively documented, especially as applicable to the Gulf of Mexico where only three field studies have been conducted.

The limited data from field studies suggest that organic enrichment of the sediment will be a dominant impact of SBF-cuttings discharges. Biodegradability of these materials is therefore an important factor in assessing their potential environmental fate and effects.

Available standard methods yield results that are highly variable across available freshwater and seawater protocols. These methods (all aqueous, most freshwater, and all but one aerobic) also are not very relevant to the conditions under which discharged materials will be found (i.e., a largely anoxic, marine sediment matrix). Nonetheless, one could try to identify tests that, despite these shortcomings, still could offer useful insight into the potential fate of these materials. Unfortunately, field data for which potential correlations could be examined are too scant for meaningful quantitative analyses to these standard laboratory methods.

Seabed simulation protocols and solid-phase tests have been developed to better represent receiving water conditions. Still, the issue of layering versus sediment mixture of test substances cannot be resolved absent better field data of actual initial deposition and longer term sediment depth profiles of these materials in discharged cuttings. It seems likely the real world situation is a mixture of the two.

Each of the existing biodegradation test methods has advantages and disadvantages. The seabed simulations better represent field conditions, but they are expensive and have limited market availability. The standard aqueous test methods are not relevant to field conditions, but are more rapid, more widely available, and less expensive. The solid phase test combines the benefits of these two extremes: it mimics receiving water (sediment) conditions, is reproducible, and can be made simplistic enough to perform at moderate expense.

9. SEABED SURVEYS

9.1   Background

This chapter presents a summary of the seabed surveys conducted at sites where cuttings contaminated with SBFs (SBF-cuttings) have been discharged. Because more surveys have been performed and more detailed information has been collected at sites where WBFs (exclusively) have been discharged, results from WBF sites are also presented for comparison. The technical performance of SBFs is comparable to that of OBFs, and EPA is projecting that SBFs may be used as a replacement to OBFs more so than as a replacement of WBFs. However, as far as environmental effects of the discharge are concerned, EPA believes that SBFs are more comparable to WBFs. Also, WBFs are currently allowed for discharge in certain offshore and coastal areas, while OBFs (and OBF-cuttings) are not. For these reasons, EPA sees it fitting to compare the environmental effects of SBF-cuttings discharge with those of WBF and WBF-cuttings discharge.

The literature available to EPA for SBF discharge sites include studies performed in the Gulf of Mexico and in the North Sea. These studies have been performed both by regulatory bodies and/or industry groups. The results are available in the open literature. For WBF discharge sites, EPA used the Offshore Proposed Effluent Guidelines Regulatory Impact Analysis (Technical Support Document Vol. III; *Avanti* Corporation, 1993) as a source of information on field studies. This volume contains extensive lists of case studies on environmental impacts from oil and gas effluent discharges. Many of these studies were reviewed for information regarding seafloor and benthic impacts of water-based fluids and associated cuttings. In addition to this volume, additional citation searches for studies of the impacts of cuttings also were performed.

Materially, SBF wastes are different from WBF wastes in at least three important ways:

•   Only SBF-cuttings are discharged, with retention of the SBF base fluid generally ranging between a low of 2 percent for the larger cuttings and a high of 20 percent for the smallest cuttings (fines). On the contrary, with WBFs, in addition to the WBF-cuttings, large volumes of WBF are also discharged. Thus, for an equal volume of hole drilled, the volume of WBF-related discharge is expected to be much greater than the volume of SBF-related discharge.

•   WBFs contain very high levels of suspended and settleable solids (and are, in fact, referred to as "muds" in the industry) that disperse in the water column and produce a plume with many fine particles that settle rather slowly. Hence, they may be transported

large distances. SBF-cuttings, however, tend not to disperse in the water column nearly to the same extent as WBFs because the particles are "oil" wet with the synthetic material. Even compared to WBF-cuttings, SBF-cuttings tend to be larger than WBF-cuttings. Again the reason is that SBFs do not disperse the cuttings particles to the same extent as WBFs. Because larger particles settle faster than smaller particles, SBF-cuttings tend to be deposited in a smaller impact area than WBF-cuttings.

- SBF-cuttings have a significant organic component that is not present in WBFs, namely the synthetic base fluid. The synthetic base fluid, in general, is insoluble in water and deposits in the sediment with the cuttings. Thus, compared to WBFs, SBFs have an additional major pollutant factor. The synthetic base fluid may have both direct and indirect adverse effects. Direct effects include physical effects as well as chemical toxic effects to benthic or epibenthic organisms. Indirect effects include both the effects on organisms that feed on these benthic organisms and the effects of anoxic/hypoxic sediment conditions from degradation of synthetic base fluids (due to their oxygen demand in local sediment).

These differences are important in making the comparison between SBF and WBF discharges, as is presented in the following sections.

9.2   Assessment of Field Studies

9.2.1   *Findings*

A large number of field studies of environmental impacts of exploratory well drilling discharges[1] in several offshore locations provide sufficient information to arrive at reasonably reliable findings for WBF seabed impacts. In contrast, existing data for SBFs are limited and do not appear to be sufficient to reliably project potential impacts. The different SBF studies used sampling designs that are incompatible and have methodological limitations (e.g., seasonal variability issues) that reduce the analytic clarity. Further field research is required to adequately characterize offshore impacts of synthetic-based fluid discharges.

Water-Based Fluids

The case studies reviewed by EPA characterize drilling fluids and cuttings dispersion, sedimentation, impacts on the sediment and benthos, and some of the potential factors influencing the magnitude of impacts. Exhibit 9-1 summarizes the major impacts of each of the reviewed studies. This review suggests that these discharges are capable of producing localized

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[1]   Studies of development operations are much more limited in both number and scope (e.g., there are no pre-versus post-drilling surveys). Therefore, conclusions of impacts for WBFs are considerably more uncertain for development drilling than for exploratory drilling.

Exhibit 9-1. Marine Studies of Water-Based Drilling Fluid Impacts

Study Source	Study Site/ Location	Water Depth (m)	Impacts (a)	
			Sediment	Biota
Menzie et al., 1980; Mariani et al., 1980	NJ 18-3 Block 684 Mid-Atlantic Continental Shelf	120	• 21 fold increase in Ba at 1.6 km • 3.6 fold increase in Pb at 200 m • 2.5 fold increase in Ni at 100 m • 4 fold increase in Vn at 100 m • increased percentages of clay size particles within 1.6 km • cuttings piles observed	• within 150 m: 1. burial of sessile mega-benthos and macrobenthos; 2. lowest values of species diversity; 3. lower numbers of species • Ba increase in tissue at 1.6 km: mollusks: 20 fold polychaetes: 40 fold brittlestars: 133 fold
Houghton et al., 1980; Lees and Houghton, 1980	Cook Inlet C.O.S.T. well Alaska Continental Shelf	62	• cuttings (1.34 mm dia.) and 20% increase in sediment Ba conc. 400 m north of platform; • no piles	• substantial decrease in number of organisms from pre- to during and post-drilling at both 100 m and 200 m
Ray and Meek, 1980; Meek and Ray, 1980	Tanner Bank California Continental Shelf	63	• most cuttings fell within 50 m, fine cuttings within 100 m - 200 m of the discharge source; • mud on cuttings washed off during settling; • no piles	ND
Zingula, 1975	South Timbalier Block 172 Louisiana Continental Shelf	33.5	• below discharge point: cuttings covered by normal marine sediments 8.5 months after drilling cessation	• below discharge point: same abundance of fauna in cuttings samples as in "normal" sea bottom at 8.5 months
US DOI, 1977	Mustang Island Block 792 Texas Continental Shelf	36	• cuttings observed at four 100 m and one 500 m station • 2.5 fold increase in Ba during drilling at 1,000 m	• specimen abundance significantly decreased along 100 m periphery; • effect to 1,000 m
CSA, 1986	East Breaks Area Block 166 Gulf of Mexico	76 - 160	• 7.5 fold increase in Ba and 60% increase in Cr at 4 km • 2 fold increase in % Fe at 500 m	ND
Boothe and Presley, 1989	Northwest Gulf of Mexico	30 m; 100 m	• Ba increase within 500 m; 2.3-11 fold for all 6 sites • Pb increase within 500 m; 3.8 fold for 1 site • Hg increase within 250 m; 4-7 fold for 2 sites	ND

Exhibit 9-1. Marine Studies of Water-Based Drilling Fluid Impacts (Continued)

Study Source	Study Site/ Location	Water Depth (m)	Impacts (a)	
			Sediment	Biota
CSA, 1988	Gainesville Area Block 707 Florida Continental Shelf	21	• increase in Ba:Fe ratio: 90% at 4,000 m • increase in Cr conc: 11% at 300 m	• absence of seagrass within 300 m • growth inhibited beyond 300 m to 3.7 km. • 77% decrease in seagrass leaf count at 3.7 km • burial of live bottom communities at 25 m
CSA, 1989	Pensacola Area Block 996 Gulf of Mexico	50 - 60	• almost 3 fold increase in Ba and Ba/Fe ratio at 2,000 m	• reduced bryozoan coverage within 2,000 m of discharge
CSA and Barry Vittor & Assoc., 1989a,b	Alabama State Waters	40 - 60	• 2 to 5 fold increase in Ba at 1,000 m	• elevated As in oysters behind barrier islands
Bothner et al., 1985	Georges Bank Block 312 Block 410 Atlantic Continental Shelf		• 25% of barite deposited within 6 km • Ba transport detected at 35 km • cuttings observed within 500 m at Block 312 • cuttings observed at 2 km station at Block 410	ND
Steinhauer et al., 1990	Santa Maria Basin California Continental Shelf	90 - 410	ND	• sediment flux related to decreased soft coral coverage • statistical power of study limited to 70% or greater
Northern Technical Services, 1981	Beaufort Sea RIST Well Alaska Coastal	8	• cuttings accumulation observed: @ discharge pt: 5-6 cm @ 3 m: 2-3 cm @ 6 m: 1-2 cm @ 30 m: <0.5 cm • elevated Co, Cu within 50 m	• decrease in number of organisms 3 months after discharge

ND = no data

(a)   Results presented represent a range of time periods relative to active drilling. Some surveys were conducted while drilling was ongoing; others took place many years after drilling ceased. For greater detail than presented in this summary, please refer to the individual study summaries that follow.

impacts but do not document larger-scale impacts. However, these studies are not sufficient to conclude that regional-scale impacts are not occurring.

Field studies of drilling fluid discharge plumes indicate that, as a generalization, plume dispersion is sufficient to minimize water quality impacts and water column toxicity concerns in energetic, open marine waters, such as the domestic OCS.

In shallow water areas (e.g., less than 5-10 meters), field data on plume dispersion are minimal, and are insufficient to conclude that water column effects present only a minor potential concern. Some modeling data suggest water quality and toxicity parameters could be adversely affected under shallow water conditions. Also, in water depths of less than 5 meters, the reliability of most models that are suitable for application to drilling fluid discharges becomes questionable. Thus, the potential water column impacts of those discharges in shallow waters (<5 meter) is not known with any degree of confidence.

The degree of impact of drilling fluids and cuttings on benthic and demersal species is highly dependent on a number of local environmental variables (e.g., depth, current and wave regimes, substrate type) and on the nature and volume of the discharges, including cuttings size and the location of the outfall in the water column. Impacts can be considered to fall into two relatively distinct categories: short-term effects due to either toxicity or burial by drilling fluid and/or cuttings; and longer-term effects due to chemical contamination or physical (textural) alteration of the sediments.

For example, Cook Inlet and Tanner Bank sites are both characterized as having strong currents. At these depths, currents significantly affect cuttings sedimentation patterns as well as cuttings transport along the bottom, entrainment and reworking of the sediment. Under these conditions, the investigators did not observe discrete cuttings piles which tend to form in more quiescent locations (Ray and Meek, 1980; Houghton et al., 1980). In the Gulf of Mexico, cuttings piles 150 m in diameter and 1 m in height have been reported (Zingula, 1975). On the other hand, cuttings seemed to be present at relatively farther distances in more energetic locations (Houghton et al., 1980; see below).

The extent of cuttings accumulation is important in assessing benthic impacts. A general trend of impacts is that specimen abundance decreased closer to the well. Several studies cited that the lowest numbers of organisms were at the 100 m stations, which were the closest stations to the well in these studies. Even in the dynamic location of Cook Inlet, authors reported that number of organisms and species diversity were significantly lower at the 100 m and 200 m sampling points than the control location (Lees and Houghton, 1980). These local effects have

been ascribed to both physical changes in sediment texture and toxic effects. However, studies have not been designed to discriminate between these two potential causative factors.

The Cook Inlet Continental Offshore Stratigraphic Test (COST) well study was the only study reviewed that carefully analyzed sediment cores for the presence of cuttings as well as conducted chemical analyses. Barium concentrations in the sediment were found to be elevated in samples containing cuttings (defined by the authors as particles >0.85 mm) as far as 400 m from the platform (Houghton et al., 1980). These analytical results suggest that some drilling fluid still adheres to the cuttings and is transported and redistributed together with the cuttings. This is in contrast to the study in which divers observed drilling fluid being washed from the cuttings as the cuttings dropped through the water column within several meters of the outfall, although this latter observation was visual in nature (Ray and Meek, 1980).

The most clearly documented point source effect of these discharges has been alterations in sediment barium (Ba), a tracer for drilling fluids solids. Observations on sediment alterations from field studies of both single-well and multiple-well facilities include:

- Increases in Ba levels of 2-fold to 100-fold above background at the drill site, with typical values of 10-fold to 40-fold

- Average measured background levels are reached, statistically, at 1,000-3,000 m; single transect values have been elevated at up to 8,000 m

- Increases in Ba fall off logarithmically with distance from the drill site; regression analyses indicate background levels are achieved at 2,000-20,000 m.

Increases in a suite of other trace metals associated with drilling fluids (As, Cd, Cr, Cu, Hg, Pb, Zn) have also been observed. These increases:

- Are of a lower magnitude than seen for Ba (generally not more than 5- to 10-fold above background)

- Are more spatially limited, when compared to background levels, than seen for Ba (generally withing 250-500 m of the drill site, although increases at 1,000-2,000 m have been noted)

- Are noted consistently as a group, but are variable for any specific metal among the various studies.

Observations on the long-term, regional scale fate of drilling fluid solids indicate that the materials may be very widely dispersed over large areas. Dispersion is related directly to bottom energies of the receiving water (more shallow waters being more energetic than deeper waters).

- In shallow water (13-34 m) Boothe and Presley (1989) found that only about 6% of discharged Ba was accounted for within a 3 km radius of three drill sites in northwestern Gulf of Mexico; in contrast, for three drill sites in deeper waters (76-102 m) within the same study, the authors found 47% to 84% of the discharged Ba was found within a 3 km radius

- At these same six sites, Ba concentrations 3 km from the drill sites ranged from 1.2 to 2.9 times predicted background at the shallow water sites and at the deep water sites ranged from 2.0 to 4.3 times predicted background (Boothe and Presley, 1989)

- Drilling fluid solids can be transported over long distances (35-65 km) to regional areas of deposition, albeit at low concentrations, based on a study of eight wells (Bothner et al., 1985).

Biological effects have routinely been detected statistically at distances of 200 m to 500 m. Less routinely, effects have been observed at greater distances (1-2 km). These effects more typically are found to fall into one of two categories: those that are statistically significant at the level of individual stations but cannot be integrated into an easily defined pattern or those that are not statistically significant at the level of individual stations but do form significant correlations at larger levels of integration. Specific observations are as follows:

- The most affected community appears to be seagrass communities. Data on seagrasses are limited to a single study, but it documented damage much more severe than in any other study to date. Approximately 9 weeks after the drilling operation commenced, seagrasses were completely absent within 300 m of the drill site; at a distance of 3.7 km from the drill site, leaf biomass and leaf numbers showed only a 25% increase compared to the increases shown at the reference station (CSA, 1988).

- Fauna also have been affected, including changes in abundance, species richness (number of species), and diversity. Taxa include annelids, mollusks, echinoderms, and crustaceans.

- Alterations to benthic community structure are virtually always observed within 300 m of the drill site. However, changes have been noted in some cases at 500-1,000 m, and a few reports indicate alterations have occurred at 1-2 km.

- Changes have been ascribed to purely physical alteration in sediment texture and to platform-associated structural effects (i.e., from the fouling community) more frequently than to toxic effects. These causes are plausible, but there are not systematic studies of their relative contribution to observed impacts. Also, alterations due to physical causes may not be any less adverse than those due to toxic pollutants, and may be more persistent.

- Bioaccumulation has been observed for a suite of metals (Ba, Cd, Cu, Hg, Ni, Pb, V), but the magnitude of this effect is usually low (i.e., less than a factor of 5).

Synthetic-Based Fluids

The extent of the literature on field studies of impacts from discharges of SBFs is much more limited than for impacts from discharges of WBFs. EPA has identified and reviewed five studies, totaling six sites, for this environmental assessment. A summary of the results are provided in Exhibit 9-2. Others survey sites, and additional surveys at some of these same six sites also exist. However, difficulties occurred in trying to review this additional information: some studies are only available in Norwegian while others are proprietary or confidential in nature. The results of the five studies reviewed also present variability in terms of assessing the potential for adverse impacts from SBFs. This limited and varied information base makes drawing any generally applicable conclusions a difficult, and potentially unreliable, endeavor.

One study on the domestic continental shelf, in 39 m of water in the Gulf of Mexico, discharged a relatively small amount (354 bbl) of PAO SBF adhering to the drill cuttings (Candler et al., 1995). At a maximum, this amount represents approximately 45 metric tons of discharged olefins, which compares to North Sea discharges of approximately 100 - 180 metric tons of synthetic base fluid at each of three study sites. The top 2 cm of sediment were sampled at stations only out to 200 m, with 2,000 m reference stations. Synthetic base fluids, as measured by total petroleum hydrocarbons (TPH), showed substantial (60% - 98%) decreases between the first and second sampling surveys (i.e., after 8 months) at all but the closest, 25-meter station. How much of this decrease was due to biodegradation, as opposed to sediment redistribution and reworking, is uncertain. Although the data are somewhat difficult to interpret, it appears that little further reductions in TPH occurred between the second and third surveys (a 16-month period). This finding for a PAO synthetic base fluid contrasts with North Sea data on ester- and ether-type synthetic base fluids that indicate a continuing decrease in synthetic fluid over time. Limited analysis of benthos (the third survey only) indicated significant differences in the diversity scores at 25 m and 50 m stations compared to reference stations.

For three North Sea study sites, EPA reviewed the impacts from the discharge of SBFs. At a well site (K14-13) in the Dutch sector located at a depth of 30 m, approximately 180 metric

Exhibit 9-2. Marine Studies of Synthetic-Based Drilling Fluid Impacts

Study Source	Study Site/ Location	Type of Synthetic Base Fluid	Water Depth (m)	Cuttings/Synthetic-Based Fluids Discharged	Impacts	
					Conc. of Base Fluid in Dry Sediment (mg/kg)	Biota [a]
Candler et al., 1995	NPI-895 Gulf of Mexico Continental Shelf	polyalpha-olefin (PAO)	39; shunted	441 bbl cuttings plus 354 bbl adhering fluids; estimated at <45 metric tons of PAO	134,428 @ 50 m[b] 2,850 @ 50 m[c] 3,620 @ 50 m[d] 1,460 @ 200 m[b] 297 @ 200 m[c] 280 @ 200 m[d]	Not Available (NA) NA Abundance/Richness depressed @ 50 m[d]
Daan et al., 1996	K14-13 North Sea/ Dutch Continental Shelf	ester	30; shunted to 5 m above seabed	361 m³ synthetic-based fluids; ≈ 180 metric tons of ester	706 @ 75 m[e] 393 @ 75 m[f] 84 @ 75 m[g] 300 @ 125 m[e] 834 @ 125 m[f] 10 @ 125 m[g] 54 @ 200 m[e] 161 @ 200 m[f] 55 @ 200 m[g]	NA Abundance/Richness depressed @ 200 m[f]; Richness depressed @ 500 m Abundance/Richness depressed @ 200 m[h]
Smith and May, 1991; Schaanning, 1995	Ula 7/12-9 North Sea/ Norwegian Continental Shelf	ester	67	749 metric tons cuttings containing 96.5 metric tons synthetic ester	85,300; 46,400; 208 @ 50, 100 and 200 m[e] 0.21, 0.22, and 1.34 @ 50, 100 and 200 m 0.38 (max.) @ 200 m	Abundance/Richness depressed @ 100 m[e] No Impact[h] No Impact[i]
Bakke et al., 1992 (in Norwegian, as cited in Schaanning, 1995)	Gyda 2/1-9 North Sea	ether	NA	160 metric tons synthetic ether	2,600 @ 50 m[j] 14,700 @ 50 m[h] 3.7 @ 50 m[d] 236 @100-200 m[j] 96 @100-200 m[h] 2.1 @100-200 m[d]	Reported as "Remarkably weak" (only 4 stations sampled)
Aquaplan, 1996 as cited in Vik et al., 1996	Eldfisk	PAO	NA	1,155 metric tons	79.8 @ 2,000 m	NA
Gjøs et al., 1995 as cited in Vik et al., 1996	Tordis	PAO	181-218	57 metric tons	8,920 @ 500 m 82 @ 1,000 m	NA

Exhibit 9-2. Marine Studies of Synthetic-Based Drilling Fluid Impacts (Continued)

Study Source	Study Site/ Location	Type of Synthetic Base Fluid	Water Depth (m)	Cuttings/Synthetic-Based Fluids Discharged	Impacts	
					Conc. of Base Fluid in Dry Sediment (mg/kg)	Biota [a]
Gjøs, 1995 as cited in Vik et al., 1996	Loke	ester	76-81	180 metric tons	93 @ 250 m[e] 5 @ 500 m[e] 10 @ 250 m[h] 5 @ 500 m[h]	NA
	Sleipner A	ester	76-81	399 metric tons Petrofree	50 @ 250 m[e] 20 @ 500 m[e] 25 @ 250 m[h] <5 @ 500 m[h]	NA
				236 metric tons Finagreen	400 @ 250 m 30 @ 500 m	NA
	Sleipner Ø	ester		380 metric tons Petrofree	2,500 @ 250 m 250 @ 500 m	NA
Gjøs et al., 1992 & 1993 as cited in Vik et al., 1996	Gyda 2/1-9	ether	70	160 metric tons	2,600 @ 50 m[j] 420 @ 100 m[j] 150 @ 200 m[j] 14,700 @ 50 m[h] 50 @ 100 m[h] 25 @ 250 m[h]	NA
Johansen, 1996 as cited in Vik et al., 1996	Heidrum	acetal	342-375	208 metric tons	618 @ 500 m[h] 33.3 @ 1,000 m[h]	NA
Larsen et al., 1995 as cited in Vik et al., 1996	Ula 2/7-29	acetal	67	130 metric tons	56,888 @ 50 m[k] 10,000 @ 100 m[k] 2,368 @ 200 m[k] 2,000 @ 50 m[h] 2,000 @ 100 m[h] 1,000 @ 200 m[h]	NA
Feldstedt, 1991 as cited in Vik et al., 1996	Ula 7/12-A6	acetal	67	230 metric tons	650 @ 200 m[f] 156 @ 500 m[f] 18 @ 1,000 m[f]	NA

Exhibit 9-2. Marine Studies of Synthetic-Based Drilling Fluid Impacts (Continued)

Study Source	Study Site/ Location	Type of Synthetic Base Fluid	Water Depth (m)	Cuttings/Synthetic-Based Fluids Discharged	Impacts	
					Conc. of Base Fluid in Dry Sediment (mg/kg)	Biota [a]
CSA (API) 1998, Gulf of Mexico Continental Shelf	Grand Isle 95A	internal olefin	61	1,394 bbl cuttings plus 1,315 bbl adhering fluids	23,000 @ 50 m[d]	NA
	S. Marsh Island 57C	linear alpha olefin and internal olefin	39	448 bbl cuttings plus 850 bbl adhering fluids	6,700 @ 50 m[g] 41 @ 100 m[g]	NA
	S. Timbalier 148 E-3	internal olefin	33	782 bbl cuttings plus 2,390 bbl adhering fluids	1,900 @ 50 m[l]	NA
LGL Ecological Research Assoc., 1998 Gulf of Mexico Continental Slope	Pompano	90% LAO 10% ester	565	6,263 bbl adhering fluids (prior to 1997 survey) 1,486 bbl additional fluids (prior to 1998 survey)	165,051 @ 75 m[m] 198,320 @ 75 m[n]	Polychaete densities 40 times higher than background; gastropod densities 3,000 times higher than background [n]

[a] Abundance = No. of organisms; Richness = No. of taxa
[b] 9 days post discharge (pd)
[c] 8 months pd
[d] 2 years pd

[e] 1 month pd
[f] 4 months pd
[g] 11 months pd
[h] 1 year pd
[i] 2 years pd; Schaanning, 1995

[j] immediately pd
[k] 3 months pd
[l] 10 months pd
[m] 1997 survey
[n] 1998 survey

tons of ester SBF (resulting from the discharge of approximately 477 tons of adherent synthetic base fluid) were discharged (Daan et al., 1996). Surveys occurred 1 month, 4 months, and 11 months after SBF discharges ceased. The synthetic base fluid was detected in the upper 10 cm of sediment to a distance of 200 m from the discharge site (which was the farthest distance sampled in the second survey). During the second survey, sediment ester levels appeared to increase, a phenomenon that the authors surmised was related to resuspension and transport of highly contaminated and heterogeneous sediment very near the discharge becoming spread out and more well-mixed over a larger area between surveys. Significant decreases of 65% to 99% in sediment ester levels occurred, however, between the second (4 month) and third (11 month) surveys. Effects on benthos were more extensive: for the second survey effects were noted at 500 m stations, with much more pronounced effects within 200 m. Benthic analyses from the third survey indicated significant effects occurred only to 200 m. Additionally, recolonization and recovery at 500 m to 3000 m stations were also noted as occurring within the study area after 11 months.

EPA reviewed results from a study of the discharge of 97 metric tons of an ester SBF in the Norwegian sector (Ula well 7/12-9) in a water depth of 67 m (Schaanning, 1995). Surveys were conducted immediately, one year, and two years after discharge ceased. Sediment ester levels fell dramatically, with both maximum values and average values within 1,000 m decreasing more than five orders of magnitude over the course of the study, and more than three orders of magnitude between the first and second surveys. Benthic organisms were severely impacted out to 100 m in the first survey (immediately) after discharge ceased. Evidence of minor macrobenthic community changes (no details provided) were cited two years after the discharge ceased.

EPA reviewed results from a study of the discharge of 160 metric tons of an ether SBF in the Norwegian sector at the Gyda well site 2/1-9 that were presented in Schaanning (Bakke et al., 1992; 1993 as cited in Schaanning, 1995). Schaanning reports results from three surveys, one in 1991, 1992, and 1993. Ether levels seemed to fall continuously, with mean ether levels decreased by factors of 2-fold and 10-fold for 1992 and 1993 compared to 1991. This degree of degradation is considerably less than that reported above for the ester SBF at the Ula well site. Schaanning interpreted these results as indicating that a lag phase occurred in the biodegradation of the ether base fluid. Benthos were analyzed only at four stations in 1993; no data were reported, although Schaanning states that Bakke et al. (1992) observed "remarkably weak" effects.

There is very little information upon which to base any broad conclusions about the potential extent of impacts from SBFs. It appears that biological impacts may range from as little as 50 m to as much as 500 m shortly after discharges cease to as much as 200 m a year later.

Ester SBFs appear to be more readily biodegraded in North Sea studies than an ether SBF; the Gulf of Mexico study suggests PAOs also are less biodegradable than esters. Also, although esters appear to be readily biodegraded, one study indicates the persistence of uncharacterized "minor" impacts on benthos after synthetic base fluid levels have fallen to reference levels. These limited data, however, are not entirely adequate as a basis for any reliable projections concerning the potential nature and extent of impacts from discharges of SBFs. However, the reported adverse benthic community impacts are expected, given the basic SBF and marine sediment chemistry, the level of nutrient enrichment from these materials, and the ensuing development of benthic anoxia. The extent and duration of these impacts are much more speculative. Severe effects seem likely within 200 m of the discharge; impacts as far as 500 m have been demonstrated. The initiation of benthic recovery seems likely within a year, although it also seems unlikely that it will be complete within one year. And the relative impacts of the various types of SBFs is speculative given the limited marine sediment applicability of available laboratory methods for assessing toxicity and biodegradability and the paucity of field data for laboratory versus field correlations.

Drilling Fluid Impact Comparison

As described in the preceding sections, the reviewed seabed surveys measured either sediment or biologic effects from discharges of either WBFs or SBFs. Specifically, indicators of drilling fluid impact of seabed sediments are determined by measuring drilling fluid tracer concentrations (as either barium or SBF base fluid) in the sediment at varying distances from the drill site in an attempt to determine fluid dispersion and range of potential impact. Another class of impacts frequently measured are benthic community effects. The purpose of these studies is to assess potential drilling fluid affects such as increased metals and/or anoxia on biota.

Exhibit 9-3 summarizes the major impacts arising from the discharge of WBFs and SBFs. The distance in which SBF tracers are detected (100 m to 200 m) is much less than that of WBF (400 m to 35 km). Likewise, the impact on the biologic community is not as far-reaching for SBFs (50 m to 500 m) as for WBFs (25 m to 2,000 m).

9.2.2   *Study Limitations*

One of the major limitations in comparing data between the seabed surveys was the inconsistency in sampling methodology that was used, both spatially and temporally. The reviewed studies were often conducted using a variety of different sampling methods. Spatially, sampling locations were determined or chosen in one of several ways. Some studies established monitoring sites located radially from the discharge point. Others chose the drilled well location as the hub of the radial or intersecting transects. The Candler seabed study used the four

Exhibit 9-3. Water-based and Synthetic-Based Drilling Fluid Impact Comparison

| Studied seabed impact | Water-Based Fluids (a) | | | | Synthetic-Based Fluids (b) | | | |
| | Sediment | | Biota | | Sediment | | Biota | |
	Fraction of studies noting impact (c)	Max range of impact	Fraction of studies noting impact (c)	Max range of impact	Fraction of studies noting impact (c)	Max range of impact	Fraction of studies noting impact (c)	Max range of impact
Elevated tracer conc. (d)	9/10	400 m - 35 km	1/1	1.6 km	4/4	100 m - 200 m	--	--
Negative community impact	--	--	7/8	25 m - 2000 m	--	--	4/4	50 m - 500 m

(a)   A total of 17 water-based fluid seabed survey studies were reviewed.
(b)   A total of 4 synthetic-based fluid seabed survey studies were reviewed.
(c)   The fraction equals the number of studies noting an effect from the total number of studies measuring the corresponding impact.
(d)   For water-based fluids the measured tracer in both sediment and biota was barium (see Exhibit 9-1); for synthetic-based fluids either total petroleum hydrocarbons or the synthetic fluid was measured (see Exhibit 9-2).

compass directions as the transects, whereas the Daan study used only two transects, the direction of which was determined by the prevailing water current (Candler et al., 1995; Daan et al., 1996).

In one study (Daan et al., 1996), results of the pre-discharge survey were the basis for changing the transect orientations from cross-bathymetric to isobathymetric orientation. This invalidates comparison between these survey years. In another study (Schaanning, 1995), two reference stations were reasonably located at 5-6 km distance from the well site. However, these reference stations also showed a clear temporal pattern in sediment Ba and total hydrocarbon (THC) levels that suggest potential drilling waste contamination. Specifically, reference station THC levels decreased from 2.3 mg/kg to 0.25 mg/kg, to 0.09 mg/kg over 1990, 1991, and 1992 surveys. Reference station barium levels decreased from 265 mg/kg to 78 mg/kg to 55 mg/kg over the same period. These results throw some doubt on the validity of the reference stations despite their appreciable distance from the drill site.

Other variations in sampling are the sampling point locations on each of the transects. For example, sampling stations in one study were located 100 m and 500 m from the discharge point (U.S. DOI, 1977). In another, sampling stations were located much closer, e.g., 25, 65, and 85 m (CSA, 1988). In addition, several seabed surveys of WBF discharge used underwater TV

(UTV) in which divers filmed the seabed. However, the UTV of locations where cuttings were noted were not necessarily the location of these sampling stations (CSA, 1988).

Sample collection protocols often varied between studies. For example, in the North Sea Ula Well site seabed study, only the top 1 cm of sediment was collected and analyzed for ester concentrations (Smith and May, 1991). Other studies have collected deeper sediment cores, e.g., from the upper 2 cm for the Gulf of Mexico study site, or from the upper 10 cm for the Dutch sector North Sea (K14-13) study sites. This difference in sampling protocol has led authors to different conclusions. In the Smith and May study, the authors concluded that because the SBF base fluid was no longer detected in the sediment seabed, recovery had occurred. Other authors have concluded that synthetic based fluid migrated deeper into the sediment, suggesting that vertical redistribution is occurring as well as horizontal migration and redistribution.

Temporally, sampling was conducted using many different time interval configurations. Several studies conducted a pre-discharge survey in order to collect background information on the site and as a comparison or control for the drilling impact assessment. However, not all studies conducted pre-discharge surveys. Instead, reference stations, often located at arbitrary distances from the discharge point or well were used. Often, the seasonality of the pre-discharge survey was not maintained in later post-discharge surveys. Biologic parameters such as abundance, species diversity, and species richness are particularly seasonally dependent. Though spatial reference stations provide relative data to that collected in the vicinity of the discharge point, a combination of pre-discharge and post-discharge sampling surveys during the same season provides a more accurate comparison.

Though most studies reviewed included at least one reference station within the study design, several studies, such as the Mustang Island, Texas study (U.S. DOI, 1977) did not collect samples from such a station. The importance of a reference station is to provide the background or control information against which changes can be measured. The absence of background data during each sampling event discounts environmental effects, such as the above mentioned seasonal effects impinging on a larger area.

Several studies, such as that in the Beaufort Sea conducted the pre-drilling survey in the early spring, the first post-drilling survey in late spring and the final survey in late summer (Northern Technical Services, 1981). Benthic community structure undergoes significant changes during the spring and summer as growth and development occurs. This is compounded by the Arctic location which has a very short but intense growing season. The authors in this study mention seasonal impacts as a source of data variability, however, they neither designed the study to account for this variability nor conducted an analysis of the developmental effect on the benthic community during the growing season. Instead, the lack of a decrease in values of

abundance was interpreted as an indicator of no impacts by drilling effluents, rather than an indicator of potential interference in benthic growth (Northern Technical Services, 1981). The absence of a reliable temporal control results in a dependence on spatial reference station integrity, which may be compromised by discharge impacts or natural interstation differences.

Due to the importance of sampling methodology in influencing the type of results generated, the lack of a standard sampling protocol or methodology affects the level of confidence in the data. Therefore, data generated from different methods may not always be directly comparable.

Limitations were also found in data analysis and interpretation as presented by the authors.   One issue was that of the treatment of data outliers. In the Candler synthetic-based fluid study, the mean total petroleum hydrocarbons (TPH) was used to represent the concentration of TPH in the sediments. However, a closer look at the raw data reveals one replicate sample with a large TPH concentration decrease and three replicates with a concentration increase. The presentation of average TPH in all replicates masks a potential trend demonstrating synthetic-based fluid transport.

