Environmental aspects of the use and disposal of non aqueous drilling fluids associated with offshore oil & gas operations

Report No. 342
May 2003
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Environmental aspects of the use and disposal of non aqueous drilling fluids associated with offshore oil & gas operations

Report No: 342
May 2003
This report was produced by the Non-Aqueous Drilling Fluids Task Force.

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Executive Summary

New technical challenges in offshore drilling have led to the requirement of drilling fluids with drilling properties that exceed those of water based fluids. New concepts such as directional and extended reach drilling are required to develop many new resources economically. Such drilling requires fluids that provide high lubricity, stability at high temperatures and well-bore stability. These challenges have led to the development of more sophisticated non-aqueous drilling fluids (NADFs) that deliver high drilling performance and ensure environmentally sound operations.

The introduction of NADFs into the marine environment is associated with fluid adhering to discharged cuttings following treatment, since bulk discharge of NADFs is generally not allowed. This paper does not consider bulk discharge of NADFs. Significant advances have been made to reduce the toxicity and environmental impacts of NADFs. Where NADF cuttings discharge is allowed, diesel and conventional mineral oils have largely been replaced with fluids that are less toxic and less persistent. Polyaromatic hydrocarbons, the most toxic component of drilling fluids, have been reduced from 1-4% to less than 0.001% for newer fluids. New generation drilling fluids, such as paraffins, olefins and esters are less toxic and are more biodegradable than early generation diesel and mineral oil base fluids.

The purpose of this paper is to summarise the technical knowledge about discharges of cuttings when NADFs are used. The report summarises the results from over 75 publications and compiles the findings from all available research on the subject. It is intended to provide technical insight into this issue as regulations are considered in countries around the world. It should aid in the environmental assessment process for new projects as it provides a comprehensive synopsis of what is known about the environmental impacts resulting from discharge. A compilation of current regulations and practices from around the world is included in Appendix C of this report.

As summarised in this paper, discharge is one of several options that may be considered when deciding on waste management options. Other options include injection of cuttings or hauling cuttings to shore for disposal. All waste management options have both advantages and disadvantages with regard to environmental impact. This paper shows how environmental, operational and cost considerations can be weighed to decide which options might be considered for given operational and local environmental conditions. The development of more environmentally friendly fluids has been undertaken to reduce the environmental impact associated with the discharge of drill cuttings that when NADFs are used, and make that option more broadly acceptable. When applicable, offshore discharge is the safest and most economical option.

This paper also covers the tools and methods available to predict the fate and effects of drilling discharges. These include laboratory techniques that have been used to address toxicity, biodegradation and bioaccumulation characteristics of different fluids. Numerical models that can be used to predict the distribution of cuttings that are discharged into a given environment are also described.

A compilation of field monitoring results at offshore drilling sites reveals a relatively consistent picture of the fate and effects drill cuttings associated with NADFs. The degree of impact is a function of local environmental conditions (water depth, currents, temperature), and the amount and type of waste discharged. Further, at sites where cuttings associated with early generation drilling fluids were discharge, more significant temporal and spatial impacts were observed. Cuttings discharged with newer fluids resulted in a smaller zone of impact on the seafloor, and the biological community recovered more rapidly.

It is generally thought that the largest potential impact from discharge will occur in the sediment dwelling (benthic) community. The risk of water-column impact is low due to the short residence time of cuttings as they settle to the sea floor and the low water-solubility and
aromatic content of the base fluid. Impacts on the benthic biota are potentially due to several factors. These include chemical toxicity of the base fluid, oxygen depletion due to NADF biodegradation in the sediments and physical impacts from burial or changes in grain size. At sites where newer NADFs were used, field studies show that recovery is underway within one year of cessation of discharges.

The nature and degree of impacts on the benthic community tends to reflect variability between local environmental settings and differences in discharge practices. However, in sediments with substantially elevated NADF concentrations, impacts include reduced abundance and diversity of fauna. Recovery tends to follow a successional recolonisation, with initial colonisation with hydrocarbon-tolerant species and/or opportunistic species that feed on bacteria that metabolise hydrocarbons. As hydrocarbon loads diminish, other species recolonise the area to more closely resemble the original state. The implications of potential seafloor impacts depend on the sensitivity and significance of the bottom dwelling resources. In many environmental settings, the bottom sediments are already anoxic, and the addition of cuttings will have little incremental effect.

The degree and duration of impact depends on the thickness of the deposition, the original state of the sediment and the local environmental conditions. In some settings, the cuttings can be re-suspended eliminating any substantial accumulations. Initial deposition thickness depends on a number of factors including the amount of material discharged, water depth, discharge depth, the strength of currents in the area and the rate at which cuttings fall through the water column. Greater accumulation would be expected in the case of a multiple well development when compared with a single exploration well.

In conclusion, cuttings discharge appears to be a viable option in many environmental settings. Work continues to develop and implement new technologies for cuttings treatment to reduce fluid content on cuttings prior to discharge. Work also continues to improve and develop a full range of disposal options.
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1 Introduction

Exploration and development drilling activities have expanded globally into such regions as the Caspian Sea, the UK Atlantic margin, offshore Brazil and West Africa, and the deep waters of Gulf of Mexico as technology has improved the economics of finding and extracting oil and gas. New drilling concepts, including horizontal and multi-lateral wells, enable development to proceed with fewer platforms allowing these resources to be developed more economically. These techniques also have an environmental benefit of reducing the zone of seafloor disturbance.

New drilling concepts are technically challenging and require high performance drilling fluids with capabilities exceeding those available from water based fluids (WBFs). As a result, non-aqueous drilling fluids (NADFs), for which the continuous phase is primarily a non-water soluble base fluid ie non-aqueous base fluid (NABF), have also been used extensively by the petroleum industry.

The drilling process generates waste fluids and drill cuttings. Typical waste management options include reuse, offshore discharge, re-injection and onshore treatment and/or disposal. Choice of waste management options typically considers local regulations, environmental assessment and cost/benefit analysis.

Early applications of NADFs used diesel or crude oil as the base fluid. Later, to lessen environmental impacts when cuttings were discharged, mineral oils replaced diesel and crude. More recently, low toxicity mineral oil based fluids, highly refined mineral oils and synthetic fluids (esters, paraffins and olefins) have been used as base fluids. These fluids are generally less toxic due, in part, to reduced concentrations of aromatic compounds, and are less persistent in the environment.

In many jurisdictions, regulations to deal with the full range of NADF technology have not yet been developed. However, this is expected to change in the future since a number of countries have either drafted or are actively working on new regulations. Worldwide regulations on drilling discharges are summarised in Appendix C.

This document provides information useful for the development of technically based waste management practices that consider both environmental risks and the balance of cost and benefit associated with drilling discharges. Access to a full range of drilling fluid technology is necessary to achieve drilling performance objectives and providing cost-effective development, especially in deep water or where horizontal or extended reach drilling is employed. Consequently, it is essential to understand the potential environmental issues and effects associated with marine discharge of drilling wastes and the full life cycle analysis of implementing alternative options.

To this end, this document discusses what is known about the fate and effects of drilling discharges associated with the use of NADFs. In the following text, the process of oil and gas drilling is described along with the technical advantages and disadvantages of NADFs. This is followed by discussion of drill cuttings processing and waste disposal options, along with guidelines for conducting cost analyses of options. The fate and effects of drilling fluids on discharged cuttings are discussed next. Finally, the tools available to evaluate the environmental performance of NADFs, including laboratory testing, computer modelling and field studies are described along with the results of such studies.

† Drilling fluids are often referred to as muds or drilling muds
1.1. Processes of offshore oil & gas exploration and development drilling

1.1.1 Exploratory, developmental and other drilling

The two primary phases of drilling operations conducted as part of the oil and gas extraction process are exploration and development. Exploratory drilling involves drilling wells to determine whether hydrocarbons are present. Once hydrocarbons have been discovered, additional appraisal or delineation wells may be drilled to determine the size of the hydrocarbon accumulation. When the size of a hydrocarbon accumulation is defined sufficiently for commercial development, field development is started. Development wells are drilled for later production during this phase. Although the facilities used for each type of drilling may differ, the drilling process for each well is generally similar.

Exploration activities are usually of short duration, involve a relatively small number of wells, and are conducted from mobile drilling rigs. Development drilling usually occurs over a longer interval of time and involves multiple wells to different parts of the reservoir. Development wells are drilled to produce the hydrocarbon contained in the reservoir efficiently. They are drilled both as the initial means of producing the field and over the field’s life, to manage withdrawal of reserves properly and replace wells that have experienced mechanical problems.

1.1.2 Drilling rigs

Different types of facilities are commonly used for different drilling scenarios. Offshore, drilling operations are performed either from mobile offshore drilling units (MODUs) or permanent production platforms. MODUs facilitate moving drilling equipment from one drilling site to another. The two basic types of MODUs are bottom-supported units and floating units. Bottom-supported units include submersibles and jack-ups and are typically used for drilling in waters up to around 150 metres. Floating units include semi-submersibles, either anchored or dynamically positioned (Figure 1.1) and ship-shaped vessels. Floating units are typically used when drilling in deeper waters and at locations far from shore.

Permanent production platforms include fixed platforms or compliant towers (CT) or floating facilities such as tension leg platforms (TLP), or spar platforms (Figure 1.1) and FPSOs. In addition to providing a platform for drilling wells, the fixed or floating platform provides space for production facilities and living quarters.

Exploratory drilling is usually accomplished using a MODU. For development, fixed platforms represent the minimum cost solution for drilling in shallow water. When the water depth exceeds about 400 metres, development drilling is usually conducted from floating drilling units or floating production facilities.

The type of facility used for drilling will have some influence on waste management options. For example, the location of the wellhead can affect the ability to apply certain drilling waste disposal options, particularly cuttings re-injection. When drilling is being conducted from a fixed or floating platform or jack-up rig, the wellhead is located on the surface, above the water level. When drilling is being conducted from a semi-submersible, the wellhead is located on the seafloor. Technologies for injection into sub-sea wellheads are not mature and are discussed in more detail in Chapter 2. In addition, space and weight limitations of MODUs may limit the capability to store drilling wastes or to incorporate cuttings processing or handling equipment more so than would be the case for fixed or floating platforms.
1.1.3 Description of drilling operations

The drilling process uses a rotating drill bit attached to the end of a drill pipe, referred to as the drill string. Drilling fluids are pumped down the drill string, through the drill bit and up the annular space between the drill string and the hole. As the bit turns, it breaks off small pieces of rock (or drill cuttings (Figure 1.2)), thus deepening the hole. The drilling fluid removes the cuttings from the hole, cools the drill bit, and maintains pressure control of the well as it is being drilled. As the hole becomes deeper, additional lengths of pipe are added to the drill string as necessary. Periodically, the drill string is removed and the unprotected section of the borehole is permanently stabilised by installing another type of pipe, called casing. Cement is then is pumped into the annular space between the casing and the borehole wall to secure the casing and seal off the upper part of the borehole. The casing maintains well-bore stability and pressure integrity. Each new portion of casing is smaller in diameter than the previous portion through which it is installed. The process of drilling and adding sections of casing continues until final well depth is reached. For further information on the drilling process see the following web site: www.howstuffworks.com/oil-drilling.htm.

As shown in Figure 1.3, drilling fluid is pumped downhole through the drill string and ejected through the nozzles in the drill bit at high speeds and at high pressure. As discussed in Section 1.2, this fluid is frequently a mixture of water and/or various types of non-aqueous base fluids, special clays, and certain minerals and chemicals.
The drilling fluid serves several purposes:

- **Maintaining pressure**: The column of drilling fluid in the borehole provides a hydrostatic head that counteracts the natural pressure of fluids in the formations being drilled. This prevents the potentially dangerous, uncontrolled flow of fluids into the well and is vital for safe drilling operations.

- **Removing cuttings from the borehole**: Drilling fluid moves the drill cuttings away from the bit and out of the borehole. The jets of drilling fluid lift the cuttings from the bottom of the hole and away from the bit so the cuttings do not interfere with the effectiveness of the drill bit. The drilling fluid circulates and rises to the surface through the annulus between the drill string and the casing.

- **Cooling and lubricating**: Drilling fluid cools and lubricates the drill bit and drill string. Lubrication is especially important when drilling extended reach or horizontal wells.

- **Protecting, supporting and stabilizing the borehole wall**: Drilling fluids can contain additives to reduce shale swelling and minimise sloughing of the side wall into the well.

- **Protecting permeable zones from damage**: Mud additives can build a filter cake on the wall of the well, preventing deep penetration of the fluid into the formation causing damage to near well bore permeability.

Ultimately, drilling fluids and drill cuttings become wastes at different stages of the drilling process. Drill cuttings are generated throughout the drilling process as formation is cut and removed, although higher quantities of cuttings are generated when drilling the first few hundred metres of the well because the borehole diameter is the largest during this stage. Substantial waste fluid must be handled at completion of drilling because essentially the entire drilling fluid system must be removed from the hole as it is either replaced by completion equipment and fluids or by plugging operations to abandon an unsuccessful well. After completion of drilling, fluid components can be recovered by treatment at the rig or by returning the entire fluid to the supplier.

In many areas, regulatory standards do not allow discharge of whole non-aqueous fluid into the environment. The high cost of non-aqueous drilling fluids provides a strong incentive to recover and reuse the fluid. When onshore infrastructure is available or additional wells are being drilled in the area, waste NADF’s are recovered and recycled. Otherwise they must be disposed of onshore in an acceptable manner.

Processing of drill cuttings and waste disposal options are discussed in greater detail in Chapter 2.
1.2. Types of drilling fluids

1.2.1 Drilling fluid composition

Drilling fluids consist of a continuous liquid phase, to which various chemicals and solids have been added to modify the operational properties of the resulting mix. Key operational properties include density, viscosity, fluid loss, ion-exchange parameters, reactivity and salinity.

There are two primary types of drilling fluids: water based fluids (WBFs) and non-aqueous drilling fluids (NADFs). WBFs consist of water mixed with bentonite clay and barium sulphate (barite) to control mud density and thus, hydrostatic head. Others substances are added to gain the desired drilling properties. These additives include thinners (e.g. lignosulphonate, or anionic polymers), filtration control agents (polymers such as carboxymethyl cellulose or starch) and lubrication agents (e.g. polyglycols) and numerous other compounds for specific functions. WBF composition depends on the density of the fluid. An example, WBF composition (in wt%) for a 1,190 kg/m³ (9.93 lb/gal) fluid is: 76 wt% water, 15% barite, 7% bentonite and 2% salts and other additives (Figure 1.4; National Research Council (US), 1983).

NADFs are emulsions where the continuous phase is the NABF with water and chemicals as the internal phase. The NADFs comprise all non-water and non-water dispersable base fluids. Similar to WBFs, additives are used to control the properties of NADFs. A typical NADF composition is shown in Figure 1.5. Emulsifiers are used in NADFs to stabilise the water-in-oil emulsions. As with WBFs, barite is used to provide sufficient density. Viscosity is controlled by adjusting the ratio of base fluid to water and by the use of clay materials. The base fluid provides sufficient lubricity to the fluid, eliminating the need for lubricating agents. NADF composition depends on fluid density. The United States Environmental Protection Agency (USEPA) (1999a) presented an example NADF composition of (in wt%) 47% base fluid, 33% barite and 20% water. This example does not reflect a 2-5% content of additives such as fluid loss agents and emulsifiers that would be used in a NADF.

For the purposes of this report, NABFs are grouped according to aromatic hydrocarbon concentrations (which contribute to fluid toxicity) as follows:
Group I non-aqueous fluids (high aromatic content)

These were the first NABFs used and include diesel and conventional mineral oil based fluids. They are refined from crude oil and are a non-specific collection of hydrocarbon compounds including paraffins, olefins and aromatics, and polycyclic aromatic hydrocarbons (PAHs). Group I NABFs are defined by having PAH levels greater than 0.35%.

Diesel oil based fluids: The PAH content of diesel-oil fluids is typically in the range of 2-4% and the aromatic content is up to 25%.

Conventional mineral oil (CMO) based fluids: These were developed as a first step in addressing the concerns over the potential toxicity of diesel oil-based fluids and to minimise fire and safety issues. CMOs are manufactured by refining crude oil, with the distillation process controlled to the extent that total aromatic hydrocarbons are about half that of diesel. The PAH contents are 1-2%.

Because of concerns about toxicity, diesel-oil cuttings are not discharged. However, in situations where transportation of cuttings to shore or injection of cuttings is possible, such fluids may still be in use.

Group II non-aqueous fluids (medium aromatic content)

These fluids, usually referred to as Low Toxicity Mineral Oil Based Fluids (LTMBF) were developed as a second step in addressing the concerns over the potential toxicity of diesel-based fluids. Group II NABFs are also developed from refining crude oil, but the distillation process is controlled to the extent that total aromatic hydrocarbon concentrations (between 0.5 and 5%) are less than those of Group I NABFs and PAH content is less than 0.35% but greater than 0.001%.

Group III non-aqueous fluids (low to negligible aromatic content)

These fluids are characterised by PAH contents less than 0.001% and total aromatic contents less than 0.5%. Group III includes synthetic based fluids which are produced by chemical reactions of relatively pure compounds and can include synthetic hydrocarbons (olefins, paraffins, and esters). Base fluids derived from highly processed mineral oils using special refining and/or separation processes (paraffins, enhanced mineral oil based fluid (EMBF), etc) are also included. In some cases, fluids are blended to attain particular drilling performance conditions.

Synthetic hydrocarbons: Synthetic hydrocarbons are produced solely from the reaction of specific, purified chemical feedstock as opposed to being distilled or refined from petroleum. They are generally more stable in troublesome high temperature downhole conditions than the esters, ethers and acetals, and their rheological properties are more adaptable to deep water drilling environments. By virtue of the source materials and the manufacturing process, they have very low total aromatic hydrocarbon and PAH content (<0.001%). The most common synthetic hydrocarbons are esters, polymerised olefins (linear alpha olefin (LAO), internal olefin (IO)) and synthetic paraffins.

Highly processed mineral oils: These fluids are produced by refining and/or separation processes and can have composition and properties similar to those of synthesised paraffins. The composition of these fluids depends on the feedstock and the refining or separation processes used.

Some of the commonly used commercial NABFs are listed in Appendix D.

Historically, diesel and mineral oils were the base fluids (together referred to as Group I NABFs) used in NADFs. The drilling advantages of Group I NABFs can be obtained with the use of the Group II and Group III NABFs that have technical performance properties and uses similar to Group I fluids. Group II and III NABFs have lower aromatic content.
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and PAH than diesel oil or mineral oil and have lower acute toxicity. Depending on local regulatory requirements, cuttings from wells drilled with the NADFs are currently being discharged in many offshore areas such as the Gulf of Mexico, Azerbaijan, Angola, Nigeria, Equatorial Guinea, Congo, Thailand, Malaysia, Newfoundland, Australia and Indonesia instead of being barged to shore for disposal or injected offshore.

1.2.2 Advantages and disadvantages of NADFs

In most cases, WBFs are less expensive than NADFs and are used where practicable. WBFs are not well suited for certain drilling applications. For example, WBFs are not suited for use in some demanding drilling operations, including the drilling of highly deviated and horizontal wells often associated with offshore developments. WBFs can be problematic where water sensitive clays/shales are present, because interactions of the formation with water will cause the drill pipe to stick or the walls of the hole to slough in.

In these situations, NADFs are used in place of WBFs. Often, both WBFs and NADFs are used in drilling the same well. WBFs may be used to drill some portions (particularly the shallow portion) of the well, and then NADFs will be substituted for the deeper portions.

Although NADFs are generally more expensive on a per barrel basis than WBFs, the increased expense is usually offset by improved drilling performance. NADFs offer the following significant advantages:

- **Well-bore stability:** Because NADFs do not contain water as a free phase, they typically exhibit low reactivity with water-sensitive formations (primarily shales) encountered and consequently avoid damage to the formation. Thus clay swelling and borehole stability problems are minimised. The resultant improved drilling efficiency leads to lower operational and environmental risks.

- **Lubricity:** Some of the additives used to formulate NADFs can considerably reduce the friction factor (over that of WBFs) between the drill string and the sides of the borehole. Minimising friction and the ability to transfer the weight to the bit are very important factors in drilling highly deviated extended reach and horizontal wells. Higher lubricity also lowers the incidence of stuck pipe, which can significantly lower drilling efficiency. Without sufficient lubricity, deviated or horizontal wells may not be able to reach their drilling target, leading to the need for additional platforms to develop a resource. Such additional costs may make development of the resource non-economic, and thereby prevent development. If the resource can be developed using additional platforms and wells, the environmental footprint would be substantially increased. Therefore, lubricity is critically important in modern drilling fluid systems.

- **High temperature stability:** Whereas the properties of WBFs generally degrade at high temperatures (>350°F/175°C), most NADFs are more stable in high temperature applications, such as those encountered in deeper wells.

- **Low mud weight:** Lower mud weights can be achieved with NADFs than with WBFs due to the lower specific gravity of NADF base fluids. Low mud weight systems are desirable for wells drilled in highly fractured formations with low fracture strength, wells with low productivity, and wells with lost circulation zones.

- **Hydrate formation prevention:** There is a somewhat greater risk of forming gas hydrates in WBFs than NADFs. Gas hydrates are (relatively) stable solids that can plug lines and valves when they form. They form under certain conditions of pressure and temperature in the presence of free gas and water. These conditions can occur during critical well control operations and may present a risk to operations, especially in deep water. For this reason, chemicals (salt, methanol, and/or glycol) are often added to WBFs used for deep water wells to prevent hydrate formation. The water phase of a NADF does not normally contribute to hydrate problems, because it is present in a relatively low concentration (20%
or less by volume) and it generally has a high salt content (primarily for shale inhibition).

The following benefits can be derived from the above properties:

- **Safety**: Reduction in drilling time and the need for well-bore maintenance activity reduces the health and safety risks to personnel for each well drilled. Use of NADFs reduces drilling time for wells drilled through sensitive shales, and horizontal, or highly deviated extended reach wells. In addition NADF use results in fewer drilling problems and consequent remedial work.

- **Improved rate of penetration**: Drilling with NADFs can often result in more efficient drilling (less time to drill a well) by reducing well-bore friction-resulting in better stabilisation of the bottom hole assembly, providing improved lubricity, providing better well-bore stability resulting in less time for cleaning the hole, and by keeping the bit cutting surfaces cleaner. For the Chirag Field in the Caspian Sea, the first three wells were drilled with water-based mud with an average drilling time of 46.3 days. Subsequently three wells were drilled at the same location with a synthetic paraffin to about the same depth as the wells drilled with WBM. The average drilling time for the latter wells was 23.5 days. This case suggests that non-aqueous drilling fluids reduce drilling fluids in half compared to water-based drilling fluids (National Ocean Industries Association, *et al* 2000)

- **Reduced waste generation**: The volume of cuttings produced from drilling with NADFs will be less than that generated from drilling with WBFs. Hole maintenance is better when drilled with NADF, resulting in less sidewall wash out and a hole that is close to gauge; *ie* nominal bit diameter. In addition, NADFs are more tolerant to the buildup of fine particulate materials before the drilling properties degrade. Therefore, they can be reused for a longer period of time than WBFs prior to their disposal.