Two issues related to data analysis concern the broader environmental field study problems of natural, sampling, and analytical variability as well as the statistical power of analyzing and interpreting the data gathered. Because of high levels of natural, sampling, and analytical variability and high costs inherent to marine field studies, the statistical power of such studies is limited. That is, in order to detect an effect that is statistically significant, the magnitude of the change in a given parameter ranges from "large" for chemistry data to "very large" for biological data. Many of the surveys reviewed concluded that the discharge of drilling fluids and cuttings do not produce an effect on biota or have shown statistically significant adverse effect only to a limited spatial extent, i.e, to several hundred meters.   For example, the CSA, 1989 study at the Pensacola Block 996 states that "...only catastrophic, large scale changes (e.g., complete mortality) would be evident from these [observed photographic] data. Qualitative and quantitative visual data revealed that such mortalities did not occur." Even in the Santa Maria Basin study, one of the most sophisticated and well-funded studies conducted, sampling at 60 photoquadrants per station per cruise resulted in the ability to statistically resolve 70% reductions or greater in coral coverage. This level of detectability gives some measure of definition to and confidence in the study's conclusion that "No statistically significant changes were noted."

In summary, the lack of standard sampling methodology, differing monitored and analyzed parameters and differing study purposes presented in the reviewed articles severely limits the ability to compare effects of WBF and SBF on the seafloor. However, realizing the

data limitations, useful information can be extracted from the various studies and used in evaluating general trends and ranges of impacts.

9.3   Summary of Relevant Field Studies

9.3.1   *Water-Based Fluids*

Zingula, R.P. 1975. Effects of Drilling Operations on the Marine Environment. in: Conference Proceedings on Environmental Aspects of Chemical Use in Well-Drilling Operations, Houston, Texas, May 21-23, 1975.

The author described observations of cuttings piles in drilling and post-drilling sites in the Gulf of Mexico. According to the author, diver surveys and side scan sonar records have shown typical accumulation in the Gulf of Mexico to be approximately 150 feet in diameter (46 meters), with the outline being circular, elongate, or star burst, depending on currents. Maximum elevation of these piles immediately after drilling a well appears to be less than 3 feet (1 meter). Several months after drilling, the height of the cuttings piles is less than 6 inches. No specific observations were cited to support these data.

In 1971, cuttings piles were photographed while drilling occurred in South Timbalier Block 111. The water depth was approximately 80 feet (24 meters). Photographs were taken below the platform to illustrate "normal" bottom conditions and 70 feet downcurrent where cuttings were present. According to the author, mobile organisms such as crabs were moving around on top of the fresh cuttings piles.

In order to observe cuttings after cessation of drilling, a site was chosen in South Timbalier Block 172, which had not been drilled for 8-1/2 months. Water depth was 110 feet (33.5 meters). The first dive was to record "typical" bottom conditions in the Gulf, outside the area of any cuttings accumulation. The sea bottom consisted of a thin surface layer of very soft and unconsolidated mud, underlain by sticky clay with some sand. The bottom was highly burrowed, and there were numerous whole and broken mollusk shells.

The second dive identified a pile of cuttings. The surface was also highly burrowed, indicating the presence of numerous benthic organisms. In addition, there was a thin accumulation of very soft and unconsolidated mud, indicating that marine sediments are already covering the cuttings.

A sample was taken of the top two inches of sediment cuttings at the location of the second dive. The cuttings were somewhat rounded by partial disaggregation of the clays from

the swelling due to seawater adsorption and possibly from abrasive current action. These clay chips also showed a brownish oxidation on the exterior, further evidence that the chips were undergoing weathering.

Fauna in the cuttings sample were compared to that found in the "normal" sea bottom sample. According to the author, both samples contained essentially the same fauna, and in essentially the same abundance. Present in both were nearly 30 species of foraminifera, more than 15 species of mollusks and micromollusks, several species of bryozoans (both free specimens and coating mollusk shells), echnoid spines, ophiuriod ossicles, crab fragments, etc.

Ray, J.P. and E.A. Shinn. 1975. Environmental Effects of Drilling Muds and Cuttings. in: Conference Proceedings on Environmental Aspects of Chemical Use in Well-Drilling Operations, Houston, Texas. May 21-23, 1975.

Diver observations of the benthic environment in the vicinity of a drilling platform were described by the authors. During cuttings discharge, the heavier cuttings fall straight to the bottom to add to the cuttings pile. According to the authors, there is no doubt that sessile benthic organisms which cannot move about are buried by the cutting pile.

In depths below the effects of wave action, the cuttings piles produce a hard substrate capable of supporting a diverse and large number of organisms. It must be noted that this study did not collect any sediment cores so that no accounting of the benthic community was taken, either pre- or post-drilling. The authors, however, concluded that there are no observable detrimental effects on the marine life beneath Gulf of Mexico platforms.

U.S. Department of the Interior. 1977. Baseline Monitoring Studies, Mississippi, Alabama, Florida, Outer Continental Shelf, 1975-1976. Volume VI. Rig Monitoring. (Assessment of the Environmental Impact of Exploratory Oil Drilling). Prepared by the State University System of Florida, Institute of Oceanography. Contract 08550-CT5-30, Bureau of Land Management, Washington, D.C.

A study was conducted to provide a pre-, during-, and post-drilling assessment of selected biological, chemical and geological aspects of the environment in the vicinity of an exploratory drilling well. The monitoring survey was centered on a drilling location near the north lease line of Mustang Island (Texas) Block 792. Water depth was approximately 36 m.

The sampling pattern was in the form of a wheel with eight spokes centered on the well. Sampling points were located at distances of 100, 500, and 1,000 m from the drill site along each spoke. Thus, there were a total of twenty-five sampling points, including the drill site before and after operations and twenty-four points during drilling.

For clay mineralogy and standard sediment parameter analyses, two sediment samples were collected from each station by a diver filling PVC cores with sediment. A 9.1-m semi-balloon trawl was towed at a speed of three to six km/hour to collect macroepifaunal samples from each of the sampling points for trace element and histopathological analyses. The low number of epifauna in the study site limited histopathological examination to specimens of only two species of nektonic shrimp. One sediment core sample was also collected by divers at each station. The core was then subsampled for foraminifera and the remainder of the core was archived.

The clay mineralogy of the bottom sediments consisted predominantly of smectite followed by illite and kaolinite. Smectite levels did not change throughout the study period, however, illite levels significantly increased, whereas kaolinite decreased during and after drilling. Sand, clay and $CaCO_3$ levels increased and silt levels decreased during drilling operations.

During the active drilling phase, the authors noted that drill cuttings were specifically observed at only four 100-m periphery stations and one 500-m periphery station. Drill cuttings were still observed at these same five stations in the after-drilling phase but were notably less abundant.

The foraminiferal community composition indicated a "stressed environment" prior to drilling operations, and drilling activities further increased the stress. Total and live specimen abundance in samples collected during drilling were significantly less than those in the pre-drilling samples. The greatest effect on specimen abundances occurred along the 100-m periphery, but adverse effects were demonstrated out to the 1000-m periphery. However, the authors did not state if the cores at 100 m where the benthic fauna were sampled included cuttings samples.

Ray, J.P. and R.P. Meek. 1980. Water Column Characterization of Drilling Fluids Dispersion from an Offshore Exploratory Well on Tanner Bank. in: Symposium, Research on Environmental Fate and Effects of Drilling Fluids and Cuttings, Lake Buena Vista, Florida, January 21-24,1980. API, Washington, DC.

From January to March of 1977, a drilling muds and cuttings discharge monitoring program was conducted from a semi-submersible drilling platform on Tanner Bank, 161 km west of Los Angeles, California. The drill site was located in 63 m of water. Discharges during the study were from a 0.3 m diameter pipe located at a depth of approximately 12 m below the surface of the water. Photographic records were made by scuba divers using 35 mm stills and 16 mm movies. Surveys of bottom conditions directly beneath the discharge and in adjacent areas

were made from a research submersible. Observations and aerial photographs of plume characteristics also were made from helicopters.

Diver observations showed that as cuttings exit the discharge pipe, the materials simultaneously separate in three directions: upward, downward and horizontally. The heavier cuttings and some associated mud began an immediate vertical drop. Cuttings were often "glued" together by drilling mud and fell to the bottom as large aggregates. The authors hypothesized that this may be a mechanism for the transport of small quantities of undiluted drilling mud directly to the sea floor beneath the discharge point. However, the divers observed that much of the mud adhering to the cuttings was washed off as they fell through the water column. These lighter fractions dispersed horizontally under current influences.

Observations made beneath the platform and on the nearby reef from the research submersible showed no visible signs of mud or cuttings accumulation. The authors stated that due to the high energy water movements present on Tanner Bank, these results were not unexpected.

Meek, R.P. and J.P. Ray. 1980. Induced Sedimentation, Accumulation and Transport Resulting from Exploratory Drilling Discharges of Drilling Fluids and Cuttings on the Southern California Outer Continental Shelf. in: Symposium, Research on Environmental Fate and Effects of Drilling Fluids and Cuttings, Lake Buena Vista, Florida, January 21-24,1980. API, Washington, DC.

From January to March of 1977, a drilling fluids and cuttings discharge monitoring program was conducted from a semi-submersible drilling platform on Tanner Bank, 161 km west of Los Angeles, California. The drilling site was located in 63 m of water. The authors investigated sedimentation because of concerns that accumulations of sediments including cuttings could smother important biotic assemblages such as the relatively rare stylasterine hydrocoral, *Allopora californica*.

To evaluate the spatial and temporal distribution of settled solids, 19 sediment traps were placed at various distances around the exploratory drilling platform. In addition, 9 pre-operational, 45 operational, and 11 post-operational sediment grabs were taken at varying distances from the drilling platform to evaluate accumulation and transport of the settling materials. A pair of modified Van Veen samplers were used to capture undisrupted surface sediments. Both sediment and grab samples were analyzed for total solids and WBF trace element concentrations of barium, chromium, and lead using atomic absorption spectroscopy.

Over the 85-day study period, 2,854 barrels of muds and cuttings were discharged. Cuttings discharge accounted for approximately 96% or 825,530 kg of the total discharged

solids. Based on particulate composition, water depths and currents, the largest cuttings falling at speeds of 10 cm/sec fell straight down and would not reach traps just outside the platform perimeter. An analysis of the materials collected from traps located at 65 m and 120 m downcurrent of the discharge source demonstrated that finer materials were captured at the 120 m trap as would be expected given lower settling velocities as particle size decreases. However, both traps captured some fine cuttings and mud components with low settling velocities (less than or equal to 1 cm/sec). This indicated to these authors that within 200 m of the discharge, some aggregation of fine particles has also occurred.

Based on cuttings fall velocities, the decreasing measured sedimentation rate with increasing distance from the source, and the conglomerate effect of flocculation of drilling fluid components, the authors stated that the vast majority of the solids unaccounted for most probably fell to the bottom within the 50 m radius directly beneath the platform. From direct observations made by divers and submersible craft during the course of this study, who noted the absence of cuttings piles, the authors concluded that the majority of these settled solids were resuspended from the sea bed and redistributed. The authors calculated from sediment trap and adjacent pre-an post-drilling grab data that 70 to 80% of the settled solids and components were transported.

Houghton, J.P., et al. 1980. Drilling Fluid Dispersion Studies at the Lower Cook Inlet, Alaska, C.O.S.T. Well. in: Symposium, Research on Environmental Fate and Effects of Drilling Fluids and Cuttings, Lake Buena Vista, Florida, January 21-24, 1980. API, Washington, DC.

This study presents results of oceanographic studies and measurements and modeling predictions of the fate of discharged fluids and cuttings in the environment. The Lower Cook Inlet Continental Stratigraphic Test (COST) well was drilled between June 7, 1977 and September 26, 1977 with the *Ocean Ranger* semi-submersible drilling vessel. The well was located in the central portion of Lower Cook Inlet approximately 57 km WSW of Homer, Alaska and 38 km ENE of Augustine Island. The water depth at the site was 62 m.

The physical marine environment in Cook Inlet is dominated by large tidal fluctuations and strong currents. The authors measured these oceanographic parameters. Mean and diurnal ranges were calculated to be 4.6 m and 5.3 m, respectively. Currents were measured at the COST well using current drogues and two arrays of Endeco 105 current meters. Current meter data indicated mean maximum flood currents of 52, 62, and 78 cm/sec for meters placed near the bottom, at midwater, and near the surface, respectively. Mean maximum ebb currents were 42, 68, and 104 cm/sec, respectively at similar depths.

The seabed in the COST well area was reported to be typically sand or gravel waves, with heights occasionally greater than 3 m. Sea floor reconnaissance at the well site and adjacent areas was conducted using UTV and various bottom samplers. The authors mapped the drilling mud plume upon discharge using a dye injected into the drilling effluent. In addition, plume modeling was conducted and results were compared to field data.

Bottom sampling and specially designed drilling effluent traps were used to define deposition of cuttings on the sea floor in the vicinity of the drilling vessel. Two specially designed drilling effluent traps were constructed to measure the potential deposition rates and their particle size distribution. One trap (T-2) was deployed approximately 2.9 km WNW of the *Ocean Ranger*; the other trap (T-1) was deployed 100 m NNE of the discharge point from the platform. Samples from the drilling effluent traps were passed through a 0.85-mm screen and the portion of the sample larger than 0.85 mm was examined under a microscope on a grain by grain basis for the presence of cuttings. Approximately 2.4 gm of cuttings were identified in T-1 giving a calculated deposition rate of 5.24×10^3 g/hr/m^2. No cuttings were identified in the control trap T-2.

Bottom samples were obtained with a Souter-Van Veen grab sampler at various locations near the drilling vessel. Core samples 8 cm in diameter were taken from the sampler, sectioned vertically at 0.5-cm intervals, then screened, and examined for cuttings (defined as particles greater than 0.85 mm in diameter). These analyses indicated that the sea floor was sufficiently mobile to entrain cuttings to a depth of at least 12 cm into the sea floor by the end of the well (approximately 3 months duration). The maximum cuttings percentage in the sediments identified in any bottom sample was less than 3 percent by weight and was found 100 m north of the discharge. Analysis for barium sulfate and barium showed that drilling mud was being carried to the sea floor with the cuttings. Though the authors do not state in the text, presented data indicate that 1.34 mm cuttings are found 400 m north of the platform with slightly elevated barium concentrations of 680 µg/g in the corresponding sediment sample. Background or pre-drilling barium sediment concentrations were 560 µg/g.

The authors concluded that the heavier cuttings material deposited on the sea floor was entrained vertically into the sediment since the sandy bottom was quite mobile. Benthic sampling, core analysis, and UTV examination verified that cuttings did not accumulate on the sea floor as a cuttings pile. In addition, the relatively low increase in sediment barium levels suggests that near-bottom currents agitate newly fallen cuttings with the natural sands exerting a washing action that cleanses cuttings of adhering barite.

Lees, D.C. and J.P. Houghton. 1980. Effects of Drilling Fluids on Benthic Communities at the Lower Cook Inlet C.O.S.T. Well. in: Symposium, Research on Environmental Fate and Effects of Drilling Fluids and Cuttings, Lake Buena Vista, Florida, January 21-24, 1980. API, Washington, DC.

The major purposes of this study were to (1) determine species composition and abundance of the benthos in the area of the well site, and (2) evaluate the extent to which changes were attributable to drilling activities. The Lower Cook Inlet Continental Stratigraphic Test (COST) well was drilled between June 7, 1977 and September 26, 1977 with the *Ocean Ranger* semi-submersible drilling vessel. The well was located in the central portion of Lower cook Inlet approximately 57 km WSW of Homer, Alaska and 38 km ENE of Augustine Island. The water depth at the site was 62 m.

Benthic samples were obtained by Ponar grab samples before, during and at the conclusion of drilling operations. For each of the time periods, the number of species, species diversity, and number of organisms were evaluated for 10 stations, each at 100 m north, 200 m north, and the control located 1,700 m east of the drilling vessel.

Results are presented in Exhibit 9-4. The authors mentioned that the increase in the number of organisms and variation in the number of species and species diversity for the June, July and September time points (corresponding to before, during and after drilling) is most probably due to seasonal variations. However, the authors did not discuss that compared to the control location samples, the number of organisms had substantially decreased in the during- and post-drilling surveys at both the 100-m and 200-m locations.

Mariani, G., Sick, L., and Johnson, C. 1980. An Environmental Monitoring Study to Assess the Impact of Drilling Discharges in the Mid-Atlantic. III. Chemical and Physical Alterations in the Benthic Environment. in: Symposium on Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Lake Buena Vista, Florida, January 21-24, 1980. API, Washington, DC.

The objective of this study was to characterize and determine chemical (trace metal) and physical (grain size, clay mineralogy) changes of the sediment. This study also analyzed tissue of three representative benthic taxa for trace metal content: brittle stars (primarily *Amphioplus macilentus*), molluscs (primarily *Lucinoma filosa*) and polychaetes.

Two benthic sampling surveys were conducted. A pre-drilling survey was conducted in July and August 1978 and a post-drilling survey was conducted in July 1979. The pre-drilling survey area comprised a 1.6 km radius around the well site while the post-drilling survey was extended to a 3.2 km radius.

Exhibit 9-4. Comparison of Sampling Area of Averages for Numbers of Species, Organisms, and Species Diversity for the Survey Periods

Survey Period	100-m	200-m	Control
	Mean number of species (S)		
June	9.9 ± 3.2 (a)	___	8.5 ± 3.1 (b)
July	9.0 ± 2.1	12.4 ± 2.5	17.5 ± 3.5
September	10.7 ± 1.6	11.3 ± 2.7	15.8 ± 5.7
	Mean number of organisms (N)		
June	35.1 ± 21.3[a]	___	43.3 ± 37.4[b]
July	28.2 ± 14.4	41.8 ± 9.9	80.0 ± 61.4
September	59.7 ± 29.9	41.4 ± 20.5	183.7 ± 110.4
	Mean species diversity (H)		
June	2.10 ± 0.4[a]	___	1.51 ± 0.31[b]
July	1.98 ± 0.51	2.16 ± 0.48	2.70 ± 0.40
September	2.00 ± 0.23	2.17 ± 0.23	1.78 ± 0.54

(a)   Based on samples 3, 4, 11, 16, 17, 18, 19 in the area of both 100-m and 200-m stations.
(b)   Based on samples 28, 29, 30, and 31 about 1,000 m from Anchor Buoy 4 (AB-4).

Six samples were collected with a Smith-McIntyre or modified Ponar Grab at each station for the physical, chemical, and biological analyses. Upon retrieval of each grab, two sediment cores (one for sediment granulometry and one for trace metal analyses) were taken near the center of the grab.

The physical alterations that took place during the post-drilling survey included increased percentages of clay size particles within the immediate vicinity of the well site (46 meters) and extending out to approximately 800 meters. The increased percentages of clay within the sampling grid were accompanied by changes in proportions of clay minerals in the area. The authors stated that these changes in clay percentage and mineralogy suggest that fine materials were deposited around the well site during drilling operations.

Increases in the concentration of lead, barium, nickel, vanadium, and zinc for bottom sediments were detected during the post-drilling survey. The authors presented metals concentration data as a spatial distribution, highlighting the trend of metals in sediment concentrated around the drill site in the pre-drilling survey and distributed at low but fairly even concentrations to 1.6 km in the post-drilling survey. Barium concentration increased 21 fold at 1.6 km, lead increased 3.6 fold at 200 m, nickel increased 2.5 fold at 100 m, and vanadium increased 4 fold at 100 m.

Analysis of tissue samples of brittle stars, molluscs and polychaetes collected during the post-drilling survey revealed that each group had significantly higher barium and mercury content than tissue samples collected during the pre-drilling survey. The barium concentration in mollusks, brittlestars, and polychaetes collected at 1.6 km increased 20 fold, 133 fold, and 40 fold, respectively, whereas mercury concentration increased 4 fold, 18 fold, and 30 fold, respectively at the same distance. Increased mercury content was detected in these organisms despite the fact that data showed mercury concentrations in the sediment were below the detection limit of 0.05 μg/g, indicating that the mercury was bioaccumulating.

Menzie, C., Maurer, D., and Leathem, W. 1980. An Environmental Monitoring Study to Assess the Impact of Drilling Discharges in the Mid-Atlantic. IV. The Effects of Drilling Discharges on the Benthic Community. in: Symposium on Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Lake Buena Vista, Florida, January 21-24, 1980. API, Washington, DC.

The objective of this paper was to describe the short-term environmental effects of drilling fluids and drilled cuttings on marine benthos around exploratory well NJ 18-3, Block 684 on the Mid-Atlantic Continental Shelf. The study was conducted within two weeks following the termination of drilling. The leased block was located approximately 156 km off the coast of New Jersey and had an approximate water depth of 120 meters.

Two surveys were conducted to examine the abundance and composition of the benthic fauna in the vicinity of the well site. A pre-drilling survey was conducted in July and August 1978 and a post-drilling survey was conducted in July 1979. The pre-drilling survey area comprised a 3.2 km diameter area around the well site while the post-drilling survey was extended to a 6.4 km diameter area.

UTV surveys were conducted during the pre- and post-drilling surveys to provide information on the spatial distribution of megabenthic epifauna around the well site and to examine physical changes in the benthic environment resulting from drilling operations. Ten UTV transects (200-1,000 m in length) were made throughout the survey area during the pre-drilling survey, while 11 transects (150-900 m in length) were made during the post-drilling survey.

During the pre-drilling survey, 40 benthic stations were sampled, of which 22 were analyzed in a radial pattern around the well site, while during the post-drilling survey, 48 benthic stations were sampled, of which 41 were analyzed. The rest of the samples were held for later possible analysis. Six grab samples were collected at each station, of which two were analyzed for fauna while the remainder were held for future analysis.

Benthic samples were washed on a 0.5 mm mesh sieve to remove silt, clay, and fine sands. The material retained on the sieve was preserved with 10% buffered formalin-Rose Bengal solution. Macrobenthos were sorted from these samples and identified with the aid of stereoscopic and compound microscopes.

Seafloor UTV observations during the pre-drilling survey revealed a nearly featureless bottom topography interrupted by burrowing and feeding mounds of benthic invertebrates. During the pre-drilling survey, the sediments were comprised of medium-fine sands with a silt and clay content of 16-25%. During the post-drilling survey, bottom UTV observations revealed that sediments in the immediate vicinity (approximately a 75 m radius) around the well site were comprised of patches of drilling discharges (primarily semi-consolidated, natural subsurface clay materials) which altered the microtopography of the area. Mounds of this material were generally less than 10 cm in height. Debris (e.g., small pieces of pipe, tires, rope) was also observed in the immediate vicinity of the well site. Side scan sonar showed the bottom scour marks of anchor chains radiating out from the well site. Sediments in areas beyond the immediate vicinity of the well site appeared similar to those observed during the pre-drilling survey.

Fish (primarily hake, *Urophycis* spp.) and crabs (primarily *Cancer borealis*) increased substantially between pre- and post-drilling surveys in the immediate vicinity of the well. The authors speculated that these organisms may have been attracted to the region as a result of the increased microrelief afforded by the cuttings accumulations. High densities of sand stars were observed near the well site, apparently associated with accumulations of mussels (*Mytilus edulia*) that had fallen from the drilling rig and associated anchor chains.

Sessile megabenthos (pennatulids) and macrobenthos were subjected to burial by drilled cuttings within the immediate vicinity (i.e., within approximately a 75 m radius) of the well site.

Measures of species diversity, species richness, and species evenness obtained prior to the onset of drilling were high and relatively constant over the sampling area. Species diversity of macrobenthos collected during the post-drilling survey were within the general range observed for the shelf-break region, though some values were lower. The lowest values during the post-drilling survey were observed in the immediate vicinity of the well site (75 m). Lower numbers of species generally reflect the lower numbers of organisms observed at some stations.

Based on the patchiness in the distribution of the species and in density, the author hypothesized that the variability represented differences between plots in which the infauna had been buried by cuttings and those which had escaped burial or in which recolonization had occurred, but supporting data were not presented.

Differences in the nature of infaunal assemblages were particularly clear when pre- and post-drilling survey data for densities of major taxa were compared. Pooled densities of annelids, molluscs, echinoderms, and crustaceans were all lower in the post-drilling survey.

In summary, this study concluded that the discharge of drill cuttings caused local and at least short-term effects on the fauna in the vicinity of the well site. Increases and/or decreases in abundance were probably related mostly to: (1) physical alterations of the substrate (e.g., rapid deposition and burial, increased surface relief or increased clay content of the sediment), as well as (2) effects of predation by hake, crabs, and starfish. No toxic effects were identified.

EG&G Environmental Consultants. 1982. A Study of Environmental Effects of Exploratory Drilling on the Mid-Atlantic Outer Continental Shelf-Final Report of the Block 684 Monitoring Program. 1982. Prepared for Offshore Operators Committee. October 1982.

This survey is the second in a series conducted at the exploratory well site NJ 18-3, Block 684 on the Mid-Atlantic Outer Continental Shelf. This survey was taken one year after drilling operations had stopped at the site. Forty-one sites were sampled ranging from 23 m to 3.2 km from the discharge location. The study evaluated the fate of drilling fluids discharges based on: 1) percent clay, 2) trace metal concentration (Ba, Cr, V) in the sediment, and 3) benthos impacts (trace metal concentration in organisms and density of mega and marcobenthos). Analysis of this survey indicated the percent clay levels decreased from the drill site out to 800 m measured during the first study, to levels common with predrill levels. However, several patches of increased clays were measured out to 750 m. Because trace metal leachate levels measured in the first post-drill survey did not link to discharge characteristics provided by Ayers et al (1980), analysis for trace metals was limited to barium, chromium, and vanadium (Ba, Cr, V). Ba measurements from the second study indicate a shift in the Ba concentrations in the direction of the predominate current (southwest), with 3-fold increases above predrill levels measured to 400 m from the discharge point. There appeared to be an even distribution of megabenthos with respect to distance from the discharge point. All four dominant macrobenthos, although depressed below predrill densities, increased from densities found during the first post-drill survey. Species richness as with abundance increased from the first post-drill survey, however they did not reach predrill levels. Impacts were seen out to 1.2 km. These impacts were not, however, correlated to Ba concentration. Chromium in increased concentration from predrill levels was detected in polychaetes out to 1.2 km from the discharge point.

Northern Technical Services. 1981. Beaufort Sea Drilling Effluent Disposal Study. Prepared for the Reindeer Island Stratigraphic Test Well Participants. Under the direction of Sohio Alaska Petroleum Company. 329 pp.

Sohio Alaska Petroleum Company (SOHIO) completed the Reindeer Island Stratigraphic Test (RIST) well in Prudhoe Bay area of the Beaufort Sea in early 1979. A study was conducted to evaluate the effects of above- and below-ice discharges. At the time of the study, normal procedure for handling drilling mud and cuttings from offshore wells was to haul them to an onshore disposal site.

Test Plot 1 was the discharge location at a water depth of 8 m. Monitoring locations were oriented radially from the discharge point ranging from less than 5 m to 500 m distance from the discharge point. The control location was denoted as Test Plot 3 which was about 1 km south of Test Plot 1.

Results at Test Plot 1 indicated a strong sorting of materials by grain size. Larger particles were deposited closer to the discharge point while finer materials, including drilling muds, were deposited further away from the discharge point. Freshwater drilling muds readily flocculated upon discharge into seawater. According to the authors' observations, these flocs were loosely deposited on the seafloor during winter and could be resuspended with the slightest agitation.

The authors stated that it is likely that flocculation extends to cuttings since clay-sized particles in the drilling mud tend to coat cuttings during the drilling process and thus provide sites for attachment of other clay-sized particles.

Diver observations were conducted at Test Plot 1 on May 4, 1979, 4 days after the test discharge. A 5- to 6-cm thick accumulation of mud and cuttings was observed on the seafloor in the vicinity of the discharge point. UTV observations the following day indicated a 2- to 3-cm deposition at a distance 3 m east of the discharge point. The consistency of the deposited materials was such that materials would be suspended with the slightest agitation. At a distance of 6 m east of the discharge site, 1 to 2 cm of loosely deposited drilling effluents was observed. By a distance of 30 m east of the discharge, accumulation of drilling muds on the seafloor was estimated to be less than 0.5 cm thick. Organisms observed during the post-discharge survey at Test Plot 1 included amphipods, a snail, several fish and mysids, an hydroid, an anemone, numerous snail and isopod tracks, and numerous worm tubes.

Benthic sampling was conducted at Test Plots 1 and 3 prior to and subsequent to the test discharge of drilling effluents. All samples were obtained using a Petite Ponar bottom grab

sampler. Fifteen random replicate samples were taken at each of the test plots during sampling periods on April 7-10, May 9, and August 3-4, 1979. For the April and May surveys, samples were obtained through holes augered in the sea ice in random 5 m by 5 m squares within each of the 50 m by 50 m test plots. For the August survey, randomness in samples was achieved by drifting in a boat within a 25 m radius of the center of the test plot.

Benthic data were analyzed and are summarized in Exhibit 9-5. The authors calculated the number of taxa, species diversity, evenness and species richness values by pooling the 15 replicate samples taken at each test plot during the sampling period.

Exhibit 9-5. Summary of Benthic Data Collected at Test Plots

Collection Date	Test Plot [a]	Abundance (no./m^2)	No. of Taxa	Shannon Function of Diversity	Even-ness	Species Richness	Biomass (gm/m^2 wet wt)
April 7, 1979	1	551.1	45	2.96	0.83	6.97	10.0
April 8, 1979	3	809.4	54	3.32	0.83	7.91	29.4
May 9, 1979	1	1240.0	63	3.11	0.75	8.70	33.9
May 9, 1979	3	1529.9	65	3.50	0.84	8.73	59.2
August 3, 1979	1	1202.7	67	2.94	0.70	9.30	18.4
August 3, 1979	3	2678.0	76	3.09	0.71	9.50	55.0

[a] Test Plot 1 refers to the discharge location and Test Plot 3 to the control location.

The authors did not seem to stress that the time difference in sampling is strongly affected by the natural growing season. As presented in Exhibit 9-6, from pre-drilling in April to immediately after discharge in May, there is a significant increase in the number of organisms per square meter (abundance) most probably due to the beginning of the growing season. From May to August, there is a 75% increase in abundance in the control location (Test Plot 3) and a 3% decrease in Test Plot 1. Though the authors do not present the percentage change nor the percentage difference between the control and test plot data, it is clear that in the time between May and August there should be a normal increase in numbers of organisms. This lack of increase in Test Plot 1 implies that the drilling discharges may have interfered with organism population growth during that time period.

Exhibit 9-6. Comparison of Abundance Data Collected at Test Plots

	April 7, 1979		May 9, 1979		August 3, 1979	
	1	3	1	3	1	3
Abundance	551.1	809.4	1240.0	1529.9	1202.7	2678.0
Increase from April to May Sample	---	---	125%	89%	---	---
Increase from May to August Sample	---	---	---	---	-3%	75%

Trace metal analysis was conducted on replicate Ponar and whole drilling mud samples in order to detect possible effects of below ice drilling effluent disposal. The majority of the bottom samples were obtained at random locations within 50 by 50 m of test plot 1 (the discharge site) and test plot 3 (control site). As indicated by analysis of the samples at each of the sites, variations of trace metals at the test discharge site was similar to variations found at the control location. According to the authors, these results of the trace metal analysis confirm that drilling muds are quite swiftly resuspended and removed from the seafloor after initial settlement.

Bothner, M.H. et al. 1985. The Georges Bank Monitoring Program 1985: Analysis of Trace Metals. U.S. Geological Survey Circular 988.

This study was designed to establish the concentration of trace metals in sediments prior to drilling on Georges Bank and to monitor the changes in concentrations that could be attributed to petroleum-exploration activities. The first cruise of the monitoring program occurred just before exploratory drilling commenced in July 1981, and nine subsequent cruises were conducted on a seasonal basis (November, February, May, and July) over a 3-year period. Eight exploratory wells had been drilled at that time on Georges Bank. The first was started on July 22, 1981, and the last well was completed on September 27, 1982.

Of 12 trace elements analyzed, only barium was found to increase in concentration during the period when the eight exploratory wells were drilled. The maximum post-drilling concentration of barium reached 172 ppm in bulk sediments near the drill site in Block 410. This concentration was higher than the pre-drilling concentration at that location by a 5.9-fold factor. No drilling-related changes in the concentrations of the 11 other metals were observed in bulk sediments at any of the locations sampled in the program. Analyses of sediment trap material for Ba-enriched matter showed that resuspension can occur up to at least 25 m above the seafloor.

The authors estimated that about 25 percent of the barite discharged at block 312 was present in the sediments within 6 km of the rig, 4 weeks after drilling was completed at that

location. In their evaluation of the rate at which barite decreases within the site-specific survey, the authors considered only the area between the 0.5- and 2-km circles. They also excluded the actual drill site, where large within-station variability was measured. For almost a year following completion of the well, the inventory of barite decreased rapidly, with a half-life of 0.34 year. During the next year, the inventory decreased at a slower rate (half-life of 3.4 years).

To see how far Ba from drilling mud could be traced, the authors analyzed the fine fraction of sediment at two stations approximately 65 km west of the Block 312 drill site and at two stations approximately 35 km to the east of the easternmost drill site. At the two western stations they measured maxima in Ba concentrations during cruises 8 and 10 in 1983. The authors were surprised to find that maxima in the Ba concentrations, although of lower magnitude, were also recorded at similar times at the two eastern stations. The maximum value at one eastern stations on cruise 7 was statistically higher than the mean of the first 6 cruises at the 99.5 percent level of confidence (t test). These findings were considered significant because they suggested that Ba in the finest fraction of drilling mud may have been transported over very wide areas of the bank, to the east as well as to the west.

The barite discharged during the exploratory phase of drilling is associated with the fine fraction of sediment and was found widely distributed around the bank. Evidence indicated barium transport in the predominant, westerly current direction as far as Great South Channel (115 km west of the drilling), and to stations 35 km east of the easternmost drilling site, against the predominant current. Small increases in barium concentrations were measured also at the heads of both Lydonia and Oceanographer Canyons, located 8 km and 39 km, respectively, seaward of the nearest exploratory well.

Throughout the 3 years of monitoring , the concentrations of Ba in bulk sediments from the upstream control stations were fairly consistent with time. On the basis of those data, the authors judged that no increase in Ba had occurred at those stations. They found no increases in the concentration of other metals as a result of drilling at the upstream locations during the 3 years of monitoring. In contrast, there were measurable changes in the concentrations of Ba in Block 410 (stations 16, 17, and 18).

The scatter in their data indicated to the authors that Ba was not distributed homogeneously over the sampling area. This heterogeneity was probably caused by the intermittent discharge of drilling fluids into ocean currents that continuously change direction of flow throughout the tidal cycle. A few cuttings were found during both year 2 and year 3 at a station located 2 km to the east of the drill site, in Block 410. On cruise 9, cuttings were observed at all stations within 500 m of the drill site in Block 312.

At coring stations 50 km west of transect III, the authors observed an enrichment of the Ba/Al ratio in surface sediments and interpreted that as evidence for a small recent addition of Ba. A rough calculation referred to from an earlier report (Bothner et al, 1984) suggested that 69 percent of the barite discharged by all eight exploratory wells could be accounted for in the sediments within the western half of a circle 130 km in diameter and centered on station 5. They then concluded that the barite from drilling mud was associated with the fine-sediment fraction in low concentration and was widely distributed.