- **Suspension of drilling**: In locations where severe weather is an issue, drilling operations may need to be suspended on occasions and a hole may need to be left exposed to the drilling fluid for extended periods of time. The well-bore stability characteristic of NADFs allows sensitive shale formations to be left exposed during such periods without the extensive remedial work that could be required if WBFs were used.

The use of NADFs can also lead to some disadvantages relative to the use of WBFs. These disadvantages include:

- **Cost**: The cost of NABFs is on the order of USD$250 to $2,500/m³ ($50 to $500/Barrel). The wide range of NABF costs depends on the cost of materials for the base fluid (refined versus synthesised). Synthetic base fluids tend to be 3 to 5 times more expensive than mineral oils. Cost can be prohibitive, particularly in situations where lost circulation of the drilling fluid is experienced. In such circumstances, options may include using WBF or Group I fluids with injection or onshore disposal of cuttings.

- **Physical properties**: This is a particular issue for cold waters. Cold temperatures can cause the viscosity of some base fluids, such as the conventional esters, to rise to an unacceptable level. Therefore, it is important to choose a base fluid that has acceptable drilling properties for the drilling situation envisioned.

- **Reduced logging quality**: Due to the insulating properties of the base fluid, use of NABFs may not be acceptable in applications where electrical log information is critical.
2 Drill cuttings processing and waste disposal option

As discussed in Chapter 1, as part of the drilling process, drill cuttings are brought to the surface with drilling fluid for processing (Figure 1.3). It is at this stage that drill cuttings are removed from the fluid, become waste, and processing and disposal begins (Figure 2.1). On the drilling rig, solids control equipment removes unwanted solids from the drilling fluid to provide the maximum practical recovery of drilling fluid for re-use. Disposal options for the waste solids comprise offshore discharge, offshore re-injection, and onshore disposal.

Figure 2.1: Schematic flow chart showing separation of cuttings from drilling fluids and options for drill cuttings disposal

This chapter will first discuss solids control techniques for recovering drilling fluid and will then discuss attributes of the disposal options. Finally, factors to be considered in cost analyses of disposal options as well as example analyses for three different geographic areas will be presented.

2.1 Solids control equipment

The solids control system sequentially applies different technologies to remove formation solids from the drilling fluid and to recover drilling fluid so that it can be reused. The challenge faced in processing is to remove formation solids while at the same time minimizing loss of valuable components such as barite, bentonite and NABF. Ultimately, the solids waste stream will comprise the drill cuttings (small pieces of stone, clay, shale and sand) and solids in the drilling fluid adhering to the cuttings (barite and clays).

Some drill cuttings, particularly in WBF, disintegrate into very small particles called “fines”, which can build-up in the drilling fluid increasing the drilling fluid solids content and degrading the flow properties of the drilling fluid. If drilling fluid solids cannot be controlled efficiently, dilution with fresh drilling fluids might be necessary to maintain the performance characteristics of the drilling fluid system. The increase of fluid volume resulting from dilution becomes a waste. For WBF systems, when the drilling fluid in use cannot meet the critical operational properties, then that fluid may be replaced by freshly prepared drilling fluid or a different type of fluid. Used water-based fluids are typically disposed of by discharging into the sea, in accordance with local regulations.
Unlike WBFs, used NADFs are recycled instead of being discharged because of regulatory requirements and the expense of the fluid.

The components of the solids control system will depend upon the type of drilling fluid used, the formations being drilled, the available equipment on the rig, and the specific requirements of the disposal option.

Solids control may involve both primary and secondary treatment steps. Figure 2.2 illustrates the most advanced type of system in use by industry.

As part of primary treatment, cuttings are first processed through equipment designed to remove large cuttings and then through a series of shale shakers with sequentially finer mesh sizes, designed to remove progressively smaller drill cuttings. Shale shakers are the primary solids control devices. Each stage of the process produces partially dried cuttings and a liquid stream. Where no secondary treatment is employed, partially dried cuttings output will be disposed of by the selected option.

Where secondary treatment is used, the partially dried cuttings may be further processed using specialised equipment commonly called cuttings dryers followed by additional centrifugal processing. Cuttings dryers, sometimes used to process NADF cuttings, include such equipment as specialised shale shakers and centrifuges that apply higher centrifugal forces than can be developed by conventional shale shakers.

Figure 2.2: Example solids control system for non-aqueous fluids including a secondary treatment system (vertical cuttings dryer)

Centrifuges are used to remove particles that can contribute to fines build-up. If the centrifuges are unable to remove the fines adequately, waste fluid requiring disposal will be generated. The waste streams from the cuttings dryer and decanting centrifuge are then disposed of using the selected option.

Secondary treatment allows recovery of additional NADF for re-use, and results in a waste stream (cuttings) with a lower percentage of the drilling fluid retained on the cuttings. Some of the considerations when deciding whether to install secondary treatment equipment include:
• Volumes of waste fluid requiring disposal
• Operational delays due to equipment downtime
• Compatibility of cuttings size and consistency with dryer design
• Space limitation on drilling rigs
• Regulatory limits on percentage of fluid retained on solids for discharge.
• Additional cost associated with the equipment and required operators. Installation costs for a single well may be large (e.g., for a single exploration well), with little environmental benefit.
• Savings from fluid recovery

Figure 2.3 shows an example of cuttings that have been processed through cuttings dryer.

### 2.2 Cuttings collection and handling

Once the cuttings have passed through the solids control system, the cuttings collection and handling system takes the waste stream of cuttings with adhering drilling fluid and delivers it to the next stage of the disposal process. If discharge is the selected disposal option, handling requirements will be minimal and no additional storage is required.

For non-discharge options, some type of cuttings transport system (such as an auger conveyor, or vacuum system) will be required. Furthermore, storage (bags, cuttings boxes, tanks) will be needed due to limitations in the rate at which cuttings can be accepted by subsequent processing steps. The storage capacity will need to be sufficiently large to handle variations in cuttings generation rates and any downtime associated with injection or offloading of cuttings. If the storage capacity is exceeded, drilling operations may need to be shutdown. Space limitations on the drilling rig may place a limit on the rate at which cuttings can be accepted for further processing.

### 2.3 Cuttings disposal options

The primary options available for disposal of NADF drilling cuttings are:

- **Offshore discharge:** where NADF cuttings are discharged overboard from the drilling vessel or platform after undergoing treatment by solids control equipment.
- **Offshore re-injection:** where drill cuttings are ground to fine particle sizes and disposed of, along with entrained NADFs, by injection into permeable subterranean formations;
- **Onshore disposal:** where cuttings and the associated NADFs are collected and transported for treatment (e.g., thermal desorption, land farming) if necessary and final disposal by techniques such as land filling, land spreading, injection, or re-use.

Within each of these options, there is a variety of alternatives. Discharge of bulk or whole NADFs is not an acceptable environmental practice and specifically prohibited in some jurisdictions. When onshore infrastructure is available, NADFs are recovered and recycled. NADFs can be reused on other wells that are being drilled in the area. If neither option is available, cuttings must be disposed of onshore in an acceptable manner.
In making decisions regarding drill cuttings disposal, one must consider not only potential environmental impacts of an option, but also the potential impacts of alternatives. These other impacts include costs, resource use, air emissions, transportation and handling risks, occupational hazards, and chemical exposure. All of these factors are part of a comparative framework in which the relative environmental, operational (including human health and safety), and economic “costs and benefits” can be evaluated.

A framework of key parameters by which all disposal technologies can be evaluated is shown in Table 2.1.

Table 2.1: Framework of parameters for evaluating disposal options (modified from CAPP, 2001)

<table>
<thead>
<tr>
<th>Economic</th>
<th>Operational</th>
<th>Environmental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immediate costs</td>
<td>Safety</td>
<td>Air emissions from drilling and supporting operations</td>
</tr>
<tr>
<td>$/m^3 for disposal</td>
<td>Human health issues/chemical exposure*</td>
<td>Power requirements</td>
</tr>
<tr>
<td>Energy cost</td>
<td>Processing rate</td>
<td>Reduction in volume of waste</td>
</tr>
<tr>
<td>Maintenance cost</td>
<td>Mechanical reliability</td>
<td>By-products of process</td>
</tr>
<tr>
<td>Labour cost</td>
<td>Size and portability of unit(s)</td>
<td>Compliance with regulations</td>
</tr>
<tr>
<td>Equipment cost</td>
<td>Space availability</td>
<td>Receiving physical environment</td>
</tr>
<tr>
<td>Transportation costs</td>
<td>Energy requirements</td>
<td>Marine species potentially at risk</td>
</tr>
<tr>
<td>Disposal costs of end products</td>
<td>Condition of end products</td>
<td>Potential environmental stressors</td>
</tr>
<tr>
<td>Future liabilities</td>
<td>Method of disposal after processing</td>
<td>Removal of hydrocarbons from solids and water</td>
</tr>
<tr>
<td></td>
<td>Weather conditions</td>
<td>Removal of heavy metals from solids and water</td>
</tr>
<tr>
<td></td>
<td>Availability of appropriate facilities/infrastructure</td>
<td>Environmental issues at onshore site including potential impact to ground and surface water</td>
</tr>
</tbody>
</table>

The following section describes for each option the techniques and equipment used, the advantages and disadvantages from economic, operational, and environmental perspective, and the worldwide experience with its application. This is followed by a more in-depth discussion of factors that must be considered for a cost analysis of disposal options as well as examples of several country and project specific cost analyses.

2.3.1 Offshore discharge

The Offshore Discharge option is broadly applicable. However, its use may limit the range of acceptable NADF base fluids. Consequently, in evaluating potential discharge one will need to consider regulatory requirements that may influence an operator’s choice of fluid or decision to employ secondary treatment equipment.

The advantages and disadvantages of offshore discharge are summarised in Table 2.2. The base case here does not include secondary treatment equipment.

Technique and equipment

The Offshore Discharge option (hereafter referred to as the “Discharge” option) is operationally simple and may require no additional equipment to that conventionally found on a drilling rig. The option involves discharging the cuttings, after treatment, to the local environment. Specifically, once drilling fluid is removed from the cuttings by shale shakers and perhaps other secondary control equipment, the cuttings containing residual fluid are mixed with sea water and discharged to the sea through a pipe known as a “downcomer”. The end of the downcomer is typically located a few metres below the water surface. Unlike the other disposal options, no temporary storage for cuttings is required.
Environmental Life Cycle and Implications

The discharged cuttings and adsorbed fluids will fall to the seafloor and accumulate to different degrees. Accumulation will depend on the volume and characteristics of the fluid discharged and the characteristics of the local receiving environment. As a consequence, immediately following drilling discharges, NABF concentration in the sediments will typically be elevated and benthic biota may be affected. Typically, NABF concentrations will decrease with time and biota will recover, but the time scales vary depending upon the NABF, the thickness of the accumulation, and the characteristics of the receiving environment (eg water depth, temperature, waves and currents). Recovery for thicker accumulations (or piles) is thought to be much slower than for thin accumulations. Impacts to water column of the NADF cuttings are considered to be negligible, because the cuttings settle quickly (leading to short exposure times in the water column) and the water solubility of the base fluids is low.

<table>
<thead>
<tr>
<th>Table 2.2 Advantages (+) and disadvantages (-) of offshore discharge (modified from CAPP, 2001)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Economics</strong></td>
</tr>
<tr>
<td>+ Very low cost per unit volume treatment</td>
</tr>
<tr>
<td>+ No potential liabilities at onshore facilities</td>
</tr>
<tr>
<td>- Potential future offshore liability</td>
</tr>
<tr>
<td>- Cost of analysis of discharges and potential impacts (eg, compliance testing, discharge modelling, field monitoring programmes)</td>
</tr>
<tr>
<td>+ No shore-based infrastructure required</td>
</tr>
<tr>
<td>+ No weather restrictions</td>
</tr>
</tbody>
</table>

Worldwide application

In most offshore operating areas around the world, discharge of WBF and WBF cuttings is routine practice except in highly sensitive areas. NADF cuttings are discharged offshore in a number of geographic locations subject to local regulations. Regulatory requirements and industry practice for offshore discharge are discussed for most oil producing countries in Appendix C.

2.3.2 Offshore cuttings re-injection

Cuttings may be injected into subsurface geological formations (Figure 2.4) at the drilling site, offshore or onshore. The overall process is similar for each sub-option. For this discussion we consider cuttings re-injection on site. The associated advantages and disadvantages are summarised in Table 2.3.

Technique and equipment

Cuttings re-injection involves grinding cuttings to a small size, slurrying them to create a stable suspension, and injecting the cuttings and the associated NADFs into a subsurface geological formation. Cuttings may be injected into the annulus of a well being drilled, or into a dedicated or dual-use disposal well, ie one that will later be completed for production. There are both operational and economic considerations in choosing the appropriate injection option. Expenses associated with dedicated and/or dual use wells will be greater than for annular injection. However, potential operational problems, such as blockage of the annular spaces, may be fewer.
A related approach is to inject cuttings at another location (platform or other). However, this approach shares many disadvantages, though typically to a lesser extent, with the Onshore Disposal option described in the following subsection (eg, boat rental, fuel use, increased air emissions, increased chance of worker injuries, etc).

Cuttings re-injection may not be a viable option for all operations.

- A thorough technical analysis must be completed to evaluate the suitability of a site and operation for cuttings re-injection. The presence of a suitable geological formation capable of accepting and containing the waste on a long-term basis is critical to the operation. In addition, the slurry injection should not pose any threat to drilling operations or production reservoirs.

- This technique is used on land and on offshore platforms with surface wellheads. Since the technology for injecting through sub-sea wellheads from floating facilities and in deep water is not mature, the technique would not likely be applicable to fields in deep water developed exclusively with sub-sea wellheads at this time.

- Logistical implications may also limit the applicability of re-injection. Mobile Offshore Drilling Units drilling single exploration wells are not likely to have the space to accommodate the necessary additional equipment and storage.

In general, this option can be of most practical and economic value in field development situations where a large number of wells are being drilled from a single location.

Additional equipment is required for the Re-injection option relative to the Discharge option. A special wellhead and a modified casing programme relative to the base-case production wells will likely be required. However, this may apply to only one or two wells for the dedicated and dual-use disposal well situations, whereas more wells would likely be affected in the annular injection case. Additional equipment, as shown in Figure 2.5, is required under any re-injection scenario and includes the following:

- auger conveyer or vacuum system to transport cuttings from the shale shaker to be ground and slurried;
- centrifugal pumps or grinding units are required to process the cuttings and seawater mixture;
- a slurry tank to store the ground cuttings/seawater mixture prior to injection;
- a ‘triplex’ cementing pump to inject cuttings slurry downhole

If injection operations have to be shut down due to problems with injection equipment or well operations, or if the system is unable to handle the quantity of cuttings being generated from drilling, then either drilling will need to cease or another disposal option will need to be implemented. Operators are sometimes granted temporary provision to discharge (depending upon the fluid they are using) during the start-up phase or during upset conditions.
Environmental aspects of the use and disposal of non aqueous drilling fluids associated with offshore oil & gas operations

Environmental life cycle and implications

Re-injection has the advantage relative to offshore discharge of completely avoiding discharge of cuttings and adsorbed NADFs to the sea and, after settlement on to the seabed. This advantage needs to be weighed against the environmental cost of the associated increased fuel use and air emissions. Relative to onshore disposal, re-injection eliminates the use of landfill space and the associated potential for impacts to groundwater resources. In some cases, depending upon the onshore disposal technique employed and the distance between the drilling rig and the disposal site, injection may also require less fuel use and result in fewer air emissions.

There have been occasions where the injected slurry has breached to the surface. However, by properly designing the cuttings injection programme and taking special consideration of the local geological conditions this risk can be managed.

As discussed above, certain operational factors may preclude exclusive use of this option. These factors could reduce the environmental advantages of the re-injection option to a limited extent.

- First, if onshore disposal were chosen as the primary backup option, offloading from a MODU or loading onto the platform might be difficult or unsafe in certain weather/sea state conditions. Such transfers carry many similar operational/safety risks associated with the Onshore Disposal option. Thus to minimise the potential for drilling delays, discharge would be required as a back-up option as well.

- Second, one must consider the consequences of operating when injection is not possible (eg, if the well became plugged). In such instances, cuttings must be discharged at the rig site or transported to shore; otherwise, drilling delays may occur. Both of these back-up options carry environmental costs, as described in this chapter.

In summary, the use of the re-injection option would drastically reduce, but not necessarily eliminate, impacts to the seafloor or the use of onshore landfills.
Table 2.3  Advantages (+) and disadvantages (-) of cuttings re-injection

<table>
<thead>
<tr>
<th>Economics</th>
<th>Operational</th>
<th>Environmental</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ Enables use of a less expensive</td>
<td>+ Cuttings can be injected if pre-</td>
<td>+ Elimination of seafloor impact</td>
</tr>
<tr>
<td>drilling fluid</td>
<td>treated</td>
<td></td>
</tr>
<tr>
<td>+ No offsite transportation</td>
<td>+ Proven technology</td>
<td>+ Limits possibility of surface</td>
</tr>
<tr>
<td>needed</td>
<td>- Extensive equipment and</td>
<td>and ground water contamination</td>
</tr>
<tr>
<td>+ Ability to dispose of other</td>
<td>labour requirements</td>
<td></td>
</tr>
<tr>
<td>wastes that would have to be</td>
<td>- Application requires receiving</td>
<td>- Increase in air pollution due to</td>
</tr>
<tr>
<td>taken to shore for disposal</td>
<td>formations with appropriate</td>
<td>large power requirements</td>
</tr>
<tr>
<td>- Expensive and labour-intensive</td>
<td>properties</td>
<td></td>
</tr>
<tr>
<td>- Shutdown of equipment can</td>
<td>- Casing and wellhead design</td>
<td>- Possible breach to seafloor if</td>
</tr>
<tr>
<td>halt drilling activities</td>
<td>limitations</td>
<td>not designed correctly</td>
</tr>
<tr>
<td></td>
<td>- Over-pressuring and</td>
<td></td>
</tr>
<tr>
<td></td>
<td>communication between</td>
<td></td>
</tr>
<tr>
<td></td>
<td>adjacent wells</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Variable efficiency</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Difficult for exploration wells</td>
<td></td>
</tr>
<tr>
<td></td>
<td>due to lack of knowledge of formations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Limited experience on floating</td>
<td></td>
</tr>
<tr>
<td></td>
<td>drilling operations and in deep</td>
<td></td>
</tr>
<tr>
<td></td>
<td>water</td>
<td></td>
</tr>
</tbody>
</table>

Worldwide application

Cuttings generated from drilling have been injected offshore in a number of locations including the North Sea, Gulf of Mexico, Alaska, and eastern Canada. Most offshore injection programmes to date have been conducted from fixed leg platforms or jack-ups and have involved injection into a surface wellhead. Additional technology is required to inject through subsea wellheads from a floating drilling platform. The immaturity of this technology has resulted in limited use of re-injection from floating facilities and in deep water. There are only a few instances where injection through sub-sea well-heads has been employed, consequently, there is not a large database of information on its reliability (Ferguson et al. 1993; Saasen et al., 1998).

In some instances, where there is a multi-well development from a fixed platform, and where suitable geological formations exist, re-injection has been shown to be a technically and viable disposal option. For example, for a recent North Sea platform development (Kunze and Skorve, 2000), the injection experience was positive and operational downtime was limited. During this development, LTMBF cuttings, oily waste and drainage water, as well as production residue from the adjacent floating production storage and offloading unit (FPSO) were injected into a dedicated injection well that was later completed as a production well. Use of a dedicated well minimised concerns about annular plugging, hanger erosion, and casing collapse of producers. Although a number of disposal options was available, the combination of suitable geological conditions for injection, the development scenario which made using a dedicated injection well economic, and the regulatory restrictions combined to make re-injection the best option available in this situation based on cost, operational, and environmental considerations.

Recent surveys show that re-injection can be successful, with improvements over the last few years, reducing downtime considerably. But as mentioned previously, re-injection may not be a suitable option for all drilling situations, particularly exploratory and deep water drilling. The applicability of this technology needs to be evaluated and compared by cost-benefit to other options on a case-by-case basis.

2.3.3 Onshore disposal

Cuttings may be processed on the drilling rig, stored, and transported to shore for disposal. Consequently, there are two components of onshore disposal that must be considered when
evaluating the viability of this option. The first is marine transport (i.e. ship-to-shore which is common to all potential onshore disposal options) and the associated advantages and disadvantages (Table 2.4). Second are the advantages and disadvantages associated with the selected onshore disposal option (Table 2.5).

**Technique and equipment**

In the Onshore Disposal option, cuttings and the associated NADFs are collected on the rig, stored, and transported to shore for disposal (Figure 2.6). Onshore the following options may be available:

- Treatment to remove or reduce oil content (e.g. composting, incineration, thermal desorption) followed by disposal by land-farming or landfilling;
- Re-use as fuel;
- Re-use as construction materials;
- Disposal in landfills without treatment (minimum oil content requirements may require prior treatment);
- Disposal by land-farming;
- Disposal by injection.

**Figure 2.6: Schematic diagram of onshore cuttings disposal options**

This option is not technically complicated, but it involves a substantial amount of equipment, effort and cost. The option involves the following steps:

- Cuttings from the shale shakers are stored in storage containers (boxes, bags, or tanks);
- Storage containers are off-loaded by crane to a workboat or other vessel or cuttings may be pumped by vacuum into tanks on a workboat;
- The vessel transports the cuttings (and containers) to shore;
- Containers are offloaded from the boat to the dock at port;
- As trucks or other ground transport vehicles are available, cuttings (and containers) are loaded into the trucks;
• The trucks transport the cuttings to the land disposal or treatment facility;
• Equipment at the facility offloads the cuttings from the trucks, while other equipment may provide further treatment or manipulation (e.g., bulldozers, grinding and slurrification units);
• The treated cuttings may be placed in a landfill and buried, incinerated, spread on land, or injected into a suitably isolated injection zone;
• Empty containers are transported back to the port by truck and, ultimately, back to the rig by boat.

As indicated by the description above, onshore disposal involves a substantial amount of additional equipment relative to the Discharge option. On the platform itself, incremental equipment requirements are primarily limited to storage containers, such as 2-m³ cuttings boxes to hold the cuttings prior to and during transport. However, this option also involves increased use of existing rig equipment, such as the crane. If vacuum transfer equipment is used, less lifting will be required.

Off the platform, equipment requirements are substantial. These include rental of one or more dedicated boats (or barges), use of port facilities, rental of trucks, and use of equipment at the disposal facility. If injection is involved, grinding, slurrification, and pumps for injection will be required at the site.

Once onshore, there are a number of options for treatment/disposal of cuttings.

Disposal options include injection, land-spread, land-farm, and land-fill disposal. If necessary or optimal, cuttings may be treated prior to disposal biologically (by for example composting) or thermally (thermal desorption or incineration). Once treated, the cuttings can be land-filled, land-spread, or re-used for example in road construction.