This study demonstrates that drilling fluid solids may be widely distributed over large areas in relatively short period of time if they are discharged in high energy marine environments such as the Georges Bank. Transport was observed over distances of 35 - 115 km, both in the anticipated direction of deposition and opposite that of predominant current flow. This study indicated that in such environments, assessing low-level, regional-scale contamination effects is the primary source of concern.

Neff, J. M. M. Bothner, N. Maciolek, and J. Grassle. 1989. Impacts of Exploratory Drilling For Oil and Gas on the Benthic Environment of Georges Bank. Marine Environmental Research 27 (1989).

This study was conducted over a three year period to determine the impact of discharges from exploratory drilling to benthic community of Georges Bank and was conducted in conjunction with the previous reviewed article by Bothner et al. (1985). The authors conducted benthic fauna analyses at 46 sample sites that included 31 sites adjacent to two drilling platforms. Sampling took place quarterly and pre-, during, and post-drilling. The authors indicated changes in the benthic communities near the platforms during and immediately after drilling activities, but attributed these changes to natural changes within the community populations.

Continental Shelf Associates. 1988. Monitoring of Drillsite A in the Gainesville Area Block 707. Prepared for Sohio Petroleum Company, Houston, TX, April 26, 1988. 124 pp.

The purpose of this study was to assess the environmental impacts of proposed exploratory drilling in Gainesville Area Block 707 on several seagrass and live-bottom communities. Gainesville Area Block 707 is located approximately 60 km from the west coast of Florida in water depths of 21 m.

Two surveys were conducted and results analyzed. Survey 1 was a pre-drilling survey. The drill rig moved onsite on May 25, 1984, and began drilling discharges on June 3, 1984. Survey 2 (August 9 - August 23, 1984) occurred during drilling. A third survey was also conducted, but because it followed a severe hurricane that disrupted the benthos across a wide area of the northwest Florida continental shelf, most of the results were not used.

According to other studies the authors referenced in this area, plant densities or bottom coverages within offshore seagrass and algae stands range from 20 to 50%. *Halophila* species comprise about 79% of the plant material present while various species of microalgae account for the remainder. *Halophila decipiens* was found to be the only seagrass species present in the vicinity of the Block 707 drill site.

Sampling stations were located within 300 m of the discharge point in a radial pattern. The closest stations were located 25 m, 65 m, and 85 m from the discharge. Live bottom monitoring stations were located 25 m and 500 m from the drill site and 3 reference stations were located greater than 9 km from the drilling operations. Six randomly placed quadrants were permanently established and photographed. An additional 10 stations were established beyond 300 m during survey 2.

During the second survey, visual observations revealed the absence of all seagrass within 300 m of the discharge site. An accumulation of cuttings around the discharge site was also observed, particularly along the northwest radial within 30 m of the discharge point. Farther from the drill site, growth was inhibited as a function of the concentrations of the two drilling effluent indicators, barium and barium:iron ratios in the fine-grained fraction (<63 μm) of surficial sediments.

To determine whether or not exposure to drilling effluents affected the seagrass, the authors evaluated the relationships between changes of the indicators of discharged drilling effluents and the changes in standing crop of the seagrass. The indicators of discharged drilling effluents were the barium concentrations and barium:iron ratios in the fine-grained fraction (<63 μm) of the surficial sediments. The fine-grained fraction was analyzed because barium sulfate in the discharged drilling effluents is in the silt/clay particle-size range and the sediments around the drill site were sand. Thus, metal concentrations in the fine-grained fraction were more efficient tracers of the settleable fraction of the discharged drilling effluents. Logarithmic transformations of the mean changes of these indicators were used in the correlation analysis.

The authors presented Ba:Fe ratio data as well as chromium concentration data. The data showed a 90% increase in the Ba:Fe ratio at 4,000 m from the discharge point and an 11% increase in the chromium concentration at 300 m.

Results of analysis indicated that there were statistically significant negative correlations between changes of the drilling effluent indicators and changes of the seagrass standing crop. Larger changes in drilling effluent indicators (e.g., increases in sediment Ba levels or of Ba:Fe ratios) were associated with smaller changes in seagrass standing crop (i.e., although seagrass

standing crop increased, the magnitude of the change was negatively correlated to effluent indicators).

Both leaf biomass and leaf count increased from the pre-drilling to the during-drilling surveys, most probably due to the growing season. However, while leaf count increased 1,212% at the reference station, it only increased 282% and 84%, respectively, at the 4,000 m- and 1,300 m-stations (77% and 93% decreases in growth).

Impacts to the live bottom community at the 25 m station resulted primarily from burial of cuttings. The authors concluded that smothering by drilling muds and cuttings may have been important at distances close to the drill site. Farther from the drill site, reduction in the light levels reaching the seafloor as a result of increased turbidity in the water column was thought to be the primary factor.

Two follow-up surveys were conducted one year and two years after drilling. According to the authors, these surveys indicated seagrass recovery had occurred. However, data regarding the extent of recovery were not provided.

Boothe, P.N. and B.J. Presley. 1989. Trends in Sediment Trace Element Concentrations Around Six Petroleum Drilling Platforms in the Northwestern Gulf of Mexico. In: F.R. Englehardt, J.P. Ray, and A.H. Gillam (Eds.) Drilling Wastes. Elsevier Applied Science, London. pp. 3-22.

The goal of this study was to determine typical concentrations of drilling fluid residuals in surface and subsurface sediment within 500 m of six offshore drilling sites in the northwestern Gulf of Mexico. Three types of drilling sites were studied: exploratory sites as isolated as possible from other wells; developmental sites with multiple, recently completed wells; and production sites where considerable time had elapsed since drilling was completed. For each of the three types, a location was chosen in shallow water, i.e., about 30 m in depth and in deep water, i.e., about 100 m in depth. NOTE: In the authors' use of the relative, descriptive terms "shallow" and "deep" in their report, the term "deep" (i.e., ~100 m) is not the same as the term used in reference to this rulemaking, for which "deep" wells are defined as those in waters greater than 1,000 m in depth.

Sediment was collected at 40 stations around each drilling site using a circularly- and radially-symmetrical pattern. Background concentrations were determined by analyzing sediments from 4 control stations located 3,000 m from each drilling site in addition to subsurface sediments located well below the possible influence of surface discharges (4-31 cm depth).

Barium mass balance data show that only a fraction of the total Ba, and presumably similar drilling mud components, are present in near-site sediments. At nearshore study sites, approximately 94% of the discharged Ba had been transported more than 3,000 m from the drilling sites. Offshore sites were more variable, showing transport beyond 3,000 m for 16%, 28%, and 53% of the discharged barium. Multiple regression analysis suggested excess sediment Ba distribution was largely controlled by water depth.

The total excess Ba within 500 m of these sites was highly correlated with the total Ba used at the site. Thus, the effect of multiple wells on near-site sediments is directly additive. Discriminant analysis suggested that statistically significant ($\geq$ twice background levels) Ba enrichment existed in surface sediments at 25 of the 30 control (3,000 m) stations studied. Ba levels at "control" sites were up to 4.5 times subsurface background levels. Statistically significant elevations in sediment mercury concentrations within 125 m of the site (4-7 times mean control levels) were observed at the Vermillion 321 and High Island sites (both deep water sites) and were strongly correlated to Ba levels. The High Island site also showed a significant Pb gradient, showing mean levels within 125 m 5-fold higher than controls and 3.8-fold higher within 500 m; Pb was highly correlated with Ba at this site. Other study sites exhibited patchy distributions of elevated sediment Pb levels, but no consistent spatial trends.

Sediment levels of Cd, Cu, and Zn were determined in only 9 or 10 surficial samples at each site, so evaluations were tenuous with such small sample sizes. Observations made included the following. Cd appeared elevated at the High Island and Vermillion 321 sites and was correlated to Ba at the Vermillion site. Cu showed no consistent trend at any site except for small elevations within 125 m at the High Island site, and was correlated to Ba. Zn showed consistent gradients at the High Island and Vermillion 321 sites, with elevation 5-10 times control levels, and was correlated to Ba and distance at both sites. Within 250 m of the Vermillion 321 and High Island sites, 4- to 5-fold elevations of hydrocarbons over control station levels were observed. However, among the six (all gas) platforms, hydrocarbon contamination was generally low.

Continental Shelf Associates, Inc. and Barry A. Vittor and Associates, Inc. 1989a. Environmental Monitoring in Block 132 Alabama State Waters, Summary Report. Prepared for: Shell Offshore, Inc.

The program objective as presented in this report was to determine whether or not drilling discharges affected the biotic assemblages living in the vicinity of the discharge site. The program consisted of three sampling elements: 1) continuous recording of near-bottom current speed and direction; 2) analysis of surficial sediments collected within 1,000 m of the discharge

site for sediment grain size, trace metals, and oil and grease; and 3) sampling and analysis of macroinfaunal assemblages present within 1,000 m of the discharge site.

Sampling was conducted during four surveys: Survey 1, prior to drilling discharge; Survey 2, two months after drilling discharges commenced; Survey 3, five days after drilling discharges ceased; Survey 4, eight months after drilling discharges ceased. The sampling pattern consisted of eight radials centered at the discharge site and oriented toward north, northeast, east, southeast, south, southwest, west, and northwest. Stations were located along each radial at 122 m, 500 m, and 1,000 m. In addition, four stations were located at 91 m on the four primary radials, i.e., north, east, south, and west. The analyses conducted were: 1) sediment grain size analyses; 2) chemical analyses; and 3) analyses of biological samples.

Near bottom currents predominantly flowed southeastward and, to a lesser extent, northwestward. Sand predominated at many of the stations in the study area on all four surveys. However, sediments did appear to become progressively finer as the program progressed. The authors found that changes in sediment grain size resulting from drilling discharges could not be easily separated from non-drilling-related changes. They concluded that changes observed within 122 m of the discharge site were probably related to drilling discharges. Changes of similar magnitude were observed by the authors farther away, but were thought due to non-drilling-related causes based on examination of the barium distribution.

The authors analyzed for 10 trace metals (aluminum, arsenic, barium, cadmium, chromium, copper, iron, lead, mercury, and zinc) and oil and grease at 16 stations located within 1,000 m of the discharge site on the four surveys. Their results showed that except for barium, the trace metal concentrations in the whole-sediment samples were correlated with the quantity of fine-grained particles in the sediments. Their analysis of the mean concentrations of Ba in the fine-grained fractions were shown to be consistently greater during survey 3 compared to Survey 1 at all stations located within 1,000 m of the discharge site where trace metal concentrations were determined. During Survey 4, only one of the sixteen stations was statistically greater than during Survey 1.

The study states that changes in other trace metals concentrations did not appear related to drilling discharges. The concentration ranges of aluminum, arsenic, cadmium, chromium, copper, lead, and mercury in whole sediments were within or near ranges reported in previous studies conducted in offshore Alabama waters. The authors' statistical analysis revealed no changes that were attributable to drilling discharges.

The authors found that the mean mercury concentrations in fine fractions during Surveys 2 and 3 were statistically greater than those observed during Surveys 1 and 4. It was concluded

that mercury concentrations were not positively correlated with barium concentrations and therefore, probably not associated with discharged barite.

At each of the four surveys, the authors collected ten replicate samples, at each of 16 stations, and analyzed them to determine the composition of the macroinfaunal assemblage. The macroinfaunal assemblage summary parameters (number of taxa, density, diversity, evenness, and species richness) were calculated for all stations and surveys. The values of these parameters were within ranges expected for this area and were related to sediment grain size, but not to proximity to the discharge site. Considerable temporal and spatial variability was observed by the authors.

The authors used species cluster analysis and dendrograms to reflect the presence of assemblages typical of nearshore sand and silt habitats throughout the northern Gulf of Mexico. The authors grouped stations in the clustering analysis primarily on the basis of time of sampling, and not by sediment texture or distance from the discharge site. Using canonical descriminant analysis of environmental factors such as time, distance from the drill site, sediment texture, and trace metals, they indicated that benthic station groupings were determined primarily by season and not by distance from the discharge site or by drilling discharge tracers such as barium or percent clay. They found that sediment texture (percent gravel) did account for a small amount of the variability among station groups.

The study concludes that the number of macroinfaunal taxa was not related to either sediment texture or distance from the discharge site. Individual abundance was correlated with sediment texture and varied with season, but was not related to distance from the discharge site. Species diversity (H') was relatively uniform temporally and spatially. The authors indicated that the observed changes reflect the effects of sediment texture and season on numbers of individuals, and are not related to distance from the discharge site. Evenness and species richness levels varied with sediment texture and showed temporal changes. These parameters were not related to distance from the discharge site.

Continental Shelf Associates, Inc. and Barry A. Vittor and Associates, Inc. 1989b. Environmental Monitoring to Assess the Fate of Drilling Fluids Discharged into Alabama State Waters of the Gulf of Mexico. prepared for: Offshore Operators Committee.

The purpose of this study was to determine whether drilling fluids discharged into Alabama State Waters outside of the barrier islands can be detected in statistically significant levels in areas of biological concern located inside the barrier islands. To accomplish this goal, the study was divided into two monitoring efforts: area-wide monitoring and drill site monitoring. The area-wide effort involves two principal elements: 1) sampling and analysis of

surficial sediments at 12 stations for grain size, oil and grease content, and concentrations of 10 trace metals; 2) sampling and analysis of oysters for the same metals at three of the surficial sediment stations. The report summarizes methods and results of area-wide sampling from Survey I (February 1986) through Survey VI (June 1988).

Beginning between Surveys IV and V, an exploratory well was drilled in Alabama State waters Block 132. Between October 9, 1987 and February 29, 1988, approximately 7,285 m^3 of drilling fluids and 726 m^3 of cuttings were discharged. About 79% of the total volume was discharged between October 9 and November 6, 1987 (i.e., prior to Survey V).

In addition to the drilling activity, a major dredging project began during the interval between Surveys IV and V. Dredging of the Mobile Bay ship channel began in January-February 1987, when about 500,000 m^3 were dredged. Dredging resumed in October 1987 (two months before Survey V) and was expected to continue until February 1990. About 23,000 - 31,000 m^3 were dredged per day, with all of the material being placed in the offshore disposal area outside of the barrier islands.

Also, the data set from drill site monitoring in Block 132 can aid in the interpretation of the area-wide data set by indicating which variables might be affected by drilling discharges. For example, if the concentration of a metal were unaffected near the drill site, then changes in the concentration of the metal in Mobile Bay (where the nearest station is 10 km from the drill site) could not be attributed to drilling fluids from the well.

Ba concentrations increased substantially around the drill site in Block 132 during drilling. Statistically significant increases in Ba concentrations were detected to a distance of 500 m from the drill site, and apparent two to five-fold increases in mean Ba concentration were evident at four 1,000 m stations (though not statistically significant).

Eleven of the 12 stations monitored in Mobile Bay during this study showed no significant increases in fine fraction Ba concentration or barium-to-iron ratio. At Station 3, the mean of the Survey V-VI values (318 mg/kg) was about 13% higher than the mean of the Survey I-IV values (282 mg/kg), and was statistically significant.

This small increase in barium at Station 3 was thought probably due to natural variability rather than drilling fluids. No significant increases were observed at four other stations located between Station 3 and the mouth of the bay, where the drilling fluids would enter. Three of these stations had much higher silt/clay content than Station 3 and were thought more likely to retain fine drilling fluids deposits.

Increases in concentrations of some metals other than barium occurred around the drill site in Block 132. Changes in cadmium and mercury concentrations between surveys were detected, but these were not attributed to drilling discharges because the changes were spatially uniform and were not correlated with barium increases. Significant increases in arsenic (one station), copper (one station), and zinc (one station) were detected, but were attributed to natural sediment movement or sampling/analytical error associated with the small quantities of fine sediment available for analysis from one station.

In the area-wide sampling, there were several significant increases in concentration and/or metal-to-iron ratio for metals other than barium. Cadmium had the highest number of significant differences (seven stations), followed by arsenic (four stations). Significant differences were also detected for chromium (Station 12), and lead (Stations 3 and 9). In plots of station means, large increases between Surveys V and VI were noted for cadmium, copper and lead at Station 3, and copper at Station 9. The copper increases were not significant in the statistical analysis, which used the mean of Surveys V-VI.

Increases in concentrations of these other metals were thought probably not due to drilling fluids. All of the metals except aluminum and iron, which are normally associated with clay particles, are present in drilling fluids primarily as trace contaminants of barite. Because barium is more concentrated in drilling fluids (relative to normal sediments) than the other metals, increases in these other metals due to drilling fluids were expected to be accompanied by major increases in Ba. No such increases were seen during the study.

Oil and grease concentrations increased significantly at Stations 2, 5, 6, 7, 8, and 11 between Surveys II-IV and Surveys V-VI. The increase at Station 11 can be attributed to an increase in silt/clay content of the sediments (oil and grease concentrations tended to be higher in sediments containing more silt/clay). The explanation for the other increases were not known, but were thought probably not due to drilling fluids, because there were no accompanying increases in barium concentration.

Drilling fluids discharged to the ocean may contain small amounts of hydrocarbons, although they are subject to the test of "no visible sheen". At stations around the drill site in Block 132, there were some apparent increases in sediment oil and grease content during drilling, but these appeared to be related to natural sediment changes as indicated by whole sediment aluminum concentrations.

There were no statistically significant increases in the concentrations of 8 and 9 metals in oyster tissue. Arsenic concentrations in both depurated and non-depurated oysters were significantly higher on Surveys V-VI than on Surveys I-IV. The temporary increase in arsenic

concentration in oyster tissue probably is not due to drilling fluids. There are no oyster data from the drill site monitoring in Block 132, because no oysters were present there. However, arsenic concentrations in drilling fluid were no higher than those in the fine fraction of sediments from Mobile Bay. The reason for the temporary increase in arsenic concentrations in oysters is not known.

A statistical difference between Surveys V-VI and Surveys I-IV does not necessarily indicate an effect of drilling. Some significant differences could reflect natural changes that did not occur during the previous year of "baseline" sampling. Other differences could be due to the channel dredging project, which began between Surveys IV and V and which continued through the monitoring program. Unfortunately, conditions in the real world are seldom ideal in the sense of a controlled experiment.

The reason for increases in metal concentrations between Surveys I-IV and Surveys V-VI was not known. Possible explanations included the following:

•   The first four surveys did not encompass the full range of non-drilling related variations in trace metal concentrations. Such variations may be attributed in part to natural seasonal and year-to-year fluctuations.

•   The channel dredging project.

•   The fine fraction at predominantly sandy stations may be different from the fine fraction at silt/clay stations, or more prone to analytical error; stations with high percentages of sand had highly variable metal concentrations or metal-to-iron ratios on one or more surveys and support this hypothesis.

Continental Shelf Associates, Inc. 1989. Pre-drilling and Post-drilling Surveys for Pensacola Area Block 996. Prepared for Texaco Producing Inc.

A monitoring study of a single exploratory well located in approximately 60 m water depth was conducted in Pensacola Block 996 to detect any obvious impacts to the hard bottom epibiotic community of nearby live-bottom areas. The study involved collected pre-drilling and post-drilling video and quantitative still camera data, as well as post-drilling surface sediment chemistry data. Drill site sediment Ba levels at 3 stations within 250 m of the discharge, expressed as either bulk phase or fine-fraction values, were 40-125 times greater than the average reference station value (which in turn was about twice the reported background level). Sediment barium levels (bulk and fine fraction) at 2000 m averaged twice the reference station levels. Bulk phase sediment chromium levels were only elevated at the drill site; fine-fraction chromium levels were 50% and 20% above reference levels at 250 m and 500 m, respectively.

Background was defined at three reference stations located approximately 3,500 m from the drill site. However, reference station values must be regarded with caution for three reasons: 1) predrilling samples were not taken, 2) values obtained in the post-drilling survey (45-70 ppm Ba; 19-22 ppm Cr) were substantially higher than an earlier, nearby baseline conducted prior to drilling (29 ppm Ba; 3 ppm Cr), and 3) a continuous distance-dependent decrease in bulk and fine-fraction Ba and fine-fraction Cr occurred to the farthest radial array stations, including the reference stations.

Only "catastrophic, large-scale changes (e.g., complete mortality)" would be detectable from the photographic and video data collected. No such "catastrophic" effects were observed. Overall, photographic data from stations within 2,000 m of the drill site showed a 55% decrease in total biotic coverage for pre- versus post-drilling surveys; reference station values decreased 19%. Overall decreases, at both drill site and reference stations, were primarily due to dramatic (i.e., 95%) decreases in bryozoan coverage between surveys.

This study presents a typical picture of what exploratory well impacts will be on sediment chemistry. The significant confounding factor here is the "true" background level of Ba and Cr. If the earlier study values are used as reference values, then sediment Ba levels are elevated four-fold at 2 km, and sediment Cr values are 8- to 10-fold higher within 500 m of the discharge. This range of values is expected for these types of discharges.

Steinhauer, M. et al. 1990. California OCS Phase II Monitoring Program Year-Three Annual Report. Chapter 13. Program Synthesis and Recommendations.

The California Outer Continental Shelf (OCS) Phase II Monitoring Program (CAMP) study is a good example of the difficulties inherent to marine impact assessment. The specific objectives of CAMP were:

- To detect and measure potential long-term (or short-term) chemical, physical, and biological changes in the benthic environment around development platforms in areas of soft-bottom and hard-bottom substrates in the southern Santa Maria Basin.

- To determine whether the changes observed were caused by drilling-related activities or whether they were the product of natural physical, chemical, and biological processes in the study area.

The study area is on the southern portion of the Santa Maria Basin OCS. All but one station were located at water depths ranging from 90 m to 410 m. At the soft-bottom site, a semi-radial array of stations was located around the proposed future site of Platform Julius in water depths raging from 123 m to 169 m. At the hard-bottom site, stations were located on

high- and low-relief hard features, and in adjacent soft-sediment locations in 105 m to 213 m of water near the site of Platform Hidalgo.

In the development of CAMP, its design explicitly addressed the importance of taking synoptic measurements from replicate samples and keeping replicate data separate. Also, in the absence of pre-impact sampling it could be argued that control sites and impacted sites always differed and, in the absence of control sites, it could be argued that change at impacted sites was not caused by the impact. CAMP's design also employed an optimal-impact study design, with pre-impact as well as post-impact sampling, and control site as well as impacted site sampling.

Postponement of platform emplacement and drilling at the soft-bottom site and an abbreviated drilling schedule at the hard-bottom site necessitated changes in the scope and schedule of the monitoring program. Monitoring at the soft-bottom site was thought to provide valuable baseline information on physical, chemical, and biological features and processes in the area. This information was thought to be valuable in the design and execution of future monitoring studies of platform discharges when the platform is installed at the Julius site.

Although the soft-bottom components of the monitoring program were prematurely concluded due to a lack of industry activity, certain aspects of the monitoring design were believed useful. Biological data supported the idea that meaningful levels of change could be detected for dominant species and for more encompassing parameters such as diversity. Chemical data supported the idea that barium could be used as a tracer of activity in spite of high, but invariate, natural levels in the region.

Data representing different sampling occasions provided evidence of significant temporal variation in both the macrofauna and meiofauna. Within-year variations, although significant, did not follow the same patterns consistently from one year to the next. Nevertheless, these results were taken to demonstrate the importance of conducting repeated sampling before and after initiation of drilling activities, to provide a basis for differentiating between natural temporal variations in benthic community parameters and impacts caused by drilling and production activities.

Monitoring at the hard-bottom site near Platform Hidalgo provided information on platform effects and on discharges associated with drilling of seven wells between November 1987 and January 1989. The original hypothesis for determining platform-related effects established two major criteria: 1) a before-and-after farfield/nearfield effect (i.e., space-time interaction) and 2) a change in organism abundance correlated to the dose of drilling wastes (relative flux of chemical signals, from sediment trap data). Of the 10 species tested for a time-space interaction, only the solitary coral, *Caryophyllia* sp., showed such an effect. Due to an

incomplete data set from the sediment trap fluxes at the three stations where a significant time-space interaction was observed for this species, data are only available for a limited period (November 1987 and October 1988).

There were insufficient number of stations to calculate an analysis of variance with depth and time as additional covariates. Given these limitations, together with those of limited data from the sediment traps, the best test of a platform-related effect on *Caryophyllia* were scatter diagrams. Neither total sediment flux nor total PAH concentrations were related to the effect, although in both cases one station that showed a loss of *Caryophyllia* cover between 1987 and 1988 had a slightly greater relative flux of these materials. However, tests of the relationship between *Caryophyllia* sp. abundance in a larger data set indicated a highly significant relationship between sediment flux and species abundance.

These data would seem to support a hypothesis of impact. However, the authors presented a disturbing analysis. Although the change in percent cover of *Caryophyllia* seems to support a conclusion of drilling-related impacts, it was noted that the change between sampling periods was less than 50 percent. the original power analysis indicated that, with a sampling replication of 60 photo-quadrants per station per time, the minimum change in the density of this species that could be detected with 95 percent confidence for 80 percent of the time was approximately 70 percent. This power analysis-to-effect comparison raises questions as to whether this effect in a single species was a chance event. The sampling error was greater than the range of the effect detected. Therefore, despite the time-space interaction and a relationship between dose and response, the authors concluded that significant doubts remain as to whether there was a real platform-related effect on this species.

CAMP monitoring data has revealed several variables that may limit the ability of any monitoring program to detect change related to oil and gas activity in the region. The densities and numbers of species with transect location has been shown to vary along all isobaths. Potential sources of hydrocarbons from natural seeps confound the ability to relate change to oil and gas activities. Fishing activities risk in-situ instrument deployments and also affect bottom communities. Finally, the difficulty of scheduling surveys to coincide with drilling activities for appropriate before-and-after comparisons is a basic problem in any monitoring program, and it has been shown in this program to be particularly difficult to control.

9.3.2 *Synthetic-Based Fluids*

Smith, J. and S.J. May. 1991. Ula Wellsite 7/12-9 Environmental Survey 1991. A report to SINTEF SI from the Field Studies Council Research Centre. November 1991.

This paper is the second in a series of three lead by Janet Smith, identifying the results of yearly sampling at the Ula well site 7/12-9 in the North Sea. This paper also includes a comparison of the 1990 to 1991 results. The authors report that sampling was conducted one year after the discharge of an ester-based drilling fluid. The sample stations were along two transects, one to the southwest (SW) and one to the southeast (SE), with distances from the discharge location of 50, 100, 200, 500, 800, 1,200, 2,500, and 5,000 m to the SW and 100, 200, 500, and 1,200 m to the SE. A reference station was located 6,000 m to the northwest of the discharge point. The ten replicate samples taken at this reference station were "treated as two sets of five replicates to make data analysis easier," and are referred to as Ref. A and Ref. B. Samples were taken for total hydrocarbon (THC), ester, metals, grain size analysis, and biological analysis.

THC reported for the 1990 samples were highest at 200 and 500 m to the SW and 100 and 200 m to the SE. These THC levels were reported at 774 and 86.4 mg/kg for the SW stations and 184 and 205 mg/kg for the SE stations, respectively. The THC levels for the 1991 survey were dramatically reduced to 13.6, 5.9, 64.0, and 3.8 mg/kg for same stations listed above. Although there was an increase in THC levels for the 50 and 100 m SW stations, it was not above background levels measured at the reference station. There was an overall decreasing trend for the THC concentration from 1990 to 1991.

The ester concentrations reported in 1990 were 85,300, 46,400, and 208 mg/kg for the 50, 100, and 200 m SW stations, respectively. The reported ester values for these stations for 1991 dropped to 0.21, 0.22, and 1.34 mg/kg, respectively.

Barium concentrations for 1990 were reported highest at the 50-200 m SW and 100-200 m SE stations. There was an increase in Ba concentration along the SW transect from 1,720 to 2,890 mg/kg, out to 200 m. The Ba concentration decreased along the SE transect, with the highest level of 3,770 mg/kg at 100 m. There was an overall decrease in 1991 Ba levels.

The authors also report dramatic changes in the benthic communities from 1990 to 1991 as summarized in Exhibit 9-7. Although one station showed an increased abundance of the opportunistic *C. capitata*, this isolated instance of taxonomic indicator of stress was not taken to demonstrate any generalized impact had occurred from the discharge of this material.

Exhibit 9-7. 1990 and 1991 North Sea Benthic Community Data

Sample Station	Taxa		Individuals	
	1990	**1991**	**1990**	**1991**
50 m SW	4	51	16	379
100 m SW	7	44	167	370
100 m SE	35	52	234	405
Reference A	66	48	385	340
Reference B	53	58	356	329

Candler, John E., S. Hoskin, M. Churan, C.W. Lai, and M. Freeman. 1995. Sea-floor Monitoring for Synthetic-Based Mud Discharged in the Western Gulf of Mexico. SPE 29694 Society of Petroleum Engineers Inc. March 1995.

The authors monitored the fate and effects of discharged SBF and associated cuttings (SBF-cuttings). The authors measured the fate of the polyalphaolefin (PAO) on three sampling cruises to an oil platform that had discharged SBF-cuttings consisting of 441 bbl of cuttings and 354 bbl of adhering SBF. The cruises were conducted nine days, eight months, and 24 months after the discharge had stopped. The effects of the SBF and cuttings on the benthos were measured only on the third sampling cruise. The sampling grid was a series of stations along two perpendicular transects running in north/south and east/west directions from the discharge point. The sampling stations were located along each of the transects at distances of 25 m, 50 m, 100 m, and 200 m from the discharge point. Samples from 2,000 m were used as reference points. The authors used chemical analysis for barium, total petroleum hydrocarbons (TPH) and oil and grease (O&G) to determine the presence of PAO base fluid in sediment samples. The authors stated that TPH was the better of the two organic analyses for detecting the synthetic material because the TPH test excludes certain polar organic compounds (e.g., fatty matter from animal and vegetable sources) often detected in O&G tests. Effects on the benthos were determined by a community analysis system which measured the species richness (number of taxa), evenness (how equally the total number of organisms is distributed), and diversity (measure of interaction of richness and evenness).

The authors indicated that the greatest initial distribution of TPH, as measured nine days after discharge, was along the north/south transect with maximum values of 39,470 mg/kg (3.9 percent) at 100-m north and 134,428 mg/kg (13.4 percent) at 50-m south. In addition, TPH was initially measured above 1,000 mg/kg in all four directions with the furthest locations of 100-m south and 200-m north. The results from the second sampling survey (eight months later) indicated a decrease in average TPH for all distances except at 25 m. There was an increase in average TPH at 25 m predominately to the south and west (from 203 to 7,283 and 2,827 to

25,747 mg/kg, respectively), indicating a southwesterly drift in the sediment. Results from the third and final sampling survey (24 months later), while indicating a decrease in the average TPH at 25 m, also indicated an increase in TPH at all but one of the four 25-m stations. The decrease of the west 25-m station (from 25,747 to 8,330 mg/kg) overshadowed the increase of TPH at the other three stations. Two stations beyond 25 m (50-m south and west) each measured an increase to greater than 1,000 mg/kg TPH.

Although not discussed by the authors, the chemical analysis for the third survey indicated an increase or no change in TPH for 10 of the 16 stations within 200 m of the discharge. There was a slight increase in TPH for the 2,000-m west reference station. Sediment TPH and barium data suggest little degradation of PAO (as indicated by TPH) between the second and third surveys, although migration of fluids to further stations may be occurring. Exhibits 9-8 and 9-9 present average PAO (as indicated by TPH) and Ba levels versus distance for these surveys.

The benthic analysis, at 24 months after SBF-cuttings discharge terminated, indicated three sample stations that were significantly different than the reference stations. These three sample stations were 25- and 50-m south and 25-m west from the discharge location. The highest TPH values were also measured at these three stations. The variability for species richness, abundance, diversity, and evenness was reported to be much higher among all sample stations within 200 meters of the discharge site than the variability among the reference stations.

Schaanning, M. 1995. Evaluation of Overall Marine Impact of the Novadril Mud System. NIVA Report 0-95018.

This report reviews available laboratory data on the toxicity, bioaccumulation, and biodegradability of three types of polyalphaolefin (PAO)-based SBF. The report compares the finding of experimental studies on PAOs to field surveys of ester- and ether-based synthetic muds. The author cites results of Smith and Moore (1990) and Smith and Hobbs (1993), in which three surveys were conducted at the Ula well site 7/12-9 in the North Sea in 1990 immediately after discharge of 97 tons of synthetic esters ceased, in 1991 one year later, and in 1992 two years later. Sampling pattern information for these surveys is given in the summary of Smith and May (1991).

Schaanning reports that during the 1990 survey, the maximum concentration of synthetic ester detected was 85,300 mg/kg at 50 m from the well. The average concentration of synthetic ester for eight sample sites (between 0 and 1 km; no further detail provided) was 16,546 mg/kg compared to 2.3 mg/kg at a reference station 5,000 meters distant. Benthic organisms were severely impacted out to 100 m. Schaanning reports that in 1991 and 1992, the maximum

Exhibit 9-8. Sediment TPH vs. Distance from Drill Site

Sediment TPH are DIRECTIONALLY-AVERAGED (N, S, E, W) values
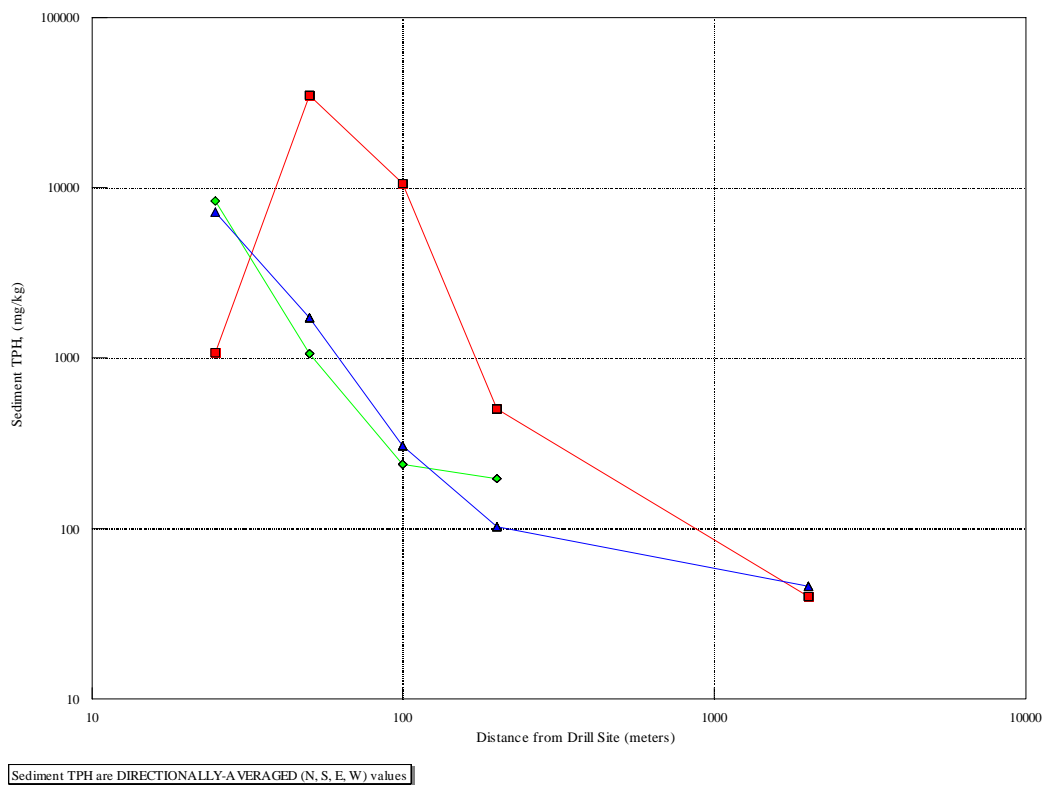
Exhibit 9-9. Sediment Barium vs. Distance from Drill Site

Sediment Barium levels are DIRECTIONALLY-AVERAGED (N, S, E, W) values
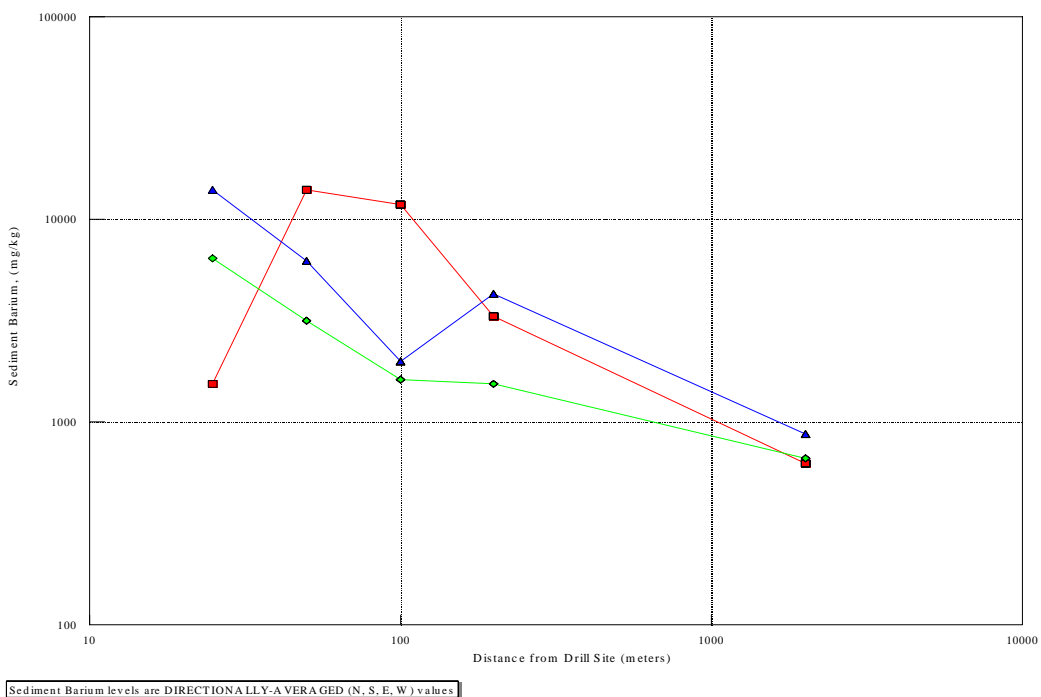
concentrations of synthetic ester base fluid were 11.7 and 0.38 mg/kg, respectively. In 1991, the average ester concentration at eight stations within 1,000 m of the drill site was 2.5 mg/kg, approximately 10-fold higher than that at a reference station 6,000 m distant from the drill site. In 1992, the average ester concentration at eight stations within 1,000 m was 0.24 mg/kg, approximately 3-fold higher than at the reference station 6,000 m distant. Schaanning reports other multivariate analyses of benthos (Smith and Hobbs, 1993) provided evidence that minor changes to the macrobenthic communities were still present two years after the discharge ceased.

Schaanning also cites a three-year study by Bakke et al. (1992) of a discharge of cuttings contaminated with an ether-based SBF. The surveys were conducted at the Gyda well site 2/1-9, just after the discharge of 160 tons of ether SBF ceased and annually for the next two years. Bakke reports that the maximum concentrations of synthetic ether at 50 m southwest from the platform were 2,600, 14,700, and 3.7 mg/kg for 1991, 1992, and 1993, respectively. The mean concentrations for the stations between 100 and 200 m from the platform for 1991, 1992, and 1993 were 236, 96, and 2.1 mg/kg ether, respectively. Although no benthic data are presented for the four stations at which benthic biota were analyzed, Bakke reports benthic impacts were "remarkably weak" for the high concentration of synthetic ether detected in 1992.

It should be noted that Schaanning includes brief discussions of additional seabed studies, which are not referenced to studies or reports, from the North Sea. The information presented from these studies is limited and does not include any quantitative results from benthic analyses.

Daan, R., K. Booij, M. Mulder, and E. Van Weerlee. 1996. Environmental Effects of a Discharge of Cuttings Contaminated with Ester-Based Drilling Muds in the North Sea, Environmental Toxicology and Chemistry, Vol. 15, No. 10, pp. 1709-1722. April 9, 1996.

The authors conducted field surveys in the Dutch sector of the North Sea for the effects of discharged drill cuttings contaminated with an ester-based fluid over an 11-month period. A total of 181 metric tons of ester (in a total estimated amount of 477 tons of an ester-based SBF) was discharged. Three sampling surveys were conducted 1, 4, and 11 months after the drilling was completed. The authors also conducted a background survey prior to drilling to determine natural variations of macrofauna and background chemistry. This background survey was conducted prior to platform placement along a northeast-southwest transect that followed local residual current patterns, with station located from the well site at distances of 75, 200, 500, 1,000, and 3,000 m to the NE, and 75 m to the SW. However, because of the changes in sediment type beyond 200 m, this transect was not used in the post-drilling surveys. The first post-drilling survey was conducted one month after ester-based SBF discharges ceased to determine ester base fluid concentrations only and was sampled northward from the drill site at distances of 75, 125, and 200 m to the N, then 75 m to the NE of the well site. There were no

benthos samples taken during this survey. The second and third post-drilling surveys occurred four and 11 months after ester-based SBF discharges ceased. Both surveys included benthos and chemistry samples taken at 75, 125, 200, 500, 1,000, and 3,000 m to the N, at 75, 125, and 200 m to the NE, and at 75 m to the SW.

The chemical analysis for the three post-drilling surveys indicated the ester base fluid was confined to distances under 200 m from the well site. Once beyond the 200 m station, ester base fluid concentrations were at background levels. However, the analysis also showed an increase in the ester base fluid from the one- to four-month surveys for all distances out to 200 m. Analyses from the 11-month survey indicated a sharp decline in ester base fluid at all stations.

Sediment grain size distributions and benthic macrofaunal abundance from the background survey indicated similar communities occurred only out to 200 m. As a result, benthos background results used for analysis were limited to stations at 75, 125, and 200 m from the discharge location. The benthic analysis from the second survey indicated effects out to 500 m from the well site and was attributed to the echinoderm *Echinocardium cordatum*. Ecordatum is highly sensitive to organic enrichment and living adults were found up to 500 m from the well site. Additionally, a bivalve that was one of the dominant species at 500 m was not found at the closer stations. There was a gradual increase in species abundance with distance. When compared to the background levels, the species abundance beyond 500 m after four months was lower, but the authors attributed this to seasonal fluctuations. Benthos analysis from the third post-drilling survey at 11 months indicated significant impacts out to 200 m. The authors indicate that species abundance, while significantly different from the reference stations, showed recovery of the sediments was apparent after 11 months.

BP Exploration Operating Company Ltd. 1996. BP Single well 15/20b-12 (Donan) synthetic mud (Petrofree) second post-drilling environmental survey. Environment & Technology Ltd. ERT Draft Report No. 96/062/3 June 1996.

This survey was the second of two surveys at the BP single well site 15/20b-12, located in the North Sea. Although the first survey was not available for review, this second report compared the 1995 and 1996 seabed survey results for this well site. The first survey was conducted in August 1995 approximately 5 months after drilling shutdown. The second survey was conducted in June 1996, 15 months after drilling shut down. The discharge of Petrofree, an ester SBF, amounted to 304 metric tons and was discharged at a depth of 142 m. The observations taken by the authors were: 1) Side-scan sonar for cutting depth (piles), 2) Petrofree base fluid concentrations in 0-2 cm, 2-5 cm, and 5-10 cm of sediment, 3) barium concentrations, 4) redox measurements at 2 cm and 4 cm, and 5) biota . Sampling sites were at 25-5,000 m

down-current (South) from the platform, 25-200 m up-current to the North, and 25-100 m to the East, West, Northeast, Northwest, and Southwest.

The 1995 survey indicated the highest concentration of Petrofree in the surface sediment (0-2 cm) was located within 25 meters of the platform. The sampling point with the highest concentration was 25 m Southwest, with an ester concentration of 8,389 mg/kg. Concentrations within 25 meters of the platform ranged from 1,055 to 8,389 mg/kg. The highest concentration at the furthermost station was 105.5 mg/kg at 200 meters north of the platform. The concentrations of Petrofree (base fluid) within 2-5 cm of sediment within 25 m ranged from 8.4 to 1,935 mg/kg. The concentrations of Petrofree within 5-10 cm of sediment within 25 m ranged from 0.9 to 105.3 mg/kg. Petrofree was measured at a concentration of 1,081 mg/kg in 10-15 cm subsurface sediment at 25 meters north. Barium concentration ranged from 70,100 mg/kg at the center to 661 mg/kg at 1,200 m south. Redox and side-scan sonar results for 1995 were not reported. Although data are not given for effects on benthic communities for the 1995 survey, the report indicated that the number of species, evenness, and diversity were statistically significant in relation to Petrofree concentration and distance.

The 1996 survey indicated lower concentrations for surface sediment (0-2 cm) for most sample sites. The authors reported changes ranging from 1.1-fold lower concentrations to 13.5-fold lower concentrations from 1995 to 1996.   Sediment concentration of Petrofree ranged from 133.1 to 1,785 mg/kg for the 25 m range. The highest concentration at the furthermost point was 0.1 mg/kg measured at 500 m south. Variability among subsurface sediment (2-5 and 5-10 cm) Petrofree concentrations prevented development of trends for subsurface concentrations. Barium concentration ranged from 22,000 at the center to 572 mg/kg at 1,200 m south. Redox readings indicated anaerobic conditions within 200 meters of the platform. The depth profile indicated cutting piles of up to 15 cm out to 50 meters from the platform. Biota measurements indicated clear impacts at 50 m, with transition communities developing between 100 to 300 m. The authors stated the benthic communities at 1,200 meters indicated impacts associated with industrial activity and trace amounts of Petrofree were measured at that location.

Vik, E.A., S. Dempsey, B. Nesgard. 1996. Evaluation of Available Test Results from Environmental Studies of Synthetic Based Drilling Muds. OLF Project, Acceptance Criteria for Drilling Fluids. Aquateam Report No. 96-010.

The authors provided a summary of results from eleven seabed studies, three of which have been separately reviewed in this report. Many of these reports were unavailable in English. The authors presented a short review of sampling grids, discharge volumes, discharge depths, and results. The information provided by authors was limited for each seabed survey and the results are included in Exhibit 9-2. However, a critical review of each original report has not been

provided in this Environmental Assessment. The overall trends of these reports were: (1) concentrations decreased with distance from discharge point; (2) concentrations measured were not discharge volume dependent; and (3) concentrations decreased with time, although there were a few instances where the concentrations actually increased.

Continental Shelf Associates, Inc. 1998. Joint EPA/Industry Screening Survey to Assess the Deposition of Drill Cuttings and Associated Synthetic Based Mud on the Seabed of the Louisiana Continental Shelf, Gulf of Mexico. 21 October 1998, Data Report. Prepared for API Health and Environmental Sciences Dept.

The authors provided a data report on a joint EPA/Industry screening cruise, which was conducted to provide a preliminary evaluation of the areal extent of observable physical, chemical, and biological impacts of drill cuttings contaminated with SBFs (SBF-cuttings) and to evaluate sampling methods that will be used in future more detailed surveys. Three sites were surveyed for organics (SBF associated hydrocarbons, TOC and PAH), sediment grain size, odor and visual characteristics, and water column profiles. Oxidation-reduction potential, macrofauna and sediment toxicity samples were taken at selected sites. Side-scan sonar and Benthos MiniROVER remote operated vehicle (ROV) television camera were used to identify accumulation of drill cuttings. Sampling sites were located on a radial grid and along four transects that were parallel with bathymetry when possible. The stations were at distances of 50, 150, and 2000 m from the platform, with the 2000 m stations serving as the references stations. Two additional stations, 100 m from the platform, were sampled at two of the sites. The highest concentration of SBF associated hydrocarbons (1,900, 6,500, and 23,000 mg hydrocarbon/kg dry sediment) were found within 50 m of the platforms. The furthermost station at which SBF-associated hydrocarbons were found was 100 m for one platform. The concentration measured at that one station was 41 mg hydrocarbons/kg dry sediment. Nine sediment samples were also taken for sediment toxicity tests using the 10-day sediment toxicity test (ASTM E 1367-92; ASTM, 1992). Two of the nine sediment samples taken would have been considered toxic to marine amphipods using the current sediment testing guidelines. Percent survival of amphipods exposed to those two samples was 77% and 62%. SBF associated hydrocarbons were not measurable at the detection level for these two samples. Analyses of impacts to marcofauna were not complete at the time of this report. Conclusions drawn by the authors were elevated concentrations of SBF-associated hydrocarbons were scattered around the platform rather than in a continuous pattern; side-scan techniques could be improved; ROV use is not appropriate near soft muddy seafloors; and a better methodology for evaluating electrochemical potential (Eh) is needed.

EPA also gathered samples for duplicating testing, and is also holding samples for macrofaunal enumeration. EPA has not yet completed its analyses and evaluation. EPA intends to complete this work and report the results in the future.

LGL Ecological Research Associates, Inc., 1998. Opportunistic Sampling at a Synthetic Drilling Fluid Discharge Site on the Continental Slope of the Northern Gulf of Mexico: the Pompano Development, 10-11 July 1997 and 13-14 March 1998. Prepared for BP Exploration, Inc.

The authors conducted two benthic studies to assess the impacts of the discharge of drill cuttings contaminated with the SBF Petrofree LE (a 90% LAO/10% ester blend) on benthic communities in 565 meters water depth. The studies were conducted 9 months apart with the first (July 1997) conducted 4 months after discharge ceased. Prior to this July survey, 6,263 bbls of SBF had been discharged. An additional 1,486 bbls of SBF was discharged for 2 months prior to the second survey in March of 1998. The surveys analyzed benthic sediment samples for both chemical concentrations of Petrofree LE and changes in benthic communities along four transects (NE, SE, SW, and NW). Sampling stations were located at 25 m intervals with the SW and NE transects extending to 75 m and the NW and SE transects extending to 50 m. As a result of chemical analyses from the July 1997 survey, the NW transect was extended to 90 m during the March 1998 survey. Samples for chemical analysis were divided into surficial samples (0-2 cm) and subsurface samples (2-5 cm).

Chemical analyses results for both surveys indicate the highest concentration of SBF for both surficial and subsurface samples were found along the NE transect and were located at the 75 m station. Concentrations of SBF at this location for the surface samples were 165,051 mg/kg for 1997 and 198,320 mg/kg for 1998. Concentrations at these locations for subsurface samples were 8,332 mg/kg for 1997 and 85,821 mg/kg for 1998. The authors suggest the possible reasons for high concentrations of SBF may be due to slower biodegradation rates than those noted in the North Sea or the initial concentration of Petrofree LE was higher than that measured. There were no statistical differences between the July 1997 and March 1998 surficial and subsurface concentrations. However, the March 1998 values were higher, lending some weight to the hypothesis that the initial Petrofree LE concentration was higher than measured.

Results of the March 1998 benthic survey indicate an increase of polychaetes and gastropods as compared to MMS background data. Polychaete densities were nearly 40 times higher than background data. Gastropod densities were nearly 3,000 times higher than background. The authors postulated that biodegradation may have sustained bacterial activity at a level that lead to an increase in these benthic macrofauna.

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APPENDIX A

CALCULATION OF
GULF OF MEXICO SHRIMP CATCH

Exhibit A-1. Calculation of Gulf of Mexico Shrimp Catch

	Texas	Louisiana	Source/Comment
Landings (lbs)	75,078,833	88,229,189	NMFS, 1997/Avg. of 1995-96 landings
Catch:Landings Ratio	0.85	1.23	Offshore Environmental Assessment, Table 3-9 (Avanti, 1993)
Catch (lbs)	63,817,008	108,657,202	Landings * Catch/Landings ratio

Catch by Location (lbs)
 	
0-3 miles
    Coastal
    Offshore
 	
3-80 miles
	
	36,758,597
	24,517,984
	12,240,613
	
	27,058,411
		
		62,586,549
		47,252,844
		15,333,704
		
		46,070,654
			Offshore Environmental Assessment, Table 3-9 (Avanti, 1993)/catch * 0.576 = 0-3 mile portion of catch 0-3 mile portion * 0.668 (TX) or 0.755 (LA) determines portion of 0-3 mile segment that is offshore (as opposed to coastal)

Offshore Area (mi^2)
  0-3 mile
  3-80 mile
	
	1,107
	28,413
		
		1,314
		33,726
			Offshore Environmental Assessment, Table 3-11 (Avanti, 1993)

Catch/Area (lbs/mi^2)
  0-3 mile
  3-80 mile
	
	11,057
	1,331
		
		11,669
		1,752	

Weighted Average Catch (lb/mi^2)	11,443		Assumes all shallow wells drilled are in the Territorial Seas (0-3 mi); weighted by total catch/state

APPENDIX B

**REANALYSIS OF
WATER QUALITY CRITERIA ASSESSMENT**

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF
WATER

December 29, 1998

MEMORANDUM

TO: Administrative Record, Synthetic-Based Drilling Fluids Effluent Guideline

FROM: Kathy Zirbser

SUBJECT: Revised Federal Water Quality Criteria

Water quality analyses in the Environmental Assessment of the Proposed Effluent Limitations
Guidelines Standards for Synthetic-Based Drilling Fluids and Other Non-Aqueous Drilling
Fluids in the Oil and Gas Extraction Point Source Category (hereafter referred to as the
Environmental Assessment) are based on national water quality criteria as recommended by EPA
in February 1997. These water quality criteria are now superseded by the recently revised criteria
as published in the Federal Register on Thursday, December 10, 1998 (attached). There is
insufficient time to incorporate the revised criteria into the Environmental Assessment Document
prior to rule proposal. EPA has, however, conducted an analysis to determine how the analysis
would change incorporating the new 1998 criteria recommendations. This analysis is attached
hereto.

Changes in criteria for four pollutants affect the analysis. The criteria changes are as follows (in redline/strikeout format):

Pollutant	National Recommended Water Quality Criteria		
	Saltwater Acute (μg/l)	Saltwater Chronic (μg/l)	Human Health for Consumption of Organisms Only (μg/l)
Arsenic	69	36	~~0.14~~
Copper	~~2.4~~ 4.8	~~2.4~~ 3.1	---
Mercury	1.8	~~0.025~~ 0.94	~~0.15~~ 0.051
Phenol			~~4,600,000~~

In the Environmental Assessment water quality assessment, modeled pollutant concentrations are compared to the most stringent of the saltwater acute, saltwater chronic, and human health (organism consumption) criteria. With the above changes to the national recommended water quality criteria, these most stringent values change as follows:

Pollutant	Most Stringent Criterion for Comparison to Modeled Concentrations (μg/l)
Arsenic	~~0.14~~ 36
Copper	~~2.4~~ 3.1
Mercury	~~0.025~~ 0.051
Phenol	~~4,600,000~~ No criterion

For each of the above pollutants, the criterion for comparison with modeled pollutant concentrations becomes less stringent. As a result, the number of modeled criteria exceedances for pore water is reduced (for the water column analysis, no exceedances are projected, as was the case using the 1997 criteria). The total number of projected exceedances for model wells (under both current practice and the discharge option) is reduced from 19 (using 1997 criteria) to 10 (using 1998 criteria). The changes in exceedances are as follows:

Factors by Which Pore Water Pollutant Concentrations at the Edge of the 100-meter Mixing Zone Would Exceed Federal Water Quality Criteria Recommendations for each Regulatory Option and Model Well[a]

Discharge Region	Pollutant	Shallow Water				Deep Water			
		Development Well		Exploratory Well		Development Well		Exploratory Well	
		Current Practice	Discharge Option	Current Practice	Discharge Option	Current Practice	Discharge Option	Current Practice	Discharge Option
Gulf of Mexico	Arsenic	~~1.3~~ ---	---[c]	~~2.7~~ ---	---	~~1.9~~ ---	~~1.1~~ ---	~~4.3~~ ---	~~2.5~~ ---
	Chromium	---	---	1.7	---	1.3	---	2.8	1.6
	Mercury	---	---	---	---	---	---	~~1.2~~ ---	---
	Metals Composite[b]	1.1	---	2.3	1.3	1.7	---	3.7	2.1
California	Arsenic	---	---	Not applicable		~~1.2~~ ---	---	Not applicable	
	Metals Composite[b]	---	---	Not applicable		~~1.1~~ ---	---	Not applicable	
Cook Inlet, Alaska	Arsenic	---	---	Not applicable		Not applicable		Not applicable	
	Metals Composite[b]	---	---	Not applicable		Not applicable		Not applicable	

(a) There would be no exceedances for any pollutants with the zero discharge option.
(b) Metals composite includes cadmium, copper, lead, nickel, silver, and zinc.
(c) "---" indicates no exceedances are predicted.

Part IV

Environmental Protection Agency

National Recommended Water Quality Criteria; Notice; Republication

ENVIRONMENTAL PROTECTION AGENCY

[FRL–OW–6186–6a]

National Recommended Water Quality Criteria; Republication

Editorial Note: FR Doc. 98-30272 was originally published as Part IV (63 FR 67548-67558) in the issue of Monday, December 7, 1998. At the request of the agency, due to incorrect footnote identifiers in the tables, the corrected document is being republished in its entirety.

AGENCY: Environmental Protection Agency (EPA).

ACTION: Compilation of recommended water quality criteria and notice of process for new and revised criteria.

SUMMARY: EPA is publishing a compilation of its national recommended water quality criteria for 157 pollutants, developed pursuant to section 304(a) of the Clean Water Act (CWA or the Act). These recommended criteria provide guidance for States and Tribes in adopting water quality standards under section 303(c) of the CWA. Such standards are used in implementing a number of environmental programs, including setting discharge limits in National Pollutant Discharge Elimination System (NPDES) permits. These water quality criteria are not regulations, and do not impose legally binding requirements on EPA, States, Tribes or the public.

This document also describes changes in EPA's process for deriving new and revised 304(a) criteria. Comments provided to the Agency about the content of this Notice will be considered in future publications of water quality criteria and in carrying out the process for deriving water quality criteria. With this improved process the public will have more opportunity to provide data and views for consideration by EPA. The public may send any comments or observations regarding the compilation format or the process for deriving new or revised water quality criteria to the Agency now, or anytime while the process is being implemented.

ADDRESSES: A copy of the document, ''National Recommended Water Quality Criteria'' is available from the U.S. EPA, National Center for Environmental Publications and Information, 11029 Kenwood Road, Cincinnati, Ohio 45242, phone (513) 489–8190. The publication is also available electronically at: http://www.epa.gov/ost. Send an original and 3 copies of written comments to W–98–24 Comment Clerk, Water Docket, MC 4104, US EPA, 401 M Street, S.W., Washington, D.C. 20460. Comments may also be submitted electronically to

OW-Docket@epamail.epa.gov. Comments should be submitted as a WP5.1, 6.1 or an ASCII file with no form of encryption. The documents cited in the compilation of recommended criteria are available for inspection from 9 to 4 p.m., Monday through Friday, excluding legal holidays, at the Water Docket, EB57, East Tower Basement, USEPA, 401 M St., S.W., Washington, D.C. 20460. For access to these materials, please call (202) 260–3027 to schedule an appointment.

FOR FURTHER INFORMATION CONTACT: Cindy A. Roberts, Health and Ecological Criteria Division (4304), U.S. EPA, 401 M. Street, S.W., Washington, D.C. 20460; (202) 260–2787; roberts.cindy@epamail.epa.gov.

SUPPLEMENTARY INFORMATION:

I. What Are Water Quality Criteria?

Section 304(a)(1) of the Clean Water Act requires EPA to develop and publish, and from time to time revise, criteria for water quality accurately reflecting the latest scientific knowledge. Water quality criteria developed under section 304(a) are based solely on data and scientific judgments on the relationship between pollutant concentrations and environmental and human health effects. Section 304(a) criteria do not reflect consideration of economic impacts or the technological feasibility of meeting the chemical concentrations in ambient water. Section 304(a) criteria provide guidance to States and Tribes in adopting water quality standards that ultimately provide a basis for controlling discharges or releases of pollutants. The criteria also provide guidance to EPA when promulgating federal regulations under section 303(c) when such action is necessary.

II. What is in the Compilation Published Today?

EPA is today publishing a compilation of its national recommended water quality criteria for 157 pollutants. This compilation is also available in hard copy at the address given above.

The compilation is presented as a summary table containing EPA's water quality criteria for 147 pollutants, and for an additional 10 pollutants, criteria solely for organoleptic effects. For each set of criteria, EPA lists a **Federal Register** citation, EPA document number or Integrated Risk Information System (IRIS) entry (www.epa.gov/ngispgm3/iris/irisdat). Specific information pertinent to the derivation of individual criteria may be found in cited references. If no criteria are listed

for a pollutant, EPA does not have any national recommended water quality criteria.

These water quality criteria are the Agency's current recommended 304(a) criteria, reflecting the latest scientific knowledge. They are generally applicable to the waters of the United States. EPA recommends that States and Tribes use these water quality criteria as guidance in adopting water quality standards pursuant to section 303(c) of the Act and the implementing of federal regulations at 40 CFR part 131. Water quality criteria derived to address site-specific situations are not included; EPA recommends that States and Tribes follow EPA's technical guidance in the ''Water Quality Standards Handbook—2nd Edition,'' EPA, August 1994, in deriving such site-specific criteria. EPA recognizes that in limited circumstances there may be regulatory voids in the absence of State or Tribal water quality standards for specific pollutants. However, States and Tribes should utilize the existing State and Tribal narrative criteria to address such situations; States and Tribes may consult EPA criteria documents and cites in the summary table for additional information.

The national recommended water quality criteria include: previously published criteria that are unchanged; criteria that have been recalculated from earlier criteria; and newly calculated criteria, based on peer-reviewed assessments, methodologies and data, that have not been previously published.

The information used to calculate the water quality criteria is not included in the summary table. Most information has been previously published by the Agency in a variety of sources, and the summary table cites those sources.

When using these 304(a) criteria as guidance in adopting water quality standards, EPA recommends States and Tribes consult the citations referenced in the summary table for additional information regarding the derivation of individual criteria.

The Agency intends to revise the compilation of national recommended water quality criteria from time to time to keep States and Tribes informed as to the most current recommended water quality criteria.

III. How Are National Recommended Water Quality Criteria Used?

Once new or revised 304(a) criteria are published by EPA, the Agency expects States and Tribes to adopt promptly new or revised numeric water quality criteria into their standards consistent with one of the three options

in 40 CFR 131.11. These options are: (1) Adopt the recommended section 304(a) criteria; (2) adopt section 304(a) criteria modified to reflect site-specific conditions; or, (3) adopt criteria derived using other scientifically defensible methods. In adopting criteria under option (2) or (3), States and Tribes must adopt water quality criteria sufficient to protect the designated uses of their waters. When establishing a numerical value based on 304(a) criteria, States and Tribes may reflect site specific conditions or use other scientifically defensible methods. However, States and Tribes should not selectively apply data or selectively use endpoints, species, risk levels, or exposure parameters in deriving criteria; this would not accurately characterize risk and would not result in criteria protective of designated uses.

EPA emphasizes that, in the course of carrying out its responsibilities under section 303(c), it reviews State and Tribal water quality standards to assess the need for new or revised water quality criteria. EPA generally believes that five years from the date of EPA's publication of new or revised water quality criteria is a reasonable time by which States and Tribes should take action to adopt new or revised water quality criteria necessary to protect the designated uses of their waters. This period is intended to accommodate those States and Tribes that have begun a triennial review and wish to complete the actions they have underway, deferring initiating adoption of new or revised section 304(a) criteria until the next triennial review.

IV. What is the Status of Existing Criteria While They Are Under Revision?

The question of the status of the existing section 304(a) criteria often arises when EPA announces that it is beginning a reassessment of existing criteria. The general answer is that water quality criteria published by EPA remain the Agency's recommended water quality criteria until EPA revises or withdraws the criteria. For example, while undertaking recent reassessments of dioxin, PCBs, and other chemicals, EPA has consistently upheld the use of the current section 304(a) criteria for these chemicals and considers them to be scientifically sound until new, peer reviewed, scientific assessments indicate changes are needed. Therefore, the criteria in today's notice are and will continue to be the Agency's national recommended water quality criteria for States and Tribes to use in adopting or revising their water quality standards until superseded by the publication of

revised criteria, or withdrawn by notice in the **Federal Register**.

V. What is the Process for Developing New or Revised Criteria?

Section 304(a)(1) of the CWA requires the Agency to develop and publish, and from time to time revise, criteria for water quality accurately reflecting the latest scientific knowledge. The Agency has developed an improved process that it intends to use when deriving new criteria or conducting a major reassessment of existing criteria. The purpose of the improved process is to provide expanded opportunities for public input, and to make the process more efficient.

When deriving new criteria, or when initiating a major reassessment of existing criteria, EPA will take the following steps.

1. EPA will first undertake a comprehensive review of available data and information.

2. EPA will publish a notice in the **Federal Register** and on the Internet announcing its assessment or reassessment of the pollutant. The notice will describe the data available to the Agency, and will solicit any additional pertinent data or views that may be useful in deriving new or revised criteria. EPA is especially interested in hearing from the public regarding new data or information that was unavailable to the Agency, and scientific views as to the application of the relevant Agency methodology for deriving water quality criteria.

3. After public input is received and evaluated, EPA will then utilize information obtained from both the Agency's literature review and the public to develop draft recommended water quality criteria.

4. EPA will initiate a peer review of the draft criteria. Agency peer review consists of a documented critical review by qualified independent experts. Information about EPA peer review practices may be found in the Science Policy Council's Peer Review Handbook (EPA 100–B–98–001, www.epa.gov).

5. Concurrent with the peer review in step four, EPA will publish a notice in the **Federal Register** and on the Internet, of the availability of the draft water quality criteria and solicit views from the public on issues of science pertaining to the information used in deriving the draft criteria. The Agency believes it is important to provide the public with the opportunity to provide scientific views on the draft criteria even though we are not required to invite and respond to written comments.

6. EPA will evaluate the results of the peer review, and prepare a response document for the record in accordance with EPA's Peer Review Handbook. EPA at the same time will consider views provided by the public on issues of science. Major scientific issues will be addressed in the record whether from the peer review or the public.

7. EPA will then revise the draft criteria as necessary, and announce the availability of the final water quality criteria in the **Federal Register** and on the Internet.

VI. What is the Process for Minor Revisions to Criteria?

In addition to developing new criteria, and conducting major reassessments of existing criteria, EPA also from time to time recalculates criteria based on new information pertaining to individual components of the criteria. For example, in today's notice, EPA has recalculated a number of criteria based on new, peer-reviewed data contained in EPA's IRIS. Because such recalculations normally result in only minor changes to the criteria, do not ordinarily involve a change in the underlying scientific methodologies, and reflect peer-reviewed data, EPA will typically publish such recalculated criteria directly as the Agency's recommended water quality criteria. If it appears that a recalculation results in a significant change EPA will follow the process of peer review and public input outlined above. Further, when EPA recalculates national water quality criteria in the course of proposing or promulgating state-specific federal water quality standards pursuant to section 303(c), EPA will offer an opportunity for national public input on the recalculated criteria.

VII. How Does the Process Outlined Above Improve Public Input and Efficiency?

In the past, EPA developed draft criteria documents and announced their availability for public comment in the **Federal Register**. This led to new data and views coming to EPA's attention after draft criteria had already been developed. Responding to new data would sometimes lead to extensive revisions.

The steps outlined above improve the criteria development process in the following ways.

1. The new process is Internet-based which is in line with EPA policy for public access and dissemination of information gathered by EPA. Use of the Internet will allow the public to be more engaged in the criteria development process than previously and to more

knowledgeably follow criteria development. For new criteria or major revisions, EPA will announce its intentions to derive the new or revised criteria on the Internet and include a list of the available literature. This will give the public an opportunity to provide additional data that might not otherwise be identified by the Agency.

2. The public now has two opportunities to contribute data and views, before development and during development, instead of a single opportunity after development.

3. EPA has instituted broader and more formal peer review procedures. This independent scientific review is a more rigorous disciplinary practice to ensure technical improvements in Agency decision making. Previously, EPA used the public comment process outlined above to obtain peer review. The new process allows for both public input and a formal peer review,

resulting in a more thorough and complete evaluation of the criteria.

4. Announcing the availability of the draft water quality criteria on the Internet will give the public an opportunity to provide input on issues of science in a more timely manner.

VIII. Where Can I Find More Information About Water Quality Criteria and Water Quality Standards?

For more information about water quality criteria and Water Quality Standards refer to the following: Water Quality Standards Handbook (EPA 823–B94–005a); Advanced Notice of Proposed Rule Making (ANPRM), (63 FR 36742); Water Quality Criteria and Standards Plan—Priorities for the Future (EPA 822–R–98–003); Guidelines and Methodologies Used in the Preparation of Health Effects Assessment Chapters of the Consent Decree Water Criteria Documents (45 FR

79347); Draft Water Quality Criteria Methodology Revisions: Human Health (63 FR 43755, EPA 822–Z–98–001); and Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses (EPA 822/R–85–100); National Strategy for the Development of Regional Nutrient Criteria (EPA 822–R–98–002).

These publications may also be accessed through EPA's National Center for Environmental Publications and Information (NCEPI) or on the Office of Science and Technology's Home-page (www.epa.gov/OST).

IX. What Are the National Recommended Water Quality Criteria?

The following compilation and its associated footnotes and notes presents the national recommended water quality criteria.