<table>
<thead>
<tr>
<th>Economics</th>
<th>Operational</th>
<th>Environmental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste can be removed from drilling location eliminating future liability at the rig site</td>
<td>Safety hazards associated with loading and unloading of waste containers on workboats and at the shorebase</td>
<td>+ No impacts on benthic community</td>
</tr>
<tr>
<td>Transportation cost can be high for vessel rental and vary with distance of shorebase from the drilling location</td>
<td>Increased handling of waste is necessary at the drilling location and at shorebase</td>
<td>+ Avoids impacts to environmentally sensitive areas offshore</td>
</tr>
<tr>
<td>Transportation may require chartering of additional supply vessels</td>
<td>Additional personnel required</td>
<td>– Fuel use and consequent air emissions associated with transfer of wastes to a shore base</td>
</tr>
<tr>
<td>Additional costs associated with offshore transport equipment (vacuums, augers, cuttings boxes or bulk containers), and personnel</td>
<td>Risk of exposure of personnel to aromatic hydrocarbons is greater</td>
<td>– Increased risk of spills in transfer (transport to shore and offloading)</td>
</tr>
<tr>
<td>Operational shut-down due to inability to handle generated cuttings would make operations more costly</td>
<td>Efficient collection and transportation of waste are necessary at the drilling location</td>
<td>– Disposal onshore creates new problems (e.g., potential groundwater contamination)</td>
</tr>
<tr>
<td>– Weather or logistical issues may preclude loading and transport of cuttings, resulting in a shut down of drilling or need to discharge</td>
<td>May be difficult to handle logistics of cuttings generated with drilling of high rate of penetration large diameter holes</td>
<td>– Potential interference with shipping and fishing from increased vessel traffic and increased traffic at the port</td>
</tr>
</tbody>
</table>
### Table 2.5 Advantages (+) and disadvantages (-) of onshore treatment/disposal options

<table>
<thead>
<tr>
<th>Option</th>
<th>Operational</th>
<th>Environmental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Re-injection</td>
<td>+ Expensive if existing site not available</td>
<td>+ Minimal potential for groundwater impact</td>
</tr>
<tr>
<td></td>
<td>+ Simple process with little equipment needed</td>
<td>+ Biodegradation of hydrocarbons</td>
</tr>
<tr>
<td></td>
<td>- Requires suitable geological formations</td>
<td>- Air emissions from equipment use and off-gassing from degradation process</td>
</tr>
<tr>
<td></td>
<td>+ Without prior treatment</td>
<td>+ Inexpensive relative to re-injection, thermal processing and incineration</td>
</tr>
<tr>
<td>Land-spreading</td>
<td>+ Relatively inexpensive if land is available</td>
<td>+ Effective removal and recycling of hydrocarbons from solids</td>
</tr>
<tr>
<td></td>
<td>- Long-term liability</td>
<td>- Potential for onshore spills</td>
</tr>
<tr>
<td></td>
<td>+ Can not be used for wastes with high salt content</td>
<td>- Air emissions associated with transport and equipment operation</td>
</tr>
<tr>
<td></td>
<td>- Requires suitable facilities</td>
<td>- Heavy metals and salts are concentrated in processed solids</td>
</tr>
<tr>
<td></td>
<td>- Requires limited space and equipment</td>
<td>- Associated hydrocarbon combustion emissions</td>
</tr>
<tr>
<td></td>
<td>+ Requires limited treatment process parameters</td>
<td>- Residual requires further disposal</td>
</tr>
<tr>
<td></td>
<td>- Requires several operators</td>
<td>- Need to dispose of residual solid/ash</td>
</tr>
<tr>
<td></td>
<td>+ More rapid biodegradation than land-farming</td>
<td>- High temperatures salts can transform into acid components</td>
</tr>
<tr>
<td></td>
<td>+ More efficient in cold climates</td>
<td>- May involve substantial monitoring requirements</td>
</tr>
<tr>
<td>Landfill</td>
<td>+ Inexpensive relative to other onshore options</td>
<td>+ Destruction of hydrocarbons</td>
</tr>
<tr>
<td></td>
<td>- Requires land rental or lease</td>
<td>- Material can be transformed to prevent heavy metal leaching</td>
</tr>
<tr>
<td></td>
<td>+ Requires appropriate management and monitoring</td>
<td>- Residue requires further disposal</td>
</tr>
<tr>
<td></td>
<td>- Land requirements</td>
<td>- Material can be recovered for energy production</td>
</tr>
<tr>
<td></td>
<td>+ Requires suitable management and monitoring requirements</td>
<td>- Residual requires further disposal</td>
</tr>
<tr>
<td></td>
<td>- Only available if maximum oil content of waste is met</td>
<td>- Tissue arising from leaching of heavy metals and other contaminants</td>
</tr>
<tr>
<td>Composting</td>
<td>+ Inexpensive relative to other re-injection, thermal processing and incineration</td>
<td>+ Time required for incineration is relatively short</td>
</tr>
<tr>
<td></td>
<td>+ Requires limited treatment process parameters</td>
<td>- Several operators required</td>
</tr>
<tr>
<td></td>
<td>- Requires limited space and equipment</td>
<td>- Safety concerns</td>
</tr>
<tr>
<td></td>
<td>- Requires clean source of bulking agent</td>
<td>- Requires hot oil feed equipment</td>
</tr>
<tr>
<td></td>
<td>- Requires clean source of bulking agent</td>
<td>- Thermal oil feed equipment</td>
</tr>
<tr>
<td></td>
<td>- Requires reasonable space for air pollution equipment</td>
<td>- Thermal oil feed equipment</td>
</tr>
<tr>
<td></td>
<td>- Requires reasonable space for air pollution equipment</td>
<td>- Incineration</td>
</tr>
</tbody>
</table>

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Onshore injection is similar in process to that described for offshore injection and requires the presence of a suitable injection formation with appropriate properties for the disposal and containment of the cuttings and associated NADFs. In general, containment is more important if there is potential cross contamination of fresh water aquifers.

Land-spreading involves spreading untreated cuttings evenly over an area followed by mechanical tilling with addition of nutrients, water, air and or oxygen as necessary to stimulate biodegradation by naturally occurring oil-degrading bacteria. Land-spreading is generally limited to one application.

Land-farming is similar to land-spreading except material is applied several times at the same location. Depending upon the location of the land-farm, a liner, overliner, and/or sprinkler system may be required. Both land-spreading and land-farming are more efficient in warm tropical climates, and may be inapplicable in areas where the ground is frozen part of the year.

Landfills are widely used for containing waste. Under this option, cuttings, either treated or untreated, would be placed in a containment unit with a liner and cover that have been designed to contain the waste. The ability of the landfill to contain waste will depend upon the quality of the design and materials, and underlying geological units. Landfills must be continually maintained and monitored to sustain their effectiveness in containing waste.

Composting may be an alternative to land-spreading or land-farming in areas where land is limited and/or in cold climates. Composting is a process in which wastes are mixed with bulking agents to enhance aeration and microbial numbers. The mixture may be tilled periodically to increase aeration, and additional nutrients or moisture added as required. As with land-farming, the primary process acting is biodegradation. With composting, the combination of placing the material in a pile, and addition of bulking agent result in high temperatures in the pile, which further increase rates of biodegradation and volatilisation. This gives composting an advantage over land-spreading or land-farming in cold climates. The treated residue requires subsequent disposal, for example by placement in a landfill. Since the volume and mass of the waste is increased by addition of the bulking agent, substantially more waste may require disposal unless the treated material can be land-spread.

Thermal technologies that have been used to treat wastes include thermal desorption and incineration. With thermal desorption, the cuttings are placed in a treatment unit and then heated. The liquids are volatilised and re-condensed back to two phases: water and NABF. The resulting waste streams are water, oil and solids. The wastewater will require treatment prior to disposal. The resulting solid residue has essentially no residual hydrocarbons, but does retain salt and heavy metals, and can be disposed of in a landfill or by land-spreading, or may be used in road construction. Depending upon the process used, recovered hydrocarbons can be used as fuel or reused as base fluid in the drilling fluid system.

Incineration involves heating cuttings in direct contact with combustion gases and oxidizing the hydrocarbons. Solid/ash and vapour phases are generated. The gases produced from this operation may be passed through an oxidiser, wet scrubber, and bag house before being vented to the atmosphere. Stabilisation of residual materials may be required prior to disposal to prevent constituents from leaching into the environment.

Ultimately, once treated, cuttings may be used for construction or other alternative uses. Other proposed applications include incorporation into roofing tiles, use for landfill or trench cover (UKOOA, 1999), in road construction or as soil re-conditioner. However for these uses, it is necessary to remove as much salt as possible.
Environmental life cycle and implications

Relative to the Discharge option, the Onshore Disposal option has the advantage that it does not leave an accumulation of cuttings and associated NADFs on the seafloor. Thus, local impacts to the seafloor and biota are avoided. However, the Onshore Disposal option has several disadvantages. Aside from the high cost associated with the boat rental, fuel costs, ground transport, and treatment/disposal, these disadvantages include:

- Increased potential for accidents involving workers (e.g., during crane lifts at platform and at port, boat transport, truck transport, landfill/disposal site operations);
- Increased potential for accidents involving the civilian population near the port and disposal facilities (e.g., traffic accidents);
- Increased air emissions and fuel use associated with almost every step of the process (e.g., platform-to-boat transfer, boat transport to port, port transfer, truck operation, facility equipment operation);
- Increased potential for fuel spills from vessels associated with transport of cuttings to shore;
- Potential for nearshore or onshore spills of the cuttings, associated with loading, offloading, and transport of the cuttings to shore during rough weather or during transport to the disposal site;
- Use of landfill space, which is a relatively precious commodity in many developed countries as well as in most developing countries;
- Use of land (e.g., ~0.04 acres/well for a landfill, depending on assumptions) that might be used for better purposes;
- Potential for groundwater contamination, particularly at the landfill/disposal or injection site, but also at other onshore handling locations;
- Minor nuisance impacts to the civilian population near the port and disposal facilities (e.g., traffic, noise, dust, odour);
- Potential interference with shipping and fishing from increased vessel traffic and increased traffic at the port.

Injecting drilling wastes alleviates the problem of land-use for landfills. However, disposal either in landfills or by injection may lead to long-term liability problems should wastes leak into nearby groundwater.

In addition to the disadvantages above, the Onshore Disposal option also involves increased exposures of workers to NADFs relative to the Discharge option. However, exposure is unlikely to represent a significant health issue except when diesel or conventional mineral oil fluids are used.

From an operational perspective, use of the Onshore Disposal option involves the potential for drilling delays due to the inability to offload cuttings during heavy seas. As storage space on platforms or drill ships is limited, a delay in offloading could lead to the need to temporarily suspend drilling operations if a strict “no discharge” policy is followed.

Worldwide application

Cuttings are disposed of onshore in many locations, particularly those where drilling is conducted in environmentally sensitive areas (such as near shore) or those with highly restrictive discharge requirements. Conventionally, cuttings have been hauled to shore in cuttings boxes (or “skips”). However, more recently in the North Sea some operators have been using bulk containers for storage, which may eliminate deck space issues and pumping the cuttings directly to a waiting vessel. This system helps lessen some of the safety issues associated with
this option, crane lifts and manual handling, however, requires greater capital and operating expense and is still subject to weather related delays.

Worldwide, a wide range of onshore disposal and treatment options is employed. The selected option varies depending upon such factors as local infrastructure (e.g. does a managed landfill exist?), local regulations, and land availability.

Onshore injection of offshore wastes has seen limited application.

Drilling wastes have been disposed of using land-spreading in several states in the US. (Texas, Oklahoma, Louisiana). Guidelines are available for application rates to avoid damage to the soil or crop production.

Land-farming is conducted in such areas as Louisiana, Venezuela, and Western Canada. While land-farming is an accepted option to treat onshore drilling waste, it has been used less extensively to treat offshore wastes. In some areas land-farming may not be feasible due to lack of available land, rockiness or lack of topsoil, frozen ground, concerns over residual soil productivity, or long hauling distances.

Dedicated landfills are available to manage wastes generated from drilling offshore in areas of significant drilling activity such as the Gulf of Mexico, the North Sea, and Western Australia. In more remote and less developed areas, appropriate landfill areas may not be available. However, limited applications have occurred in such places as Egypt and Russia.

Composting has been used to manage routinely generated waste from petroleum operations. Numerous projects have been successfully completed in the United States, Canada, Indonesia, Africa, and Russia. Composting has seen limited use to treat offshore wastes.

Thermal desorption has been used in the UK, Venezuela, Ecuador, Kazakhstan, Canada and the US where it is selected primarily for its capacity to recover base fluid immediately for reuse in a fluid system. Incineration has rarely been used in the Western Hemisphere for treating drill cuttings due primarily to its prohibitive cost. It was used on a limited basis in Eastern Canada prior to changing to another option.

Re-use of treated cuttings for construction or other alternative uses has been limited, and safety, health, and environmental issues associated with these uses are still under evaluation. In Scotland, cuttings have been used for construction of bike paths. Other proposed uses include use as a trench or land-fill covering material.

2.4 Drill cuttings disposal options cost analysis

The cost of drill cuttings disposal depends on costs for drilling rigs, drilling fluids, solids control equipment, transportation and handling of cuttings, cuttings injection equipment and onshore treatment and disposal. Costs for these items vary widely around the world.

Estimates of disposal costs are also highly dependent on assumptions used for the analysis, e.g. the amount of waste per well, the length of time required to drill a well, and estimates of increased drilling time due to equipment breakdowns or inability to offload cuttings due to bad weather. The following sections summarise the factors that need to be considered in performing a cost analysis and discuss example cost analyses for a series of likely disposal scenarios. Data needed for the cost analysis were drawn from both published sources and contacts with industry staff.

Factors to be considered in a cost analysis include the following:
Drilling time

The length of time required to drill a well is not uniform between areas and projects. It will vary with the geological specifics of the area and any technical challenges posed by drilling. The costs associated with operating the rig will be the largest overall cost associated with drilling a well. Rig rates will vary according to the technical capabilities of the drilling rig, the region where the drilling will be conducted, and the terms of agreements negotiated between operators and drilling companies.

The length of time required to drill a well is important for two reasons. First, there may be an incremental cost associated with reduction in drilling rates (and consequently requirement for additional drilling time) associated with a disposal option. For example, selection of WBF versus NADF may avoid the cost of non-discharge cuttings disposal options but may add days to a technically challenging drilling operation. The use of onshore cuttings disposal options may result in additional costs due to drilling down-time associated with inability to offload cuttings for marine transport in rough weather. Second, the cost of equipment rental and operation (including dedicated personnel) associated with disposal options is proportional to the length of time required to drill a well.

The length of time needed to drill wells varies according to the technical difficulty of the drilling process. Drilling times have been estimated to range from 30-45 days for wells in waters less than 300 metres (m) deep and 60-90 days for wells in deeper waters (API/NOIA 2000).

The selection of non-discharge disposal options may result in increased drilling time to drill a well. The maximum rate of penetration during drilling can be limited by the maximum cuttings handling capacity of advanced solids control equipment, cuttings re-injection plants, and offloading operations (van Slyke 2000). Downtime of equipment associated with cuttings handling, offloading, and injection will also increase drilling time. Increased drilling time translates into increased drilling costs. Van Slyke (2000) reviewed operational data on the increases in drilling time associated with the use of advanced solids control equipment, injection, and shore-based disposal. Van Slyke found that drilling time increases by as much as 3 days per well. Kunze and Skorve (2000) presented no information on reduction in rates of penetration due to injection plant capacity limits, but did report that there was no downtime during an offshore cuttings injection programme. For the example analyses, the effects of capacity limitations and downtime are considered by assuming an increase in drilling time of 1.5 days per well for the non-discharge disposal options and for discharge options that include use of secondary solids control equipment.

The daily rate for a drilling rig includes the operating costs of the rig and of any associated helicopters or workboats needed to service the rig. Drilling rig costs depend on the technical capabilities of the rig. Deep water drilling is most likely to require the use of NADF and rigs with deep water capabilities are estimated to cost $300,000/day.

Volume of hole drilled per well

The total volume of cuttings waste generated per well can be estimated as the sum of the nominal volume of hole drilled, the amount of hole washout, and the volume of drilling fluid retained on the cuttings. Requirements for containers and support vessels will depend upon the volume of cuttings. Once cuttings are brought ashore, treatment and disposal costs will be dependent upon this volume as well. A cuttings density, including formation solids, adhering drilling fluid, and water of 1.7t/m$^3$ was assumed to estimate the costs of disposal or treatment steps that are dependent on waste mass rather than volume.

It was assumed for the example analysis that 1675m of 17.5-inch and 1600m of 12.25-inch diameter sections of the well are drilled with NADF. Assuming that an additional 7.5% of
nominal hole volume is removed by washout (EPA, 1999), this yields a volume of 410m³ (2,580 bbl) of rock removed.

**Drilling fluid consumption**

Three factors contribute to net consumption of NADF during the drilling process.

- Retention of NADF in the cuttings waste stream
- Downhole NADF loss
- Losses due to maintenance – losses during transfers or spillage, NADF mud that becomes contaminated during use, and additional NADF added to maintain desired fluid properties.

For the purpose of the example analyses, it was assumed that downhole and maintenance losses accounted for 239m³ (1500 bbl) NADF consumed per well. Losses in the cuttings waste stream depend on the assumed base fluid content of cuttings. The example analyses assumed that conventional solids control equipment could achieve 15% base fluid content on cuttings and that secondary solids control equipment could achieve 5% base fluid content on cuttings.

Calculated NADF losses on cuttings are based on assumptions made about the base fluid content of cuttings, the base fluid content of the NADF (40wt %), and the relative densities of the rock removed from the hole (2.5g/cc) and the drilling mud (1.2t/m³ or 10lb/gal). Based on these assumptions, the estimated ratios of NADF volume lost on cuttings to cuttings volume drilled were 1.3 and 0.6 for conventional and secondary solids control equipment, respectively.

**Cost of secondary solids control systems**

The use of secondary solids control equipment adds both costs and savings to the overall economics of cuttings disposal. Daily charges for rental and operation of secondary solids control equipment increases costs are offset to some extent by savings from recovering additional NADF which would otherwise go to waste.

The example presented here analyses use and estimated daily cost of $3,000 to rent and operate secondary solids control equipment. In practice, the reductions in base fluid on cuttings achievable with advanced solids control equipment do not translate completely into reduced NADF loss. The increased fine particle content in NADF recovered from secondary solids control equipment can ultimately reduce the actual recoverable NADF by 50% (API/NOIA 2000). Nominal base-fluid-on-cuttings contents achievable with different solids control options are used for this analysis. The cuttings base fluid content achievable in practice is dependent not only on the choice of solids control equipment but also on the type of base fluid, the nature of the formation being drilled, and the rate of penetration. For the purposes of estimating waste volumes and disposal costs, it is assumed that only 50% of the incremental recovery achieved by advanced solids control equipment can be counted as usable NADF.

**Cost of drilling fluid consumed**

The cost of the drilling fluid includes the cost for the base fluid, barite and other additives. For NADFs, the base fluid used will be the primary determinant of cost. Group I and Group II fluids will be less costly than Group III fluids. Within Group III fluids, the esters are generally the most expensive, and enhanced mineral oils, paraffins and olefins are cheaper. Costs of drilling fluids will have high geographic variability depending upon local availability of products. There will likely be a higher drilling fluid cost when the discharge option is selected. This is due to the use of a more costly fluid than would be required for the re-injec-
tion or onshore disposal option. In the given example, Group II and Group III fluids were estimated to cost $516 and $1,195 per cubic metre, respectively.

Discharge disposal costs

Some cost items are specific to the discharge option. These include the possible use of a more costly base fluid and the required environmental monitoring of seabed conditions at discharge sites. Environmental monitoring studies are typically carried out on a regional basis so that the costs can be shared among a number of wells. A basic monitoring study might entail costs of $400,000 for sample collection and analysis at a given site. A more detailed regional study could cost $3,000,000. For the example cost analyses, discharge option cases were charged with $100,000/well for monitoring costs based on an assumed scenario in which the cost of a regional monitoring study is shared over 30 wells.

Cuttings transportation and handling

Non-discharge disposal options require equipment such as auger or vacuum systems to move the cuttings from the solids control equipment to the offloading point or the on-site injection plant. For the example analyses, all non-discharge options incurred a cost of $2,500/day for rental and operation of cuttings handling equipment and $277/ton of waste for transport to shore or to an alternate offshore disposal site.

Onshore cuttings treatment and disposal

The availability of any of the range of onshore cuttings disposal options depends on local regulations and waste disposal infrastructure. Cuttings brought ashore may be disposed of directly in landfarms or landfill facilities without further treatment. Regional regulations in many cases require pretreatment to reduce concentrations of salts or hydrocarbons prior to disposal. Literature data on onshore treatment and disposal were used for example analyses involving these options. The example of cost analyses for scenarios involving onshore disposal were based on information on the cost of onshore treatment and disposal collected from literature sources (Table 2.6). Cost estimates were converted, where necessary, to U.S. dollars using September 2000 exchange rates. Cost estimates stated on a volume basis were converted to a weight basis using an assumed density of cuttings waste of 1.7 metric tons per cubic metre.

Offshore re-injection disposal costs

Disposal by injection is subject to the cost of a disposal well and the cost of operating the surface equipment. Wastes can be injected into a dedicated disposal well, injected into the annulus of a producing well, or injected into a well that is later converted to a producing well. The cost of a disposal well can in some cases be spread over a number of producing wells. For this analysis, an apportioned cost of $300,000 per well drilled is assumed for the capital cost of the injection well and a daily cost of $2,500 is assumed for the operation of the surface plant. Also to be considered are any potential cost-savings that may be gained by having the capability to inject other wastes (waste drilling fluids, oily waste water) that might otherwise have to be transported to shore for disposal onshore. These cost-savings may help offset the costs of equipment and/or the disposal well.
### Table 2.6 Costs for onshore cuttings treatment and disposal options

<table>
<thead>
<tr>
<th>Cost Parameter</th>
<th>Value</th>
<th>Units</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal Treatment (UK)</td>
<td>251</td>
<td>$/t</td>
<td>UKOOA [1999]</td>
</tr>
<tr>
<td>Incineration Treatment (UK)</td>
<td>111</td>
<td>$/t</td>
<td>UKOOA [1999]</td>
</tr>
<tr>
<td>Landfarm (USA)</td>
<td>37</td>
<td>$/t</td>
<td>API/NOIA (2000)</td>
</tr>
<tr>
<td>Untreated Landfill (UK)</td>
<td>74</td>
<td>$/t</td>
<td>UKOOA [1999]</td>
</tr>
<tr>
<td>Onshore Injection (Median, USA)</td>
<td>130</td>
<td>$/t</td>
<td>Calculated from Veil (1998) and API/NOIA (2000)</td>
</tr>
</tbody>
</table>

### Example cuttings disposal cost analyses

The cost assumptions discussed above were used to develop example cuttings disposal cost analyses for a variety of realistic disposal scenarios. The costs were put on a comparative basis by calculating the difference between the disposal related costs of the option of interest and a base case. The base case was defined as discharge of cuttings drilled with Group II NADF and basic solids control equipment.

The incremental costs per well range from $450,000 for discharge of cuttings drilled with a Group III and basic solids control equipment to $1,400,000 for onshore landfill disposal after thermal treatment of cuttings drilled with a Group II NADF (Figure 2.7).