NATIONAL RECOMMENDED WATER QUALITY CRITERIA FOR PRIORITY TOXIC POLLUTANTS

	Priority pollutant	CAS No.	Freshwater CMC (μg/L)	Freshwater CCC (μg/L)	Saltwater CMC (μg/L)	Saltwater CCC (μg/L)	Human health Water + organism (μg/L)	Human health Organism only (μg/L)	FR cite/source
1	Antimony	7440360					14 B,Z	4300 B	57 FR 60848
2	Arsenic	7440382	340 A,D,K	150 A,D,K	69 A,D,bb	36 A,D,bb	0.018 C,M,S	0.14 C,M,S	62 FR 42160
3	Beryllium	7440417					J,Z	J	57 FR 60848
4	Cadmium	7440439	4.3 D,E,K	2.2 D,E,K		9.3 D,bb	J,Z	J	62 FR 42160
5a	Chromium III	16065831	570 D,E,K	74 D,E,K			J,Z Total	J	EPA 820/B–96–001
5b	Chromium VI	18540299	16 D,K	11 D,K	1,100 D,bb	50 D,bb	J,Z Total	J	62 FR 42160
6	Copper	7440508	13 D,E,K,cc	9.0 D,E,K,cc	4.8 D,cc,ff	3.1 D,cc,ff	1,300		62 FR 42160
7	Lead	7439921	65 D,E,bb,gg	2.5 D,E,bb,gg	210 D,bb	8.1 D,bb	J	J	62 FR 42160
8	Mercury	7439976	1.4 D,K,hh	0.77 D,K,hh	1.8 D,ee,hh	0.94 D,ee,hh	0.050 B	0.051 B	62 FR 42160
9	Nickel	7440020	470 D,E,K	52 D,E,K	74 D,bb	8.2 D,bb	610 B	4,600 B	62 FR 42160
10	Selenium	7782492	L,R,T	5.0 T	290 D,bb,dd	71 D,bb,dd	170 Z	11,000	IRIS 09/01/91
11	Silver	7440224	3.4 D,E,G		1.9 D,G				62 FR 42160
12	Thallium	7440280					1.7 B	6.3 B	57 FR 60848
13	Zinc	7440666	120 D,E,K	120 D,E,K	90 D,bb	81 D,bb	9,100 U	69,000 U	IRIS 10/01/92
14	Cyanide	57125	22 K,Q	5.2 K,Q	1 Q,bb	1 Q,bb	700 B,Z	220,000 B,H	EPA 820/B–96–001
15	Asbestos	1332214					7 million fibers/L I		57 FR 60848
16	2,3,7,8-TCDD Dioxin	1746016					1.3E–8 C	1.4E–8 C	62 FR 42160
17	Acrolein	107028					320	780	57 FR 60848
18	Acrylonitrile	107131					0.059 B,C	0.66 B,C	57 FR 60848
19	Benzene	71432					1.2 B,C	71 B,C	62 FR 42160
20	Bromoform	75252					4.3 B,C	360 B,C	57 FR 60848
21	Carbon Tetrachloride	56235					0.25 B,C	4.4 B,C	57 FR 60848
22	Chlorobenzene	108907					680 B,Z	21,000 B,H	57 FR 60848
23	Chlorodibromomethane	124481					0.41 B,C	34 B,C	62 FR 42160
24	Chloroethane	75003							
25	2-Chloroethylvinyl Ether	110758							
26	Chloroform	67663					5.7 B,C	470 B,C	62 FR 42160
27	Dichlorobromomethane	75274					0.56 B,C	46 B,C	62 FR 42160
28	1,1-Dichloroethane	75343							
29	1,2-Dichloroethane	107062					0.38 B,C	99 B,C	57 FR 60848
30	1,1-Dichloroethylene	75354					0.057 B,C	3.2 B,C	57 FR 60848
31	1,2-Dichloropropane	78875					0.52 B,C	39 B,C	57 FR 60848
32	1,3-Dichloropropene	542756					10 B	1,700 B	62 FR 42160
33	Ethylbenzene	100414					3,100 B,Z	29,000 B	62 FR 42160
34	Methyl Bromide	74839					48 B	4000 B	62 FR 42160
35	Methyl Chloride	74873					J	J	57 FR 60848
36	Methylene Chloride	75092					4.7 B,C	1600 B,C	57 FR 60848
37	1,1,2,2-Tetrachloroethane	79345					0.17 B,C	11 B,C	57 FR 60848
38	Tetrachloroethylene	127184					0.8 C	8.85 C	62 FR 42160
39	Toluene	108883					6,800 B,Z	200,000 B	62 FR 42160
40	1,2-Trans-Dichloroethylene	156605					700 B,Z	140,000 B	62 FR 42160
41	1,1,1-Trichloroethane	71556					J,Z	J	62 FR 42160
42	1,1,2-Trichloroethane	79005					0.60 B,C	42 B,C	57 FR 60848
43	Trichloroethylene	79016					2.7 C	81 C	57 FR 60848
44	Vinyl Chloride	75014					2.0 C	525 C	57 FR 60848
45	2-Chlorophenol	95578					120 B,U	400 B,U	62 FR 42160
46	2,4-Dichlorophenol	120832					93 B,U	790 B,U	57 FR 60848
47	2,4-Dimethylphenol	105679					540 B,U	2,300 B,U	62 FR 42160
48	2-Methyl-4,6-Dinitrophenol	534521					13.4	765	57 FR 60848
49	2,4-Dinitrophenol	51285					70 B	14,000 B	57 FR 60848
50	2-Nitrophenol	88755							
51	4-Nitrophenol	100027							
52	3-Methyl-4-Chlorophenol	59507					U	U.	

NATIONAL RECOMMENDED WATER QUALITY CRITERIA FOR PRIORITY TOXIC POLLUTANTS—Continued

	Priority pollutant	CAS No.	Freshwater		Saltwater		Human health for consumption of:		FR cite/source
			CMC (µg/L)	CCC (µg/L)	CMC (µg/L)	CCC (µg/L)	Water + organism (µg/L)	Organism only (µg/L)	
53	Pentachlorophenol	87865	19 [F,K]	15 [F,K]	13 [bb]	7.9 [bb]	0.28 [B,C]	8.2 [B,C,H]	62 FR 42160
54	Phenol	108952					21,000 [B,U]	4,600,000 [B,H,U]	62 FR 42160
55	2,4,6-Trichlorophenol	88062					2.1 [B,C,U]	6.5 [B,C]	57 FR 60848
56	Acenaphthene	83329					1,200 [B,U]	2,700 [B,U]	57 FR 60848
57	Acenaphthylene	208968							62 FR 42160
58	Anthracene	120127					9,600 [B]	110,000 [B]	62 FR 42160
59	Benzidine	92875					0.00012 [B,C]	0.00054 [B,C]	57 FR 60848
60	BenzoaAnthracene	56553					0.0044 [B,C]	0.049 [B,C]	62 FR 42160
61	BenzoaPyrene	50328					0.0044 [B,C]	0.049 [B,C]	62 FR 42160
62	BenzobFluoranthene	205992					0.0044 [B,C]	0.049 [B,C]	62 FR 42160
63	BenzoghiPerylene	191242							62 FR 42160
64	BenzokFluoranthene	207089					0.0044 [B,C]	0.049 [B,C]	62 FR 42160
65	Bis2-ChloroethoxyMethane	111911							57 FR 60848
66	Bis2-ChloroethylEther	111444					0.031 [B,C]	1.4 [B,C]	62 FR 42160
67	Bis2-ChloroisopropylEther	39638329					1,400 [B]	170,000 [B]	62 FR 42160
68	Bis2-EthylhexylPhthalate [x]	117817					1.8 [B,C]	5.9 [B,C]	57 FR 60848
69	4-Bromophenyl Phenyl Ether	101553							57 FR 60848
70	Butylbenzyl Phthalate [w]	85687					3,000 [B]	5,200 [B]	62 FR 42160
71	2-Chloronaphthalene	91587					1,700 [B]	4,300 [B]	62 FR 42160
72	4-Chlorophenyl Phenyl Ether	7005723							62 FR 42160
73	Chrysene	218019					0.0044 [B,C]	0.049 [B,C]	62 FR 42160
74	Dibenzoa,hAnthracene	53703					0.0044 [B,C]	0.049 [B,C]	62 FR 42160
75	1,2-Dichlorobenzene	95501					2,700 [B,Z]	17,000 [B]	62 FR 42160
76	1,3-Dichlorobenzene	541731					400	2,600	62 FR 42160
77	1,4-Dichlorobenzene	106467					400 [z]	2,600	57 FR 60848
78	3,3'-Dichlorobenzidine	91941					0.04 [z]	0.077 [B,C]	57 FR 60848
79	Diethyl Phthalate [w]	84662					23,000 [B]	120,000 [B]	57 FR 60848
80	Dimethyl Phthalate [w]	131113					313,000	2,900,000	57 FR 60848
81	Di-n-Butyl Phthalate [w]	84742					2,700 [B]	12,000 [B]	57 FR 60848
82	2,4-Dinitrotoluene	121142					0.11 [C]	9.1 [C]	IRIS 11/01/97
83	2,6-Dinitrotoluene	606202							57 FR 60848
84	Di-n-Octyl Phthalate	117840							57 FR 60848
85	1,2-Diphenylhydrazine	122667					0.040 [B,C]	0.54 [B,C]	62 FR 42160
86	Fluoranthene	206440					300 [B]	370 [B]	62 FR 42160
87	Fluorene	86737					1,300 [B]	14,000 [B]	62 FR 42160
88	Hexachlorobenzene	118741					0.00075 [B,C]	0.00077 [B,C]	62 FR 42160
89	Hexachlorobutadiene	87683					0.44 [B,C]	50 [B,C]	57 FR 60848
90	Hexachlorocyclopentadiene	77474					240 [B,U,Z]	17,000 [B,H,U]	57 FR 60848
91	Hexachloroethane	67721					1.9 [B,C]	8.9 [B,C]	62 FR 42160
92	Ideno 1,2,3-cdPyrene	193395					0.0044 [B,C]	0.049 [B,C]	57 FR 60848
93	Isophorone	78591					36 [B,C]	2,600 [B,C]	57 FR 60848
94	Naphthalene	91203							57 FR 60848
95	Nitrobenzene	98953					17 [B]	1,900 [B,H,U]	57 FR 60848
96	N-Nitrosodimethylamine	62759					0.00069 [B,C]	8.1 [B,C]	62 FR 42160
97	N-Nitrosodi-n-Propylamine	621647					0.005 [B,C]	1.4 [B,C]	62 FR 42160
98	N-Nitrosodiphenylamine	86306					5.0 [B,C]	16 [B,C]	57 FR 60848
99	Phenanthrene	85018							62 FR 42160
100	Pyrene	129000					960 [B]	11,000 [B]	62 FR 42160
101	1,2,4-Trichlorobenzene	120821					260 [z]	940	IRIS 11/01/96
102	Aldrin	309002	3.0 [G]		1.3 [G]		0.00013 [B,C]	0.00014 [B,C]	62 FR 42160
103	alpha-BHC	319846					0.0039 [B,C]	0.013 [B,C]	62 FR 42160
104	beta-BHC	319857					0.014 [B,C]	0.046 [B,C]	62 FR 42160
105	gamma-BHC (Lindane)	58899	0.95 [K]		0.16 [G]		0.019 [C]	0.063 [C]	62 FR 42160
106	delta-BHC	319868							62 FR 42160
107	Chlordane	57749	2.4 [G]	0.0043 [G,aa]	0.09 [G]	0.004 [G,aa]	0.0021 [B,C]	0.0022 [B,C]	62 FR 42160 / IRIS 02/07/98

No.	Chemical	CAS							Reference
108	4,4'-DDT	50293	1.1 [G]	0.001 [G,aa]	0.13 [G]	0.001 [G,aa]	0.00059 [B,C]	0.00059 [B,C]	62 FR 42160
109	4,4'-DDE	72559					0.00059 [B,C]	0.00059 [B,C]	62 FR 42160
110	4,4'-DDD	72548					0.00083 [B,C]	0.00084 [B,C]	62 FR 42160
111	Dieldrin	60571	0.24 [K]	0.056 [K,O]	0.71 [G]	0.0019 [G,aa]	0.00014 [B,C]	0.00014 [B,C]	62 FR 42160
112	alpha-Endosulfan	959988	0.22 [G,Y]	0.056 [G,Y]	0.034 [G,Y]	0.0087 [G,Y]	110 [B]	110 [B]	62 FR 42160
113	beta-Endosulfan	33213659	0.22 [G,Y]	0.056 [G,Y]	0.034 [G,Y]	0.0087 [G,Y]	110 [B]	110 [B]	62 FR 42160
114	Endosulfan Sulfate	1031078					110 [B]	110 [B]	62 FR 42160
115	Endrin	72208	0.086 [K]	0.036 [K,O]	0.037 [G]	0.0023 [G,aa]	0.76 [B]	0.76 [B]	62 FR 42160
116	Endrin Aldehyde	7421934					0.81 [B,H]	0.81 [B,H]	62 FR 42160
117	Heptachlor	76448	0.52 [G]	0.0038 [G,aa]	0.053 [G]	0.0036 [G,aa]	0.00021 [B,C]	0.00021 [B,C]	62 FR 42160
118	Heptachlor Epoxide	1024573	0.52 [G,V]	0.0038 [G,V,aa]	0.053 [G,V]	0.0036 [G,V,aa]	0.00010 [B,C]	0.00011 [B,C]	62 FR 42160
119	Polychlorinated Biphenyls PCBs			0.014 [N,aa]		0.03 [N,aa]	0.00017 [B,C,P]	0.00017 [B,C,P]	63 FR 16182
120	Toxaphene	8001352	0.73	0.0002 [aa]	0.21	0.0002 [aa]	0.00073 [B,C]	0.00075 [B,C]	62 FR 42160

Footnotes:

[A] This recommended water quality criterion was derived from data for arsenic (III), but is applied here to total arsenic, which might imply that arsenic (III) and arsenic (V) are equally toxic to aquatic life and that their toxicities are additive. In the arsenic criteria document (EPA 440/5–84–033, January 1985), Species Mean Acute Values are given for both arsenic (III) and arsenic (V) for five species and the ratios of the SMAVs for each species range from 0.6 to 1.7. Chronic values are available for both arsenic (III) and arsenic (V) for one species; for the fathead minnow, the chronic value for arsenic (V) is 0.29 times the chronic value for arsenic (III). No data are known to be available concerning whether the toxicities of the forms of arsenic to aquatic organisms are additive.

[B] This criterion has been revised to reflect The Environmental Protection Agency's q1* or RfD, as contained in the Integrated Risk Information System (IRIS) as of April 8, 1998. The fish tissue bioconcentration factor (BCF) from the 1980 Ambient Water Quality Criteria document was retained in each case.

[C] This criterion is based on carcinogenicity of 10^{-6} risk. Alternate risk levels may be obtained by moving the decimal point (e.g., for a risk level of 10^{-5}, move the decimal point in the recommended criterion one place to the right).

[D] Freshwater and saltwater criteria for metals are expressed in terms of the dissolved metal in the water column. The recommended water quality criteria value was calculated by using the previous 304(a) aquatic life criteria expressed in terms of total recoverable metal, and multiplying it by a conversion factor (CF). The term "Conversion Factor" (CF) represents the recommended conversion factor for converting a metal criterion expressed as the total recoverable fraction in the water column to a criterion expressed as the dissolved fraction in the water column. (Conversion Factors for saltwater CCCs are not currently available. Conversion factors derived for saltwater CMCs have been used for both saltwater CMCs and CCCs.) See "Office of Water Policy and Technical Guidance on Interpretation and Implementation of Aquatic Life Metals Criteria," October 1, 1993, by Martha G. Prothro, Acting Assistant Administrator for Water, available from the Water Resource center, USEPA, 401 M St., SW, mall code RC4100, Washington, DC 20460; and 40 CFR§131.36(b)(1). Conversion Factors applied in the table can be found in Appendix A to the Preamble—Conversion Factors for Dissolved Metals.

[E] The freshwater criterion for this metal is expressed as a function of hardness (mg/L) in the water column. The value given here corresponds to a hardness of 100 mg/L. Criteria values for other hardness may be calculated from the following: CMC (dissolved) = exp $\{m_A [\ln(\text{hardness})]+b_A\}$ (CF), or CCC (dissolved) = exp $\{m_C [\ln(\text{hardness})]+b_C\}$ (CF) and the parameters specified in Appendix B to the Preamble—Parameters for Calculating Freshwater Dissolved Metals Criteria That Are Hardness-Dependent.

[F] Freshwater aquatic life values for pentachlorophenol are expressed as a function of pH, and are calculated as follows: CMD=exp(1.005(pH)−4.869); CCC=exp(1.005 (pH)−5.134). Values displayed in table correspond to a pH of 7.8.

[G] This Criterion is based on 304(a) aquatic life criterion issued in 1980, and was issued in one of the following documents: Aldrin/Dieldrin (EPA 440/5–80–019), Chlordane (EPA 440/5–80–027), DDT (EPA 440/5–80–038), Endosulfan (EPA 440/5–80–046), Endrin (EPA 440/5–80–047), Heptachlor (440/5–80–052), Hexachlorocyclohexane (EPA 440/5–80–054), Silver (EPA 440/5–80–071). The Minimum Data Requirements and derivation procedures were different in the 1980 Guidelines than in the 1985 Guidelines. For example, a "CMC" derived using the 1980 Guidelines was derived to be used as an instantaneous maximum. If assessment is to be done using an averaging period, the values given should be divided by 2 to obtain a value that is more comparable to a CMC derived using the 1985 Guidelines.

[H] No criterion for protection of human health from consumption of aquatic organisms excluding water was presented in the 1980 criteria document or in the 1986 Quality Criteria for Water. Nevertheless, sufficient information was presented in the 1980 document to allow the calculation of a criterion, even though the results of such a calculation were not shown in the document.

[I] This criterion for asbestos is the Maximum Contaminant Level (MCL) developed under the Safe Drinking Water Act (SDWA).

[J] EPA has not calculated human health criterion for this contaminant. However, permit authorities should address this contaminant in NPDES permit actions using the State's existing narrative criteria for toxics.

[K] This recommended criterion is based on a 304(a) aquatic life criterion that was issued in the 1995 Updates: Water Quality Criteria Documents for the Protection of Aquatic Life in Ambient Water, (EPA–820–B–96–011, September 1996). This value was derived using the GLI Guidelines (60 FR 15393–15399, March 23, 1995; 40 CFR 132 Appendix A); the difference between the 1985 Guidelines and the GLI Guidelines are explained on page iv of the 1995 Updates. None of the decisions concerning the derivation of this criterion were affected by any considerations that are specific to the Great Lakes.

[L] The CMC=1/[(f1/CMC1)=(f2/CMC2)] where f1 and f2 are the fractions of total selenium that are treated as selenite and selenate, respectively, and CMC1 and CMC2 are 185.9 µg/l and 12.83 µg/l, respectively.

[M] EPA is currently reassessing the criteria for arsenic. Upon completion of the reassessment the Agency will publish revised criteria as appropriate.

[N] PCBs are a class of chemicals which include aroclors, 1242, 1254, 1221, 1232, 1248, 1260, and 1016, CAS numbers 53469219, 11097691, 11104282, 11141165, 12672296, 11096825 and 12674112 respectively. The aquatic life criteria apply to this set of PCBs.

[O] The derivation of the CCC for this pollutant did not consider exposure through the diet, which is probably important for aquatic life occupying upper trophic levels.

[P] This criterion applies to total pcbs, i.e., the sum of all congener or all isomer analyses.

[Q] This recommended water quality criterion is expressed as µg free cyanide (as CN)/L.

[R] This value was announced (61 FR 58444–58449, November 14, 1996) as a proposed GLI 303(c) aquatic criterion. EPA is currently working on this criterion and so this value might change substantially in the near future.

[S] This recommended water quality criterion refers to the inorganic form only.

[T] This recommended water quality criterion is expressed in terms of total recoverable metal in the water column. It is scientifically acceptable to use the conversion factor of 0.922 that was used in the GLI to convert this to a value that is expressed in terms of dissolved metal.

[U] The organoleptic effect criterion is more stringent than the value for priority toxic pollutants.

v This value was derived from data for heptachlor and the criteria document provides insufficient data to estimate the relative toxicities of heptachlor and heptachlor epoxide.

w Although EPA has not published a final criteria document for this compound it is EPA's understanding that sufficient data exist to allow calculation of aquatic criteria. It is anticipated that industry intends to publish in the peer reviewed literature draft aquatic life criteria generated in accordance with EPA Guidelines. EPA will review such criteria for possible issuance as national WQC.

x There is a full set of aquatic life toxicity data that show that DEHP is not toxic to aquatic organisms at or below its solubility limit.

y This value was derived from data for endosulfan and is most appropriately applied to the sum of alpha-endosulfan and beta-endosulfan.

z A more stringent MCL has been issued by EPA. Refer to drinking water regulations (40 CFR 141) or Safe Drinking Water Hotline (1–800–426–4791) for values.

aa This CCC is based on the Final Residue Value procedure in the 1985 Guidelines. Since the publication of the Great Lakes Aquatic Life Criteria Guidelines in 1995 (60FR 15393–15399, March 23, 1995), the Agency no longer uses the Final Residue Value procedure for deriving CCCs for new or revised 304(a) aquatic life criteria.

bb This water quality criterion is based on 304(a) aquatic life criterion that was derived using the 1985 Guidelines (Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses, PB85-227049, January 1985) and was issued in one of the following criteria documents: Arsenic (EPA 440/5-84-033), Cadmium (EPA 440/5-84-032), Chromium (EPA 440/5-84-029), Copper (EPA 440/5-84-031), Cyanide (EPA 400/5-84-028), Lead (EPA 440/5-84-027), Nickel (EPA 440/5-84-027), Cyanide (EPA 400/5-84-031), Copper ... Toxaphene (EPA 440/5-86-009), Zinc (EPA 440/5-87-003).

cc When the concentration of dissolved organic carbon is elevated, copper is substantially less toxic and use of Water-Effect Ratios might be appropriate.

dd The selenium criteria document (EPA 440/5-87-006), September 1987) provides that if selenium is as toxic to saltwater fishes in the field as it is to freshwater fishes in the field, the status of the fish community should be monitored whenever the concentration of selenium exceeds 5.0 µg/L in salt water because the saltwater CCC does not take into account uptake via the food chain.

ee This recommended water quality criterion was derived on page 43 of the mercury criteria document (EPA 440/5-84-026, January 1985). The saltwater CCC of 0.025 µg/L given on page 23 of the criteria document is based on the Final Residue Value procedure in the 1985 Guidelines. Since the publication of the Great Lakes Aquatic Life Criteria Guidelines in 1995 (60FR15393-15399, March 23, 1995), the Agency no longer uses the Final Residue Value procedure for deriving CCCs for new or revised 304(a) aquatic life criteria.

ff This recommended water quality criterion was derived in Ambient Water Quality Criteria Saltwater Copper Addendum (Draft, April 14, 1995) and was promulgated in the Interim Final National Toxics Rule (60FR22228-222237, May 4, 1995).

gg EPA is actively working on this criterion and so this recommended water quality criterion may change substantially in the near future.

hh This recommended water quality criterion was derived from data for inorganic mercury (II), but is applied here to total mercury. If a substantial portion of the mercury in the water column is methylmercury, this criterion will probably be under protective. In addition, even though inorganic mercury is converted to methylmercury and methylmercury bioaccumulates to a great extent, this criterion does not account for uptake via the food chain because sufficient data were not available when the criteria was derived.

NATIONAL RECOMMENDED WATER QUALITY CRITERIA FOR NON PRIORITY POLLUTANTS

	Non priority pollutant	CAS No.	Freshwater CMC (µg/L)	Freshwater CCC (µg/L)	Saltwater CMC (µg/L)	Saltwater CCC (µg/L)	Human health — Water + organism (µg/L)	Human health — Organism only (µg/L)	FR cite/source
1	Alkalinity			20000 F					Gold Book
2	Aluminum pH 6.5–9.0	7429905	750 G,I	87 G,I,L					53 FR 33178
3	Ammonia	7664417	FRESHWATER CRITERIA ARE pH DEPENDENT—SEE DOCUMENT		SALTWATER CRITERIA ARE pH AND TEMPERATURE DEPENDENT D				EPA822–R–98–008 / EPA440/5–88–004
4	Aesthetic Qualities				NARRATIVE STATEMENT—SEE DOCUMENT				Gold Book
5	Bacteria				FOR PRIMARY RECREATION AND SHELLFISH USES—SEE DOCUMENT				Gold Book
6	Barium	7440393					1,000 A		Gold Book
7	Boron				NARRATIVE STATEMENT—SEE DOCUMENT				Gold Book
8	Chloride	16887006	860000 G	230000 G					Gold Book
9	Chlorine	7782505	19	11	13	7.5	C		Gold Book
10	Chlorophenoxy Herbicide 2,4,5,-TP	93721					10 A	10 A	Gold Book
11	Chlorophenoxy Herbicide 2,4-D	94757					100 A,C	100 A,C	Gold Book
12	Chloropyrifos	2921882	0.083 G	0.041 F,H	0.011 G	0.0056 G			Gold Book
13	Color				NARRATIVE STATEMENT—SEE DOCUMENT F				Gold Book
14	Demeton	8065483		0.1 F,H		0.1 F,H			Gold Book
15	Ether, Bis Chloromethyl	542881					0.00013 E	0.00078 E	IRIS 01/01/91
16	Gases, Total Dissolved				NARRATIVE STATEMENT—SEE DOCUMENT F				Gold Book
17	Guthion	86500		0.01 F,H		0.01 F,H			Gold Book
18	Hardness				NARRATIVE STATEMENT—SEE DOCUMENT				Gold Book
19	Hexachlorocyclo-hexane-Technical	319868					0.0123	0.0414	Gold Book
20	Iron	7439896		1000 F			300 A		Gold Book
21	Malathion	121755		0.1 F,H		0.1 F,H			Gold Book
22	Manganese	7439965					50 A	100 A	Gold Book
23	Methoxychlor	72435		0.03 F,H		0.03 F,H	100 A,C		Gold Book
24	Mirex	2385855		0.001 F,H		0.001 F,H			Gold Book
25	Nitrates	14797558					10,000 A		Gold Book
26	Nitrosamines						0.0008	1.24	Gold Book

No.	Compound	CAS Number	Freshwater CMC	Freshwater CCC	Saltwater CMC	Saltwater CCC	Human Health (Water + Organism)	Human Health (Organism Only)	Publication
27	Dinitrophenols	25550587					70	14,000	Gold Book
28	Nitrosodibutylamine,N	924163					0.0064 A	0.587 A	Gold Book
29	Nitrosodiethylamine,N	55185					0.0008 A	1.24 A	Gold Book
30	Nitrosopyrrolidine,N	930552					0.016	91.9	Gold Book
31	Oil and Grease		NARRATIVE STATEMENT—SEE DOCUMENT F						Gold Book
32	Oxygen, Dissolved	7782447	WARMWATER AND COLDWATER MATRIX—SEE DOCUMENT O						Gold Book
33	Parathion	56382	0.065 J	0.013 J					Gold Book
34	Pentachlorobenzene	608935					3.5 E	4.1 E	IRIS 03/01/88
35	pH		6.5–9 F		6.5–8.5 F,K		5–9		Gold Book
36	Phosphorus Elemental	7723140				0.1 F,K			Gold Book
37	Phosphate Phosphorus		NARRATIVE STATEMENT—SEE DOCUMENT						Gold Book
38	Solids Dissolved and Salinity						250,000 A		Gold Book
39	Solids Suspended and Turbidity		NARRATIVE STATEMENT—SEE DOCUMENT F						Gold Book
40	Sulfide-Hydrogen Sulfide	7783064		2.0 F,H		2.0 F,H			Gold Book
41	Tainting Substances		NARRATIVE STATEMENT—SEE DOCUMENT						Gold Book
42	Temperature		SPECIES DEPENDENT CRITERIA—SEE DOCUMENT M						Gold Book
43	Tetrachlorobenzene,1,2,4,5-	95943					2.3 E	2.9 E	IRIS03/01/91
44	Tributyltin TBT		0.46 N	0.063 N	0.37 N	0.010 N			62 FR 42554
45	Trichlorophenol,2,4,5-	95954					2,600 B,E	9,800 B,E	IRIS 03/01/88

Footnotes:

A This human health criterion is the same as originally published in the Red Book which predates the 1980 methodology and did not utilize the fish ingestion BCF approach. This same criterion value is now published in the Gold Book

B The organoleptic effect criterion is more stringent than the value presented in the non priority pollutants table.

C A more stringent Maximum Contaminant Level (MCL) has been issued by EPA under the Safe Drinking Water Act. Refer to drinking water regulations 40 CFR 141 or Safe Drinking Water Hotline (1–800–426–4791) for values.

D According to the procedures described in the Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses, except possibly where a very sensitive species is important at a site, freshwater aquatic life should be protected if both conditions specified in Appendix C to the Preamble—Calculation of Freshwater Ammonia Criterion are satisfied.

E This criterion has been revised to reflect The Environmental Protection Agency's q1* or RfD, as contained in the Integrated Risk Information System (IRIS) as of April 8, 1998. The fish tissue bioconcentration factor (BCF) used to derive the original criterion was retained in each case.

F The derivation of this value is presented in the Red Book (EPA 440/9–76–023, July, 1976).

G This value is based on a 304(a) aquatic life criterion that was derived using the 1985 Guidelines (Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses, PB85–227049, January 1985) and was issued in one of the following criteria documents: Aluminum (EPA 440/5–86–008); Chloride (EPA 440/5–88–001); Chloropyrifos (EPA 440/5–86–005).

H This CCC is based on the Final Residue Value procedure in the 1985 Guidelines. Since the publication of the Great Lakes Aquatic Life Criteria Guidelines in 1995 (60 FR 15393–15399, March 23, 1995), the Agency no longer uses the Final Residue Value procedure for deriving CCCs for new or revised 304(a) aquatic life criteria.

I This value is expressed in terms of total recoverable metal in the water column.

J This value is based on a 304(a) aquatic life criterion that was issued in the 1995 Updates: Water Quality Criteria Documents for the Protection of Aquatic Life in Ambient Water (EPA–820–B–96–001). This value was derived using the GLI Guidelines (60 FR 15393–15399, March 23, 1995; 40 CFR 132 Appendix A); the differences between the 1985 Guidelines and the GLI Guidelines are explained on page iv of the 1995 Updates. No decision concerning this criterion was affected by any considerations that are specific to the Great Lakes.

K According to page 181 of the Red Book: For open ocean waters where the depth is substantially greater than the euphotic zone, the pH should not be changed more than 0.2 units from the naturally occurring variation or any case outside the range of 6.5 to 8.5. For shallow, highly productive coastal and estuarine areas where naturally occurring pH variations approach the lethal limits of some species, changes in pH should be avoided but in any case should not exceed the limits established for fresh water, i.e., 6.5–9.0.

L There are three major reasons why the use of Water-Effect Ratios might be appropriate. (1) The value of 87 μg/l is based on a toxicity test with the striped bass in water with pH=6.5–6.6 and hardness <10 mg/L. Data in "Aluminum Water-Effect Ratio for the 3M Plant Effluent Discharge, Middleway, West Virginia" (May 1994) indicate that aluminum is substantially less toxic at higher pH and hardness, but the effects of pH and hardness are not well quantified at this time. (2) In tests with the brook trout at low pH and hardness, effects increased with increasing concentrations of total aluminum even though the concentration of dissolved aluminum was constant, indicating that total recoverable is a more appropriate measurement than dissolved, at least when particulate aluminum is primarily aluminum hydroxide particles. In surface waters, however, the total recoverable procedure might measure aluminum associated with clay particles, which might be less toxic than aluminum associated with aluminum hydroxide. (3) EPA is aware of field data indicating that many high quality waters in the U.S. contain more than 87 μg aluminum/L, when either total recoverable or dissolved is measured.

M U.S. EPA, 1973. Water Quality Criteria 1972. EPA–R3–73–033. National Technical Information Service, Springfield, VA.; U.S. EPA. 1977. Temperature Criteria for Freshwater Fish: Protocol and Procedures. EPA–600/3–77–061. National Technical Information Service, Springfield, VA.

N This value was announced (62 FR 42554, August 7, 1997) as a proposed 304(a) aquatic life criterion. Although EPA has not responded to public comment, EPA is publishing this as a 304(a) criterion in today's notice as guidance for States and Tribes to consider when adopting water quality criteria.

O U.S. EPA. 1986. Ambient Water Quality Criteria for Dissolved Oxygen. EPA 440/5–86–003. National Technical Information Service, Springfield, VA.

NATIONAL RECOMMENDED WATER QUALITY CRITERIA FOR ORGANOLEPTIC EFFECTS

	Pollutant	CAS No.	Organoleptic effect criteria (µg/L)	FR cite/source
1	Acenaphthene	208968	20	Gold Book
2	Monochlorobenzene	108907	20	Gold Book
3	3-Chlorophenol		0.1	Gold Book
4	4-Chlorophenol	106489	0.1	Gold Book
5	2,3-Dichlorophenol		0.04	Gold Book
6	2,5-Dichlorophenol		0.5	Gold Book
7	2,6-Dichlorophenol		0.2	Gold Book
8	3,4-Dichlorophenol		0.3	Gold Book
9	2,4,5-Trichlorophenol	95954	1	Gold Book
10	2,4,6-Trichlorophenol	88062	2	Gold Book
11	2,3,4,6-Tetrachlorophenol		1	Gold Book
12	2-Methyl-4-Chlorophenol		1800	Gold Book
13	3-Methyl-4-Chlorophenol	59507	3000	Gold Book
14	3-Methyl-6-Chlorophenol		20	Gold Book
15	2-Chlorophenol	95578	0.1	Gold Book
16	Copper	744058	1000	Gold Book
17	2,4-Dichlorophenol	120832	0.3	Gold Book
18	2,4-Dimethylphenol	105679	400	Gold Book
19	Hexachlorocyclopentadiene	77474	1	Gold Book
20	Nitrobenzene	98953	30	Gold Book
21	Pentachlorophenol	87865	30	Gold Book
22	Phenol	108952	300	Gold Book
23	Zinc	7440666	5000	45 FR 79341

General Notes:

1. These criteria are based on organoleptic (taste and odor) effects. Because of variations in chemical nomenclature systems, this listing of pollutants does not duplicate the listing in Appendix A of 40 CFR Part 423. Also listed are the Chemical Abstracts Service (CAS) registry numbers, which provide a unique identification for each chemical.

National Recommended Water Quality Criteria

Additional Notes

1. Criteria Maximum Concentration and Criterion Continuous Concentration

The Criteria Maximum Concentration (CMC) is an estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed briefly without resulting in an unacceptable effect. The Criterion Continuous Concentration (CCC) is an estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect. The CMC and CCC are just two of the six parts of a aquatic life criterion; the other four parts are the acute averaging period, chronic averaging period, acute frequency of allowed exceedence, and chronic frequency of allowed exceedence. Because 304(a) aquatic life criteria are national guidance, they are intended to be protective of the vast majority of the aquatic communities in the United States.

2. Criteria Recommendations for Priority Pollutants, Non Priority Pollutants and Organoleptic Effects

This compilation lists all priority toxic pollutants and some non priority toxic pollutants, and both human health effect and organoleptic effect criteria issued pursuant to CWA § 304(a). Blank spaces indicate that EPA has no CWA § 304(a) criteria recommendations. For a number of non-priority toxic pollutants not listed, CWA § 304(a) ''water + organism'' human health criteria are not available, but, EPA has published MCLs under the SDWA that may be used in establishing water quality standards to protect water supply designated uses. Because of variations in chemical nomenclature systems, this listing of toxic pollutants does not duplicate the listing in Appendix A of 40 CFR Part 423. Also listed are the Chemical Abstracts Service CAS registry numbers, which provide a unique identification for each chemical.

3. Human Health Risk

The human health criteria for the priority and non priority pollutants are based on carcinogenicity of 10^{-6} risk. Alternate risk levels may be obtained by moving the decimal point (e.g., for a risk level of 10–5, move the decimal point in the recommended criterion one place to the right).

4. Water Quality Criteria Published Pursuant to Section 304(a) or Section 303(c) of the CWA

Many of the values in the compilation were published in the proposed California Toxics Rule (CTR, 62 FR 42160). Although such values were published pursuant to Section 303(c) of the CWA, they represent the Agency's most recent calculation of water quality criteria and thus are published today as the Agency's 304(a) criteria. Water quality criteria published in the proposed CTR may be revised when EPA takes final action on the CTR.

5. Calculation of Dissolved Metals Criteria

The 304(a) criteria for metals, shown as dissolved metals, are calculated in one of two ways. For freshwater metals criteria that are hardness-dependent, the dissolved metal criteria were calculated using a hardness of 100 mg/l as $CaCO_3$ for illustrative purposes only. Saltwater and freshwater metals' criteria that are not hardness-dependent are calculated by multiplying the total recoverable criteria before rounding by the appropriate conversion factors. The final dissolved metals' criteria in the table are rounded to two significant figures. Information regarding the calculation of hardness dependent conversion factors are included in the footnotes.