The cost analysis examples are very sensitive to two costing assumptions. These assumptions are an important factor in the difference between this and other analyses of cuttings disposal costs (e.g., EPA, 1999).

Increased drilling time: It was assumed that the selection of any non-discharge disposal option or the use of secondary solids control equipment with a discharge option introduces a 1.5 day increase in drilling a 45-day well. At an assumed rig cost of $300,000/d, the increased drilling time can account for more than 50% of the incremental cost over the reference case. Other analyses (USEPA, 1999) have assumed no increase in drilling time for the alternative disposal options.

- Credit for recovered NADF: The assumption that NADF mud recovered through the use of secondary solids control equipment is worth only 50% of the cost of new NADF has a strong influence on the trade-off between savings from increased NADF recovery and the cost of installing and operating secondary solids control equipment. Other analyses (USEPA, 1999) assigned a 100% value to the recovered NADF.
3 Evaluation of fate & effects of drill cuttings discharge

Offshore discharge of drill cuttings has been a standard disposal practice for cuttings generated at offshore drilling facilities. There are a variety of environmental aspects relating to the fate and effects of marine discharge of cuttings coated with NADFs. This chapter addresses those aspects.

3.1 Overview of fate & effects of discharged NADF cuttings

This section addresses the general environmental fate and effects of NADF cuttings once discharged into the ocean. Subsequent sections provide more detail of the physical, chemical and biological processes associated with the discharge of NADF cuttings.

Figure 3.1 illustrates the deposition and fate of drill cuttings as they fall through the water column and settle on the sea floor. Initial deposition is largely dependent on water depth and currents, as well as the volume and density of the discharged cuttings. Persistence on the seafloor is related to sediment transport and re-suspension as well as biodegradation of the base fluid. Biological effects of cuttings are dependent on the toxicity of the cuttings and the spatial extent of the cuttings deposition. Effects may be related to a combination of physical burial, drilling fluid toxicity and drilling fluid-induced sediment anoxia.

3.1.1 Initial seabed deposition

The initial cuttings deposition on the seabed is the result of a number of physical processes that may differ significantly from site to site. The pattern of cuttings deposition will be determined by the following conditions at each site:

- Quantities and rate of cuttings discharged
- Cuttings discharge configuration (i.e., depth of discharge pipe)
- Oceanographic conditions (e.g., current velocities, water column density gradient)
- Total amount and concentration of NADFs on cuttings
- Water depth
- Fall velocity distribution of the cuttings particles and aggregates.

Since the particles are wet with the NADF, the cuttings tend to aggregate once they are discharged. The aggregates fall at a greater fall velocity (more quickly?) than the particles in the more easily dispersed WBF cuttings. Less dispersion and greater fall velocity of the NADF covered cuttings generally results in smaller area but thicker deposition on the seabed compared to WBF cuttings discharged under the same conditions. The degree of aggregation may be affected by the impingement of the water used to wash them into the ‘downcomer’, and may be a function of oil on cuttings content.

The water column impacts from discharging NADF cuttings are considered to be negligible due to the following:

- low solubility of NABF in seawater.
- low water column dispersion and residence time due to rapid settling rate
- drilling discharges are intermittent and transient.
3.1.2. Physical persistence

Once cuttings are deposited on the seabed, the physical persistence of the cuttings and elevated NADF levels will depend upon the natural energy of re-suspension and transport on the seafloor coupled with biodegradation of the base fluids. In addition, shale cuttings can weather naturally and disaggregate into silt/clay particles due to hydration upon exposure to seawater. Duration of benthic community impact is related to the persistence of NADF cuttings accumulations and associated hydrocarbons in the sediment. Field studies (provided in Section 3.4) indicate that for NADF cuttings discharges, the areas that recovered most rapidly were those characterised by higher energy seabed conditions. Because of the tendency for adhesion between NADF cuttings, re-suspension of NADF cuttings requires higher current velocities than those required for WBF cuttings. Laboratory tests found that the critical current velocity for required for erosion of NADF cuttings was 36 cm/s for cuttings with 5% oil content. Critical velocity was not found to be a strong function of oil content (Delvigne 1996).

Since cuttings would be expected to be less persistent in areas with thinner deposits recovery from any impacts would be expected to be more rapid than areas with deep piles. Therefore, it is important to consider factors that govern the initial deposition thickness and the potential for erosion in assessing recovery potential.

Initial deposition thickness will depend on the current profile and water depth. Stronger currents lead to wider dispersion before deposition, and greater water depth generally will lead to thinner initial deposits.

The potential for erosion is dependent on currents near the seafloor. In relatively shallow water, tidal currents and storm events often provide sufficient energy for substantial erosion.
Therefore, shallow areas with high currents are not likely to experience substantial accumulations of cuttings for extended periods of time (Dann and Mulder, 1994). Although it is commonly assumed that bottom currents are relatively low in deep water settings, this is not always the case. For example, in the deep water Gulf of Mexico, currents with velocities in excess of 100 cm/s have been observed (Hamilton and Lugo-Fernandez 2001; Nowlin et al 2001). Therefore, local environmental conditions are very important in determining the characteristics of the initial deposition and the likelihood of extended persistence of accumulations of discharged cuttings.

3.1.3. Benthic impacts and recovery

The deposition of drill cuttings may result in physical smothering of benthic organisms regardless of the nature of cuttings, WBF or NADF. The initial deposition of cuttings can also have a physical impact on bottom-dwelling animals by altering the sediment particle size distribution of the substrate. Since NADFs are biodegradable organic compounds, their presence with the cuttings on the sediments increases the oxygen demand in the sediments. This organic enrichment of the sediment, can lead to anoxic/anaerobic conditions as biodegradation of the organic material occurs. Anoxic conditions may also result from burial of organic matter by sediment redistribution. Most field studies following discharge of Group III NADF cuttings indicated increased anaerobic conditions in subsurface sediments.

3.1.3.1 Biodegradation and organic enrichment:

Organic compounds in the sediment, whether NABF, or settled biomass such as algae and other detrital material, will biodegrade by the actions of the naturally occurring microorganisms. NADF biodegradation rates will depend upon seafloor environmental conditions (temperature, oxygen availability in sediments) as well as NADF concentrations and NADF type. Biodegradation occurs more rapidly under aerobic conditions (with oxygen) than under anaerobic conditions (in the absence of oxygen). With very few exceptions, oxygen is present in seawater at the sea floor. Therefore, aerobic conditions occur at the exposed surface of the cuttings accumulations and impacted seabed as oxygen diffuses from the water to the sediments. Laboratory studies have indicated that the activity of sediment re-worker organisms in the sediments further enhances oxygen transfer into the sediments and the rate of biodegradation (Munro et al 1997b). Likewise, oxygen is more available to dispersed or re-mobilised particles containing NABF than deep inside impacted sediments.

When the rate of biodegradation in sediments is greater than the rate of diffusion of oxygen into the sediments, oxygen becomes limited and sediments become anaerobic. Anaerobic (or anoxic) conditions would be expected to occur deeper within the cuttings accumulation or impacted sediment. If anoxic conditions are generated, additional anaerobic biodegradation may occur by specific populations of microorganisms.

The term used to describe the effects of NABF biodegradation in sediments is organic enrichment. In certain environments, the subsurface is already anoxic due to natural processes, and in other cases, the anoxic zone may begin only a few centimetres from the surface. In such environments, the impacts of biodegradation following discharge may be less.

If anoxia is induced, benthic organisms, macro and meio fauna that require oxygen for survival may not be able to compete with bacteria for oxygen. As a consequence, the rapid biodegradation of NADF may lead indirectly to sediment toxicity. Furthermore, if the concentration of hydrogen sulphide becomes high enough in the sediments, it may impact benthic populations. As a result of these factors, benthic populations may be altered in the affected sediments until the NADF has been sufficiently removed to mitigate the organic enrichment and organisms can recolonise the sediments.
As the NABF biodegrades, the NADF cuttings aggregate becomes more hydrophilic (water soluble) and the fine particulate solids are released. Bottom currents can then more easily disperse the cuttings (as discussed in section 2.1.2). The rate and extent to which this can occur will depend upon the biodegradability of the fluid and velocity of local currents. Laboratory results have shown that the sediment characteristics may have an effect on the rate of biodegradation (Munro et al 1998). Sediments with a greater fraction of clay and silt particles supported more rapid biodegradation than sediments that were sandier.

3.1.3.2 Chemical toxicity and bioaccumulation:

In addition to the potential effects from anoxia, chemical toxicity and bioaccumulation of NABF components could also lead to benthic impacts. As mentioned earlier, the impacts to the water column are minimal and the majority of impacts that are measured are in the benthic communities. The toxicity of NADF cuttings on benthic communities is a combination of fluid toxicity and anoxic conditions.

It is difficult to distinguish the effects of chemical toxicity from those of oxygen deprivation. Recent statistical analysis of North Sea monitoring data suggests that the impacts to benthic biota can be related to anoxic conditions caused by rapid biodegradation of hydrocarbons contained in the base fluid (Jensen et al 1999). This suggests that the biodegradation rate of hydrocarbons in the sediment may determine the extent of impacts on the benthic biota, and faster degradation rates may lead to larger initial impacts.

The potential for significant bioaccumulation of NABFs in aquatic species is believed to be low. Bioaccumulation of NABF in benthic species occurs when organisms exposed to hydrocarbons incorporate those compounds within their biomass. The extent of bioaccumulation is a function of incorporation of a compound into the tissue mass of the organisms countered by the ability of the organism to depurate or metabolise the compound.

An associated condition is taint, namely alteration on the odour or taste of edible tissue resulting from the uptake of certain substances, including certain hydrocarbons. Some complications with detecting taint are that flesh that contains hydrocarbon may have no detectable taint. There is no evidence that NADFs cause taint in concentrations discharged to the environment. Davies et al (1989) reviewed a series of taint studies on fish caught near platforms in the North Sea where cuttings containing oil based muds were discharged. Fish testing panels were unable to determine an off taste (taint) in fish caught in the vicinity of these platforms.

3.1.3.3 Recovery

The recovery of the benthic communities is dependent upon the type of community affected, the thickness, area extent and persistence of the cuttings (due to a combination of seafloor redistribution and biodegradation), and the availability of colonising organisms. Field studies have indicated that in the short-term, impacts from discharging NABFs can range from minor alterations in the biological community structure at moderate distances (i.e., 100s of metres) from the discharge point to significant mortality of biota in the immediate vicinity of the outfall. Field studies on NABFs have shown a decrease in faunal abundance and diversity near the well sites, with a corresponding increase in opportunistic species. Typically, over the longer term, the affected areas are recolonised by biological communities in a successional manner. Initial colonisation is by species that are tolerant of hydrocarbons and/or opportunistic species that feed on bacteria which metabolise hydrocarbons. As time passes, and hydrocarbon loads diminish, other species return via in-migration and reproduction, and the community structure returns to something more closely resembling its former state. Figure 3.2 shows the seafloor near a site where NADF cuttings were discharged.
Environmental aspects of the use and disposal of non aqueous drilling fluids associated with offshore oil & gas operations

The potential implications of seafloor impacts will depend on the sensitivity/significance of the bottom resources. Highly sensitive regions would be those of high productivity and diversity that are important feeding and spawning areas. Such areas could include coral reefs, mangroves, fish nursery areas and deep water chemosynthetic communities. In these sensitive environments, more detailed environmental assessments would be carried out to better understand potential risks and appropriate disposal options would be considered.

Deep water benthic communities are not as well characterised as many other shallow water communities. However, studies associated with oil and gas development have significantly increased our understanding of deep water biology. Deep water benthic communities tend to be characterised by low in abundance and high in diversity. Several deep water studies are underway in a variety of water depths and in different parts of the world to understand the impacts of NABFs on deep water environments.

3.2 Laboratory studies

Laboratory tests can be used to assess the biodegradability, toxicity and potential for bioaccumulation of NABFs. Test protocols have been incorporated into some national and regional regulatory frameworks. Laboratory data provide a means of differentiating products in terms of their environmental performance. It is commonly assumed that fluids that are less toxic and more biodegradable in laboratory studies have a higher likelihood of causing less impact on the seafloor. However, laboratory tests, while useful tools, are not always predictive of ecological impacts because they cannot account for the complexities and variables of the marine environment. For example, while esters have been shown to be highly biodegradable in the laboratory, they have caused low oxygen concentrations in field sediments resulting in greater biological impact than less biodegradable NABFs (Jensen et al, 1999).

The Harmonised Mandatory Control System (OSPAR 2001) for the North East Atlantic, and the USEPA’s effluent discharge permits in the US, require various laboratory tests to determine if a material is suitable for offshore discharge. Laboratory tests may be used either as a regulatory compliance tool or as a research tool to evaluate the impacts of NABF on the seafloor under controlled conditions. However, caution should be used when trying to extrapolate results from laboratory tests. Laboratory data are generated under tightly controlled, constant environmental conditions, while seafloor conditions are highly variable and usually much different from the conditions in the laboratory.
3.2.1 Characterisation of NADF biodegradability

In some parts of the world, approval for overboard discharge of cuttings drilled with non-aqueous drilling fluids also requires laboratory biodegradation testing of the base fluid. The concept of using biodegradation as a fluid-compliance criterion is that a material that degrades readily in laboratory tests will not persist for extensive periods of time in the environment upon discharge. Quantifying biodegradation rates of NADF base oils used in drilling fluids is complicated by a number of factors that could affect biodegradation rates both in the laboratory and in the field.

There have not been widely-accepted seabed survey protocols that have been applied to test biodegradation for varying field conditions. This is a further reason why there is no mechanism to compare laboratory to field data directly. As noted in Section 2.1.3, it is clear that under certain environmental conditions (e.g. low currents, and static piles), evidence suggests long-term persistence of the NABF will persist in the environment for a long time. However, under other environmental conditions, evidence suggests the environment is able to accommodate discharged cuttings, by biodegradation or other mechanisms. Biodegradability of NABFs is being studied in the laboratory using different types of experimental protocols: standard laboratory tests, solid phase tests, and simulated seabed tests. While the performance of each fluid is test specific, a few generalisations can be made from the results of laboratory biodegradation tests that have been reported in the literature to date:

- Non-aqueous base fluids exhibit a range of degradation rates. Under comparable conditions, esters seem to degrade most quickly, and other base fluids have more similar degradation rates. The extent to which the range of base fluids appears to differentiate themselves in degradation rates depends upon the testing protocol used.
- All Group II and Group III NABFs have been shown to biodegrade to some degree with at least one laboratory test.
- Laboratory tests have shown Group III fluids generally biodegrade more rapidly than Group II, although there is still disagreement or debate over how this information relates to the biodegradation occurring in a cuttings pile or on the seabed. Aspects of these tests that affect biodegradation rates include the degree of oxygen present, temperature, and the effects of inocula.
- Increased temperature increases rate of biodegradation
- A lag phase was reported in many of the tests, and so, the reported half-life used to quantitatively describe the biodegradation process should be used with caution.
- The half lives of fluids in sediments increases with concentration of base fluid in the sediments. However, the rate of biodegradation in mg/kg/day of esters increased with higher concentrations of fluid in sediment.
- Sediment type, (e.g. sand versus clay/silt) affects degradation rate; degradation occurs more rapidly in silt/clay sediments, than in sandier sediment.
- Degradation occurs more rapidly under aerobic conditions than under anaerobic conditions.
- Evaluation of degradation should include consideration of aerobic conditions, as might be found in the periphery of cuttings accumulation, and anaerobic conditions, as might be found in internal portions of a cuttings pile.
- Compounds that degraded in standardised freshwater tests also degraded in standardised seawater tests, but at a slower rate. However, the slower rate may be due in part to lower initial concentrations of microbial inocula used in the seawater tests.

The specific tests are discussed below.
3.2.1.1 Standard laboratory biodegradation tests

The standard laboratory methods that have been used to test biodegradability of NABFs fall into two categories: methods that consider aerobic biodegradation, and methods that consider anaerobic biodegradation. A number of different biodegradation protocols are in use in different laboratories, and the reported test data show a high degree of variability. For example, test protocols using aerobic or oxygenated conditions yield different biodegradation rates than tests that reflect anaerobic conditions. Therefore it is not appropriate to compare results when different test protocols are used. A more in depth description of the various tests that can be used to measure biodegradation can be found elsewhere. A brief description of the standard tests is found in the Table 3.1.

<table>
<thead>
<tr>
<th>Test</th>
<th>A/An</th>
<th>F/M</th>
<th>Inoculum source</th>
<th>Analyte measured</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>OECD 301B</td>
<td>A</td>
<td>F</td>
<td>Sewage Sludge</td>
<td>CO₂ Generation</td>
<td></td>
</tr>
<tr>
<td>OECD 301D</td>
<td>A</td>
<td>F</td>
<td>Sewage Sludge</td>
<td>Oxygen loss</td>
<td>Dissolved oxygen is measured</td>
</tr>
<tr>
<td>OECD 301 F</td>
<td>A</td>
<td>F</td>
<td>Sewage Sludge</td>
<td>Oxygen loss</td>
<td>Manometer method with greater range than the D version of the test</td>
</tr>
<tr>
<td>OECD 306</td>
<td>A</td>
<td>M</td>
<td>Sewage Sludge</td>
<td>Oxygen loss</td>
<td>Marine version of 301 D</td>
</tr>
<tr>
<td>BODIS</td>
<td>A</td>
<td>F</td>
<td>Sewage Sludge</td>
<td>Oxygen loss</td>
<td>Similar to OECD 301 D for insoluble substances</td>
</tr>
<tr>
<td>Marine BODIS</td>
<td>A</td>
<td>M</td>
<td>Sewage Sludge</td>
<td>Oxygen loss</td>
<td></td>
</tr>
<tr>
<td>ISO 11734</td>
<td>An</td>
<td>F</td>
<td>Sewage Sludge</td>
<td>Gas formation</td>
<td>Anaerobic closed bottle test. Gas measured by pressure transducer</td>
</tr>
</tbody>
</table>

A- Aerobic; An-Aerobic; F- Freshwater; M-Marine water

Generally the tests in this table are designed for the evaluation of water-soluble compounds and do not perform as well with non-aqueous fluids.

3.2.1.2 ISO 11734 modified for NADF biodegradation:

On February 5, 1999, the EPA published the initial guidelines for the discharge of synthetic drilling fluids on cuttings for the United States. These guidelines documented that drilling fluids must be more biodegradable than an internal olefin that was 16 to 18 carbons long (IO1618) to be considered in compliance for discharge. Therefore, a substantial modification of ISO 11734:1995 (Closed Bottle Test or CBT) was developed to discriminate specifically the IO1618 and more rapidly biodegrading fluids from less biodegradable fluids. The modifications of the standard ISO 11734 are that natural sediment replaces fresh water and sewage sludge, seawater is used instead of a nutrient solution and the dosage of fluid added is greater than the standard 11734. The concentration of fluid is higher than normally used with ISO 11734.

The American Petroleum Institute (API) developed the modified ISO 11734 test for synthetic fluids and this was accepted by the EPA as a method for demonstrating compliance with the biodegradation guidelines. The test was found to contain an appropriate compromise of the following characteristics while also allowing clear performance comparisons to the CI618IO standard:

- Discriminatory power between of fluids
- Reproducibility/repeatability
- Ecological relevance
- Standard performance of chemical controls
- Practicality and cost
Serum bottles are filled with a homogeneous NABF/sediment mixture with seawater and an indicator to detect oxygen. The bottles are sealed and the headspace flushed with nitrogen to remove oxygen. Gas generated by biodegradation is measured in the bottles by a pressure transducer. The amount of gas produced is compared to controls and standards. If the base fluid produces more gas after 275 days of incubation than an IO1618, then the test fluid is considered in compliance for biodegradation. A brief detail of the test is in Table 3.2.

### Table 3.2 Characteristics of the modified ISO 11734 for NABF

<table>
<thead>
<tr>
<th>Test</th>
<th>A/An</th>
<th>F/M</th>
<th>Inoculum source</th>
<th>Analyte measured</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO11734 (NADF)</td>
<td>An</td>
<td>M</td>
<td>Naturally occurring microorganisms in sediments</td>
<td>Gas generated by anaerobic biodegradation</td>
<td>This is a compliance test developed to address specific regulations by USEPA</td>
</tr>
</tbody>
</table>

Results of the CBT indicate that this modification of the anaerobic test is adequate for discriminating the biodegradation performance of various Group III fluids (Candler et al 2000). Esters biodegraded the fastest under this test. Linear alpha olefins and internal olefins biodegrade next fastest with rates dependent on molecular weight. Type II fluids, paraffins, and mineral oils degrade very slowly if at all under the conditions of this test.

However, care must be taken so that the results of the test are not misinterpreted by being used beyond their regulatory function. The CBT test is purely a compliance test developed to discriminate between a subset of Group III fluids. It is inadequate for predicting the relative biodegradation rates of fluids that degrade more slowly than internal olefins and is not an appropriate tool for predicting rates of NADF removal in sediments. To the degree laboratory tests can mimic sub-sea conditions, those issues are better evaluated with simulated seabed studies.

#### 3.2.1.3 The SOAEFD solid phase test

In the North Sea, it was recognised that under some environmental conditions, large piles of cuttings were likely to persist. It was also recognised that base fluids in such a situation were unlikely to degrade at rates represented by aerobic test protocols of aqueous suspensions or extracts. Therefore, work was undertaken to determine relative degradation rates of NADFs should they be present in large static cuttings piles.

The SOAEFD Test (also referred to as the Solid Phase Test) was originally developed at the Scottish Office Agriculture, Environment, and Fisheries Department (Munro et al, 1997a). The basic approach of the SOAEFD Test is to mix clean marine sediments with base fluids used in NADFs and to fill glass jars with the homogeneous NABF/sediment mixtures. The glass jars are placed in troughs through which a continuous laminar flow of natural ambient temperature seawater is passed. At various time intervals sets of three jars are removed and analysed for NABF. The entire sediment volume is chemically analysed to determine total losses of the base fluid. The rate of NABF removal is reported as half-life of NABF loss and with first order rate constants. Like the Closed Bottle Test, no microbial inoculum was used. Biodegradation was catalysed by the naturally occurring sediment bacteria. The original test was conducted at seawater temperatures of 10-15°C (Munro et al, 1997a), but has been modified to accommodate other environmental conditions (25°C) to mimic conditions in Nigeria. A short description of the test is in Table 3.3.
The SOAEFD solid phase sediment test is neither a purely aerobic or anaerobic marine biodegradation test for non-water soluble drilling chemicals. Although oxygenated water flows across the top of the jar, oxygen diffusion limitations into the sediment can limit the bulk of the sediment/fluid in the sample jars from being exposed to oxygen.