6. Correction of Chemical Abstract Services Number

The Chemical Abstract Services number (CAS) for Bis(2-Chloroisopropyl) Ether, has been corrected in the table. The correct CAS number for this chemical is 39638–32–9. Previous publications listed 108–60–1 as the CAS number for this chemical.

7. Maximum Contaminant Levels

The compilation includes footnotes for pollutants with Maximum Contaminant Levels (MCLs) more stringent than the recommended water quality criteria in the compilation. MCLs for these pollutants are not included in the compilation, but can be found in the appropriate drinking water regulations (40 CFR 141.11–16 and 141.60–63), or can be accessed through the Safe Drinking Water Hotline (800–426–4791) or the Internet (http://www.epa.gov/ost/tools/dwstds-s.html).

8. Organoleptic Effects

The compilation contains 304(a) criteria for pollutants with toxicity-based criteria as well as non-toxicity based criteria. The basis for the non-toxicity based criteria are organoleptic effects (e.g., taste and odor) which would make water and edible aquatic life unpalatable but not toxic to humans. The table includes criteria for organoleptic effects for 23 pollutants. Pollutants with organoleptic effect criteria more stringent than the criteria based on toxicity (e.g., included in both the priority and non-priority pollutant tables) are footnoted as such.

9. Category Criteria

In the 1980 criteria documents, certain recommended water quality criteria were published for categories of pollutants rather than for individual pollutants within that category. Subsequently, in a series of separate actions, the Agency derived criteria for specific pollutants within a category. Therefore, in this compilation EPA is replacing criteria representing categories with individual pollutant criteria (e.g., 1,3-dichlorobenzene, 1,4-dichlorobenzene and 1,2-dichlorobenzene).

10. Specific Chemical Calculations

A. Selenium

(1) Human Health

In the 1980 Selenium document, a criterion for the protection of human health from consumption of water and organisms was calculated based on a BCF of 6.0 L/kg and a maximum water-related contribution of 35 μg Se/day. Subsequently, the EPA Office of Health and Environmental Assessment issued an errata notice (February 23, 1982), revising the BCF for selenium to 4.8 L/kg. In 1988, EPA issued an addendum (ECAO–CIN–668) revising the human health criteria for selenium. Later in the final National Toxic Rule (NTR, 57 FR 60848), EPA withdrew previously published selenium human health criteria, pending Agency review of new epidemiological data.

This compilation includes human health criteria for selenium, calculated using a BCF of 4.8 L/kg along with the current IRIS RfD of 0.005 mg/kg/day. EPA included these recommended water quality criteria in the compilation because the data necessary for calculating a criteria in accordance with EPA's 1980 human health methodology are available.

(2) Aquatic Life

This compilation contains aquatic life criteria for selenium that are the same as those published in the proposed CTR. In the CTR, EPA proposed an acute criterion for selenium based on the criterion proposed for selenium in the Water Quality Guidance for the Great Lakes System (61 FR 58444). The GLI and CTR proposals take into account data showing that selenium's two most prevalent oxidation states, selenite and selenate, present differing potentials for aquatic toxicity, as well as new data indicating that various forms of selenium are additive. The new approach produces a different selenium acute criterion concentration, or CMC, depending upon the relative proportions of selenite, selenate, and other forms of selenium that are present.

EPA notes it is currently undertaking a reassessment of selenium, and expects the 304(a) criteria for selenium will be revised based on the final reassessment (63 FR 26186). However, until such time as revised water quality criteria for selenium are published by the Agency, the recommended water quality criteria in this compilation are EPA's current 304(a) criteria.

B. 1,2,4-Trichlorobenzene and Zinc

Human health criteria for 1,2,4-trichlorobenzene and zinc have not been previously published. Sufficient information is now available for calculating water quality criteria for the protection of human health from the consumption of aquatic organisms and the consumption of aquatic organisms and water for both these compounds. Therefore, EPA is publishing criteria for these pollutants in this compilation.

C. Chromium (III)

The recommended aquatic life water quality criteria for chromium (III) included in the compilation are based on the values presented in the document titled: 1995 Updates: Water Quality Criteria Documents for the Protection of Aquatic Life in Ambient Water, however, this document contains criteria based on the total recoverable fraction. The chromium (III) criteria in this compilation were calculated by applying the conversion factors used in the Final Water Quality Guidance for the Great Lakes System (60 FR 15366) to the 1995 Update document values.

D. Ether, Bis (Chloromethyl), Pentachlorobenzene, Tetrachlorobenzene 1,2,4,5- Trichlorophenol

Human health criteria for these pollutants were last published in EPA's Quality Criteria for Water 1986 or ''Gold Book''. Some of these criteria were calculated using Acceptable Daily Intake (ADIs) rather than RfDs. Updated q1*s and RfDs are now available in IRIS for ether, bis (chloromethyl), pentachlorobenzene, tetrachlorobenzene 1,2,4,5-, and trichlorophenol, and were used to revise the water quality criteria for these compounds. The recommended water quality criteria for ether, bis (chloromethyl) were revised using an updated q1*, while criteria for pentachlorobenzene, and tetrachlorobenzene 1,2,4,5-, and trichlorophenol were derived using an updated RfD value.

E. PCBs

In this compilation EPA is publishing aquatic life and human health criteria based on total PCBs rather than individual arochlors. These criteria replace the previous criteria for the seven individual arochlors. Thus, there are criteria for a total of 102 of the 126 priority pollutants.

Dated: October 26, 1998.

J. Charles Fox,

Assistant Administrator, Office of Water.

Appendix A—Conversion Factors for Dissolved Metals

Metal	Conversion factor freshwater CMC	Conversion factor freshwater CCC	Conversion factor saltwater CMC	Conversion factor saltwater CCC
Arsenic	1.000	1.000	1.000	1.000
Cadmium	1.138672-[(ln hardness) (0.041838)]	1.101672-[(ln hardness) (0.041838)]	0.994	0.994
Chromium III	0.316	0.860		
Chromium VI	0.982	0.962	0.993	0.993
Copper	0.960	0.960	0.83	0.83
Lead	1.46203-[(ln hardness) (0.145712)]	1.46203-[(ln hardness) (0.145712)]	0.951	0.951
Mercury	0.85	0.85	0.85	0.85
Nickel	0.998	0.997	0.990	0.990
Selenium			0.998	0.998
Silver	0.85		0.85	
Zinc	0.978	0.986	0.946	0.946

Appendix B—Parameters for Calculating Freshwater Dissolved Metals Criteria That Are Hardness-Dependent

Chemical	m_A	b_A	m_C	b_C	Freshwater conversion factors (CF)	
					Acute	Chronic
Cadmium	1.128	−3.6867	0.7852	−2.715	1.136672-[ln (hardness)(0.041838)]	1.101672-[ln (hardness)(0.041838)]
Chromium III	0.8190	3.7256	0.8190	0.6848	0.316	0.860
Copper	0.9422	−1.700	0.8545	−1.702	0.960	0.960
Lead	1.273	−1.460	1.273	−4.705	1.46203-[ln (hardness)(0.145712)]	1.46203-[ln (hardness)(0.145712)]
Nickel	0.8460	2.255	0.8460	0.0584	0.998	0.997
Silver	1.72	−6.52			0.85	
Zinc	0.8473	0.884	0.8473	0.884	0.978	0.986

Appendix C—Calculation of Freshwater Ammonia Criterion

1. The one-hour average concentration of total ammonia nitrogen (in mg N/L) does not exceed, more than once every three years on the average, the CMC calculated using the following equation:

$$CMC = \frac{0.275}{1+10^{7.204-pH}} + \frac{39.0}{1+10^{pH-7.204}}$$

In situations where salmonids do not occur, the CMC may be calculated using the following equation:

$$CMC = \frac{0.411}{1+10^{7.204-pH}} + \frac{58.4}{1+10^{pH-7.204}}$$

2. The thirty-day average concentration of total ammonia nitrogen (in mg N/L) does not exceed, more than once every three years on the average, the CCC calculated using the following equation:

$$CCC = \frac{0.0858}{1+10^{7.688-pH}} + \frac{3.70}{1+10^{pH-7.688}}$$

Editorial Note: FR Doc. 98-30272 was originally published as Part IV (63 FR 67548-67558) in the issue of Monday, December 7, 1998. At the request of the agency, due to incorrect footnote identifiers in the tables, the corrected document is being republished in its entirety.

[FR Doc. 98–30272 Filed 12–4–98; 8:45 am]

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APPENDIX C

BRANDSMA, 1996
FIGURE 2

Exhibit C-1. Figure 2, Brandsma, 1996
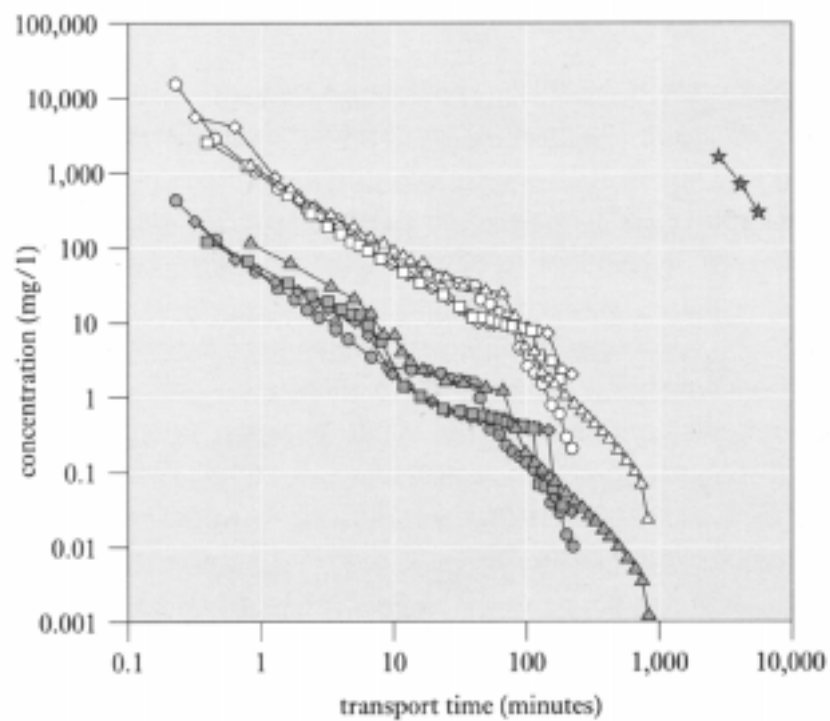
▫	Solids
■	Oil
★	LC50

APPENDIX D

**CALCULATION OF
SEDIMENT PORE WATER POLLUTANT CONCENTRATIONS
FOR WATER QUALITY ANALYSES**

Exhibit D-1. Gulf of Mexico Deep Water Development Model Well
Pore Water Pollutant Concentration: Current Technology
Technology = Discharge Assuming 11% (wt) Base Fluid Retention on Discharged Cuttings and 0.2% (vol.) Crude Contamination in SBF
Dry Cuttings Generated per Well: 778,050 lbs
Whole Drilling Fluid Discharged per Well: 588 bbls

Pollutant Name	Avg. Conc. of Pollutants in Drilling Waste	Pollutant Loadings per Well (lbs) Current Technology (11%)	Percent Pollutant/Synthetic (%)	Pollutant Sediment Conc. at 100 m (mg/kg)	Partition Coefficient[-1] or Leach Factors	Pore Water Conc. at 100 m (mg/l) (a)
Conventional Pollutants	lbs/lb disch. cuttings					
TSS (associated with adhering SBF)		78,414				
TSS (associated with dry cuttings)		778,050				
TSS (total)		856,464				
Total Oil (synthetic plus crude)		112,075		1.00e+04		
Priority Pollutant Organics	lbs/bbl drilling fluid					
Naphthalene	1.01e-03	0.5911	5.27e-04	5.29e-02	0.0795	4.59e-03
Fluorene	5.48e-04	0.3224	2.88e-04	2.89e-02	0.0407	1.28e-03
Phenanthrene	1.30e-03	0.7647	6.82e-04	6.84e-02	0.0113	8.45e-04
Phenol	7.22e-08	0.0000	3.79e-08	3.80e-06	11.3380	4.71e-05
Total Priority Pollutant Organics		1.6782				
Priority Pollutants, Metals	lbs/lb dry SBF					
Cadmium	1.10e-06	0.0863	7.70e-05	7.72e-03	0.1100	9.28e-04
Mercury	1.00e-07	0.0078	7.00e-06	7.02e-04	0.0180	1.38e-05
Antimony	5.70e-06	0.4470	3.99e-04	4.00e-02		
Arsenic	7.10e-06	0.5567	4.97e-04	4.98e-02	0.0050	2.72e-04
Beryllium	7.00e-07	0.0549	4.90e-05	4.91e-03		
Chromium	2.40e-04	18.8194	1.68e-02	1.68e+00	0.0340	6.26e-02
Copper	1.87e-05	1.4663	1.31e-03	1.31e-01	0.0063	9.03e-04
Lead	3.51e-05	2.7523	2.46e-03	2.46e-01	0.0200	5.38e-03
Nickel	1.35e-05	1.0586	9.45e-04	9.47e-02	0.0430	4.45e-03
Selenium	1.10e-06	0.0863	7.70e-05	7.72e-03		
Silver	7.00e-07	0.0549	4.90e-05	4.91e-03		
Thallium	1.20e-06	0.0941	8.40e-05	8.42e-03		
Zinc	2.00e-04	15.7220	1.40e-02	1.41e+00	0.0041	6.30e-03
Total Priority Pollutant Metals		41.21				
Non-Conventional Pollutants	lbs/lb dry SBF or bbl SBF					
Aluminum	9.07e-03	711.2071	6.35e-01	6.37e+01		
Barium	1.20e-01	9,409.6800	8.40e+00	8.42e+02	0.0021	1.93e+00
Iron	1.53e-02	1,203.2079	1.07e+00	1.08e+02	0.1300	1.53e+01
Tin	1.46e-05	1.1448	1.02e-03	1.02e-01		
Titanium	8.75e-05	6.8612	6.12e-03	6.14e-01		
Alkylated benzenes	5.66e-03	3.3273	2.97e-03	2.98e-01		
Alkylated naphthalenes	5.32e-02	31.2808	2.79e-02	2.80e+00		
Alkylated fluorenes	6.40e-03	3.7654	3.36e-03	3.37e-01		
Alkylated phenanthrenes	8.09e-03	4.7574	4.24e-03	4.26e-01		
Alkylated phenols	6.37e-07	0.0004	3.34e-07	3.35e-05		
Total biphenyls	1.05e-02	6.1834	5.52e-03	5.53e-01		
Total dibenzothiophenes	9.15e-06	0.0054	4.80e-06	4.82e-04		
Total Non-Conventional Pollutants		11,381.42				
Total Loadings and Reductions (lbs)		979,963				

(a)   Pore water conc. = (Pollutant Sed. Conc. * Partition Coeff or Leach Factor) * 35.5 kg sediment / 32.5 liter pore water unit volume

Exhibit D-2. Gulf of Mexico Deep Water Development Model Well
Pore Water Pollutant Concentrations: Discharge Option
Technology = Discharge Assuming 7% (wt) Base Fluid Retention on Discharged Cuttings and 0.2% (vol) Crude Contamination in SBF
Dry Cuttings Generated per Well: 778,050 lbs
Whole Drilling Fluid Discharged Per Well: 337

Pollutant Name	Avg. Conc. of Pollutants in Drilling Waste	Pollutant Loadings per Well (lbs) Discharge Option (7%)	Percent Pollutant/Synthetic (%)	Pollutant Sediment Conc. at 100 m (mg/kg)	Partition Coefficient[-1] or Leach Factors	Pore Water Conc. at 100 m (mg/l) (a)
Conventional Pollutants	**lbs/lb disch. cuttings**					
TSS (associated with adhering SBF)		44,886				
TSS (associated with dry cuttings)		778,050				
TSS (total)		822,936				
Total Oil (synthetic plus crude)		64,190		5.74e+03		
Priority Pollutants, Organics	**lbs/bbl drilling fluid**					
Naphthalene	1.01e-03	0.3388	5.28e-04	3.03e-02	0.0795	2.63e-03
Fluorene	5.48e-04	0.1848	2.88e-04	1.65e-02	0.0407	7.35e-04
Phenanthrene	1.30e-03	0.4382	6.83e-04	3.92e-02	0.0113	4.84e-04
Phenol	7.22e-08	2.43e-05	3.79e-08	2.18e-06	11.34	2.70e-05
Total Priority Pollutants, Organics		0.9618				
Priority Pollutants, Metals	**lbs/lb dry SBF**					
Cadmium	1.10e-06	0.0494	7.69e-05	4.42e-03	0.1100	5.31e-04
Mercury	1.00e-07	0.0045	6.99e-06	4.02e-04	0.0180	7.90e-06
Antimony	5.70e-06	0.2559	3.99e-04	2.29e-02		
Arsenic	7.10e-06	0.3187	4.96e-04	2.85e-02	0.0050	1.56e-04
Beryllium	7.00e-07	0.0314	4.89e-05	2.81e-03		
Chromium	2.40e-04	10.7726	1.68e-02	9.64e-01	0.0340	3.58e-02
Copper	1.87e-05	0.8394	1.31e-03	7.51e-02	0.0063	5.17e-04
Lead	3.51e-05	1.5755	2.45e-03	1.41e-01	0.0200	3.08e-03
Nickel	1.35e-05	0.6060	9.44e-04	5.42e-02	0.0430	2.55e-03
Selenium	1.10e-06	0.0494	7.69e-05	4.42e-03		
Silver	7.00e-07	0.0314	4.89e-05	2.81e-03		
Thallium	1.20e-06	0.0539	8.39e-05	4.82e-03		
Zinc	2.00e-04	8.9996	1.40e-02	8.05e-01	0.0041	3.61e-03
Total Priority Pollutant Metals		23.59				
Non-Conventional Pollutants	**lbs/lb dry SBF or bbl SBF**					
Aluminum	9.07e-03	407.1115	6.34e-01	3.64e+01		
Barium	1.20e-01	5,386.3200	8.39e+00	4.82e+02	0.0021	1.11e+00
Iron	1.53e-02	688.7442	1.07e+00	6.16e+01	0.1300	8.75e+00
Tin	1.46e-05	0.6553	1.02e-03	5.87e-02		
Titanium	8.75e-05	3.9275	6.12e-03	3.52e-01		
Alkylated benzenes	5.66e-03	1.9070	2.97e-03	1.71e-01		
Alkylated naphthalenes	5.32e-02	17.9280	2.79e-02	1.60e+00		
Alkylated fluorenes	6.40e-03	2.1581	3.36e-03	1.93e-01		
Alkylated phenanthrenes	8.09e-03	2.7266	4.25e-03	2.44e-01		
Alkylated phenols	6.37e-07	0.0002	3.34e-07	1.92e-05		
Total biphenyls	1.05e-02	3.5439	5.52e-03	3.17e-01		
Total dibenzothiophenes	9.15e-06	0.0031	4.80e-06	2.76e-04		
Total Non-Conventional Pollutants		6,515.03				
Total Loadings and Reductions (lbs)		**893,666**				

(b)   Pore water conc. = (Pollutant Sed. Conc. * Partition Coeff or Leach Factor) * 35.5 kg sediment / 32.5 liter pore water unit volume

Exhibit D-3. Gulf of Mexico Deep Water Exploratory Model Well
Pore Water Pollutant Concentrations: Current Technology
Technology = Discharge Assuming 11% (wt) Base Fluid Retention on Discharged Cuttings and 0.2% (vol.) Crude Contamination in SBF
Dry Cuttings Generated per Well: 1,729,910 **lbs**
Whole Drilling Fluid Discharged per Well: 1308 **bbls**

Pollutant Name	Avg. Conc. of Pollutants in Drilling Waste	Pollutant Loadings per Well (lbs) Current Technology (11%)	Percent Pollutant/Synthetic (%)	Pollutant Sediment Conc. at 100 m (mg/kg)	Partition Coefficient^{-1} or Leach Factors	Pore Water Conc. at 100 m (mg/l) (a)
Conventional Pollutants	**lbs/lb disch. cuttings**					
TSS (associated with adhering SBF)		174,346				
TSS (associated with dry cuttings)		1,729,910				
TSS (total)		1,904,256				
Total Oil (synthetic plus crude)		249,187		2.23e+04		
Priority Pollutant Organics	**lbs/bbl drilling fluid**					
Naphthalene	1.01e-03	1.3148	5.28e-04	1.18e-01	0.0796	1.02e-02
Fluorene	5.48e-04	0.7172	2.88e-04	6.42e-02	0.0407	2.85e-03
Phenanthrene	1.30e-03	1.7010	6.83e-04	1.52e-01	0.0113	1.88e-03
Phenol	7.22e-08	0.0001	3.79e-08	8.46e-06	11.34	1.05e-04
Total Priority Pollutant Organics		3.7331				
Priority Pollutants, Metals	**lbs/lb dry SBF**					
Cadmium	1.10e-06	0.1918	7.70e-05	1.72e-02	0.1100	2.06e-03
Mercury	1.00e-07	0.0174	7.00e-06	1.56e-03	0.0180	3.07e-05
Antimony	5.70e-06	0.9938	3.99e-04	8.90e-02		
Arsenic	7.10e-06	1.2379	4.97e-04	1.11e-01	0.0050	6.05e-04
Beryllium	7.00e-07	0.1220	4.90e-05	1.09e-02		
Chromium	2.40e-04	41.8430	1.68e-02	3.75e+00	0.0340	1.39e-01
Copper	1.87e-05	3.2603	1.31e-03	2.92e-01	0.0063	2.01e-03
Lead	3.51e-05	6.1195	2.46e-03	5.48e-01	0.0200	1.20e-02
Nickel	1.35e-05	2.3537	9.45e-04	2.11e-01	0.0430	9.90e-03
Selenium	1.10e-06	0.1918	7.70e-05	1.72e-02		
Silver	7.00e-07	0.1220	4.90e-05	1.09e-02		
Thallium	1.20e-06	0.2092	8.40e-05	1.87e-02		
Zinc	2.00e-04	34.9564	1.40e-02	3.13e+00	0.0041	1.40e-02
Total Priority Pollutant Metals		91.62				
Non-Conventional Pollutants	**lbs/lb dry SBF or bbl SBF**					
Aluminum	9.07e-03	1,581.3008	6.35e-01	1.42e+02		
Barium	1.20e-01	20,921.5200	8.40e+00	1.87e+03	0.0021	4.30e+00
Iron	1.53e-02	2,675.2173	1.07e+00	2.39e+02	0.1300	3.40e+01
Tin	1.46e-05	2.5455	1.02e-03	2.28e-01		
Titanium	8.75e-05	15.2553	6.12e-03	1.37e+00		
Alkylated benzenes	5.66e-03	7.4016	2.97e-03	6.63e-01		
Alkylated naphthalenes	5.32e-02	69.5839	2.79e-02	6.23e+00		
Alkylated fluorenes	6.40e-03	8.3762	3.36e-03	7.50e-01		
Alkylated phenanthrenes	8.09e-03	10.5829	4.25e-03	9.47e-01		
Alkylated phenols	6.37e-07	0.0008	3.34e-07	7.46e-05		
Total biphenyls	1.05e-02	13.7550	5.52e-03	1.23e+00		
Total dibenzothiophenes	9.15e-06	0.0120	4.80e-06	1.07e-03		
Total Non-Conventional Pollutants		25,305.55				
Total Loadings and Reductions (lbs)		**2,178,844**				

(a)   Pore water conc. = (Pollutant Sed. Conc. * Partition Coeff or Leach Factor) * 35.5 kg sediment / 32.5 liter pore water unit volume

D-3

Exhibit D-4. Gulf of Mexico Deep Water Exploratory Model Well
Pore Water Pollutant Concentrations: Discharge Option
Technology = Discharge Assuming 7% (wt) Base Fluid Retention on Discharged Cuttings and 0.2% (vol) Crude Contamination in SBF
Dry Cuttings Generated per Well: 1,729,910 lbs
Whole Drilling Fluid Discharged Per Well: 749 bbls

Pollutant Name	Avg. Conc. of Pollutants in Drilling Waste	Pollutant Loadings (lbs) Discharge Option (7%)	Percent Pollutant/Synthetic (%)	Pollutant Sediment Conc. at 100 m (mg/kg)	Partition Coefficient[-1] or Leach Factors	Pore Water Conc. at 100 m (mg/l) (a)
Conventional Pollutants	**lbs/lb disch. cuttings**					
TSS (associated with adhering SBF)		99,799				
TSS (associated with dry cuttings)		1,729,910				
TSS (total)		1,829,709				
Total Oil (synthetic plus crude)		142,719		1.28e+04		
Priority Pollutants, Organics	**lbs/bbl drilling fluid**					
Naphthalene	1.01e-03	0.7529	5.28e-04	6.74e-02	0.0795	5.85e-03
Fluorene	5.48e-04	0.4107	2.88e-04	3.68e-02	0.0407	1.63e-03
Phenanthrene	1.30e-03	0.9740	6.82e-04	8.72e-02	0.0113	1.08e-03
Phenol	7.22e-08	5.41e-05	3.79e-08	4.84e-06	11.34	6.00e-05
Total Priority Pollutants, Organics		2.1377				
Priority Pollutants, Metals	**lbs/lb dry SBF**					
Cadmium	1.10e-06	0.1098	7.69e-05	9.83e-03	0.1100	1.18e-03
Mercury	1.00e-07	0.0100	6.99e-06	8.93e-04	0.0180	1.76e-05
Antimony	5.70e-06	0.5689	3.99e-04	5.09e-02		
Arsenic	7.10e-06	0.7086	4.96e-04	6.34e-02	0.0050	3.46e-04
Beryllium	7.00e-07	0.0699	4.89e-05	6.25e-03		
Chromium	2.40e-04	23.9518	1.68e-02	2.14e+00	0.0340	7.96e-02
Copper	1.87e-05	1.8662	1.31e-03	1.67e-01	0.0063	1.15e-03
Lead	3.51e-05	3.5029	2.45e-03	3.14e-01	0.0200	6.85e-03
Nickel	1.35e-05	1.3473	9.44e-04	1.21e-01	0.0430	5.66e-03
Selenium	1.10e-06	0.1098	7.69e-05	9.83e-03		
Silver	7.00e-07	0.0699	4.89e-05	6.25e-03		
Thallium	1.20e-06	0.1198	8.39e-05	1.07e-02		
Zinc	2.00e-04	20.0097	1.40e-02	1.79e+00	0.0041	8.02e-03
Total Priority Pollutant Metals		52.44				
Non-Conventional Pollutants	**lbs/lb dry SBF or bbl SBF**					
Aluminum	9.07e-03	905.1670	6.34e-01	8.10e+01		
Barium	1.20e-01	11,975.8800	8.39e+00	1.07e+03	0.0021	2.46e+00
Iron	1.53e-02	1,531.3458	1.07e+00	1.37e+02	0.1300	1.95e+01
Tin	1.46e-05	1.4571	1.02e-03	1.30e-01		
Titanium	8.75e-05	8.7324	6.12e-03	7.82e-01		
Alkylated benzenes	5.66e-03	4.2384	2.97e-03	3.79e-01		
Alkylated naphthalenes	5.32e-02	39.8458	2.79e-02	3.57e+00		
Alkylated fluorenes	6.40e-03	4.7965	3.36e-03	4.29e-01		
Alkylated phenanthrenes	8.09e-03	6.0601	4.25e-03	5.42e-01		
Alkylated phenols	6.37e-07	0.0005	3.34e-07	4.27e-05		
Total biphenyls	1.05e-02	7.8765	5.52e-03	7.05e-01		
Total dibenzothiophenes	9.15e-06	0.0069	4.80e-06	6.13e-04		
Total Non-Conventional Pollutants		14,485.41				
Total Loadings and Reductions (lbs)		**1,986,968**				

(a)   Pore water conc. = (Pollutant Sed. Conc. * Partition Coeff or Leach Factor) * 35.5 kg sediment / 32.5 liter pore water unit volume

Exhibit D-5. Gulf of Mexico Shallow Water Exploratory Model Well
Pore Water Pollutant Concentrations: Current Technology
Technology = Discharge Assuming 11% (wt) Base Fluid Retention on Discharged Cuttings and 0.2% (vol.) Crude Contamination in SBF
Dry Cuttings Generated per Well: 1,077,440 lbs
Whole Drilling Fluid Discharged per Well: 814 bbls

Pollutant Name	Avg. Conc. of Pollutants in Drilling Waste	Pollutant Loadings per Well (lbs) Current Technology (11%)	Percent Pollutant/Synthetic (%)	Pollutant Sediment Conc. at 100 m (mg/kg)	Partition Coefficient[-1] or Leach Factors	Pore Water Conc. at 100 m (mg/l) (a)
Conventional Pollutants	**lbs/lb disch. cuttings**					
TSS (associated with adhering SBF)		108,588				
TSS (associated with dry cuttings)		1,077,440				
TSS (total)		1,186,028				
Total Oil (synthetic plus crude)		155,202		1.39e+04		
Priority Pollutant Organics	**lbs/bbl drilling fluid**					
Naphthalene	1.01e-03	0.8182	5.27e-04	7.32e-02	0.0796	6.37e-03
Fluorene	5.48e-04	0.4463	2.88e-04	3.99e-02	0.0407	1.78e-03
Phenanthrene	1.30e-03	1.0586	6.82e-04	9.47e-02	0.0113	1.17e-03
Phenol	7.22e-08	0.0001	3.79e-08	5.26e-06	11.34	6.52e-05
Total Priority Pollutant Organics		2.3232				
Priority Pollutants, Metals	**lbs/lb dry SBF**					
Cadmium	1.10e-06	0.1194	7.70e-05	1.07e-02	0.1100	1.28e-03
Mercury	1.00e-07	0.0109	7.00e-06	9.72e-04	0.0180	1.91e-05
Antimony	5.70e-06	0.6190	3.99e-04	5.54e-02		
Arsenic	7.10e-06	0.7710	4.97e-04	6.90e-02	0.0050	3.77e-04
Beryllium	7.00e-07	0.0760	4.90e-05	6.80e-03		
Chromium	2.40e-04	26.0611	1.68e-02	2.33e+00	0.0340	8.66e-02
Copper	1.87e-05	2.0306	1.31e-03	1.82e-01	0.0063	1.25e-03
Lead	3.51e-05	3.8114	2.46e-03	3.41e-01	0.0200	7.45e-03
Nickel	1.35e-05	1.4659	9.45e-04	1.31e-01	0.0430	6.16e-03
Selenium	1.10e-06	0.1194	7.70e-05	1.07e-02		
Silver	7.00e-07	0.0760	4.90e-05	6.80e-03		
Thallium	1.20e-06	0.1303	8.40e-05	1.17e-02		
Zinc	2.00e-04	21.7719	1.40e-02	1.95e+00	0.0041	8.73e-03
Total Priority Pollutant Metals		57.06				
Non-Conventional Pollutants	**lbs/lb dry SBF or bbl SBF**					
Aluminum	9.07e-03	984.8823	6.35e-01	8.82e+01		
Barium	1.20e-01	13,030.5600	8.40e+00	1.17e+03	0.0021	2.68e+00
Iron	1.53e-02	1,666.2068	1.07e+00	1.49e+02	0.1300	2.12e+01
Tin	1.46e-05	1.5854	1.02e-03	1.42e-01		
Titanium	8.75e-05	9.5014	6.12e-03	8.50e-01		
Alkylated benzenes	5.66e-03	4.6062	2.97e-03	4.12e-01		
Alkylated naphthalenes	5.32e-02	43.3038	2.79e-02	3.88e+00		
Alkylated fluorenes	6.40e-03	5.2127	3.36e-03	4.67e-01		
Alkylated phenanthrenes	8.09e-03	6.5860	4.24e-03	5.89e-01		
Alkylated phenols	6.37e-07	0.0005	3.34e-07	4.64e-05		
Total biphenyls	1.05e-02	8.5600	5.52e-03	7.66e-01		
Total dibenzothiophenes	9.15e-06	0.0074	4.80e-06	6.67e-04		
Total Non-Conventional Pollutants		15,761.01				
Total Loadings and Reductions (lbs)		**1,357,050**				

(a)   Pore water conc. = (Pollutant Sed. Conc. * Partition Coeff or Leach Factor) * 35.5 kg sediment / 32.5 liter pore water unit volume

Exhibit D-6. Gulf of Mexico Shallow Water Exploratory Model Well
Pore Water Pollutant Concentrations: Discharge Option
Technology = Discharge Assuming 7% (wt) Retention on Discharged Cuttings and 0.2% (vol) Crude Contamination

Dry Cuttings Generated per Well:	**1,077,440**	**lbs**	
Whole Drilling Fluid Discharged Per Well:	**466**	**bbls**	

Pollutant Name	Avg. Conc. of Pollutants in Drilling Waste	Pollutant Loadings per Well (lbs) Discharge Option (7%)	Percent Pollutant/Synthetic (%)	Pollutant Sediment Conc. at 100 m (mg/kg)	Partition Coefficient[-1] or Leach Factors	Pore Water Conc. at 100 m (mg/l) (a)
Conventional Pollutants	**lbs/lb disch. cuttings**					
TSS (associated with adhering SBF)		62,158				
TSS (associated with dry cuttings)		1,077,440				
TSS (total)		1,139,598				
Total Oil (synthetic plus crude)		88,890		7.96e+03		
Priority Pollutants, Organics	**lbs/bbl drilling fluid**					
Naphthalene	1.01e-03	0.4684	5.27e-04	4.19e-02	0.0796	3.65e-03
Fluorene	5.48e-04	0.2555	2.87e-04	2.29e-02	0.0407	1.02e-03
Phenanthrene	1.30e-03	0.6060	6.82e-04	5.42e-02	0.0113	6.69e-04
Phenol	7.22e-08	3.37e-05	3.79e-08	3.01e-06	11.34	3.73e-05
Total Priority Pollutants, Organics		1.3300				
Priority Pollutants, Metals	**lbs/lb dry SBF**					
Cadmium	1.10e-06	0.0684	7.69e-05	6.12e-03	0.1100	7.35e-04
Mercury	1.00e-07	0.0062	6.99e-06	5.56e-04	0.0180	1.09e-05
Antimony	5.70e-06	0.3543	3.99e-04	3.17e-02		
Arsenic	7.10e-06	0.4413	4.96e-04	3.95e-02	0.0050	2.16e-04
Beryllium	7.00e-07	0.0435	4.89e-05	3.89e-03		
Chromium	2.40e-04	14.9179	1.68e-02	1.34e+00	0.0340	4.96e-02
Copper	1.87e-05	1.1624	1.31e-03	1.04e-01	0.0063	7.16e-04
Lead	3.51e-05	2.1817	2.45e-03	1.95e-01	0.0200	4.27e-03
Nickel	1.35e-05	0.8391	9.44e-04	7.51e-02	0.0430	3.53e-03
Selenium	1.10e-06	0.0684	7.69e-05	6.12e-03		
Silver	7.00e-07	0.0435	4.89e-05	3.89e-03		
Thallium	1.20e-06	0.0746	8.39e-05	6.68e-03		
Zinc	2.00e-04	12.4627	1.40e-02	1.12e+00	0.0041	5.00e-03
Total Priority Pollutant Metals		32.66				
Non-Conventional Pollutants	**lbs/lb dry SBF or bbl SBF**					
Aluminum	9.07e-03	563.7668	6.34e-01	5.05e+01		
Barium	1.20e-01	7,458.9600	8.39e+00	6.68e+02	0.0021	1.53e+00
Iron	1.53e-02	953.7710	1.07e+00	8.54e+01	0.1300	1.21e+01
Tin	1.46e-05	0.9075	1.02e-03	8.12e-02		
Titanium	8.75e-05	5.4388	6.12e-03	4.87e-01		
Alkylated benzenes	5.66e-03	2.6369	2.97e-03	2.36e-01		
Alkylated naphthalenes	5.32e-02	24.7906	2.79e-02	2.22e+00		
Alkylated fluorenes	6.40e-03	2.9842	3.36e-03	2.67e-01		
Alkylated phenanthrenes	8.09e-03	3.7703	4.24e-03	3.37e-01		
Alkylated phenols	6.37e-07	0.0003	3.34e-07	2.66e-05		
Total biphenyls	1.05e-02	4.9005	5.51e-03	4.39e-01		
Total dibenzothiophenes	9.15e-06	0.0043	4.80e-06	3.82e-04		
Total Non-Conventional Pollutants		9,021.93				
Total Loadings and Reductions (lbs)		**1,237,544**				