Tests using the SOAEFD approach were conducted with a suite of NABFs for 3 different concentrations (100, 500, and 5000mg/kg) of NADF in sterilised sediment (Munro et al., 1998). Seven different base fluids were studied: acetal, internal olefin (IO), n-paraffin, poly alpha olefin (PAO), linear alpha olefin (LAO), mineral oil, and ester. Ester mud products were found to degrade significantly more rapidly than all the other base fluids at all concentrations. The results indicate that the IO, LAO, n-paraffin, the mineral oil and PAO fluids degrade to a substantial extent at 100mg/kg. At 5000mg/kg, the rates of degradation of the synthetic and paraffin base fluids were similar to the mineral oil except for the ester that biodegraded faster than the other fluids. However under the conditions of the test, the recovery of spiked fluid in the time zero analyses of the fluid in sediments was about 85% of the theoretical, and none of the fluids besides esters biodegraded more than 20% over the length of the test. Care should be taken on the interpretation of these results. The lack of discrimination between fluids may be a function of the testing conditions rather than a lack of different biodegradation rates. Candler et al. (1999) reported comparable results in tests similar to the SOAEFD protocol.

A separate set of SOAEFD tests was conducted to simulate conditions offshore Nigeria (estuarine sediments at 25°C; Munro et al., 1997b) as opposed to North Sea conditions (marine sediments at 10-15°C) simulated by earlier tests (Munro et al., 1997). Tests were conducted using a non-sterilised sediment and 120mg/kg NADF. Biodegradation rates were higher at the higher temperature. The greater biodegradation rate has been attributed in part to enhanced oxygen transport into the seabed due to activity of small animal life burrowing in the sediment (sediment re-workers).

### 3.2.1.4. Simulated seabed studies

Other laboratory methods have been developed to study biodegradability of non-aqueous fluids under simulated North Sea seabed conditions. The primary method of this group, the NIVA Simulated Seabed approach, was originally developed at the Norwegian Institute for Water Research (NIVA), and has been through numerous modifications since it was first introduced in 1991. Most simulated seabed studies are now based on variants of the NIVA test. The objective of the simulated seabed study is to determine the fate of the test compound in the environment by simulating the conditions of the seabed as closely as possible.

The test set-up consists mainly of a series of replicate experimental systems that were maintained in easily accessible indoor basins called benthic chambers. The benthic chambers were approximately 50cm×50cm×35cm deep. A cuttings and NADF mixture was suspended in seawater and added to the overlying water in the benthic chambers (Schanning et al. 1994, Schanning et al., 1994b; Schanning et al., 1995). The suspensions settled onto a 25cm deep bed of natural sediment. Once the cuttings settled on the sediments, the chambers were flushed with seawater drawn from a depth of 40 to 60 metres from the Oslofjord. The water in the...
chamber was being replaced at a rate of one or twice per day. The loss of NABFs deposited on cuttings was measured over a period of 150 to 187 days by TPH analysis of the top layer of sediments. Environmental characteristics such as Ba concentration, pH, Eh and oxygen uptake of the chamber were also measured. Later modifications included quantification of sediment organisms throughout the test.

This test method includes many of the potential physical and biological processes affecting the behaviour of cuttings on the seabed under controlled laboratory conditions. The test was designed to mimic the aerobic and anaerobic conditions, and the bioturbation processes that are present on the seabed caused by benthic organisms. The results indicate that ester degraded faster than ethers and mineral oils. Some mussel mortality was observed in all the chambers compared to the control. Eh values and oxygen uptake of the sediments were generally consistent with biodegradation of NABF. Mortality of benthic organisms was associated with the disappearance of esters.

Several problems were identified with the initial studies, however. These included the non-homogenous distribution of cuttings on the surface of the sediments at the start of the test and the associated questions regarding initial conditions and the potential for some of the test fluids to have been washed away by water rather than biodegraded. Some of the questions have been resolved in subsequent refinements to the NIVA test method. However, Vik et al (1996) concluded that in order to resolve all the issues with the design of the NIVA method, the cost of the experiments would increase dramatically.

### 3.2.2 Characterisation of toxicity and bioaccumulation

#### 3.2.2.1 Aquatic and sediment toxicity of drilling fluids

With the introduction of more highly refined mineral oils and the synthetic based fluids, the aquatic toxicity of NABFs has been significantly reduced. Early-generation OBFs, which consisted of diesel or mineral oil, exhibited significant toxicity as a result of water-soluble aromatic and polyaromatic hydrocarbons. More recent LTMBFs possess considerably less aromatic hydrocarbons and are less toxic. New-generation enhanced mineral oils, paraffins and synthetics have little or no aromatic content and generally are even less toxic.

Since NABFs possess low water solubility and are only present in the water column for a short time after discharge, it is becoming more widely accepted that water column toxicity testing does not fully address all the environmental risks associated with NADF discharge on cuttings. Sediment toxicity tests are probably more relevant to the discharge of NADF cuttings than are aqueous phase or water column toxicity tests because most of the fluid is anticipated to end up in the sediment.

Sediment toxicity tests are performed on sediment dwelling organisms (e.g., corophium volutator or leptocheirus plumulosis). Field validation research, infaunal surveys and bioassays of waste materials have shown that sediment dwelling amphipods are sensitive to sediment contaminants. Furthermore, they have maximum exposure potential since they are intimately associated with sediments, and have limited mobility.

Table 3.4 summarises toxicity data available on NABFs, including data on sediment dwelling amphipods. Data are presented in terms of the medium lethal concentration, LC$_{50}$ or the effect concentration for cell reproduction EC$_{50}$ (algae). Toxicity varies with test species and drilling fluids. However, it is clear that diesel oil is more toxic than more highly refined mineral oils and Group III fluids. Though Group III fluids have relatively low toxicity to sediment-dwelling organisms, with LC$_{50}$ greater than 1,000mg/l of sediment, the relative ranking of the different SBMs in terms of sediment toxicity is generally consistent across the different species. The esters appear to be the least toxic, followed by the IOs and LAOs.
Differences in toxicity of SBMs Group III fluids may be due to differences in molecular size and polarity, which affects water solubility and bioavailability.

### Table 3.4 Aquatic toxicity of non-aqueous-based fluids (LC$_{50}$ or EC$_{50}$, mg/l)

<table>
<thead>
<tr>
<th>Test organism</th>
<th>Ester</th>
<th>LAO</th>
<th>IO</th>
<th>Paraffin</th>
<th>LTMBF</th>
<th>EMBF</th>
<th>Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algae, Skeletonema costatum</td>
<td>60,000 (Vik et al. 1996)</td>
<td>&gt;10,000 (Mckee et al. 1995)</td>
<td>1,000-10,000 (Baker Hughes Inteq. 1996)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Mysid, Mysidopsis bahia</td>
<td>1,000,000 (Baroid)</td>
<td>794,450 (Mckee et al. 1995)</td>
<td>150,000-1,000,000 (Zevallos et al. 1996 and Baker Hughes Inteq. 1996)</td>
<td>NA</td>
<td>13,200</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Copepod, Acartia tonsa</td>
<td>50,000 (Baroid)</td>
<td>&gt;10,000 (Mckee et al. 1995)</td>
<td>10,000 (MI Drilling Fluids, 1995)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Mussel, Abra alba</td>
<td>8,000 (Vik et al. 1996)</td>
<td>277 (Friedheim and Conn. 1996)</td>
<td>303 (Friedheim and Conn. 1996)</td>
<td>572</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Amphipod, Corophium volutator</td>
<td>&gt;10,000</td>
<td>1,028 (Friedheim and Conn. 1996)</td>
<td>1,560-7,131 (Friedheim and Conn. 1996)</td>
<td>NA</td>
<td>2,747 (Harris, 1998)</td>
<td>7,146 (Candler et al. 1997)</td>
<td></td>
</tr>
</tbody>
</table>

NA: Not available

### 3.2.2.2 Aquatic toxicity and regulations

In some parts of the world, approval for discharge of drill cuttings into the sea requires toxicity testing to determine the potential for adverse effects on aquatic life (see Appendix C for discharge requirements).

In the North Sea, base fluids and chemicals used in the drilling process must undergo aquatic toxicity testing for hazard evaluation (OSPAR, 1995a, 1995b). Tests are performed with three types of aquatic species representing the aquatic food chain - an alga and a herbivore (for which aqueous phase tests are conducted), and a sediment re-worker (for which the sediment phase is used). The most common species tested are the marine alga, *Skeletonema costatum*, the copepod, *Acartia tonsa* and the sediment dwelling amphipod, *Corophium volutator*.

In the United States, discharge approval is based on compliance with effluent toxicity limits at the point of discharge. Present discharge permits require measurement of the aquatic toxicity of the suspended particulate phase of drilling effluents to the mysid shrimp, *Mysidopsis bahia*. Historical studies with water-based muds showed sediment toxicity tests to be considerably less sensitive than the suspended particulate phase, thus sediment tests were dropped as a testing requirement for those types of discharges.

The USEPA recently published guidelines for the discharge of cuttings containing synthetic based drilling fluids (Federal Register, January 22, 2001). In these guidelines, EPA requires all synthetic based fluids to be discharged with drill cuttings to be no more toxic than a $C_{16}^{16}-C_{18}^{18}$ internal olefin base fluid, as determined in a 10-day sediment toxicity test (ASTM E1367-92) with *Leptocheirus plumulosis*. In addition, drilling muds used offshore must undergo a 4-day toxicity test with *Leptocheirus plumulosis*, prior to drill cuttings being discharged. In this 4-day test, drilling muds must be no more toxic than a $C_{16}^{16}-C_{18}^{18}$ formulated drilling mud. Otherwise, drill cuttings discharge cannot proceed.

Overall, laboratory studies have shown that in most cases NADFs exhibit low toxicity and can generally meet toxicity requirements in countries where toxicity data are required. However, in isolated instances where the NADF may fail to meet toxicity requirements due to the base fluid or chemical additives in the fluid system, alternative options (including possibly changing the base fluid) may need to be evaluated.
3.2.2.3 Characterisation of NABF bioaccumulation

Bioaccumulation is the uptake and retention in the tissues of an organism of a chemical from all possible external sources (water, food, and substrate). Bioaccumulation may be a concern when aquatic organisms accumulate chemical residues in their tissues to levels that can result in toxicity to the aquatic organism or to the consumer of that aquatic organism.

Group I and Group II NADFs may contain some polyaromatic hydrocarbons (PAH) and other high molecular weight branched hydrocarbons that have the potential to bioaccumulate in benthic invertebrates. However, bioaccumulation in higher trophic levels, such as in fish or mammals, is unlikely since these animals have enzyme systems to metabolise PAH compounds. In the case of Group III NABFs, significant bioaccumulation appears unlikely due to their extremely low water solubility and consequent low bioavailability.

Two types of data are used to evaluate a chemical’s bioaccumulative potential: the octanol:water partition coefficient and the bioconcentration factor. The octanol:water partition coefficient, often expressed as log P<sub>OW</sub>, is a physico-chemical measure of a chemical’s propensity to partition into octanol relative to water. It is used as a chemical surrogate for bioaccumulative potential. Generally, it is recognised that organic chemicals with a log P<sub>OW</sub> between 3 and 6 have the potential to bioaccumulate significantly. Chemicals with log P<sub>OW</sub> values greater than 6 are not considered to bioaccumulate as readily because their low water solubility prevents them from being taken up by aquatic organisms and the physical size of the molecules is such that they cannot pass through membranes. Those with P<sub>OW</sub> values less than 3 tend to not sorb readily into the octanol and readily desorb back into the water phase. Therefore, such compounds do not readily bioaccumulate.

Determination of a bioconcentration factor (BCF) is an <i>in vivo</i> measure of bioaccumulative potential. Basically, an organism is exposed to a constant concentration of the test material in water until equilibrium is reached between the concentration in the water and the concentration in the tissues of the organism. The BCF is the tissue concentration divided by the water concentration at equilibrium. BCF values greater than 1,000 (or log BCF>3) can be a cause for concern. Compounds with BCFs<1000 (or log BCF<3), are less likely to accumulate in tissues due to their relatively high water solubility. However, this type of test is fraught with technical challenges when evaluating highly water insoluble substances like Group III fluids. Substances with extremely low water solubility have a tendency to precipitate out of solution or bind to suspended particles, which can make it difficult to determine the BCF accurately.

Table 3.5 summarises octanol-water partition coefficient (log P<sub>OW</sub>) and BCF data for the most commonly used Group III fluids. With the exception of esters, all of the base fluids have a log P<sub>OW</sub> exceeding 6. This means that bioaccumulation will be limited by their extremely low water solubility. Esters have log P<sub>OW</sub> less than 3. Therefore, they are not expected to bioaccumulate.
BCF values generated in tests with the blue mussel, Mytilus edulis, appear high for both the IO and LAO. However, it is questionable whether these values are reflective of true systemic bioaccumulation because of the difficulty of maintaining steady concentrations of the base fluid in solution. Furthermore, at least with the IO, depuration of the SBF was very rapid after the mussels were transferred to clean water. Ninety five percent of the IO was eliminated from the mussels within five days (Environmental and Resource Technology 1994). This rapid depuration suggests that the IO was likely adhering to the surfaces of the mussel and not absorbed systemically. In her environmental assessment of drilling fluids, Meinhold (1998) concluded that SBFs are unlikely to be accumulated by shellfish. In the only study performed with fish, PAO residues were limited to the stomach, suggesting that SBFs are not readily absorbed into the tissues (Rushing et al., 1991).

In summary, the organic chemical constituents in WBMs do not bioaccumulate. Some trace components of OBMs could bioaccumulate in lower trophic levels but not in higher vertebrates such as fish and mammals, which are capable of metabolising PAHs. NABFs are not expected to bioaccumulate significantly because of their extremely low water solubility and consequent low bioavailability. Their propensity to biodegrade further reduces the likelihood that exposures will be long enough that a significant bioaccumulative hazard will result.

### 3.3 Computer modelling of NADF cuttings discharges

#### 3.3.1 Introduction

Modelling has been used to assess impacts from drilling discharges by the oil industry and regulatory agencies worldwide. Several computer models exist that predict the behaviour of drilling fluids and drill cuttings discharged into the marine environment. These models use input describing the ambient environment near a discharge point and characteristics of the effluent to predict trajectory and shape of discharge plumes, the concentrations of soluble and insoluble discharge components in the water column, and the accumulation of discharged solids on the seabed. Thus, discharge modelling provides a tool to estimate environmental loadings from cuttings discharges.

While modelling is a useful tool that can be used to assess NADF cuttings discharges, it should be used in combination with other information to get a more complete understanding of potential environmental disturbance. Models are limited by the quality of the input data used to describe future discharge events and most models do not account for re-suspension and transport of particles after initial deposition. Re-suspension and transport of cuttings particles can be significant in high-energy environments.

This section describes computer modelling input requirements, uses, limitations, and data needs with respect to discharge of cuttings produced with NADF. A discussion of some anticipated model predictions of seabed accumulations in deep water is included at the end of the section.

#### 3.3.2 Model input requirements

One model widely used by the oil industry is the Offshore Operators Committee (OOC) Mud and Produced Water Discharge Model (the OOC Model) (Brandsma et al., 1992, Smith et al., 2001, Nedwed et al., 2001, Brandsma, 2001). The following paragraph describes specific requirements and capabilities of the OOC Model. It is expected that discharge models in general will require the same input and provide similar output.

The OOC Model is used for numerical simulation of the behaviour of discharges from a single, submerged, circular port that can be oriented in any direction. The discharge rate is...
assumed to be constant. Effluents are assumed to consist of a water-miscible fluid phase and may contain particles that are heavier (eg drilling fluid solids or drill cuttings) or lighter (eg oil droplets) than the ambient fluid. For drilling discharges, the effluent is described by bulk density, discharge rate, discharge pipe configuration, and mud and cuttings particles settling velocities. NADF cuttings discharges are described to the model by assuming that the base fluid adheres to the cuttings particles and that the continuous phase is the water that is used to wash cuttings into the receiving water after performing solids control processing on the rig. The receiving water is described by water depth, temperature, salinity, and current velocity. The model’s output consists of calculations of the trajectory and shape of the discharge plume, the concentrations of soluble and insoluble discharge components in the water column, and the accumulation of discharged solids on the seabed. The model predicts the initial fate of discharged solids, from the time of discharge to initial settling on the seabed. This prediction does not account for re-suspension and transport of previously deposited solids and as such provides a conservative estimate of potentially harmful seafloor concentrations of base fluids. As discussed in Section 3.1, re-suspension and transport will likely act to lessen persistence of NADFs and hasten recovery.

### 3.3.3 Model uses

Discharge models provide the oil industry and regulators with a tool that can be used to predict the initial spatial extent and thickness of cuttings accumulations on the seabed. This information in conjunction with other data, eg the energy available for re-suspension and transport of deposited cuttings and the efficiency of biodegradation in the particular environment, will assist in determining the acceptability of discharges associated with planned exploration and development drilling.

Predictions of seabed cuttings accumulations might also be used to design cuttings disposal practices. In some settings, it may be highly desirable to limit the dispersion of cuttings into a sensitive environmental area. In such cases, it may be feasible to discharge cuttings near the seafloor to limit the area affected by cuttings. The discharge model can predict the effect of discharge point location.

### 3.3.4 Limitations and needs

Since discharge models use data collected in the past to predict future events, the accuracy of predictions is limited by the degree that historic data represent future conditions. Thus, models need data that accurately describe discharge conditions expected during discharge events in order to provide useful predictions.

Of particular importance to modelling NADF cuttings discharges is data describing the fall velocities of the cuttings particles. Currently, there is a limited amount of information in the literature describing the fall velocities of drill cuttings generated with non-aqueous fluids. One source of data that may be used is NADF cuttings fall velocity data adapted from Delvigne (1996) for untreated oil based mud (OBM) cuttings produced from a well drilled in the North Sea. NADF cuttings particles in general are expected to behave similarly to OBM cuttings.

Although research is underway to address this need, no published data on the fall velocity of cuttings produced with Group III NADFs exist.

Most discharge models do not address re-suspension and transport of particles after initial deposition. For example, the OOC Model assumes that particles remain indefinitely at their initial settling location. In reality, currents re-suspend particles and spread them over a larger area. Thus, particularly where currents near the seabed are strong, cuttings accumulations will tend to dissipate over time because of current forces alone. As discussed in Section 3.4,
field studies have found that cuttings accumulations tend to redistribute and disperse in high-energy environments. If re-suspension and transport of cuttings are not considered when evaluating the acceptability of a drilling discharge, the model might predict that unacceptably thick cuttings accumulations will be generated, when, in fact, strong currents near the seabed might cause cuttings accumulations to dissipate rapidly.

### 3.3.5 Discharge modelling results

The OOC Model was used to predict seabed solids loading under two drilling discharge scenarios (Melton et al., 2000). The model output is shown in Figures 3.3a and 3.3b. Under the first scenario, a 4000m well drilled with WBF only was simulated to release 703m$^3$ of WBF solids (eg bentonite and barite) and 623m$^3$ of WBF cuttings into 1200 metres of water. Under the second scenario, NADF was used in place of WBF to drill all hole intervals below the conductor. Under this scenario, the release of 498m$^3$ (less hole washout was assumed) of NADF cuttings was simulated. The average current speed decreased from 17cm/s near the surface to 6cm/s near the seabed. The model predicted the seabed loading caused by discharges made near the sea surface. The modelling did not account for the discharge of WBF cuttings from the first (riser-less) section of the well that will occur near the seafloor. The discharges at the seafloor can cause significant cuttings accumulations near the well site.

NADF cuttings fall through the water column more rapidly than WBF cuttings consequently, the predicted seabed loading for NADF cuttings (greater thickness, smaller area) is higher than for WBF cuttings. The predicted maximum cuttings accumulation depths are 0.19cm for the WBF cuttings/solids and 1.3cm NADF cuttings. Cuttings loadings decrease rapidly with distance from the discharge point. For the NADF discharge, seabed cuttings loadings decrease by more than an order of magnitude less than 200 metres from the discharge point. The low deposition density and limited areal extent of solids accumulation predicted for both scenarios should cause minimal initial effects (eg smothering) and allow for rapid natural recovery.

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![Figure 3.3a](image1.png) **Figure 3.3a:** Seabed loading contours from the discharge of WBF solids and cuttings into 1200 metres of water. Contour lines show the predicted depth of cuttings accumulations; cross marks the discharge point

![Figure 3.3b](image2.png) **Figure 3.3b:** Seabed loading contours from the discharge of NADF cuttings into 1200 metres of water. Contour lines show the predicted depth of cuttings accumulations; cross marks the discharge point
3.4 Drilling fluid and cuttings discharge field studies

Field studies can provide the most realistic assessment of the impacts resulting from discharge of drilling fluid and cuttings. Field monitoring programmes can be used to determine the distribution and persistence of mud and cuttings on the seafloor and the impacts on seafloor biota from these discharges.

However, field studies have their own inherent limitations that must be considered when assessing environmental impacts. First, it is difficult to extrapolate from one field study to another because each site is unique in terms of its physical characteristics and its drilling history. External interferences such as storm events have also been known to dramatically change the seafloor environment. Second, there are concerns related to the accuracy and variability of field measurements, particularly biological analyses. Finally, it is often difficult to establish cause and effect between possible stressors and environmental impacts because there are so many variables in the offshore environment.

Many field studies have been conducted on the impacts from discharging WBF and cuttings and Group I NADF cuttings. General results of these studies are provided as a basis of comparison with those conducted on the impact of discharging Group II or Group III NADF cuttings. Studies that have been conducted on the impact of discharging Group II or Group III NADF cuttings, suggest that impacts are less than those resulting from discharge of Group I NADF cuttings. This section discusses the findings of cuttings discharge field studies. A short summary of WBF and Group I NADF cuttings discharge impacts is provided. This discussion is followed by summaries of field studies on discharges of cuttings associated with Group II and Group III fluids.

Field studies do have some inherent limitations. Regardless of the character of the fluid discharged, water depths and oceanographic conditions (currents, temperatures) will influence both the initial accumulation and distribution of cuttings and their persistence (redistribution and biodegradation). These factors must be considered when trying to compare study results. Differences in these factors limit the conclusions that can be drawn regarding impacts resulting from discharge, particularly those comparing base fluids.

3.4.1 WBF field study conclusions

There have been a number of WBF discharge seabed studies conducted around the world, in varying water depths and oceanographic environments. Most involve discharges from single wells. The effects from such discharges differ qualitatively from those of Group I NADF cuttings discharges in that discharges of WBFs and WBF cuttings do not result in hydrocarbon enrichment of sediments. The scientific literature strongly supports the view that the potential for seabed biological effects from WBF and WBF cuttings discharges depends primarily on the energy of the seafloor environment. Seafloor impacts from such discharges may not be detectable in high-energy environments, such as those in relatively shallow water with exceptionally high bottom currents (eg 62 m water depth-Lower Cook Inlet, Alaska; Lees and Houghton, 1980; Houghton et al, 1980a, and Houghton et al, 1980b). In lower energy environments, with deeper water with slow bottom currents, cuttings accumulations and minor biological impacts were observed one year after drilling (eg 120m; Baltimore Canyon-East Coast US; Ayers et al, 1980; Menzie et al, 1980; EG&G, 1982 and Gilmore et al, 1985). When impacts are observed they appear to be physical (the result of burial or alteration in sediment texture) in nature, highly-localised, and temporary (Smith et al, 1997). This is in contrast to impacts from discharge of Group I NADF cuttings that tend to be more severe and longer lasting.
3.4.2 Group I NADF cuttings discharge field study conclusions

Group I NADF cuttings are no longer discharged. However, they were discharged for a number of years in the North Sea and other areas. The most comprehensive chemical and biological studies on the impacts of discharging Group I NADF cuttings have been conducted in the North Sea. These studies found that discharges of Group I NADF cuttings had an adverse effect on the seabed biological community and that the major deleterious biological effects were confined to a 500-m zone around the well (Davies et al, 1988). Studies have indicated that these impacts have persisted in some areas even eight years after cessation of drilling (Daan and Mulder, 1996; Grahl Nielson et al, 1989). There is a transition zone outside this area where less severe biological effects are detected, and community parameters usually return to normal within 1000 metres. The shape and extent of this biological transition zone are variable, largely determined by the current regime and the scope of the drilling operation (Davies et al, 1988). Elevated hydrocarbon concentrations have been detected outside of the area of biological effects, in some cases more than 5 km from the well site (Olsgard and Gray, 1995, Daan and Mulder, 1996; Grahl-Nielson et al, 1989).