(a)   Pore water conc. = (Pollutant Sed. Conc. * Partition Coeff or Leach Factor) * 35.5 kg sediment / 32.5 liter pore water unit volume

Exhibit D-7. Gulf of Mexico Shallow Water Development Model Well
Pore Water Pollutant Concentrations: Current Technology
Technology = Discharge Assuming 11% (wt) Base Fluid Retention on Discharged Cuttings and 0.2% (vol.) Crude Contamination in SBF

Dry Cuttings Generated per Well:		514,150	lbs			
Whole Drilling Fluid Discharged per Well:		389	bbls			

Pollutant Name	Avg. Conc. of Pollutants in Drilling Waste	Pollutant Loadings per Well (lbs) Current Technology (11%)	Percent Pollutant/Synthetic (%)	Pollutant Sediment Conc. at 100 m (mg/kg)	Partition Coefficient[-1] or Leach Factors	Pore Water Conc. at 100 m (mg/l) (a)
Conventional Pollutants	**lbs/lb disch. cuttings**					
TSS (associated with adhering SBF)		51,818				
TSS (associated with dry cuttings)		514,150				
TSS (total)		565,968				
Total Oil (synthetic plus crude)		74,062		6.63e+03		
Priority Pollutant Organics	**lbs/bbl drilling fluid**					
Naphthalene	1.01e-03	0.3910	5.28e-04	3.50e-02	0.0796	3.04e-03
Fluorene	5.48e-04	0.2133	2.88e-04	1.91e-02	0.0407	8.49e-04
Phenanthrene	1.30e-03	0.5059	6.83e-04	4.53e-02	0.0113	5.59e-04
Phenol	7.22e-08	0.0000	3.79e-08	2.52e-06	11.34	3.12e-05
Total Priority Pollutant Organics		1.1102				
Priority Pollutants, Metals	**lbs/lb dry SBF**					
Cadmium	1.10e-06	0.0570	7.70e-05	5.10e-03	0.1100	6.13e-04
Mercury	1.00e-07	0.0052	7.00e-06	4.64e-04	0.0180	9.12e-06
Antimony	5.70e-06	0.2954	3.99e-04	2.64e-02		
Arsenic	7.10e-06	0.3679	4.97e-04	3.29e-02	0.0050	1.80e-04
Beryllium	7.00e-07	0.0363	4.90e-05	3.25e-03		
Chromium	2.40e-04	12.4363	1.68e-02	1.11e+00	0.0340	4.13e-02
Copper	1.87e-05	0.9690	1.31e-03	8.67e-02	0.0063	5.97e-04
Lead	3.51e-05	1.8188	2.46e-03	1.63e-01	0.0200	3.56e-03
Nickel	1.35e-05	0.6995	9.45e-04	6.26e-02	0.0430	2.94e-03
Selenium	1.10e-06	0.0570	7.70e-05	5.10e-03		
Silver	7.00e-07	0.0363	4.90e-05	3.25e-03		
Thallium	1.20e-06	0.0622	8.40e-05	5.57e-03		
Zinc	2.00e-04	10.3895	1.40e-02	9.30e-01	0.0041	4.16e-03
Total Priority Pollutant Metals		27.23				
Non-Conventional Pollutants	**lbs/lb dry SBF or bbl SBF**					
Aluminum	9.07e-03	469.9841	6.35e-01	4.21e+01		
Barium	1.20e-01	6,218.1600	8.40e+00	5.57e+02	0.0021	1.28e+00
Iron	1.53e-02	795.1109	1.07e+00	7.12e+01	0.1300	1.01e+01
Tin	1.46e-05	0.7565	1.02e-03	6.77e-02		
Titanium	8.75e-05	4.5341	6.12e-03	4.06e-01		
Alkylated benzenes	5.66e-03	2.2012	2.97e-03	1.97e-01		
Alkylated naphthalenes	5.32e-02	20.6943	2.79e-02	1.85e+00		
Alkylated fluorenes	6.40e-03	2.4911	3.36e-03	2.23e-01		
Alkylated phenanthrenes	8.09e-03	3.1473	4.25e-03	2.82e-01		
Alkylated phenols	6.37e-07	0.0002	3.35e-07	2.22e-05		
Total biphenyls	1.05e-02	4.0907	5.52e-03	3.66e-01		
Total dibenzothiophenes	9.15e-06	0.0036	4.81e-06	3.19e-04		
Total Non-Conventional Pollutants		7,521.17				
Total Loadings and Reductions (lbs)		**647,580**				

(a)　　　Pore water conc. = (Pollutant Sed. Conc. * Partition Coeff or Leach Factor) * 35.5 kg sediment / 32.5 liter pore water unit volume

Exhibit D-8. Gulf of Mexico Shallow Water Development Model Well
Pore Water Pollutant Concentrations: Discharge Option
Technology = Discharge Assuming 7% (wt) Base Fluid Retention on Discharged Cuttings and 0.2% (vol) Crude Contamination in SBF

Dry Cuttings Generated per Well: 514,150 lbs
Whole Drilling Fluid Discharged Per Well: 223 bbls

Pollutant Name	Avg. Conc. of Pollutants in Drilling Waste	Pollutant Loadings per Well (lbs) Discharge Option (7%)	Percent Pollutant/Synthetic (%)	Pollutant Sediment Conc. at 100 m (mg/kg)	Partition Coefficient[1] or Leach Factors	Pore Water Conc. at 100 m (mg/l) (a)
Conventional Pollutants	**lbs/lb disch. cuttings**					
TSS (associated with adhering SBF)		29,661				
TSS (associated with dry cuttings)		514,150				
TSS (total)		543,811				
Total Oil (synthetic plus crude)		42,418		3.80e+03		
Priority Pollutants, Organics	**lbs/bbl drilling fluid**					
Naphthalene	1.01e-03	0.2242	5.28e-04	2.01e-02	0.0796	1.74e-03
Fluorene	5.48e-04	0.1223	2.88e-04	1.09e-02	0.0407	4.87e-04
Phenanthrene	1.30e-03	0.2900	6.84e-04	2.60e-02	0.0113	3.20e-04
Phenol	7.22e-08	1.61e-05	3.80e-08	1.44e-06	11.34	1.79e-05
Total Priority Pollutants, Organics		0.6364				
Priority Pollutants, Metals	**lbs/lb dry SBF**					
Cadmium	1.10e-06	0.0326	7.69e-05	2.92e-03	0.1100	3.51e-04
Mercury	1.00e-07	0.0030	6.99e-06	2.65e-04	0.0180	5.22e-06
Antimony	5.70e-06	0.1691	3.99e-04	1.51e-02		
Arsenic	7.10e-06	0.2106	4.96e-04	1.88e-02	0.0050	1.03e-04
Beryllium	7.00e-07	0.0208	4.89e-05	1.86e-03		
Chromium	2.40e-04	7.1186	1.68e-02	6.37e-01	0.0340	2.37e-02
Copper	1.87e-05	0.5547	1.31e-03	4.96e-02	0.0063	3.42e-04
Lead	3.51e-05	1.0411	2.45e-03	9.32e-02	0.0200	2.04e-03
Nickel	1.35e-05	0.4004	9.44e-04	3.58e-02	0.0430	1.68e-03
Selenium	1.10e-06	0.0326	7.69e-05	2.92e-03		
Silver	7.00e-07	0.0208	4.89e-05	1.86e-03		
Thallium	1.20e-06	0.0356	8.39e-05	3.19e-03		
Zinc	2.00e-04	5.9470	1.40e-02	5.32e-01	0.0041	2.38e-03
Total Priority Pollutant Metals		15.59				
Non-Conventional Pollutants	**lbs/lb dry SBF or bbl SBF**					
Aluminum	9.07e-03	269.0223	6.34e-01	2.41e+01		
Barium	1.20e-01	3,559.3200	8.39e+00	3.19e+02	0.0021	7.31e-01
Iron	1.53e-02	455.1273	1.07e+00	4.07e+01	0.1300	5.78e+00
Tin	1.46e-05	0.4331	1.02e-03	3.88e-02		
Titanium	8.75e-05	2.5953	6.12e-03	2.32e-01		
Alkylated benzenes	5.66e-03	1.2619	2.97e-03	1.13e-01		
Alkylated naphthalenes	5.32e-02	11.8633	2.80e-02	1.06e+00		
Alkylated fluorenes	6.40e-03	1.4280	3.37e-03	1.28e-01		
Alkylated phenanthrenes	8.09e-03	1.8043	4.25e-03	1.61e-01		
Alkylated phenols	6.37e-07	0.0001	3.35e-07	1.27e-05		
Total biphenyls	1.05e-02	2.3451	5.53e-03	2.10e-01		
Total dibenzothiophenes	9.15e-06	0.0020	4.81e-06	1.83e-04		
Total Non-Conventional Pollutants		4,305.20				
Total Loadings and Reductions (lbs)		**590,550**				

(a)   Pore water conc. = (Pollutant Sed. Conc. * Partition Coeff or Leach Factor) * 35.5 kg sediment / 32.5 liter pore water unit volume

APPENDIX E

**CALCULATION OF
FINFISH TISSUE POLLUTANT CONCENTRATIONS**

Exhibit E-1. Recreational Finfish Tissue Pollutant Concentrations - Gulf of Mexico Current Technology

Pollutant	(A) Average Concentration (mg/l)	(B) Leach Factor	(C) Ambient Bioavailable Conc. in Plume (mg/l)	(D) Average Exposure Concentration (mg/l)	(E) BCF (l/kg) (a)	(F) Fish Tissue Concentration (mg/kg)
Naphthalene	1.170		1.01e-04	7.15e-07	426	3.04e-04
Fluorene	0.6382		5.49e-05	3.90e-07	30	1.17e-05
Phenanthrene	1.5136		1.30e-04	9.25e-07	2630	2.43e-03
Phenol	0.0001		8.60e-09	6.11e-11	1.4	8.55e-11
Cadmium	0.1707	0.11	1.62e-06	1.15e-08	64	7.34e-07
Mercury	0.0155	0.018	2.40e-08	1.70e-10	5500	9.37e-07
Antimony	0.8843		7.61e-05	5.40e-07	1	5.40e-07
Arsenic	1.1015	0.005	4.74e-07	3.36e-09	44	1.48e-07
Beryllium	0.1086		9.34e-06	6.63e-08	19	1.26e-06
Chromium	37.233	0.034	1.09e-04	7.73e-07	16	1.24e-05
Copper	2.9011	0.0063	1.57e-06	1.12e-08	36	4.02e-07
Lead	5.4453	0.02	9.37e-06	6.65e-08	49	3.26e-06
Nickel	2.0944	0.043	7.75e-06	5.50e-08	47	2.59e-06
Selenium	0.1707		1.47e-05	1.04e-07	4.8	5.00e-07
Silver	0.1086		9.34e-06	6.63e-08	0.5	3.32e-08
Thallium	0.1862		1.60e-05	1.14e-07	116	1.32e-05
Zinc	31.11	0.0041	1.10e-05	7.79e-08	47	3.66e-06
Aluminum	1,407		1.21e-01	8.59e-04	231	1.99e-01
Barium	18,516		1.59e+00	1.13e-02		
Iron	2,380		2.05e-01	1.45e-03		
Tin	2.265		1.95e-04	1.38e-06		
Titanium	13.575		1.17e-03	8.29e-06		

(a)   There are no BCFs for specific SBF compounds.

Table Calculations:

     Average number of dilutions in area within mixing zone (100 m radius) = 11,624

     SBF plume volume = time to reach 100 m * discharge rate * no. of dilutions =
         (11.1 min. * 0.0175 m^3/min) * 11,624 dilutions = 2,257.9

     Mixing zone cylinder volume = 314,000 m^3; based on 100 m radius and
         10 m depth = time to reach 100 m (11 min) * fall velocity (0.015 m/sec)

     SBF plume portion of cylinder volume =
         0.72% = fractional area of mixing zone affected by plume (2,257.9/314,000)

     C=   A * B/dilutions (B is assumed to be 1 unless otherwise noted)

     D=   C * 0.0072 (SBF plume portion of cylinder)

     F=   D * E (exposure conc. * BCF)

Exhibit E-2. Recreational Finfish Tissue Pollutant Concentrations - Gulf of Mexico Discharge Option

Pollutant	(A) Average Concentration (mg/l)	(B) Leach Factor	(C) Ambient Bioavailable Conc. in Plume (mg/l)	(D) Average Exposure Concentration (mg/l)	(E) BCF (l/kg) (a)	(F) Fish Tissue Concentration (mg/kg)
Naphthalene	0.811		6.98e-05	4.95e-07	426	2.11e-04
Fluorene	0.4424		3.81e-05	2.70e-07	30	8.11e-06
Phenanthrene	1.0494		9.03e-05	6.41e-07	2630	1.69e-03
Phenol	0.0001		8.60e-09	6.11e-11	1.4	8.55e-11
Cadmium	0.1183	0.11	1.12e-06	7.95e-09	64	5.09e-07
Mercury	0.0108	0.018	1.67e-08	1.19e-10	5500	6.53e-07
Antimony	0.6128		5.27e-05	3.74e-07	1	3.74e-07
Arsenic	0.7634	0.005	3.28e-07	2.33e-09	44	1.03e-07
Beryllium	0.0753		6.48e-06	4.60e-08	19	8.74e-07
Chromium	25.804	0.034	7.55e-05	5.36e-07	16	8.57e-06
Copper	2.011	0.0063	1.09e-06	7.74e-09	36	2.79e-07
Lead	3.774	0.02	6.49e-06	4.61e-08	49	2.26e-06
Nickel	1.4515	0.043	5.37e-06	3.81e-08	47	1.79e-06
Selenium	0.1183		1.02e-05	7.23e-08	4.8	3.47e-07
Silver	0.0753		6.48e-06	4.60e-08	0.5	2.30e-08
Thallium	0.129		1.11e-05	7.88e-08	116	9.14e-06
Zinc	21.56	0.0041	7.60e-06	5.40e-08	47	2.54e-06
Aluminum	975.2		8.39e-02	5.96e-04	231	1.38e-01
Barium	12,902		1.11e+00	7.88e-03		
Iron	1,650		1.42e-01	1.01e-03		
Tin	1.570		1.35e-04	9.59e-07		
Titanium	9.408		8.09e-04	5.75e-06		

(a)   There are no BCFs for specific SBF compounds.

Table Calculations:

   Average number of dilutions in area within mixing zone (100 m radius) = 11,624

   SBF plume volume = time to reach 100 m * discharge rate * no. of dilutions =
       (11.1 min. * 0.0175 m^3/min) * 11,624 dilutions = 2,257.9

   Mixing zone cylinder volume = 314,000 m^3; based on 100 m radius and
       10 m depth = time to reach 100 m (11 min) * fall velocity (0.015 m/sec)

   SBF plume portion of cylinder volume =
       0.72% = fractional area of mixing zone affected by plume (2,257.9/314,000)

   C=   A * B/dilutions (B is assumed to be 1 unless otherwise noted)
   D=   C * 0.0072 (SBF plume portion of cylinder)
   F=   D * E (exposure conc. * BCF)

Exhibit E-3. Recreational Finfish Tissue Pollutant Concentrations - Cook Inlet, Alaska Current Technology

Pollutant	(A) Average Concentration (mg/l)	(B) Leach Factor	(C) Ambient Bioavailable Conc. in Plume (mg/l)	(D) Average Exposure Concentration (mg/l)	(E) BCF (l/kg) (a)	(F) Fish Tissue Concentration (mg/kg)
Naphthalene	1.170		4.04e-04	7.25e-07	426	3.09e-04
Fluorene	0.6382		2.21e-04	3.96e-07	30	1.19e-05
Phenanthrene	1.5136		5.23e-04	9.38e-07	2630	2.47e-03
Phenol	0.0001		3.46e-08	6.20e-11	1.4	8.68e-11
Cadmium	0.1707	0.11	6.49e-06	1.16e-08	64	7.45e-07
Mercury	0.0155	0.018	9.64e-08	1.73e-10	5500	9.51e-07
Antimony	0.8843		3.06e-04	5.48e-07	1	5.48e-07
Arsenic	1.1015	0.005	1.90e-06	3.41e-09	44	1.50e-07
Beryllium	0.1086		3.75e-05	6.73e-08	19	1.28e-06
Chromium	37.233	0.034	4.38e-04	7.85e-07	16	1.26e-05
Copper	2.9011	0.0063	6.32e-06	1.13e-08	36	4.08e-07
Lead	5.4453	0.02	3.76e-05	6.75e-08	49	3.31e-06
Nickel	2.0944	0.043	3.11e-05	5.58e-08	47	2.62e-06
Selenium	0.1707		5.90e-05	1.06e-07	4.8	5.08e-07
Silver	0.1086		3.75e-05	6.73e-08	0.5	3.37e-08
Thallium	0.1862		6.44e-05	1.15e-07	116	1.34e-05
Zinc	31.11	0.0041	4.41e-05	7.90e-08	47	3.72e-06
Aluminum	1,407		4.86e-01	8.72e-04	231	2.01e-01
Barium	18,516		6.40e+00	1.15e-02		
Iron	2,380		8.23e-01	1.48e-03		
Tin	2.265		7.83e-04	1.40e-06		
Titanium	13.575		4.69e-03	8.41e-06		

(a)   There are no BCFs for specific SBF compounds.

Table Calculations:

Average number of dilutions in area within mixing zone (100 m radius) = 2,893

SBF plume volume = time to reach 100 m * discharge rate * no. of dilutions =
(4.2 min. * 0.0175 m^3/min) * 2,893 dilutions = 211.1 m^3

Mixing zone cylinder volume = 117,750 m^3; based on 100 m radius and
3.75 m depth = time to reach 100 m (4.2 min) * fall velocity (0.015 m/sec)

SBF plume portion of cylinder volume =
0.18% = fractional area of mixing zone affected by plume (211.1/117,750)

C=   A * B/dilutions (B is assumed to be 1 unless otherwise noted)

D=   C * 0.0018 (SBF plume portion of cylinder)

F=   D * E (exposure conc. x BCF)

Exhibit E-4.   Recreational Finfish Tissue Pollutant Concentrations - Cook Inlet, Alaska Discharge Option

Pollutant	(A) Average Concentration (mg/l)	(B) Leach Factor	(C) Ambient Bioavailable Conc. in Plume (mg/l)	(D) Average Exposure Concentration (mg/l)	(E) BCF (l/kg) (a)	(F) Fish Tissue Concentration (mg/kg)
Naphthalene	0.811		2.80e-04	5.03e-07	426	2.14e-04
Fluorene	0.4424		1.53e-04	2.74e-07	30	8.23e-06
Phenanthrene	1.0494		3.63e-04	6.50e-07	2630	1.71e-03
Phenol	0.0001		3.46e-08	6.20e-11	1.4	8.68e-11
Cadmium	0.1183	0.11	4.50e-06	8.07e-09	64	5.16e-07
Mercury	0.0108	0.018	6.72e-08	1.21e-10	5500	6.63e-07
Antimony	0.6128		2.12e-04	3.80e-07	1	3.80e-07
Arsenic	0.7634	0.005	1.32e-06	2.37e-09	44	1.04e-07
Beryllium	0.0753		2.60e-05	4.67e-08	19	8.87e-07
Chromium	25.804	0.034	3.03e-04	5.44e-07	16	8.70e-06
Copper	2.011	0.0063	4.38e-06	7.85e-09	36	2.83e-07
Lead	3.774	0.02	2.61e-05	4.68e-08	49	2.29e-06
Nickel	1.4515	0.043	2.16e-05	3.87e-08	47	1.82e-06
Selenium	0.1183		4.09e-05	7.33e-08	4.8	3.52e-07
Silver	0.0753		2.60e-05	4.67e-08	0.5	2.33e-08
Thallium	0.129		4.46e-05	8.00e-08	116	9.27e-06
Zinc	21.56	0.0041	3.05e-05	5.48e-08	47	2.57e-06
Aluminum	975.2		3.37e-01	6.04e-04	231	1.40e-01
Barium	12,902		4.46+00	8.00e-03		
Iron	1,650		5.70e-01	1.02e-03		
Tin	1.570		5.43e-04	9.73e-07		
Titanium	9.408		3.25e-03	5.83e-06		

(a)   There are no BCFs for specific SBF compounds.

Table Calculations:

Average number of dilutions in area within mixing zone (100 m radius) = 2,893

SBF plume volume = time to reach 100 m * discharge rate * no. of dilutions =
        (4.2 min. * 0.0175 m^3/min) * 2,893 dilutions = 211.1 m^3

Mixing zone cylinder volume = 117,750 m^3; based on 100 m radius and
        3.75 m depth = time to reach 100 m (4.2 min) * fall velocity (0.015 m/sec)

SBF plume portion of cylinder volume =
        0.18% = fractional area of mixing zone affected by plume (211.1/117,750)

C=   A * B/dilutions (B is assumed to be 1 unless otherwise noted)
D=   C * 0.0018 (SBF plume portion of cylinder)
F=   D * E (exposure conc. x BCF)

Exhibit E-5. Recreational Finfish Tissue Pollutant Concentrations - Offshore California Current Technology

Pollutant	(A) Average Concentration (mg/l)	(B) Leach Factor	(C) Ambient Bioavailable Conc. in Plume (mg/l)	(D) Average Exposure Concentration (mg/l)	(E) BCF (l/kg) (a)	(F) Fish Tissue Concentration (mg/kg)
Naphthalene	1.170		3.40e-04	6.90e-08	426	2.94e-05
Fluorene	0.6382		1.85e-04	3.77e-08	30	1.13e-06
Phenanthrene	1.5136		4.40e-04	8.93e-08	2630	2.35e-04
Phenol	0.0001		2.91e-08	5.90e-12	1.4	8.26e-12
Cadmium	0.1707	0.11	5.46e-06	1.11e-09	64	7.09e-08
Mercury	0.0155	0.018	8.11e-08	1.65e-11	5500	9.06e-08
Antimony	0.8843		2.57e-04	5.22e-08	1	5.22e-08
Arsenic	1.1015	0.005	1.60e-06	3.25e-10	44	1.43e-08
Beryllium	0.1086		3.16e-05	6.41e-09	19	1.22e-07
Chromium	37.233	0.034	3.68e-04	7.47e-08	16	1.20e-06
Copper	2.9011	0.0063	5.31e-06	1.08e-09	36	3.88e-08
Lead	5.4453	0.02	3.16e-05	6.43e-09	49	3.15e-07
Nickel	2.0944	0.043	2.62e-05	5.31e-09	47	2.50e-07
Selenium	0.1707		4.96e-05	1.01e-08	4.8	4.84e-08
Silver	0.1086		3.16e-05	6.41e-09	0.5	3.20e-09
Thallium	0.1862		5.41e-05	1.10e-08	116	1.27e-06
Zinc	31.11	0.0041	3.71e-05	7.53e-09	47	3.54e-07
Aluminum	1,407		4.09e-01	8.30e-05	231	1.92e-02
Barium	18,516		5.38e+00	1.09e-03		
Iron	2,380		6.92e-01	1.41e-04		
Tin	2.265		6.58e-04	1.34e-07		
Titanium	13.575		3.94e-03	8.01e-07		

(a)　　　There are no BCFs for specific SBF compounds.

Table Calculations:

　　　Average number of dilutions in area within mixing zone (100 m radius) = 3,442

　　　SBF plume volume = time to reach 100 m * discharge rate * no. of dilutions =
　　　　　(5.5 min. * 0.0175 m^3/min) * 3,442 dilutions = 331 m^3

　　　Mixing zone cylinder volume = 157,000 m^3; based on 100 m radius and
　　　　　5 m depth = time to reach 100 m (5.5 min) * fall velocity (0.015 m/sec)

　　　SBF plume portion of cylinder volume =
　　　　　0.21% = fractional area of mixing zone affected by plume (331/157,000)

　　　C=　　　A * B/dilutions (B is assumed to be 1 unless otherwise noted)
　　　D=　　　C * 0.0021 (SBF plume portion of cylinder)
　　　F=　　　D * E (exposure conc. x BCF)

Exhibit E-6. Recreational Finfish Tissue Pollutant Concentrations - Offshore California Discharge Option

Pollutant	(A) Average Concentration (mg/l)	(B) Leach Factor	(C) Ambient Bioavailable Conc. in Plume (mg/l)	(D) Average Exposure Concentration (mg/l)	(E) BCF (l/kg) (a)	(F) Fish Tissue Concentration (mg/kg)
Naphthalene	0.811		2.36e-04	4.79e-08	426	2.039e-05
Fluorene	0.4424		1.29e-04	2.61e-08	30	7.831e-07
Phenanthrene	1.0494		3.05e-04	6.19e-08	2630	1.629e-04
Phenol	0.0001		2.91e-08	5.90e-12	1.4	8.261e-12
Cadmium	0.1183	0.11	3.78e-06	7.68e-10	64	4.914e-08
Mercury	0.0108	0.018	5.65e-08	1.15e-11	5500	6.309e-08
Antimony	0.6128		1.78e-04	3.62e-08	1	3.616e-08
Arsenic	0.7634	0.005	1.11e-06	2.25e-10	44	9.910e-09
Beryllium	0.0753		2.19e-05	4.43e-09	19	8.442e-08
Chromium	25.804	0.034	2.55e-04	5.18e-08	16	8.283e-07
Copper	2.0106	0.0063	3.68e-06	7.47e-10	36	2.691e-08
Lead	3.7738	0.02	2.19e-05	4.45e-09	49	2.182e-07
Nickel	1.4515	0.043	1.81e-05	3.68e-09	47	1.731e-07
Selenium	0.1183		3.44e-05	6.98e-09	4.8	3.351e-08
Silver	0.0753		2.19e-05	4.44e-09	0.5	2.222e-09
Thallium	0.129		3.75e-05	7.61e-09	116	8.830e-07
Zinc	21.56	0.0041	2.57e-05	5.22e-09	47	2.451e-07
Aluminum	975		2.83e-01	5.75e-05	231	1.329e-02
Barium	12,902		3.75e+00	7.61e-04		
Iron	1,649		4.79e-01	9.74e-05		
Tin	1.570		4.56e-04	9.26e-08		
Titanium	9.408		2.73e-03	5.55e-07		

(a)   There are no BCFs for specific SBF compounds.

Table Calculations:

   Average number of dilutions in area within mixing zone (100 m radius) = 3,442

   SBF plume volume = time to reach 100 m * discharge rate * no. of dilutions =
       (5.5 min. * 0.0175 m^3/min) * 3,442 dilutions = 331 m^3

   Mixing zone cylinder volume = 157,000 m^3; based on 100 m radius and
       5 m depth = time to reach 100 m (5.5 min) * fall velocity (0.015 m/sec)

   SBF plume portion of cylinder volume =
       0.21% = fractional area of mixing zone affected by plume (331/157,000)

   C=   A * B/dilutions (B is assumed to be 1 unless otherwise noted)
   D=   C * 0.0021 (SBF plume portion of cylinder)
   F=   D * E (exposure conc. x BCF)

APPENDIX F

**CALCULATION OF
SEDIMENT PORE WATER POLLUTANT CONCENTRATIONS
FOR SHRIMP TISSUE
POLLUTANT CONCENTRATION CALCULATION**

Exhibit F-1. Gulf of Mexico Shallow Water Development Model Well

Pore Water Concentrations for Calculation of Shrimp Tissue Pollutant Concentrations: Current Technology

Technology = Discharge Assuming 11% (wt) Base Fluid Retention on Discharged Cuttings and 0.2% (vol.) Crude Contamination in SBF

Dry Cuttings Generated per Well: 514,150 lbs

Whole Drilling Fluid Discharged per Well: 389 bbls

Impact Area per Well: 1.9 km^2

Pollutant Name	Avg. Conc. of Pollutants in Drilling Waste	Pollutant Loadings per Well (lbs) Current Technology (11%)	Pollutant Loadings per Well (mg)	Pollutant Sediment Concentration (mg poll./kg sed.)	Sediment Partition Coefficient or Leach Percentage Factors	Estimated Pore Water Conc. (mg/l) (a)
Conventional Pollutants	**lbs/lb disch. cuttings**					
TSS (associated with adhering SBF)		51,818				
TSS (associated with dry cuttings)		514,150				
TSS (total)		565,968				
Total Oil (synthetic plus crude)		74,062		6,629		
Priority Pollutant Organics	**lbs/bbl drilling fluid**					
Naphthalene	1.01e-03	3.91e-01	1.77e+05	0.0026	0.0795	2.28e-04
Fluorene	5.48e-04	2.13e-01	9.67e+04	0.0014	0.0407	6.38e-05
Phenanthrene	1.30e-03	5.06e-01	2.29e+05	0.0034	0.0113	4.19e-05
Phenol	7.22e-08	2.81e-05	1.27e+01	1.89e-07	11.3380	2.33e-06
Priority Pollutants, Metals	**lbs/lb dry SBF**					
Cadmium	1.10e-06	5.70e-02	2.59e+04	0.0004	0.1100	4.61e-05
Mercury	1.00e-07	5.18e-03	2.35e+03	3.48e-05	0.0180	6.85e-07
Antimony	5.70e-06	2.95e-01	1.34e+05	0.0020	1.0000	2.17e-03
Arsenic	7.10e-06	3.68e-01	1.67e+05	0.0025	0.0050	1.35e-05
Beryllium	7.00e-07	3.63e-02	1.65e+04	0.0002	1.0000	2.66e-04
Chromium	2.40e-04	1.24e+01	5.64e+06	0.0836	0.0340	3.10e-03
Copper	1.87e-05	9.69e-01	4.40e+05	0.0065	0.0063	4.49e-05
Lead	3.51e-05	1.82e+00	8.25e+05	0.0122	0.0200	2.68e-04
Nickel	1.35e-05	7.00e-01	3.17e+05	0.0047	0.0430	2.20e-04
Selenium	1.10e-06	5.70e-02	2.59e+04	0.0004	1.0000	4.18e-04
Silver	7.00e-07	3.63e-02	1.65e+04	0.0002	1.0000	2.66e-04
Thallium	1.20e-06	6.22e-02	2.82e+04	0.0004	1.0000	4.57e-04
Zinc	2.00e-04	1.04e+01	4.71e+06	0.0699	0.0041	3.12e-04
Non-Conventional Pollutants	**lbs/lb dry SBF or bbl SBF**					
Aluminum	9.07e-03	4.70e+02	2.13e+08	3.1606	1.0000	3.45e+00
Barium	1.20e-01	6.22e+03	2.82e+09	41.8164	0.0021	9.59e-02
Iron	1.53e-02	7.95e+02	3.61e+08	5.3470	0.1300	7.59e-01
Tin	1.46e-05	7.57e-01	3.43e+05	0.0051		
Titanium	8.75e-05	4.53e+00	2.06e+06	0.0305		
Alkylated benzenes	5.66e-03	2.20e+00	9.98e+05	0.0148		
Alkylated naphthalenes	5.32e-02	2.07e+01	9.39e+06	0.1392		
Alkylated fluorenes	6.40e-03	2.49e+00	1.13e+06	0.0168		
Alkylated phenanthrenes	8.09e-03	3.15e+00	1.43e+06	0.0212		
Alkylated phenols	6.37e-07	2.48e-04	1.12e+02	1.67e-06		
Total biphenyls	1.05e-02	4.09e+00	1.86e+06	0.0275		
Total dibenzothiophenes	9.15e-06	3.56e-03	1.61e+03	2.39e-05		

(a) Estimated pore water conc. = Poll. sediment conc. * Sed. partition coeff. or leach factor * 35.5 kg of sediment / 32.5 liter pore water unit volume

Exhibit F-2. Gulf of Mexico Shallow Water Development Model Well

Pore Water Concentrations for Calculation of Shrimp Tissue Pollutant Concentrations: Discharge Option

Technology = Discharge Assuming 7% (wt) Base Fluid Retention on Discharged Cuttings and 0.2% (vol) Crude Contamination in SBF

Dry Cuttings Generated per Well: 514,150   **lbs**

Whole Drilling Fluid Discharged Per Well: 223   **bbls**

Impact Area per Well: 1.9   **km^2**

Pollutant Name	Avg. Conc. of Pollutants in Drilling Waste	Pollutant Loadings per Well (lbs) Discharge Option (7%)	Pollutant Loadings per Well (mg)	Pollutant Sediment Concentration (mg poll./kg sed.)	Sediment Partition Coefficient or Leach Percentage Factors	Estimated Pore Water Conc. (mg/l) (a)
Conventional Pollutants	**lbs/lb disch. cuttings**					
TSS (associated with adhering SBF)		29,661				
TSS (associated with dry cuttings)		514,150				
TSS (total)		543,811				
Total Oil (synthetic plus crude)		42,418		3,796.48		
Priority Pollutants, Organics	**lbs/bbl drilling fluid**					
Naphthalene	1.01e-03	2.24e-01	101,605	1.51e-02	0.0795	5.62e-02
Fluorene	5.48e-04	1.22e-01	55,338	8.20e-03	0.0407	1.10e-03
Phenanthrene	1.30e-03	2.90e-01	131,542	1.95e-02	0.0113	2.40e-05
Phenol	7.22e-08	1.61e-05	7	1.04e-06	11.3380	1.34e-06
Priority Pollutants, Metals	**lbs/lb dry SBF**					
Cadmium	1.10e-06	3.26e-02	14,787	2.19e-03	0.1100	2.63e-05
Mercury	1.00e-07	2.97e-03	1,347	2.00e-04	0.0180	3.92e-07
Antimony	5.70e-06	1.69e-01	76,657	1.14e-02	1.0000	1.24e-03
Arsenic	7.10e-06	2.11e-01	95,708	1.42e-02	0.0050	7.73e-06
Beryllium	7.00e-07	2.08e-02	9,435	1.40e-03	1.0000	1.53e-04
Chromium	2.40e-04	7.12e+00	3,229,582	4.79e-01	0.0340	1.78e-03
Copper	1.87e-05	5.55e-01	251,744	3.73e-02	0.0063	2.57e-05
Lead	3.51e-05	1.04e+00	471,737	6.99e-02	0.0200	1.53e-04
Nickel	1.35e-05	4.00e-01	181,437	2.69e-02	0.0430	1.27e-04
Selenium	1.10e-06	3.26e-02	14,787	2.19e-03	1.0000	2.39e-04
Silver	7.00e-07	2.08e-02	9,435	1.40e-03	1.0000	1.53e-04
Thallium	1.20e-06	3.56e-02	16,148	2.39e-03	1.0000	2.61e-04
Zinc	2.00e-04	5.95e+00	2,698,878	4.00e-01	0.0041	1.79e-04
Non-Conventional Pollutants	**lbs/lb dry SBF or bbl SBF**					
Aluminum	9.07e-03	2.69e+02	122,016,517	1.81e+01	1.0000	1.98e+00
Barium	1.20e-01	3.56e+03	1,614,791,080	2.39e+02	0.0021	5.49e-02
Iron	1.53e-02	4.55e+02	206,384,815	3.06e+01	0.1300	4.34e-01
Tin	1.46e-05	4.33e-01	196,406	2.91e-02		
Titanium	8.75e-05	2.60e+00	1,179,342	1.75e-01		
Alkylated benzenes	5.66e-03	1.26e+00	571,527	8.47e-02		
Alkylated naphthalenes	5.32e-02	1.19e+01	5,397,757	8.00e-01		
Alkylated fluorenes	6.40e-03	1.43e+00	648,638	9.62e-02		
Alkylated phenanthrenes	8.09e-03	1.80e+00	816,467	1.21e-01		
Alkylated phenols	6.37e-07	1.42e-04	64	9.49e-06		
Total biphenyls	1.05e-02	2.35e+00	1,065,944	1.58e-01		
Total dibenzothiophenes	9.15e-06	2.04e-03	925	0		

(a) Estimated pore water conc. = Poll. sediment conc. * Sed. partition coeff. or leach factor * 35.5 kg of sediment / 32.5 liter pore water unit volume

Exhibit F-3. Gulf of Mexico Shallow Exploratory Model Well

Pore Water Concentrations for Calculation of Shrimp Tissue Pollutant Concentrations: Current Technology

Technology = Discharge Assuming 11% (wt) Base Fluid Retention on Discharged Cuttings and 0.2% (vol.) Crude Contamination in SBF

Dry Cuttings Generated per Well: 1,077,440 lbs

Whole Drilling Fluid Discharged per Well: 814 bbls

Impact Area per Well: 1.9 km^2

Pollutant Name	Avg. Conc. of Pollutants in Drilling Waste	Pollutant Loadings per Well (lbs) Current Technology (11%)	Pollutant Loadings per Well (mg)	Pollutant Sediment Concentration (mg poll./kg sed.)	Sediment Partition Coefficient or Leach Percentage Factors	Estimated Pore Water Conc. (mg/l) (a)
Conventional Pollutants	**lbs/lb disch. cuttings**					
TSS (associated with adhering SBF)		108,588				
TSS (associated with dry cuttings)		1,077,440				
TSS (total)		1,186,028				
Total Oil (synthetic plus crude)		155,202		13,891.64		
Priority Pollutant Organics	**lbs/bbl drilling fluid**					
Naphthalene	1.01e-03	8.18e-01	3.71e+05	5.50e-03	0.0795	4.77e-04
Fluorene	5.48e-04	4.46e-01	2.02e+05	3.00e-03	0.0407	1.33e-04
Phenanthrene	1.30e-03	1.06e+00	4.80e+05	7.12e-03	0.0113	8.78e-05
Phenol	7.22e-08	5.88e-05	2.67e+01	3.95e-07	11.3380	4.89e-06
Priority Pollutants, Metals	**lbs/lb dry SBF**					
Cadmium	1.10e-06	1.19e-01	5.42e+04	8.03e-04	0.1100	9.66e-05
Mercury	1.00e-07	1.09e-02	4.93e+03	7.30e-05	0.0180	1.43e-06
Antimony	5.70e-06	6.19e-01	2.81e+05	4.16e-03	1.0000	4.54e-03
Arsenic	7.10e-06	7.71e-01	3.50e+05	5.18e-03	0.0050	2.83e-05
Beryllium	7.00e-07	7.60e-02	3.45e+04	5.11e-04	1.0000	5.58e-04
Chromium	2.40e-04	2.61e+01	1.18e+07	1.75e-01	0.0340	6.51e-03
Copper	1.87e-05	2.03e+00	9.21e+05	1.37e-02	0.0063	9.39e-05
Lead	3.51e-05	3.81e+00	1.73e+06	2.56e-02	0.0200	5.60e-04
Nickel	1.35e-05	1.47e+00	6.65e+05	9.86e-03	0.0430	4.63e-04
Selenium	1.10e-06	1.19e-01	5.42e+04	8.03e-04	1.0000	8.77e-04
Silver	7.00e-07	7.60e-02	3.45e+04	5.11e-04	1.0000	5.58e-04
Thallium	1.20e-06	1.30e-01	5.91e+04	8.76e-04	1.0000	9.57e-04
Zinc	2.00e-04	2.18e+01	9.88e+06	1.46e-01	0.0041	6.55e-04
Non-Conventional Pollutants	**lbs/lb dry SBF or bbl SBF**					
Aluminum	9.07e-03	9.85e+02	4.47e+08	6.62e+00	1.0000	7.23e+00
Barium	1.20e-01	1.30e+04	5.91e+09	8.76e+01	0.0021	2.00e-01
Iron	1.53e-02	1.67e+03	7.56e+08	1.12e+01	0.1300	1.59e+00
Tin	1.46e-05	1.59e+00	7.19e+05	1.07e-02		
Titanium	8.75e-05	9.50e+00	4.31e+06	6.39e-02		
Alkylated benzenes	5.66e-03	4.61e+00	2.09e+06	3.10e-02		
Alkylated naphthalenes	5.32e-02	4.33e+01	1.96e+07	2.91e-01		
Alkylated fluorenes	6.40e-03	5.21e+00	2.36e+06	3.51e-02		
Alkylated phenanthrenes	8.09e-03	6.59e+00	2.99e+06	4.43e-02		
Alkylated phenols	6.37e-07	5.18e-04	2.35e+02	3.49e-06		
Total biphenyls	1.05e-02	8.56e+00	3.88e+06	5.76e-02		
Total dibenzothiophenes	9.15e-06	7.45e-03	3.38e+03	5.01e-05		

(a) Estimated pore water conc. = Poll. sediment conc. * Sed. partition coeff. or leach factor * 35.5 kg of sediment / 32.5 liter pore water unit volume

Exhibit F-4. Gulf of Mexico Shallow Exploratory Model Well

Pore Water Concentrations for Calculation of Shrimp Tissue Pollutant Concentrations: Discharge Option

Technology = Discharge Assuming 7% (wt) Base Fluid Retention on Discharged Cuttings and 0.2% (vol) Crude Contamination in SBF

Dry Cuttings Generated per Well:		1,077,440	lbs			
Whole Drilling Fluid Discharged Per Well:		466	bbls			
Impact Area per Well:		1.9	km^2			

Pollutant Name	Avg. Conc. of Pollutants in Drilling Waste	Pollutant Loadings per Well (lbs) Discharge Option (7%)	Pollutant Loadings per Well (mg)	Pollutant Sediment Concentration (mg poll./kg sed.)	Sediment Partition Coefficient or Leach Percentage Factors	Estimated Pore Water Conc. (mg/l)
Conventional Pollutants	**lbs/lb disch. cuttings**					
TSS (associated with adhering SBF)		62,158				
TSS (associated with dry cuttings)		1,077,440				
TSS (total)		1,139,598				
Total Oil (synthetic plus crude)		88,890		7,955.74		
Priority Pollutants, Organics	**lbs/bbl drilling fluid**					
Naphthalene	0.0010052	0.4684	212,463	3.15e-02	0.0795	2.73e-04
Fluorene	0.0005483	0.2555	115,893	1.72e-02	0.0407	7.64e-05
Phenanthrene	0.0013004	0.6060	274,877	4.08e-02	0.0113	5.04e-05
Phenol	7.22e-08	3.37e-05	15	2.22e-06	11.3380	2.81e-06
Priority Pollutants, Metals	**lbs/lb dry SBF**					
Cadmium	0.0000011	0.0684	31,026	4.60e-03	0.1100	5.53e-05
Mercury	0.0000001	0.0062	2,812	4.17e-04	0.0180	8.21e-07
Antimony	0.0000057	0.3543	160,708	2.38e-02	1.0000	2.60e-03
Arsenic	0.0000071	0.4413	200,171	2.97e-02	0.0050	1.62e-05
Beryllium	0.0000007	0.0435	19,731	2.93e-03	1.0000	3.20e-04
Chromium	0.0002400	14.9179	6,766,655	1.00e+00	0.0340	3.72e-03
Copper	0.0000187	1.1624	527,257	7.82e-02	0.0063	5.37e-05
Lead	0.0000351	2.1817	989,604	1.47e-01	0.0200	3.20e-04
Nickel	0.0000135	0.8391	380,610	5.64e-02	0.0430	2.65e-04
Selenium	0.0000011	0.0684	31,026	4.60e-03	1.0000	5.02e-04
Silver	0.0000007	0.0435	19,731	2.93e-03	1.0000	3.20e-04
Thallium	0.0000012	0.0746	33,838	5.02e-03	1.0000	5.02e-04
Zinc	0.0002005	12.4627	5,652,993	8.38e-01	0.0041	3.76e-04
Non-Conventional Pollutants	**lbs/lb dry SBF or bbl SBF**					
Aluminum	0.0090699	563.7668	255,720,674	3.79e+01	1.0000	4.14e+00
Barium	0.1200000	7,458.9600	3,383,332,043	5.02e+02	0.0021	1.15e-01
Iron	0.0153443	953.7710	432,623,849	6.41e+01	0.1300	9.11e-01
Tin	0.0000146	0.9075	411,636	6.10e-02		
Titanium	0.0000875	5.4388	2,467,002	3.66e-01		
Alkylated benzenes	0.0056587	2.6369	1,196,079	1.77e-01		
Alkylated naphthalenes	0.0531987	24.7906	11,244,843	1.67e+00		
Alkylated fluorenes	0.0064038	2.9842	1,353,612	2.01e-01		
Alkylated phenanthrenes	0.0080909	3.7703	1,710,182	2.54e-01		
Alkylated phenols	0.0000006	0.0003	136	2.02e-05		
Total biphenyls	0.0105160	4.9005	2,222,832	3.30e-01		
Total dibenzothiophenes	0.0000092	0.0043	1,950	2.89e-04		

(a) Estimated pore water conc. = Poll. sediment conc. * Sed. partition coeff. or leach factor * 35.5 kg of sediment / 32.5 liter pore water unit volume

Exhibit F-5. California Shallow Water Development Model Well

Pore Water Concentrations for Calculation of Shrimp Tissue Pollutant Concentrations: Current Technology

Technology = Discharge Assuming 11% (wt) Base Fluid Retention on Discharged Cuttings and 0.2% (vol.) Crude Contamination in SBF

Dry Cuttings Generated per Well: 514,150 **lbs**

Whole Drilling Fluid Discharged per Well: 389 **bbls**

Impact Area per Well: 1.9 **km^2**

Pollutant Name	Avg. Conc. of Pollutants in Drilling Waste	Pollutant Loadings per Well (lbs) Current Technology (11%)	Pollutant Loadings per Well (mg)	Pollutant Sediment Concentration (mg poll./kg sed.)	Sediment Partition Coefficient or Leach Percentage Factors	Estimated Pore Water Conc. (mg/kg)
Conventional Pollutants	**lbs/lb disch. cuttings**					
TSS (associated with adhering SBF)		51,818				
TSS (associated with dry cuttings)		514,150				
TSS (total)		565,968				
Total Oil (synthetic plus crude)		74,062		4,130		
Priority Pollutant Organics	**lbs/bbl drilling fluid**					
Naphthalene	1.01e-03	3.91e-01	1.77e+05	0.0026	0.0795	2.28e-04
Fluorene	5.48e-04	2.13e-01	9.67e+04	0.0014	0.0407	6.38e-05
Phenanthrene	1.30e-03	5.06e-01	2.29e+05	0.0034	0.0113	4.19e-05
Phenol	7.22e-08	2.81e-05	1.27e+01	1.89e-07	11.3380	2.34e-06
Priority Pollutants, Metals	**lbs/lb dry SBF**					
Cadmium	1.10e-06	5.70e-02	2.59e+04	0.0004	0.1100	4.61e-05
Mercury	1.00e-07	5.18e-03	2.35e+03	3.48e-05	0.0180	6.85e-07
Antimony	5.70e-06	2.95e-01	1.34e+05	0.0020		2.17e-03
Arsenic	7.10e-06	3.68e-01	1.67e+05	0.0025	0.0050	1.35e-05
Berylium	7.00e-07	3.63e-02	1.65e+04	0.0002		2.66e-04
Chromium	2.40e-04	1.24e+01	5.64e+06	0.0836	0.0340	3.10e-03
Copper	1.87e-05	9.69e-01	4.40e+05	0.0065	0.0063	4.49e-05
Lead	3.51e-05	1.82e+00	8.25e+05	0.0122	0.0200	2.68e-04
Nickel	1.35e-05	7.00e-01	3.17e+05	0.0047	0.0430	2.21e-04
Selenium	1.10e-06	5.70e-02	2.59e+04	0.0004		4.18e-04
Silver	7.00e-07	3.63e-02	1.65e+04	0.0002		2.67e-04
Thallium	1.20e-06	6.22e-02	2.82e+04	0.0004		4.57e-04
Zinc	2.00e-04	1.04e+01	4.71e+06	0.0699	0.0041	3.12e-04
Non-Conventional Pollutants	**lbs/lb dry SBF or bbl SBF**					
Aluminum	9.07e-03	4.70e+02	2.13e+08	3.1606		3.45e+00
Barium	1.20e-01	6.22e+03	2.82e+09	41.8164	0.0021	9.59e-02
Iron	1.53e-02	7.95e+02	3.61e+08	5.3470	0.1300	7.59e-01
Tin	1.46e-05	7.57e-01	3.43e+05	0.0051		
Titanium	8.75e-05	4.53e+00	2.06e+06	0.0305		
Alkylated benzenes	5.66e-03	2.20e+00	9.98e+05	0.0148		
Alkylated naphthalenes	5.32e-02	2.07e+01	9.39e+06	0.1392		
Alkylated fluorenes	6.40e-03	2.49e+00	1.13e+06	0.0168		
Alkylated phenanthrenes	8.09e-03	3.15e+00	1.43e+06	0.0212		
Alkylated phenlos	6.37e-07	2.48e-04	1.12e+02	1.67e-06		
Total biphenyls	1.05e-02	4.09e+00	1.86e+06	0.0275		
Total dibenzothiophenes	9.15e-06	3.56e-03	1.61e+03	2.39e-05		

(a) Estimated pore water conc. = Poll. sediment conc. * Sed. partition coeff. or leach factor * 35.5 kg of sediment / 32.5 liter pore water unit volume

Exhibit F-6. California Shallow Water Development Model Well

Pore Water Concentrations for Calculation of Shrimp Tissue Pollutant Concentrations: Discharge Option

Technology = Discharge Assuming 7% (wt) Base Fluid Retention on Discharged Cuttings and 0.2% (vol) Crude Contamination in SBF

Dry Cuttings Generated per Well: 514,150 **lbs**

Whole Drilling Fluid Discharged per Well: 223 **bbls**

Impact Area per Well: 1.9 **km^2**

Pollutant Name	Avg. Conc. of Pollutants in Drilling Waste	Pollutant Loadings per Well (lbs) Discharge Option (7%)	Pollutant Loadings per Well (mg)	Pollutant Sediment Concentration (mg poll./kg sed.)	Sediment Partition Coefficient or Leach Percentage Factors	Estimated Pore Water Conc. (mg/kg)
Conventional Pollutants	**lbs/lb disch. cuttings**					
TSS (associated with adhering SBF)		29,661				
TSS (associated with dry cuttings)		514,150				
TSS (total)		543,811				
Total Oil (synthetic plus crude)		42,418		2,365.35		
Priority Pollutants, Organics	**lbs/bbl drilling fluid**					
Naphthalene	1.01e-03	2.24e-01	1.02e+05	1.51e-03	0.0795	1.31e-04
Fluorene	5.48e-04	1.22e-01	5.53e+04	8.20e-04	0.0407	3.66e-05
Phenanthrene	1.30e-03	2.90e-01	1.32e+05	1.95e-03	0.0113	2.40e-05
Phenol	7.22e-08	1.61e-05	7.31e+00	1.08e-07	11.3380	1.34e-06
Priority Pollutants, Metals	**lbs/lb dry SBF**					
Cadmium	1.10e-06	3.26e-02	1.48e+04	2.19e-04	0.1100	2.63e-05
Mercury	1.00e-07	2.97e-03	1.35e+03	2.00e-05	0.0180	3.92e-07
Antimony	5.70e-06	1.69e-01	7.67e+04	1.14e-03		1.24e-03
Arsenic	7.10e-06	2.11e-01	9.57e+04	1.42e-03	0.0050	7.73e-06
Berylium	7.00e-07	2.08e-02	9.43e+03	1.40e-04		1.53e-04
Chromium	2.40e-04	7.12e+00	3.23e+06	4.79e-02	0.0340	1.78e-03
Copper	1.87e-05	5.55e-01	2.52e+05	3.73e-03	0.0063	2.57e-05
Lead	3.51e-05	1.04e+00	4.72e+05	6.99e-03	0.0200	1.53e-04
Nickel	1.35e-05	4.00e-01	1.81e+05	2.69e-03	0.0430	1.27e-04
Selenium	1.10e-06	3.26e-02	1.48e+04	2.19e-04		2.39e-04
Silver	7.00e-07	2.08e-02	9.43e+03	1.40e-04		1.53e-04
Thallium	1.20e-06	3.56e-02	1.61e+04	2.39e-04		2.61e-04
Zinc	2.00e-04	5.95e+00	2.70e+06	4.00e-02	0.0041	1.79e-04
Non-Conventional Pollutants	**lbs/lb dry SBF or bbl SBF**					
Aluminum	9.07e-03	2.69e+02	1.22e+08	1.81e+00		1.98e+00
Barium	1.20e-01	3.56e+03	1.61e+09	2.39e+01	0.0021	5.49e-02
Iron	1.53e-02	4.55e+02	2.06e+08	3.06e+00	0.1300	4.35e-01
Tin	1.46e-05	4.33e-01	1.96e+05	2.91e-03		
Titanium	8.75e-05	2.60e+00	1.18e+06	1.75e-02		
Alkylated benzenes	5.66e-03	1.26e+00	5.72e+05	8.47e-03		
Alkylated naphthalenes	5.32e-02	1.19e+01	5.40e+06	8.00e-02		
Alkylated fluorenes	6.40e-03	1.43e+00	6.49e+05	9.62e-03		
Alkylated phenanthrenes	8.09e-03	1.80e+00	8.16e+05	1.21e-02		
Alkylated phenols	6.37e-07	1.42e-04	6.44e+01	9.55e-07		
Total biphenyls	1.05e-02	2.35e+00	1.07e+06	1.58e-02		
Total dibenzothiophenes	9.15e-06	2.04e-03	9.25e+02	1.37e-05		

(a) Estimated pore water conc. = Poll. sediment conc. * Sed. partition coeff. or leach factor * 35.5 kg of sediment / 32.5 liter pore water unit volume

APPENDIX G

**CALCULATION OF
SHRIMP TISSUE POLLUTANT CONCENTRATIONS**

Exhibit G-1. Commercial Shrimp Tissue Pollutant Concentrations - Gulf of Mexico Shallow Water Development Model Well, Current Technology

Pollutant	(A) Pollutant Sediment Concentration (mg poll./kg sed.)	(B) Sediment Partition Coeff.^1 or Leach Factor	(C) Estimated Pore Water Conc. (mg/l)	(D) BCF (l/kg) (a)	(E) Shrimp Tissue Conc. (mg/kg)
Naphthalene	2.60e-03	0.0795	2.28e-04	426	9.80e-02
Fluorene	1.40e-03	0.0407	6.38e-05	30	1.93e-03
Phenanthrene	3.40e-03	0.0113	4.19e-05	2630	1.11e-01
Phenol	1.89e-07	11.338	2.33e-06	1.4	3.30e-06
Cadmium	4.00e-04	0.11	4.61e-05	64	2.70e-03
Mercury	3.48e-05	0.018	6.85e-07	5500	3.45e-03
Antimony	2.00e-03		2.17e-03	1	1.99e-03
Arsenic	2.50e-03	0.005	1.35e-05	44	5.44e-04
Beryllium	2.00e-04		2.66e-04	19	4.63e-03
Chromium	8.36e-02	0.034	3.10e-03	16	4.55e-02
Copper	6.50e-03	0.0063	4.49e-05	36	1.48e-03
Lead	1.20e-02	0.02	2.68e-04	49	1.20e-02
Nickel	4.70e-03	0.043	2.20e-04	47	9.51e-03
Selenium	4.00e-04		4.18e-04	4.8	1.84e-03
Silver	2.00e-04		2.66e-04	0.5	1.22e-04
Thallium	4.00e-04		4.57e-04	116	4.85e-02
Zinc	6.99e-02	0.0041	3.12e-04	47	1.35e-02
Aluminum	3.16e+00		3.45e+00	231	7.30e+02
Barium	4.18e+01	0.0021	9.59e-02		
Iron	5.34e+00	0.13	7.59e-01		
Tin	5.10e-03				
Titanium	3.05e-02				
Alkylated benzenes	1.48e-02				
Alkylated naphthalenes	1.39e-01				
Alkylated fluorenes	1.68e-02				
Alkylated phenanthrenes	2.12e-02				
Alkylated phenols	1.67e-06				
Total biphenyls	2.75e-02				
Total dibenzothiophenes	2.39e-05				

(a)   There are no BCFs for specific SBF compounds.
See Appendix F for pollutant sediment concentration calculations.

Table Calculations:
  C=   A * B (B is assumed to be 1 unless otherwise noted) * 35.5 kg sediment / 32.5 liter pore water unit volume
  E=   C * D * 1.1% (pore water conc. * BCF * shrimp lipid percent)

Exhibit G-2. Commercial Shrimp Tissue Pollutant Concentrations - Gulf of Mexico Shallow Water Development Model Well, Discharge Option

Pollutant	(A) Pollutant Sediment Concentration (mg poll./kg sed.)	(B) Sediment Partition Coeff.^1 or Leach Factor	(C) Estimated Pore Water Conc. (mg/l)	(D) BCF (l/kg) (a)	(E) Shrimp Tissue Conc. (mg/kg)
Naphthalene	1.50e-03	0.0795	1.31e-04	426	5.62e-02
Fluorene	8.00e-04	0.0407	3.66e-05	30	1.10e-03
Phenanthrene	2.00e-03	0.0113	2.40e-05	2630	6.38e-02
Phenol	1.08e-07	11.338	1.34e-06	1.4	1.89e-06
Cadmium	2.00e-04	0.11	2.63e-05	64	1.54e-03
Mercury	1.99e-05	0.018	3.92e-07	5500	1.97e-03
Antimony	1.10e-03		1.24e-03	1	1.14e-03
Arsenic	1.40e-03	0.005	7.73e-06	44	3.12e-04
Beryllium	1.00e-04		1.53e-04	19	2.65e-03
Chromium	4.79e-02	0.034	1.78e-03	16	2.60e-02
Copper	3.70e-03	0.0063	2.57e-05	36	8.46e-04
Lead	7.00e-03	0.02	1.53e-04	49	6.86e-03
Nickel	2.70e-03	0.043	1.27e-04	47	5.44e-03
Selenium	2.00e-04		2.39e-04	4.8	1.05e-03
Silver	1.00e-04		1.53e-04	0.5	6.98e-05
Thallium	2.00e-04		2.61e-04	116	2.78e-02
Zinc	4.00e-02	0.0041	1.79e-04	47	7.71e-03
Aluminum	1.81e+00		1.98e+00	231	4.18e+02
Barium	2.39e+01	0.0021	5.49e-02		
Iron	3.06e+00	0.13	4.34e-01		
Tin	2.90e-03				
Titanium	1.75e-02				
Alkylated benzenes	8.50e-03				
Alkylated naphthalenes	7.98e-02				
Alkylated fluorenes	9.60e-03				
Alkylated phenanthrenes	1.21e-02				
Alkylated phenols	9.55e-07				
Total biphenyls	1.58e-02				
Total dibenzothiophenes	1.37e-05				

(a)   There are no BCFs for specific SBF compounds.
See Appendix F for pollutant sediment concentration calculations.

Table Calculations:

C=   A * B (B is assumed to be 1 unless otherwise noted) * 35.5 kg sediment / 32.5 liter pore water unit volume

E=   C * D * 1.1% (pore water conc. * BCF * shrimp lipid percent)

Exhibit G-3. Commercial Shrimp Tissue Pollutant Concentrations - Gulf of Mexico Shallow Water Exploratory Model Well, Current Technology

Pollutant	(A) Pollutant Sediment Concentration (mg poll./kg sed.)	(B) Sediment Partition Coeff.^1 or Leach Factor	(C) Estimated Pore Water Conc. (mg/l)	(D) BCF (l/kg) (a)	(E) Shrimp Tissue Conc. (mg/kg)
Naphthalene	5.50e-03	0.0795	4.77e-04	426	2.05e-01
Fluorene	3.00e-03	0.0407	1.33e-04	30	4.03e-03
Phenanthrene	7.10e-03	0.0113	8.78e-05	2630	2.33e-01
Phenol	3.95e-07	11.338	4.89e-06	1.4	6.91e-06
Cadmium	8.00e-04	0.11	9.66e-05	64	5.65e-03
Mercury	7.30e-05	0.018	1.43e-06	5500	7.23e-03
Antimony	4.20e-03		4.54e-03	1	4.16e-03
Arsenic	5.20e-03	0.005	2.83e-05	44	1.14e-03
Beryllium	5.00e-04		5.58e-04	19	9.71e-03
Chromium	1.75e-01	0.034	6.51e-03	16	9.53e-02
Copper	1.14e-02	0.0063	9.39e-05	36	3.10e-03
Lead	2.56e-02	0.02	5.60e-04	49	2.51e-02
Nickel	9.90e-03	0.043	4.63e-04	47	1.99e-02
Selenium	8.00e-04		8.77e-04	4.8	3.86e-03
Silver	5.00e-04		5.58e-04	0.5	2.56e-04
Thallium	9.00e-04		9.57e-04	116	1.02e-01
Zinc	1.46e-01	0.0041	6.55e-04	47	2.82e-02
Aluminum	6.62e+00		7.23e+00	231	1.53e+02
Barium	8.76e+01	0.0021	2.00e-01		
Iron	1.12e+01	0.13	1.59e+00		
Tin	1.07e-02				
Titanium	6.39e-02				
Alkylated benzenes	3.10e-02				
Alkylated naphthalenes	2.91e-01				
Alkylated fluorenes	3.51e-02				
Alkylated phenanthrenes	4.43e-02				
Alkylated phenols	3.49e-06				
Total biphenyls	5.76e-02				
Total dibenzothiophenes	5.01e-05				

(a)   There are no BCFs for specific SBF compounds.

See Appendix F for pollutant sediment concentration calculations.

Table Calculations:

C=   A * B (B is assumed to be 1 unless otherwise noted) * 35.5 kg sediment / 32.5 liter pore water unit volume

E=   C * D * 1.1% (pore water conc. * BCF * shrimp lipid percent)

Exhibit G-4. Commercial Shrimp Tissue Pollutant Concentrations - Gulf of Mexico Shallow Water Exploratory Model Well, Discharge Option

Pollutant	(A) Pollutant Sediment Concentration (mg poll./kg sed.)	(B) Sediment Partition Coeff.^1 or Leach Factor	(C) Estimated Pore Water Conc. (mg/l)	(D) BCF (l/kg) (a)	(E) Shrimp Tissue Conc. (mg/kg)
Naphthalene	3.20e-03	0.0795	2.73e-04	426	1.17e-01
Fluorene	1.70e-03	0.0407	7.64e-05	30	2.31e-03
Phenanthrene	4.10e-03	0.0113	5.04e-05	2630	1.33e-01
Phenol	2.26e-07	11.338	2.81e-06	1.4	3.95e-06
Cadmium	5.00e-04	0.11	5.53e-05	64	3.24e-03
Mercury	4.18e-05	0.018	8.21e-07	5500	4.14e-03
Antimony	2.40e-03		2.60e-03	1	2.38e-03
Arsenic	3.00e-03	0.005	1.62e-05	44	6.53e-04
Beryllium	3.00e-04		3.20e-04	19	5.56e-03
Chromium	1.00e-01	0.034	3.72e-03	16	5.46e-02
Copper	7.80e-03	0.0063	5.37e-05	36	1.77e-03
Lead	1.47e-02	0.02	3.20e-04	49	1.44e-02
Nickel	5.60e-03	0.043	2.65e-04	47	1.14e-02
Selenium	5.00e-04		5.02e-04	4.8	2.21e-03
Silver	3.00e-04		3.20e-04	0.5	1.46e-04
Thallium	5.00e-04		5.48e-04	116	5.82e-02
Zinc	8.38e-02	0.0041	3.76e-04	47	1.62e-02
Aluminum	3.79e+00		4.14e+00	231	8.76e+02
Barium	5.02e+01	0.0021	1.15e-01		
Iron	6.41e+00	0.13	9.11e-01		
Tin	6.10e-03				
Titanium	3.66e-02				
Alkylated benzenes	1.77e-02				
Alkylated naphthalenes	1.67e-01				
Alkylated fluorenes	2.01e-02				
Alkylated phenanthrenes	2.54e-02				
Alkylated phenols	2.00e-06				
Total biphenyls	3.30e-02				
Total dibenzothiophenes	2.87e-05				

(a)   There are no BCFs for specific SBF compounds.
See Appendix F for pollutant sediment concentration calculations.

Table Calculations:
        C=   A * B (B is assumed to be 1 unless otherwise noted) * 35.5 kg sediment / 32.5 liter pore water
                unit volume
        E=   C * D * 1.1% (pore water conc. * BCF * shrimp lipid percent)

Exhibit G-5. Commercial Shrimp Tissue Pollutant Concentrations - Offshore California Shallow Development Model Well, Current Technology

Pollutant	(A) Pollutant Sediment Concentration (mg poll./kg sed.)	(B) Sediment Partition Coeff.^1 or Leach Factor	(C) Estimated Pore Water Conc. (mg/l)	(D) BCF (l/kg) (a)	(E) Shrimp Tissue Conc. (mg/kg)
Naphthalene	2.60e-03	0.0795	2.28e-04	426	9.80e-02
Fluorene	1.40e-03	0.0407	6.38e-05	30	1.93e-03
Phenanthrene	3.40e-03	0.0113	4.19e-05	2630	1.11e-01
Phenol	1.89e-07	11.338	2.34e-06	1.4	3.30e-06
Cadmium	4.00e-04	0.11	4.61e-05	64	2.70e-03
Mercury	3.48e-05	0.018	6.85e-07	5500	3.45e-03
Antimony	2.00e-03		2.17e-03	1	1.99e-03
Arsenic	2.50e-03	0.005	1.35e-05	44	5.44e-04
Beryllium	2.00e-04		2.66e-04	19	4.63e-03
Chromium	8.36e-02	0.034	3.10e-03	16	4.55e-02
Copper	6.50e-03	0.0063	4.49e-05	36	1.48e-03
Lead	1.22e-02	0.02	2.68e-04	49	1.20e-02
Nickel	4.70e-03	0.043	2.21e-04	47	9.51e-03
Selenium	4.00e-04		4.18e-04	4.8	1.84e-03
Silver	2.00e-04		2.67e-04	0.5	1.22e-04
Thallium	4.00e-04		4.57e-04	116	4.85e-02
Zinc	6.99e-02	0.0041	3.12e-04	47	1.35e-02
Aluminum	3.16e+00		3.45e+00	231	7.31e+02
Barium	4.18e+01	0.0021	9.59e-02		
Iron	5.35e+00	0.13	7.59e-01		
Tin	5.10e-03				
Titanium	3.05e-02				
Alkylated benzenes	1.48e-02				
Alkylated naphthalenes	1.39e-01				
Alkylated fluorenes	1.68e-02				
Alkylated phenanthrenes	2.12e-02				
Alkylated phenols	1.67e-06				
Total biphenyls	2.75e-02				
Total dibenzothiophenes	2.39e-05				

(a)   There are no BCFs for specific SBF compounds.

See Appendix F for pollutant sediment concentration calculations.

Table Calculations:

C=   A * B (B is assumed to be 1 unless otherwise noted) * 35.5 kg sediment / 32.5 liter pore water unit volume

E=   C * D * 1.1% (pore water conc. * BCF * shrimp lipid percent)

Exhibit G-6. Commercial Shrimp Tissue Pollutant Concentrations - Offshore California, Shallow Water Development Model Well, Discharge Option

Pollutant	(A) Pollutant Sediment Concentration (mg poll./kg sed.)	(B) Sediment Partition Coeff.^1 or Leach Factor	(C) Estimated Pore Water Conc. (mg/l)	(D) BCF (l/kg) (a)	(E) Shrimp Tissue Conc. (mg/kg)
Naphthalene	1.50e-03	0.0795	1.31e-04	426	5.62e-02
Fluorene	8.00e-04	0.0407	3.66e-05	30	1.10e-03
Phenanthrene	2.00e-03	0.0113	2.40e-05	2630	6.38e-02
Phenol	1.08e-07	11.338	1.34e-06	1.4	1.89e-06
Cadmium	2.00e-04	0.11	2.63e-05	64	1.54e-03
Mercury	1.99e-05	0.018	3.92e-07	5500	1.97e-03
Antimony	1.10e-03		1.24e-03	1	1.40e-03
Arsenic	1.40e-03	0.005	7.73e-06	44	3.12e-04
Beryllium	1.00e-04		1.53e-04	19	2.65e-03
Chromium	4.79e-02	0.034	1.78e-03	16	2.60e-02
Copper	3.70e-03	0.0063	2.57e-05	36	8.46e-04
Lead	7.00e-03	0.02	1.53e-04	49	6.86e-03
Nickel	2.70e-03	0.043	1.27e-04	47	5.44e-03
Selenium	2.00e-04		2.39e-04	4.8	1.05e-03
Silver	1.00e-04		1.53e-04	0.5	6.98e-05
Thallium	2.00e-04		2.61e-04	116	2.78e-02
Zinc	4.00e-02	0.0041	1.79e-04	47	7.71e-03
Aluminum	1.81e+00		1.98e+00	231	4.18e+02
Barium	2.39e+01	0.0021	5.49e-02		
Iron	3.06e+00	0.13	4.35e-01		
Tin	2.90e-03				
Titanium	1.75e-02				
Alkylated benzenes	8.50e-03				
Alkylated naphthalenes	7.98e-02				
Alkylated fluorenes	9.60e-03				
Alkylated phenanthrenes	1.21e-02				
Alkylated phenols	9.55e-07				
Total biphenyls	1.58e-02				
Total dibenzothiophenes	1.37e-05				

(a)   There are no BCFs for specific SBF compounds.

See Appendix F for pollutant sediment concentration calculations.

Table Calculations:

C=   A * B (B is assumed to be 1 unless otherwise noted) * 35.5 kg sediment / 32.5 liter pore water unit volume

E=   C * D * 1.1% (pore water conc. * BCF * shrimp lipid percent)