In some areas of the North Sea where high volumes of cuttings were discharged, the quantity of cuttings discharged, combined with low biodegradability of these fluids, and oceanographic conditions have resulted in cuttings piles that persist today. Cuttings piles up to 26 metres high were documented in the deeper central and northern parts of the UK Sector of the North Sea around approximately 60 multi-well platforms, from which mostly Group I cuttings had been discharged (Neff et al, 2000; Cordah, 1998). Typical piles were less than 10 metres high and had footprints less than 50 metres in diameter.

As will be discussed in the following sections, the same impacts observed in the North Sea have not been duplicated in other areas. In these other areas, the combination of using a fluid lower in aromatics (a Group II or Group III NADF), improved solids control equipment, and the energy of the receiving environment has resulted in lower impacts and more rapid seafloor recovery.

3.4.3 Group II NADF cuttings discharge field study conclusions

There have been a limited number of field studies focussed on the impacts of discharging Group II NADF cuttings (LTMBF). Of those Group II NADF studies, in most cases the specific characteristics of the base fluid were not reported. Consequently, the LTMBF may or may not meet the criteria set forth in this report (0.001%<PAH<0.35% or aromatic content >0.5% and <5%). Nevertheless the results are reported here. Many of the North Sea studies have been on wells where both diesel (Group I) and LTMBF (Group II) NADF cuttings have been discharged, and no differentiation is made between impacts from the two. The findings of studies conducted in the North Sea and Northwestern Australia on LTMBF cuttings discharge are summarised in Table 3.6 and in Appendices E.2 and E.3. In addition the physical behaviour and the biological impacts of LTMBF cuttings with varying oil concentrations were studied using laboratory tests and computer modelling, and field and laboratory simulations (E&P Forum, 1996).
Three studies, one examining short term impacts of LTMBF cuttings discharges from multi-well drilling in the Southern North Sea; another studying short term impacts of single-well LTMBF discharges in the Central North Sea; and the third detailing studies of long term impacts and recovery of several well-sites in the North Sea are discussed in Davies et al, 1988 and summarised below.

Findings from studies conducted on the short-term impacts of discharges of LTMBF from 8 wells at the Vulcan Field in the high energy Southern North Sea indicated that hydrocarbons were elevated at 200 metres, lower levels were present at 500 metres, extremely low levels were
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present at 800-1200 metres, and levels were at background at 5000 metres. Although diversity indices were not markedly depressed at 200 metres, detailed analysis of species indicated that community parameters returned to background levels at 1200 metres. Hydrocarbons were detectable at low levels possibly to 2.5km.

Results from studies of LTMBF discharges from two exploration wells in the Central North Sea showed hydrocarbons at levels up to 100× background were restricted to within 100-250 metres of the well site, and that levels fell off to not much greater than 10-100× background within 500-1000 metres of the discharge location. No biological studies were conducted.

Examination of the long-term hydrocarbon persistence and biological recovery at three well sites (one drilled with LTMBF, one with Group I – diesel, and the other with WBF) in 100 metres water depth in the Central North Sea indicated that over five years after drilling, elevated hydrocarbons were not detected for the WBF site, and were detected at 750 and 2500 metres for the LTMBF and diesel fluid sites respectively. There was no observable impact on benthos at the WBF site. However, there was a marked reduction in species diversity between 50 and 500 metres at the diesel site and between 50 and 200 metres at the LTMBF site. The LTMBF site did appear to have a well-established benthic community at 200 metres.

Oliver and Fischer (1999) have summarised two studies of the impacts of drilling discharges of LTMBF on the Western Australia North West Shelf. For each of these studies, local currents appear to dominate the distribution pattern of the drilling muds. Differences in persistence are partly attributed to differences in local sediment dynamics. The first study, North Rankin A (NRA), which examined the impacts of multi-well discharges of LTMBF in 125 metres of water, indicated short term, acute effects on the benthos within 200 metres of the discharge chute in the direction of the predominant current. Species richness was significantly depressed near the NRA cuttings pile, and no species were collected from within the cuttings pile itself. A transition zone was present between 400 and 5000 metres before background faunal indices were reached. Immediately following drilling, the zone of transition between affected and unaffected areas for hydrocarbons was approximately less than 1 km up to several km in the direction of the predominant current, and approximately 200 metres at right angles to the current direction. High TPH values persisted in the cuttings pile for several years following drilling. However TPH levels at 800 metres declined to non-detectable concentrations within 6 years. There were no long-term benthic studies.

The second study, Wanaea 6, involved impacts of LTMBF cuttings discharges from a single well in 80 metres of water. Results indicate that three years following drilling, there was no evidence of severely depressed species richness and abundance (as described near the cuttings pile in the NRA study). Although it was difficult to separate clearly patterns of biologic effects resulting from drilling from those due to natural variability, reduced abundance and richness within 100 metres of the discharge point may be a result of drilling discharges. Three years following drilling, the transition between detectable and background values for hydrocarbons occurred near 1200 metres in the direction of the prevailing currents, and at 200-400 metres at right angles to this direction. Comparison of these two studies indicates that the zone of impact for a single well operation is less than that for a multi-well operation. The observed TPH persistence at this site is attributed to the presence of sub-sea installations that could entrap sediments and inhibit natural sediment dispersal.

Computer modelling of deposition of LTMBF cuttings of varying oil contents at water depths ranging from 30-250 metres revealed that at high oil contents (such as those of untreated cuttings), a large cuttings pile is deposited in the immediate vicinity of drilling operations. Modelling predicts that, at lower oil contents, thinner cuttings piles will result but they will be spread out over a wider area (E&P Forum, 1996). Laboratory studies on cuttings impact on benthic biology indicated that at sediment oil concentrations of ~1000mg/kg, biological impact is minimal and recovery rapid (E&P Forum, 1996).
Enrichment of the seabed sediments with hydrocarbons outweighs aquatic toxicity of the base oil as the primary factor to be considered in evaluating environmental impacts of discharging drilling fluids with base fluids that are less toxic than diesel. Data from Davies et al., 1988 suggest that LTMBF is less persistent than Group I – diesel. Consequently, biological recovery should be more rapid at sites where LTMBF cuttings are discharged relative to those where diesel-based OBF cuttings have been discharged. Overall, these studies highlight the importance of the local environment, particularly water depth and current regime, on determining the initial area of impact and the persistence of hydrocarbons in the area.

3.4.3.1 Studies underway

A study initiated in 1998 by Ifremer and Totalfinaelf is underway on the continental margin offshore Angola, Congo and Gabon. In this study, 9 long-term moorings were laid from in April 2000 on three deep sites, and 38 trawls and box cores were deployed in August 2000 at sites where wells had been drilled previously. Eight wells have been drilled in this area since 1998 and HDF-200 (Group II) cuttings have been discharged.

Previous studies provided data on the general structure of the benthic communities and on chemical characteristics of the sediment near well stations (Block 17 – 1350 metres depth). A comparison of the biological and chemical data obtained between stations located at 200 metres and about 10 km away from well stations showed:

- No significant differences for most of the parameters from the preliminary observations,
- No detectable level of aromatic hydrocarbon in the superficial sediment, whereas differences in barium concentrations exist,
- Unexpected richness in organic carbon of the sediment not only in the surface but down to 15 cm,
- Similarity of macrofaunal density to that observed in other deep sea sediments, with however, a presence of macrofaunal organisms deep into the sediment which can be explained by the high organic carbon content observed,
- The absence of sessile fauna due to the fluidity of the sediment and the lack of hard substrate.

3.4.4 Group III NADF cuttings discharge field study conclusions

Field studies have been conducted on the impacts resulting from the discharge of Group III fluid cuttings. At many sites where Group III fluids have been used there is a previous history of Group I or Group II cuttings discharge. Consequently, in some cases it is difficult to differentiate impacts between Group I and II and Group III fluids. In addition, although there has been a number of field studies designed to provide information on the fate and persistence of Group III cuttings on the seafloor (particularly in the North Sea) few have documented the impact on biological communities.

For this section, twelve field studies where both biological and chemical samples were taken have been examined. In addition, compilations of North Sea studies by Neff et al., 2000 and Jensen et al., 1999 and preliminary findings of Gulf of Mexico studies (USEPA, 2001) are also discussed.

Of the twelve studies considered, five involved multiple well discharges and three sampled up to two years following drilling. Five were conducted in the North Sea, three in the Gulf of Mexico, and two each offshore Eastern Canada and Australia. Only one study was conducted in water depths in excess of 500 metres. Of the twelve studies, four looked at ester-based fluid cuttings discharges, three containing linear paraffin, one PAO, one IO, one iso-paraffin, and the other two combinations of LAO/IO and LAO/ester. Summaries of the
conclusions regarding impacts are provided in Table 2.3. More detailed summaries of the field programmes are provided in Appendix E.

Although the wide range of environmental conditions (water depth, temperature, currents), discharge fluid types and volumes, and study designs makes it difficult to compare data from all these studies, the general conclusions that can reached regarding impacts from Group III cuttings discharges are discussed in the summary portion of this section.

3.4.4.1 Ester-based fluids

The best-documented and most comprehensive studies of Group III NADF cuttings discharge are those for ester-based fluid (EBF). The four studies summarised below provide evidence that esters may not persist on the seabed or in subsurface sediments over the long-term, likely due to a combination of biodegradation and seafloor dispersion. Likewise, there is evidence that there may be some short-term localised initial impacts of drilling discharges. However, there appears to be rapid recovery of the benthic community. One would expect some differences in results between the studies due to variations in discharge volumes as well as receiving environments (water depth, currents, seafloor conditions).

A study of the impacts from multi-well discharges of EBF cuttings in a high energy environment offshore Australia (the Bass Strait) indicated that although sediment ester concentrations clearly increased during drilling, eleven months following drilling esters were not detected (Terrens et al., 1998). Impacts to macrofauna were short-term (macrofauna parameters returned to background within four months) and localised (limited in area to 100 metres from platform). Despite the disappearance of esters, there was still evidence of anoxic conditions in subsurface sediments at 100 metres from the platform.

Results from field studies of EBF cuttings discharged from a single exploration well K14/13 in the Dutch Sector of the North Sea in 30 metres of water (Daan et al., 1995) showed some similar trends to Terrens et al., (1998) in terms of decrease in ester concentrations and recovery of benthic communities. However, Daan et al., (1995) showed some persistence of esters and benthic effects after 11 months. While esters were still detected at 200 metres after 11 months, concentrations (54.6mg/kg) were significantly less than they were at 4 months. At distances greater than 500 metres, esters were not detected. Evidence of anaerobic conditions was observed at all sites within 200 metres of the platform. Initial effects on benthos were similar to those observed with Group I NADF cuttings discharges: decrease in faunal density and occurrence of sensitive species (eg E. Cordatum) and increase in opportunistic species (C. capitella) with increasing proximity to the well site. After 11 months, impacts to macrofauna were detectable out to 200 metres. However, there were signs of recovery, with a reasonable number of species re-colonising the area in the vicinity of the well site and other areas within 200m.
### Table 3.3 Summary of group III cuttings discharge impacts/conclusions

#### North Sea

<table>
<thead>
<tr>
<th>Fluid type/ vol adhering fluid/ water depth</th>
<th>Refer.</th>
<th>Sediment impacts</th>
<th>Biological impacts</th>
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</thead>
</table>
| Ester/ 477 tonnes/ 30m                     | Daan et al, 1995 | • Four months following drilling, elevated sediment ester concentrations were consistently detected within 200m, with traces detectable to 3000m; ester concentrations were consistently higher than measured one month following drilling.  
• Over 11-month period ester levels decreased significantly but were still detectable (54.6mg/kg) within 200m.  
• After 11 months, there continued to be evidence of widespread anaerobic conditions in subsurface sediments out to 200m.  
• After 4 months, macrofauna were impoverished within 200m. A few species showed reduced abundance to 500 or 1000m.  
• After 11 months, macrofaunal impacts at the individual (many species reduced in abundance) and community level (low number of species per sample, reduced relative faunal abundance and overall abundance) were still observed within 200m; effects were more significant at 75m than at 125 or 200m.  
• There were signs of natural recovery within 200m after 11 months. |
| Ester/ 96.5 tonnes/ 67m                    | Smith and May, 1991 | • Immediately following drilling there was a zone of influence within 100m of the well, within which esters, THC, and metals were elevated.  
• One year following drilling, the zone of impact was significantly reduced;  
• There was evidence of anaerobic conditions in subsurface sediments out to 200m, one year following drilling.  
• Immediately following drilling, faunal communities were impacted to 100m as indicated by low species diversity, low species abundance, and high numbers of Capitella capitata.  
• One year following drilling there were substantial signs of faunal recovery (increases in number of taxa and individuals). |
| Ester/ 304 tonnes/ 142m                    | BP, 1996 | • Five months after drilling, sediment ester concentrations were highest within 25m.  
• Fifteen months after drilling, ester concentrations in surface sediments were lower at most sites than five months after drilling.  
• More than one year after drilling, sediments were anaerobic out to 200m.  
• Fifteen months post drilling, cuttings piles of up to 15cm were detected out to 50m.  
• Immediately following drilling, the number of species, evenness, and diversity were statistically significant in relationship to ester concentration and distance.  
• Biota measurements indicated clear impacts at 50m with transition communities developing between 100-300m 15 months post drilling. |
| Linear Paraffin/ 13 tonnes/ 95 m          | Neff et al, 2000 | • Uneven distribution of linear paraffin concentrations in sediment.  
• Maximum value of 1600mg/kg at 7 m.  
• Abundance of benthic fauna and number of taxa decrease with increasing linear paraffin concentration. |
| Linear Paraffin/ 57.5 tonnes/ NK          | Gardline 1998 | • Uneven distribution of linear paraffin concentration in sediment.  
• Highest linear paraffin concentration of 28,000mg/kg at 210m from the site.  
• Abundance of benthic fauna high at most sites with highest linear paraffin concentrations, but number of taxa low.  
• Indications of organic enrichment effects. |

#### Ireland

<table>
<thead>
<tr>
<th>Fluid type/ vol adhering fluid/ water depth</th>
<th>Refer.</th>
<th>Sediment impacts</th>
<th>Biological impacts</th>
</tr>
</thead>
</table>
| Linear Paraffin/ LAO/PAO/ NK               | Gardline 1998 | • Highest concentration of SBF (2550mg/kg) within 100m of site.  
• Substantial decline within 2 years.  
• Some sediment anoxia.  
• 90% of LP and LAO degraded within 2 years, little PAO degradation within 2 years.  
• NK – not known |

NK – not known
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<tr>
<th><strong>Gulf of Mexico</strong></th>
<th><strong>Fluid type/ vol adhering fluid/ water depth</strong></th>
<th><strong>Refer.</strong></th>
<th><strong>Sediment impacts</strong></th>
<th><strong>Biological impacts</strong></th>
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| PAO/ 25 tonnes/ 39m | Candler et al. 1995 | - Immediately following drilling, the highest PAO levels were at 50 and 100m; PAO levels above 1000mg/kg were found out to 200m in some directions  
- PAO levels declined in general (except at 25m) during the first 8 months; thereafter, concentrations stabilized with slight decreases in some cases and increases in others  
- Over a 24 month period areas of heavy (>10,000mg/kg) and moderate (>1000mg/kg) PAO levels decreased significantly; moderate levels were confined to within 50m  
* Compared to WBF a higher percentage of PAO cuttings are deposited on the seafloor within 200m of discharge | - No benthic analyses were conducted immediately following drilling  
- Two years following drilling, macrofaunal impacts (reduced species richness, diversity relative to reference) were limited in extent to 50m  
- Macrofaunal indices similar to background occurred in the presence of base fluid concentrations up to 1000mg/kg |
| LAO+ester/ 7659bbls/ 565m | Fechelm et al. 1999 | - Four months following drilling, cuttings were dispersed over the bottom in a patchy fashion  
- Most of the cuttings were distributed in the direction of surface and mid-level currents rather than bottom currents  
* Maximum base fluid concentrations were measured at a distance of 75m | - Analyses not fully completed  
- Numbers and density of mega- and macrofauna do not appear to be negatively impacted by elevated base fluid concentrations  
- Levels of some macrofauna are increased over background levels |
| IO and LAO/IO; 33-61m (3 rigs)/ 94-2390bbls | CSA, 1998 | - Elevated concentrations were restricted to within 50-100m of platform and were patchy in distribution  
- Highest fluid content 1900-23,000mg/kg at 50m | |

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<tr>
<th><strong>Australia</strong></th>
<th><strong>Fluid type/ vol adhering fluid/ water depth</strong></th>
<th><strong>Refer.</strong></th>
<th><strong>Sediment impacts</strong></th>
<th><strong>Biological impacts</strong></th>
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| Linear Paraffin [XP-07]/ 160 tonnes/ 78m | Oliver and Fischer, 1999 | - Immediately following drilling, there was a 1.5-2.0m high, 10-15m diameter cuttings pile; base fluid levels were high (up to 40,400mg/kg) in and adjacent to the pile; base fluid levels were highest in the upper 5cm of sediment  
* Ten months following drilling, the cuttings pile was gone; there were significant reductions in TPH and barium | - Ten months following drilling, faunal species were present at the drill-site (based on ROV visual observations)  
- Impacts on benthic infauna were not substantial (largely a reduction in abundance of two classes, and possibly a decline in the number of taxa and the total number of individuals); they were localised in area (to 100m from the discharge point) and in duration (four months)  
- No evidence of long-term impact |
| Ester/ 2000m³/ 70m | Terrens et al. 1998 | - Ester concentrations increased in sediments during drilling discharges, then rapidly decreased within 11 months after completion of drilling to non-detectable levels  
- At eleven months, samples retrieved from within 100m retained evidence of anaerobic conditions in subsurface layers despite no remaining evidence of esters  
- There is evidence that SBF discharges result in residual cohesion of subsurface sediments | |
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Field studies of impacts from EBF cuttings discharges at the Ula 7/12-9 well site in 67 metres of water in the Central North Sea showed similar trends to those previously discussed two studies (Smith and May, 1991). Immediately following discharge there was a distinct zone of impact within 100 metres of the well, where concentrations of esters and metals were elevated. Likewise, benthic infauna were impacted to a distance of 100 metres. One year following drilling, the zone of effect within 100 metres of the well appeared largely to have recovered. Cuttings and mud solids appeared in isolated patches on the seabed. There has been some speculation that the apparent rapid recovery indicated by this study was an artifact of the ester analyses being conducted on only the top 1 cm of sediment (Vik et al., 1996) and the imprecision of the positioning technique (radar) missing possible impacted sampling sites (Candler et al., 1991). Nevertheless there were also differences in the quantities of drilling fluid discharged (approximately 50% less mud was used at Ula versus K 14/13) and in the water depths of the different studies (Ula is in 60 metres of water versus 30 metres for K14/13).

Another field study, conducted in 142 metres of water in the North Sea, showed trends similar to those for the other EBF cuttings discharge sites, with decreases in ester concentrations and recovery of benthic communities over time (BP Exploration Operating Company Ltd., 1996). Results from samples taken five months following drilling indicated that the relationship between benthic indices, distance, and ester concentration was statistically significant. Five months following drilling, the highest ester concentrations in surface sediments were within 25 metres of the platform. Over the next 10 months (15 months in total after drilling) ester concentrations had decreased, but were still detectable to 500 metres. Benthic communities were still impacted at 50 metres however transitional communities had developed between 100 and 300 metres.

### 3.4.4.2 Olefins (PAO/IO/LAO)

This section summarises studies examined involved the discharge of cuttings coated with polyalphaolefin (PAO), internal olefin (IO) and linear alpha olefin (LAO)-ester blend fluids.
The discharge of PAO-coated cuttings from one well was studied at a site in 39 metres of water in the Gulf of Mexico (Candler et al., 1995). Immediately following drilling, maximum base fluid concentrations (as measured by TPH) were found 50-100 metres from the drill site. Eight months following discharge, TPH values showed substantial (60-98%) decreases from the first survey at all but the 25 metre stations, which showed increases in both the south and west directions, likely due to variation across the discharge area or redistribution and reworking of the sediment. It is uncertain whether the observed decreases were due to biodegradation or to sediment redistribution. The most significant changes in TPH concentration occurred during the first 8 months following drilling. Two years following the discharge (16 months after the previous survey) there continued to be elevated TPH concentrations at the 25 metres sites, with increases in values in the N, E, and S directions. TPH values at other stations decreased slightly or were relatively unchanged. There was no mention of evidence of anoxic conditions (black streaks or black sediment), however, this does not necessarily mean that anoxic conditions were not present. Benthic sampling performed two years after completion of drilling indicated that macrobenthic indices (richness, diversity, evenness) at three sites (two at 25 metres and one at 50 metres) were depressed compared to reference stations. These three stations were those with the highest overall TPH values. Two years after the discharge, low levels (<1000mg/kg) of PAO were observed in several stations, and showed no apparent trend of decrease.

The impacts of discharging ‘Petrofree LE’ (a 90% LAO, 10% ester SBF) from 7 wells in a deep water (565 metres) Gulf of Mexico location were investigated (Fechelm et al., 1999). The quantity of synthetic fluids (adhered to cuttings) discharged (7695 bbls) was more than 20 times that for the PAO study. ROV observations indicated that following drilling cuttings were dispersed over the bottom in a patchy fashion, with thicknesses up to 20-25 cm in some areas. The largest concentrations of cuttings were likely a result of riser-less drilling at the beginning of the well. The seafloor sediment appeared dark, interspersed with white mats four months after drilling. The highest concentrations of LE for surficial and subsurface sediments were found at 75 metres from the platform in the direction of the surface and mid-level currents, rather than in the direction of the bottom currents. Concentrations of LE were higher for surface (0-2 cm) than for subsurface (2-5cm) sediments. It is difficult to make any significant assessment of LE persistence as an additional well was drilled between the first post-drill and second survey. Final benthic analyses have not been published, however, results following the drilling of seven wells indicate increased polychaete and gastropod densities over background data.

Preliminary seabed surveys were conducted to determine the extent of observable physical and chemical impacts at three platforms in the Gulf of Mexico where synthetic (either IO or an LAO/IO combination) cuttings had been discharged from one to five wells (CSA, 1998). These surveys served as a precursor to an ongoing, more comprehensive assessment of seafloor impacts of Group III NADFs in the Gulf of Mexico. In this preliminary investigation, samples taken 10 to 25 months after the cessation of drilling indicated that elevated concentrations of synthetic base fluids were restricted to the platform vicinity (within 50 to 100 metres) and were patchy in distribution. No cuttings piles were detected. At some sites, there was evidence of anaerobic sediment conditions (black streaks) within 150 metres of the platform. In situ sediment toxicity bioassays were performed with the amphipod, Leptocheirus plumulosus. While sediments from some near field sites exhibited toxicity, the data set was not adequate to assess whether this toxicity was directly related to NADF sediment concentrations. (USEPA, 2001).

Class III fluid concentration in sediments was studied shortly after completion of drilling, and one and two years later at a site off the West Coast of Ireland where a LAO/linear paraffin/PAO formulation was discharged with cuttings in approximately 380 metres of water (Gardline, 1998 as cited in Neff et al., 2000). Shortly after drilling completion, Class
III fluids were detected at concentrations of 21 to 2550mg/kg within 100 metres of the drill-site. After one and two years, maximum concentrations within 50 metres had decreased to 1110 and 520mg/kg respectively. Examination of the gas chromatograms revealed that linear paraffins and LAOs were degraded rapidly, but PAOs were degraded slowly, if at all.

Offshore Eastern Canada, the Sable Offshore Energy Inc. (SOEI) Environmental Effects Monitoring (EEM) programme monitored the effects of discharging WBM, WBM cuttings, and ‘Novaplus’, an IO, cuttings from drilling a total of 11 wells from three locations, two in relatively shallow water (20-22 metres) and the other in 80 metres of water (JWEL, 2000a). The Scotia Shelf where these facilities are located is a high-energy environment.

The study found that drill cuttings accumulations were considerably smaller than modelled; this may be due in part to lower volumes being discharged from one site than originally modelled, however, the amount discharged at another site was close to the model input used for the prediction, and the cuttings pile was approximately half the predicted radius. Drill cuttings piles were observed within 70 metres of the discharge point at the two shallower sites. Elevated levels of TPH and barium were found at both 250 and 500 metres from the drilling platforms and were intermittent. The piles were observed to be much smaller after six months. It is likely the cuttings were re-suspended and dispersed, although burial by natural sedimentation cannot be ruled out. Biodegradation of the SBF may also be a contributing factor. No effect on the benthic communities outside the cuttings accumulations could be detected but high natural variability at the site makes effect detection very difficult. The SOEI EEM results up to December 1999, confirm that the combination of low discharge volumes, high energy seafloor conditions, and environmentally benign fluid characteristics resulted in low impacts and rapid recovery of the seafloor.

3.4.4.3 Paraffin

Oliver and Fischer (1999) have summarised the impacts of drilling discharges of linear paraffin cuttings on the Western Australia North West Shelf. The results of this study, Lynx 1a, which involved discharge of linear paraffin cuttings in 78 metres of water, indicated that immediately following drilling, there was a cuttings pile up to 2 metres high and 10-15 metres in diameter below the discharge point. Within 10 months following drilling, the cuttings pile was gone, and there were dramatic reductions in TPH and barium levels. Although benthic analyses were not conducted, visual observations at 10 months following drilling indicated benthic fauna were present at the drill-site. The rapid recovery of this area has been attributed to sediment dispersal mechanisms active in the mid-shelf water depths.

Neff et al (2000) report the findings of 2 studies conducted in the UK sector of the North Sea, in water depths of 78 to 100 metres, on impacts from discharge of linear paraffin with cuttings. In one study, 13 tonnes of fluid adhering to cuttings were discharged in 95 metres of water. The data showed that the number of benthic individuals in sediment decreased with increasing linear paraffin concentration in sediment. The maximum concentration measured was 1600mg/kg at 70 metres from the well. All the sediments except those with the highest fluid concentrations contained an abundant diverse benthic fauna. At the other site, 57.5 tonnes of fluid were discharged with cuttings into an unreported water depth. The maximum concentration measured was 28,000mg/kg at 210 metres from the well. At this site, the response was somewhat different. The number of individuals was highest in sediments from three of the four stations with the highest linear paraffin concentrations; at the fourth station, both the number of individuals and taxa were low. This is likely evidence of the organic enrichment effect where there are a large number of individuals dominated by a few opportunistic species. At both of these sites, the distribution of linear paraffin fluid in sediment was very uneven.
The Hibernia EEM programme is studying the effects of operations at the Hibernia platform located offshore Newfoundland in 80 metres of water (JWEL, 2000b). An estimated 83 wells will be drilled from a single platform over the life of the project. WBM has been used to drill the upper portions of all wells and an isoparaffin-based mud (IPAR-3 also known as 'Puredrill' or IA-35) has been used on the lower sections. Associated WBM and WBM and SBM cuttings have been discharged overboard until April 2001. Surveys were done both before drilling and one (1998) and two years (1999) after the commencement of drilling. By August 1999, cuttings had been discharged from a total of twelve wells. No post-drilling discharge surveys have been conducted.

As expected with the additional wells drilled in 1999 and 2000, surveys found that there were statistically significant increases in sediment base fluid and barium levels over those of 1998 and baseline studies in 1994. In addition, drilling wastes appear to have been transported further from the well site than originally predicted from the fate and effects model. None of the sediment samples collected caused a toxic response in the amphipod or polychaete bioassay. The results of the Hibernia EEM are not atypical of what might be expected where large volumes of Type III fluids have been discharged at a single location. Results of future surveys will provide additional information on the recovery of the site and persistence of drilling fluids once drilling discharges are completed.

3.4.4.3 Summary studies

In addition to the studies discussed above, there are two documents, which summarise findings from a number of studies where Group III cuttings were discharged in the UK sector, Neff et al, 2000, and Norwegian sector of the North Sea, Jensen et al, 1999.

Neff et al, 2000 summarise the results of seabed monitoring around 21 single well sites where Group III cuttings were discharged in the UK sector of the North Sea. Water depths ranged from 55 to 186 metres and the mass of fluid discharged with cuttings ranged from 11 to 730 tonnes. The fluids discharged with cuttings were n-Paraffin (3 wells), Linear Paraffin (6 wells), PAO (1 well), LAO (4 wells), LAB2 (3 wells), Ether (1 well), and Ester (3 wells).

The findings of this compilation were as follows (Neff et al, 2000).

- There is no clear relationship between concentrations of Group III fluids in sediments, and water depth, mass of cuttings discharged or mass of Group III fluids adhering to cuttings that are discharged.
- The amount of cuttings accumulating in sediments is dependent on a complex interaction of discharge rate and mass, water depth, current structure, and the type of fluid and cuttings.
- In most cases, SBF cuttings do not penetrate or mix deeply into surface sediments near the platform.
- Approximately one year after completion of drilling, fluid concentrations in the surface layer often decrease; however, concentrations at greater depths may increase or decrease.
- After more than a year, concentrations at all depths may decline to low values particularly if ester cuttings were discharged.
- In most cases, average Group III fluid concentrations around the rig were irregular. Shortly after drilling, the highest concentrations of fluid in sediments were located at 0 to 224 metres from the rig; approximately one year after drilling, highest concentrations were 5 to 153 metres. The distance from the rig to sediment fluid concentrations below 1000mg/kg ranged from 40 to 500 metres.
Based on these studies, Neff et al. (2000) concluded that it was likely that the area of seafloor impacted by Group III cuttings discharges is less than that from Group I cuttings discharges. With Group III cuttings discharges, the maximum distance from the discharge point to concentrations of 1000mg/kg ranged from 40 to 500 metres or less (as compared to 500 to 1000 metres). Furthermore, in all but one case, concentrations of group III fluids dropped below 50mg/kg and in most cases below 10mg/kg within 1.2km of the discharge (as compared to concentrations of 10mg/kg often extending out 10-12km from the discharge point (Davies et al, 1983; Kingston, 1992)).

Additional conclusions can be drawn from the work done by three Norwegian organisations (Akvaplan niva, Olsgard Consulting, and DNV) to compile and analyse 20 years of seabed studies on the effects of drilling discharges on the Norwegian sector of the North Sea and Norwegian Sea. In the Norwegian sector of the North Sea, Type I and Type II cuttings were discharged up until 1993. After this time, only Type III cuttings and WBFs were discharged. Although it has been assumed that environmental impacts of discharging Type III cuttings are less than those from discharging Type I and II cuttings, until now, no collation of all seabed survey data had been performed to assess general patterns in environmental effects. The results are compiled in a publication (Jensen et al, 1999) that has been submitted to the Norwegian Ministry of Oil and Energy. The Type III fluids most commonly used in this region are esters, ethers and olefins.

The major overall conclusions of the survey of field studies were as follows:

• Results from monitoring studies on fields where only SBMs and WBMs have been used indicate that discharges of cuttings associated with these fluids have little or no effect on benthic fauna outside a radius of 250 metres. The exception to this is where large volumes of drilling cuttings have been discharged;

• In general largest variations in biological diversity have been found beyond 250 metres regardless of what the sediment chemistry is, and it is difficult to isolate discharge effects from natural variation;

• Increase in the density of individuals of tolerant indicator species can be found up to 1000 metres from some installations;

• SBM cuttings discharges have had far fewer effects on soft-bottom communities than OBM cuttings discharges, and that effects on soft bottom communities from SBM cuttings discharges are rarely seen outside of 250-500 metres; and

• In older fields, previous discharges of OBM s still affect the fauna to a great extent.

3.4.4.4 Studies underway

There are large-scale joint industry, academia, government field programmes underway in both the US and Brazil to better understand the impacts of discharge Group III cuttings and to incorporate the findings into scientific based discharge regulations.

In the US Gulf of Mexico, there is a comprehensive field programme to determine the spatial distribution of cuttings, changes in distributions and concentrations of Group III cuttings in sediments over time, and physical/chemical effects of sediments containing Group III cuttings near offshore platforms where either internal olefins or LAO/ester blend fluids have been discharged with cuttings. The first two survey efforts, involved ROV surveys of 10 Gulf of Mexico shelf locations, and sampling and ROV surveys of 5 shelf (water depths ranging from 60-338m) and 3 deep water (water depths ranging from 534-558m) locations. Neither cruise detected any large mounds of cuttings under any of the rigs or platforms (USEPA, 2001). Video investigations only detected small cuttings clumps (<6") around the base of some of the facilities and 1-foot thick cuttings accumulations on facility horizontal cross
members. Beyond a 50-100 foot radius from the facility, no visible cuttings accumulations (large or small) were detected at any of the facility survey sites.

A joint industry monitoring project is underway in Brazil to document the environmental effects of NADF discharges. The study is co-funded by the Brazilian government (60%) and by the Brazilian joint industry group, IBP (40%). The Federal University of Rio Grande do Sul is leading the programme. The goals of the project are to:

1) Evaluate the effects of NADF-cuttings discharge at two sites (one shallow-water, one deep-water) to determine degree of environmental impact and degree of recovery from discharge up to one year following discharge.

2) Provide data needed for technical calibration of drilling discharge modelling predictions; and

3) Develop technical information that can be used when developing recommended practices and provided to agencies when regulations are developed for drilling discharge.

No results are available yet from this study.

3.4.4.5 Overall conclusions

- Factors including volume of cuttings discharged and characteristics of the receiving environment including water depth, temperature and current strength influence the degree of impact. This makes comparisons of field study results difficult since these factors often differ between sites.

- Field studies indicate that areas that recover most rapidly are those with high-energy seabed conditions.

- The weight of evidence suggests that esters are less persistent in the environment (see Table 3.5) and laboratory toxicity tests show esters exhibit lower toxicity to sediment organisms compared with other NABFs (see Table 3.4). On the other hand, a systematic analysis of North Sea data (Jensen et al 1999) concluded that olefins had fewer biological effects than esters. This suggests the impacts may arise from oxygen depletion and there may be a balance between short-term and long-term impacts.

- It is difficult to draw specific conclusions regarding the relative impacts of discharging cuttings for different Group III NADFs. However, overall, it appears that the persistence in sediments of Group I NADFs is greater than Group II and III NADFs. Group III cuttings discharges have had far fewer effects on soft-bottom communities than OBM cuttings discharges, and that effects on soft bottom communities from Group III cuttings discharges are rarely seen outside of 250-500 metres (Jensen et al, 1999).

- Comparison of field study summaries Tables 3.6 and 3.7 with the summaries in Appendix E suggests that impacts from discharge of Group II and Group III cuttings may have lower impacts than those observed when Group I fluids were discharged.

- It is probable that within three to five years of cessation of SBF cuttings discharges, concentrations of synthetic in sediments will have fallen to sufficiently low levels and oxygen concentrations will have increased sufficiently throughout the previously affected area that complete recovery will be possible (Neff et al, 2000).

- This is in contrast to base fluid levels from Group I NADF cuttings discharges which in some studies have shown persistence up to eight years (as discussed previously) and little decrease over a five year period (Grahl-Nielsen et al, 1989).

- Several of the Group III NADF cuttings discharge studies indicated evidence of anaerobic conditions (black streaks or sediment) in the subsurface sediments out to approximately 200 metres. The final product of anoxic biodegradation is H₂S, which reacts with the iron in the sediment to form iron sulphide (FeS) that manifests itself as blackened sediment or black streaks.
• This evidence is consistent with base fluid biodegradation leading to anoxic conditions in the sediments.

In all Group III NADF cuttings discharge studies, benthic communities showed signs that recovery had commenced within one year following drilling discharge. However, recovery was not necessarily complete within this time. In some cases benthic communities within 200 metres of the discharge site were still impacted.

Although the extent of impacts may differ, similar patterns have been noted from discharge studies in which different NADFs were used. The following patterns of effects were noted:

• Increase in the abundance of opportunistic species
• Reduced presence and numbers of sensitive species
• Overall decrease in faunal density at high NABF concentrations.

However, based on the field studies of cuttings discharge discussed above, the zones of influence for Group II &III NADF cuttings discharges appear to be reduced from those for Group I NADFs. Long-term recovery will ultimately be affected by the following:

1) Initial distribution of the cuttings (ie thin vs thick deposits)
2) Redistribution and spreading of cuttings,
3) Biodegradation or dissolution of the Group III NADF components on cuttings, and
4) Burial of the cuttings and re-colonisation of the surface sediment.

3.4.5 Field survey interpretation limitations

There are a variety of factors that limit the comparisons and interpretations that can be made from different field surveys. These factors include differences in sampling collection protocols (eg the depth to which sediment is sampled), timing of sampling relative to drilling discharge completion, and spatial sampling design. These factors are summarised along with conclusions regarding chemical and biological impacts for the surveys discussed in this report (Tables A.1 and A.2).

• Differences in the depth to which sediments are sampled can lead to varying conclusions regarding persistence of drilling fluids. Many studies reveal that over time, there are sometimes significant drilling fluid concentrations in sub-surface sediments. The depth to which sediments are sampled impacts the ability to detect such concentrations.

• Timing differences between surveys dictate the degree to which changes over time can be defined. The timing of the first post-drill surveys varied from immediately following drilling to 5-11 months following drilling. The relative timing of surveys thereafter is highly variable.

The spatial sampling grid design (transect orientation and sampling point location) influences the accuracy with which one can define impact zones. There is a wide range of distances and intervals between which samples are taken. For the surveys discussed in this report, distances of the closest sample from the well vary from 25 metres to 200 metres. Few surveys have been conducted in cuttings piles themselves, most have been conducted around the fringes of accumulations where measured concentrations are highly variable.
4 Conclusions

This document summarises the current body of knowledge about the environmental aspects of the disposal of NADF cuttings by discharge into the marine environment. Marine discharge is one of a range of disposal methods for NADF cuttings that also includes onshore disposal (transport of cuttings onshore) and cuttings re-injection. Each method has advantages and disadvantages that should be taken into account. Considerations for choosing among the available waste management practices are presented.

The following key points stem from the review of the literature on the environmental aspects of marine discharge of NADF cuttings.

• Recent advances have allowed production of a variety of NADFs with very low concentrations of toxic components.

• Initial environmental impacts on benthic organisms from the discharge of NADF cuttings are caused by physical burial. The risk of water-column impact is low due to the short residence time of cuttings as they settle to the sea floor and the low water-solubility and aromatic content of the base fluid.

• Potential impacts on the benthic biota can be caused by a number of mechanisms. These include chemical toxicity of the base fluid, oxygen depletion due to NADF biodegradation in the sediment and physical impacts from burial or changes in grain size.

• Numerous field studies have been conducted to measure the initial impacts and recovery from NADF discharge. These studies have shown that benthic community disturbance is in general very localised and temporary. Biodegradation of modern fluids can be relatively rapid, particularly when NADF concentrations are low to moderate. At sites where newer NADFs were used, field studies show that recovery was underway within one year of cessation of discharges.

• In the North Sea, ambient conditions and discharge practices caused the formation of large cuttings piles (up to tens of metres thick near large development drill sites). The large mass of these cuttings and associated base fluids extend the amount of time needed for recovery of these sites.

• The formation of large, persistent piles will not occur under many oceanographic conditions. For example, environments with high currents tend to erode piles and decrease recovery time. Deep water also tends to increase dispersion and limit the pile heights that are initially formed.

• Enhanced treatment can reduce the organic loading on cuttings and thereby limit the effects of oxygen depletion in sediments. Enhanced treatment can include (1) methods to reduce the base fluid content of cuttings before disposal and (2) methods to increase cuttings dispersion.

Several factors will influence the acceptability of NADF cuttings discharge. These include:

• existing regulations;

• environmental sensitivity of the receiving environment;

• type of NADF used, the properties of the NADF (eg biodegradability, toxicity, and bio-accumulation potential);

• total volume of drill cuttings discharged;

• methods of disposal (such as depth of discharge pipe, pre-discharge treatment;

• ambient conditions of the receiving water; and

• ability of the local environment to assimilate the cuttings and base fluid loads.

Cuttings discharge appears to be a viable option in many environmental settings. Work continues to develop and implement new technologies for cuttings treatment to reduce fluid content on cuttings prior to discharge. Work also continues to improve and develop a full range of disposal options.
References

Section 1


Section 2


Section 2.4


Section 3.1


Section 3.2


**Section 3.3**


**Section 3.4**


# Appendix A: table of acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
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<tbody>
<tr>
<td>API</td>
<td>American Petroleum Institute</td>
</tr>
<tr>
<td>BBL</td>
<td>Benthic Boundary Layer</td>
</tr>
<tr>
<td>BCF</td>
<td>Bioconcentration Factor</td>
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<tr>
<td>CAPP</td>
<td>Canadian Association of Petroleum Producers</td>
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<tr>
<td>CBT</td>
<td>Closed Bottle Test</td>
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<tr>
<td>CMO</td>
<td>Conventional Mineral Oil</td>
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<tr>
<td>CPT</td>
<td>Compliant Tower</td>
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<tr>
<td>CRI</td>
<td>Cuttings Re-Injection</td>
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<tr>
<td>CSA</td>
<td>Continental Shelf Associates</td>
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<tr>
<td>DNV</td>
<td>Det Norske Veritas</td>
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<tr>
<td>EBF</td>
<td>Ester based fluids</td>
</tr>
<tr>
<td>EC50</td>
<td>Effective Concentration [50% effected]</td>
</tr>
<tr>
<td>EEM</td>
<td>Environmental Effects Monitoring</td>
</tr>
<tr>
<td>EMBF</td>
<td>Enhanced Mineral Oil Based Fluids</td>
</tr>
<tr>
<td>EPA</td>
<td>Environmental Protection Agency (United States)</td>
</tr>
<tr>
<td>FPSO</td>
<td>Floating Production Storage and Offloading Unit</td>
</tr>
<tr>
<td>HMCS</td>
<td>Harmonised Mandatory Control System</td>
</tr>
<tr>
<td>HOCNF</td>
<td>Harmonised Offshore Chemical Notification Format</td>
</tr>
<tr>
<td>IO</td>
<td>Internal Olefin</td>
</tr>
<tr>
<td>IO 16 18</td>
<td>Internal Olefin 16 to 18 carbons in length.</td>
</tr>
<tr>
<td>LAB</td>
<td>Linear Alkyl Benzene</td>
</tr>
<tr>
<td>LAO</td>
<td>Linear-alpha-olefin</td>
</tr>
<tr>
<td>LC50</td>
<td>Lethal Concentration (50% mortality)</td>
</tr>
<tr>
<td>LDEQ</td>
<td>Louisiana Department of Environmental Quality.</td>
</tr>
<tr>
<td>Log Pow</td>
<td>Logarithm of the octanol-water partition coefficient</td>
</tr>
<tr>
<td>LTMBF</td>
<td>Low Toxicity Mineral Oil Based Fluid</td>
</tr>
<tr>
<td>MODU</td>
<td>Mobile Offshore Drilling Unit</td>
</tr>
<tr>
<td>NA</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>NABF</td>
<td>Non-Aqueous Base Fluid</td>
</tr>
<tr>
<td>NADF</td>
<td>Non-Aqueous Drilling Fluid</td>
</tr>
<tr>
<td>NIVA</td>
<td>Norwegian Institute for Water Research</td>
</tr>
<tr>
<td>NK</td>
<td>Not Known</td>
</tr>
<tr>
<td>OOC</td>
<td>Offshore Operators Committee</td>
</tr>
<tr>
<td>PAH</td>
<td>Polycyclic (or Polynuclear) Aromatic Hydrocarbons</td>
</tr>
<tr>
<td>PAO</td>
<td>Poly-alpha-olefin</td>
</tr>
<tr>
<td>mg/kg</td>
<td>Parts per Million</td>
</tr>
<tr>
<td>SOAFED</td>
<td>Scottish Office Agriculture, Fisheries and Environment Department</td>
</tr>
<tr>
<td>SOEI</td>
<td>Sable Offshore Energy Inc.</td>
</tr>
<tr>
<td>TPH</td>
<td>Total Petroleum Hydrocarbon</td>
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<tr>
<td>WBF</td>
<td>Water-Based Fluids</td>
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</tbody>
</table>
Appendix B: Glossary and abbreviations

Annular injection
Injection of fluids into the space between the drill string or production tubing and the open hole or well casing.

Annulus or Annular Space
The space between the drill string or casing and the wall of the hole or casing.

Barite
Mineral form of barium sulphate. An additive used to increase drilling fluid density.

Barrel (bbl)
42 United States gallons at 60 degrees Fahrenheit.

Brine
Water saturated with or containing high concentrations of salts including sodium chloride, calcium chloride, zinc chloride, calcium nitrate.

Casing
Large steel pipe used to “seal off” or “shut out” water and prevent caving of loose gravel formations when drilling a well. When the casings are set and cemented, drilling continues through and below the casing with a smaller bit. The overall length of this casing is called the casing string. More than one string inside the other may be used in drilling the same well.

Centrifuge
Filtration equipment that uses centrifugal force to separate substances of varying densities. A centrifuge is capable of spinning substances at high speeds to obtain high centrifugal forces. Also called the shake-out or grind-out machine.

Completion
Activities undertaken to finish work on a well and bring it to productive status.

Diesel oil
The grade of distillate fuel oil, as specified in the American Society for Testing and Materials' Standard Specification D975-81.

Drill cuttings:
Particles generated by drilling into subsurface geological formations and carried to the surface with the drilling fluid.

Drill pipe
Special pipe designed to withstand the torsion and tension loads encountered in drilling.

Drilling fluid
The circulating fluid (mud) used in the rotary drilling of wells to clean and condition the hole and to counterbalance formation pressure. A water-based drilling fluid is the conventional drilling fluid in which water is the continuous phase and the suspending medium for solids, whether or not oil is present. An oil-base drilling fluid has diesel, crude, or some other oil as its continuous phase with water as the dispersed phase.

Drilling fluid system
System consisting primarily of mud storage tanks or pits, mud pumps, stand pipe, kelly hose, kelly, drill string, well annulus, mud return flow line and solids separation equipment. The primary function of circulating the drilling fluid is to lubricate the drill bit, and to carry drill cuttings rock fragments from the bottom of the hole to the surface where they are separated.

Emulsion
A stable, heterogeneous mixture of two or more liquids (which are not normally dissolved in each other held in suspension or dispersion, one in the other, by mechanical agitation or, more frequently, by the presence of small amounts of substances known as emulsifiers. Emulsions may be oil-in-water, or water-in-oil.

Enhanced mineral oil-based drilling fluid
A drilling fluid that has an enhanced mineral oil as its continuous phase with water as the dispersed phase. Enhanced mineral oil-based drilling fluids are a subset of non-aqueous drilling fluids.

Exploratory well
A well drilled either in search of an as-yet-undiscovered pool of oil or gas (a wildcat well) or to extend greatly the limits of a known pool. It involves a relatively high degree of risk. Exploratory wells may be classified as (1) wildcat, drilled in an unproven area; (2) field extension or step-out, drilled in an unproven area to extend the proved limits of a field; or (3) deep test, drilled within a field area but to unproven deeper zones.

Flocculation
The combination or aggregation of suspended solid particles in such a way that they form small clumps or tufts resembling wool.

Footprint
The square footage covered by production equipment.

Formation
Various subsurface geological strata.

Injection well
A well through which fluids are injected into an underground stratum to increase reservoir pressure and to displace oil, or for disposal of produced water and other wastes.
Internal olefin (IO)
A series of isomeric forms of C16 and C18 alkenes.

LC50
The concentration of a test material that is lethal to 50% of the test organisms in a bioassay.

Linear alpha olefin (LAO)
A series of isomeric forms of C14 and C16 mono-enes.

MM
Million

Mud
Common term for drilling fluid.

Non-aqueous drilling fluid
A drilling fluid in which the continuous phase is a water-immiscible fluid such as an oleaginous material (eg, mineral oil, enhanced mineral oil, paraffinic oil, or synthetic material such as olefins and vegetable esters).

Oil-based drilling fluid (OBF)
A drilling fluid that has diesel oil, mineral oil, or some other oil, but neither a synthetic material nor enhanced mineral oil, as its continuous phase with water as the dispersed phase. Oil-based drilling fluids are a subset of non-aqueous drilling fluids.

Oil-based pill
Mineral or diesel oil injected into the mud circulation system as a slug, for the purpose of freeing stuck pipe.

Operator
The person or company responsible for operating, maintaining, and repairing oil and gas production equipment in a field; the operator is also responsible for maintaining accurate records of the amount of oil or gas sold, and for reporting production information to state authorities.

Poly alpha olefin (PAO)
A mix mainly comprised of a hydrogenated decene dimer C20H42 (95%), with lesser amounts of C24H48 (4.8%) and C28H56 (0.2%).

mg/kg
Parts per million.

Production facility
Any fixed or mobile facility that is used for active recovery of hydrocarbons from producing formations. The production facility begins operations with the completion phase.

PSES
Pretreatment Standards for Existing Sources of indirect dischargers.

ROC
Retention (of drilling fluids) on cuttings.

Rotary Drilling
The method of drilling wells that depends on the rotation of a column of drill pipe with a bit at the bottom. A fluid is circulated to remove the cuttings.

SPP
Suspended particulate phase.

Synthetic-based drilling fluid (SBF)
A drilling fluid that has a synthetic material as its continuous phase with water as the dispersed phase. Synthetic-based drilling fluids are a subset of non-aqueous drilling fluids.

THC
Total hydrocarbons.

TSP
Total suspended particulates.

TSS
Total Suspended Solids.

Vegetable ester
A monoester of 2-ethylhexanol and saturated fatty acids with chain lengths in the range C8–C16.

Water-based drilling fluid (WBF)
A drilling fluid in which water or a water miscible fluid is the continuous phase and the suspending medium for solids, whether or not oil is present.

Workover
The performance of one or more of a variety of remedial operations on a producing oil well to try to increase production. Examples of workover jobs are deepening, plugging back, pulling and resetting liners, and squeeze cementing.
<table>
<thead>
<tr>
<th>Country</th>
<th>Water based drilling fluids and cuttings</th>
<th>Cuttings drilled with group I &amp; group II NADF cuttings</th>
<th>Group III NADF cuttings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angola</td>
<td>• Discharge allowed</td>
<td>• Cuttings discharge allowed, muds reused.</td>
<td>• Cuttings discharge allowed, muds reused</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Oil on cuttings measured, no limit provided.</td>
<td>• Oil on cuttings measured.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Group II NADF cuttings are discharged.</td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>• Operators describe all the types of muds to be used and may make commitments for additional testing or monitoring in Environment Plans that are submitted to the government and once accepted become binding requirements.</td>
<td>• 1% oil limit on cuttings retention - effectively eliminates discharge.</td>
<td>• Group III cuttings discharge assessed on case-by-case basis.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Restriction on fluids with aromatics &gt;1%</td>
<td>• In Western Australia, technical justification, local environment, and environmental performance of fluid (in toxicity, biodegradation, and bioaccumulation) are considered. Fluid retention is limited to 10%.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Cuttings discharge allowed, muds are reused.</td>
<td>• Operators have discharged esters and IO cuttings.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Oil on cuttings measured.</td>
<td>• Requirements for monitoring programmes determined on case-by-case basis.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Group II NADF cuttings are discharged.</td>
<td>• Paraffin-based fluid cuttings have been discharged in Western Australia</td>
</tr>
<tr>
<td>Azerbaijan</td>
<td>• All discharges subject to meeting negotiated terms of specific Production Sharing Agreement</td>
<td>Discharge prohibited</td>
<td>All discharges subject to meeting negotiated terms of specific Production Sharing Agreement</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Discharge may be allowed as long as fluids have acceptable toxicity and biodegradability; however no standards for these have been set.</td>
</tr>
<tr>
<td>Bahrain</td>
<td>• May be discharged but cannot &quot;contain persistent systematic toxins&quot;</td>
<td>Use of Group I and Group II fluids requires express sanction of the competent State Authority</td>
<td>Not addressed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• No whole Group I and Group II fluids can be discharged.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• No Group I and Group II (including diesel) cuttings should be discharged except in exceptional circumstances</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Express sanction is requested for discharge of Group II drill cuttings.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• No drill cuttings should be deposited on the sea-bed in a sensitive area without the express sanction of the competent State Authority.</td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>• No specific regulatory language concerning WBF.</td>
<td>Discharge prohibited.</td>
<td>Discharge approved on a case-by-case basis by IBAMA.</td>
</tr>
<tr>
<td></td>
<td>• Current practice is to allow discharge.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Country</td>
<td>Water based drilling fluids and cuttings</td>
<td>Cuttings drilled with group I &amp; group II NADF cuttings</td>
<td>Group III NADF cuttings</td>
</tr>
<tr>
<td>------------</td>
<td>-----------------------------------------</td>
<td>------------------------------------------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>Canada</td>
<td>2002 draft guidelines allow discharge of water-based muds without restrictions but encourage operators to reduce the need for bulk disposal of drilling fluids.</td>
<td>• 2002 draft guidelines require specific approval to use Group I and Group II NADFs. Use of WBF or Group III NADF preferred. • Use of enhanced Mineral oil based muds (defined as having PAH&lt;10mg/kg) may be approved if environmental and safety performance can be demonstrated to be equivalent or better than SBM. • If re-injection is not technically or economically feasible, cuttings associated with enhanced mineral oil based mud may be discharged if treated prior to discharge with BAT; target goal of 6.9% wet weight oil on cuttings with some allowance for variation with drilling through certain formations and under certain drilling conditions • Permission for temporary discharge of drill solids due to unanticipated malfunction of re-injection equipment will be considered on a case-by-case basis.</td>
<td>• 2002 draft guidelines allow cuttings to be discharged if treated with BAT prior to discharge—provided that re-injection is not economically or technically feasible. • Target oil on cuttings retention limit of 6.9% wet weight with acknowledgement that this limit may be difficult to achieve when drilling through certain formations or under certain drilling conditions.</td>
</tr>
<tr>
<td>China</td>
<td>• Discharge allowed. • Discharge of WBF mixed with oil &gt;10% may not be discharged. • Discharge of WBF mixed with oil &lt;10% may be discharged, if difficult to recover, upon approval by the government and payment of a discharge fee. Specific information on discharge not available.</td>
<td>Government encouraging the use of low toxicity fluid. Minor volumes, when recovery is not possible, may be discharged subject to an appropriate discharge fee.</td>
<td></td>
</tr>
<tr>
<td>Congo</td>
<td>Use and discharge allowed. Use and discharge allowed, except for diesel-based drilling fluids and associated cuttings. Authorities request that cuttings be subject to mechanical treatment in order to reduce amount of fluid discharged.</td>
<td>No specific requirements</td>
<td></td>
</tr>
<tr>
<td>Denmark</td>
<td>Discharge allowed subject to pre-approval requirements for drilling fluid chemicals. Discharged allowed with limit of 1% oil on cuttings - which is not operationally attainable with current technology.</td>
<td>Considered on a case-by-case basis but no use at present.</td>
<td></td>
</tr>
<tr>
<td>Equatorial Guinea</td>
<td>• Discharge allowed. Group II NADF cuttings discharge allowed</td>
<td>Discharge allowed • Operators presently discharging EMBF (Certrex 67 special)</td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>• Use and discharge allowed [permit required] • Under OSPAR 2000/3, discharge is subject to limit of 1% oil on cuttings - which is not operationally attainable with current technology. • It is expected that authorities will not grant any more discharge permits for the Northeast Atlantic or Mediterranean Sea</td>
<td>• Under OSPAR 2000/3, cuttings contaminated with synthetic fluids may only be discharged in exceptional circumstances • It is expected that authorities will not grant any more discharge permits for the Northeast Atlantic or Mediterranean Sea</td>
<td></td>
</tr>
<tr>
<td>Gabon</td>
<td>• Use and discharge allowed. Use and discharge allowed, except for diesel based drilling fluids and associated cuttings. Authorities request that cuttings be subject to mechanical treatment in order to reduce amount of fluid discharged.</td>
<td>No specific requirements</td>
<td></td>
</tr>
</tbody>
</table>
### Cuttings Drilled with Group I & Group II NADF Cuttings

<table>
<thead>
<tr>
<th>Country</th>
<th>Water Based Drilling Fluids and Cuttings</th>
<th>Group III NADF cuttings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iran</td>
<td>May be discharged but cannot contain persistent systemic toxins. Use of Group I and Group II fluids requires express sanction of the competent State Authority. No Group I and Group II fluids can be discharged. No Group I and Group II cuttings (including diesel) should be discharged except in exceptional circumstances. Group II drill cuttings must be discharged without the express sanction of the competent State Authority.</td>
<td>Discharge allowed. Operators are using Group II NADFs and discharging cuttings. No regulatory action on Group III in NADFs. No retention limit.</td>
</tr>
<tr>
<td>Italy</td>
<td>Discharge allowed following suitable regulatory authorisation. Discharged without more than 1% oil on cuttings. Discharged not permitted in Adriatic Sea. No whole Group II fluids can be discharged.</td>
<td>Under OSPAR 2000/2, drill cuttings contaminated with synthetic fluids may only be discharged in exceptional circumstances. Extensive monitoring requirements effectively prohibit use.</td>
</tr>
<tr>
<td>Kuwait</td>
<td>May be discharged but cannot contain persistent systemic toxins. Use of Group I and Group II fluids requires express sanction of the competent State Authority. No Group I and Group II cuttings (including diesel) should be discharged except in exceptional circumstances. Express sanction is required for discharge of Group II drill cuttings. No drill cuttings should be deposited on the seabed in a sensitive area without the express sanction of the competent State Authority.</td>
<td>Group III fluid must be recovered, reconditioned, and recycled. Group III cuttings limited to 5% drilling fluid or less for discharge. Discharge prohibited in swamp areas.</td>
</tr>
<tr>
<td>Malaysia</td>
<td>Discharge allowed. Flow rate is estimated but not reported. Drilling mud makeup is monitored but not recorded.</td>
<td>Under OSPAR 2000/2, discharge is subject to limit of 1% oil on cuttings - which is not operationally attainable with current technology. Extensive monitoring requirements effectively prohibit use.</td>
</tr>
<tr>
<td>Netherlands</td>
<td>Discharge allowed. No additional monitoring requirements. No toxicity tests required. Group I and Group II cuttings contaminated with drilling fluid chemicals. Pre-application requirements include toxicity testing according to OSPAR protocols.</td>
<td>Oil on cuttings, limited to 1% with 0% goal. To discharge, must submit proof to DPR that Group I fluid has low toxicity. Group II fluid must be recovered, reconditioned, and recycled. On-site disposal of oil content does not cause sheen on the receiving water. Inspection of operations shall be allowed at all reasonable times. Sampling and monitoring required – Operator analyses cuttings samples at intervals specified by DPR.</td>
</tr>
<tr>
<td>Nigeria</td>
<td>To discharge, must submit proof that mud has low toxicity to Director of Petroleum Resources (DPR) with permit application. Group I fluids to be treated in DPR's facilities. Group II fluids to be recovered, reconditioned, and recycled. On-site disposal of oil content does not cause sheen on the receiving water. Inspection of operations shall be allowed at all reasonable times. Monitoring of drilling sites required.</td>
<td>To discharge, must submit proof that Group II NADF has low toxicity, and DPR approval required. Group II NADF must be recovered, reconditioned, and recycled. Group III (except for esters) cuttings limited to 5% drilling fluid or less for discharge. Discharge prohibited in swamp areas. DPR is considering special considerations for exploration drilling and drilling in deep water.</td>
</tr>
<tr>
<td>Malaysia</td>
<td>Discharge allowed. No oil limit. Operators are using Group II NADFs and discharging cuttings.</td>
<td>Discharge allowed. Operators are using Group III NADFs and discharging cuttings. No retention limit.</td>
</tr>
<tr>
<td>Malaysia</td>
<td>Discharge allowed. No oil limit. Operators are using Group III NADFs and discharging cuttings.</td>
<td>Discharge allowed. Operators are using Group III NADFs and discharging cuttings. No retention limit.</td>
</tr>
<tr>
<td>Nigeria</td>
<td>To discharge, must submit proof that mud has low toxicity to Director of Petroleum Resources (DPR) with permit application. Group I fluids to be treated in DPR's facilities. Group II fluids to be recovered, reconditioned, and recycled. On-site disposal of oil content does not cause sheen on the receiving water. Inspection of operations shall be allowed at all reasonable times. Sampling and monitoring required – Operator analyses cuttings samples at intervals specified by DPR.</td>
<td>To discharge, must submit proof that Group II NADF has low toxicity, and DPR approval required. Group II NADF must be recovered, reconditioned, and recycled. Group III (except for esters) cuttings limited to 5% drilling fluid or less for discharge. Discharge prohibited in swamp areas. DPR is considering special considerations for exploration drilling and drilling in deep water.</td>
</tr>
<tr>
<td>Nigeria</td>
<td>To discharge, must submit proof that mud has low toxicity to Director of Petroleum Resources (DPR) with permit application. Group I fluids to be treated in DPR's facilities. Group II fluids to be recovered, reconditioned, and recycled. On-site disposal of oil content does not cause sheen on the receiving water. Inspection of operations shall be allowed at all reasonable times. Sampling and monitoring required – Operator analyses cuttings samples at intervals specified by DPR.</td>
<td>To discharge, must submit proof that Group II NADF has low toxicity, and DPR approval required. Group II NADF must be recovered, reconditioned, and recycled. Group III (except for esters) cuttings limited to 5% drilling fluid or less for discharge. Discharge prohibited in swamp areas. DPR is considering special considerations for exploration drilling and drilling in deep water.</td>
</tr>
<tr>
<td>Country</td>
<td>Water based drilling fluids and cuttings</td>
<td>Cuttings drilled with group I &amp; group II NADF cuttings</td>
</tr>
<tr>
<td>----------------</td>
<td>----------------------------------------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| Norway         | Discharge allowed subject to pre-approval requirements for drilling fluid chemicals. Monitoring of discharge sites may be required. Pre-approval requirements include toxicity testing according to OSPAR protocols. | Under OSPAR 2000/3, discharge is subject to limit of 1% oil on cuttings— which is not operationally attainable with current technology                                                                                                                                                                                                                     | - OSPAR decision 2000/3 permits Group III cuttings discharge only under exceptional circumstances (for Norway, likely to mean only at those sites where SBFs have been previously discharged).  
- Group III discharge allowed only where technical/safety considerations preclude use of WBF.  
- When allowed, Group III content of cuttings limited to 8-18% depending on hole size.  
- Chemical monitoring of cuttings required annually, biological monitoring required every 3 years. Applications for approval require testing according to OSPAR format. |
<p>| Oman           | May be discharged but can not &quot;contain persistent systematic toxins&quot;                                                                                                                                 |                                                                                                                                                  | Not addressed                                                                                                                                                                                                                                                                                                                                                     |
| Qatar          | May be discharged but can not &quot;contain persistent systematic toxins&quot;                                                                                                                                 |                                                                                                                                                  | Not addressed                                                                                                                                                                                                                                                                                                                                                     |
| Russia-Sakhalin Island | Base case is zero discharge with discharges from exploratory drilling authorized on a case-by-case basis.                                                                 |                                                                                                                                                  | Regulatory documents do not deal specifically with Group I and Group II NADFs; regulations currently in draft form will prohibit cuttings discharge if Group I and Group II NADFs are used.                                                                                                                                                  |</p>
<table>
<thead>
<tr>
<th>Country</th>
<th>Water based drilling fluids and cuttings</th>
<th>Cuttings drilled with group I &amp; group II NADF cuttings</th>
<th>Group III NADF cuttings</th>
</tr>
</thead>
</table>
| Saudi Arabia | May be discharged but cannot contain persistent systematic toxins | • Use of Group I and Group II fluids requires express sanction of the competent State Authority  
• No whole Group I and Group II fluids can be discharged  
• No Group I and Group II (including diesel) cuttings should be discharged except in exceptional circumstances  
• Express sanction is requested for discharge of Group II drill cuttings  
• No drill cuttings should be deposited on the sea-bed in a sensitive area without the express sanction of the competent State Authority. | Not addressed |
| Spain | Use and discharge allowed (permit required) | • Under OSPAR 2000/3, discharge is subject to limit of 1% oil on cuttings - which is not operationally attainable with current technology.  
• It is expected that authorities will not grant any more discharge permits for the Northeast Atlantic or Mediterranean Sea | • Under OSPAR 2000/3, cuttings contaminated with synthetic fluids may only be discharged in exceptional circumstances  
• It is expected that authorities will not grant any more discharge permits for the Northeast Atlantic or Mediterranean Sea |
| Thailand | | • Discharge allowed if <10% oil on cuttings. Regulators are reviewing existing practices. | • No specific language concerning Group III NADFs |
| Trinidad | • No specific restrictions against offshore discharge and has historically been allowed.  
• Use must be disclosed in EIA, which is approved by the Ministry of Energy.  
• Impact of Water Pollution Rules currently being promulgated by EMA is uncertain at this time; will likely allow discharge. | • No specific restrictions against, but offshore discharge unlikely to be allowed by Ministry of Energy (MOE) during EIA approval process.  
• No offshore wells have been drilled with OBM in several years, so Ministry of Energy’s stance has not been recently tested.  
• Impact of Water Pollution Rules currently being promulgated by EMA is uncertain at this time; will likely not allow discharge. | • No specific restrictions against offshore discharge and has historically been allowed.  
• Impact of Water Pollution Rules currently being promulgated by EMA is uncertain at this time. |
| UAE | May be discharged but cannot contain persistent systematic toxins | • Use of Group I and Group II fluids requires express sanction of the competent State Authority  
• No whole Group I and Group II fluids can be discharged  
• No Group I and Group II (including diesel) cuttings should be discharged except in exceptional circumstances  
• Express sanction is requested for discharge of Group II drill cuttings  
• No drill cuttings should be deposited on the sea-bed in a sensitive area without the express sanction of the competent State Authority. | Not addressed |
<table>
<thead>
<tr>
<th>Country</th>
<th>Water based drilling fluids and cuttings</th>
<th>Cuttings drilled with group I &amp; group II NADF cuttings</th>
<th>Group III NADF cuttings</th>
</tr>
</thead>
<tbody>
<tr>
<td>United Kingdom</td>
<td>Discharge allowed subject to pre-approval requirements for drilling fluid chemicals. Pre-approval requirements include toxicity testing according to OSPAR protocols.</td>
<td>• Under OSPAR 2000/3, discharge is subject to limit of 1% oil on cuttings which is not operationally attainable with current technology. • Practice is to inject cuttings or return to shore and recover oil.</td>
<td>• Although OSPAR 2000/3 decision permits Group III cuttings discharge only under exceptional circumstances; • The UK government has made it clear that there will no exceptional circumstances arising that would lead to discharge of SBM cuttings.</td>
</tr>
<tr>
<td>United States - General Conditions</td>
<td>Coastal Waters: (e.g. inland canals and enclosed bays). Discharge prohibited except for Alaska. Alaskan coastal waters subject to same regulations as offshore waters. • Offshore Waters: Discharge allowed subject to: • &gt;3 mi. from shore (except Alaska where &gt;3mi restriction does not apply) • Limit on toxicity (LC50 of suspended particulate phase &gt;30000mg/kg) • Limit on Hg/Cd in barite (µg/kg) • No free oil (static sheen test) • No diesel oil • Discharge rate &lt; 1000 bbl/hr • Further restrictions on rate in areas of special biological sensitivity</td>
<td>Discharge prohibited.</td>
<td>Western GOM. Discharge allowed subject to the following restrictions: • Must be &gt;3 mi. from shore • Maximum retention on cuttings (wet weight basis well average over intervals drilled with SBFs) varies with fluid • 9.4% for ester or equivalent (based on toxicity and biodegradation standards) • 6.9% for fluid with equivalent environmental performance to C16-C18 IOs. • Limit on toxicity-Base fluid (LC50 of base fluid less than a C1618 internal olefin). • Limit on toxicity discharge of field mud (LC50 of whole mud is not greater than standard mud) • Limit on Biodegradation by closed bottle test biodegradation of base fluid less than a C1618 internal olefin) • Limit on Hg/Cd in barite (µg/kg) • No free oil (Reverse phase extraction method) • No diesel oil • Further restrictions on rate in areas of special biological sensitivity • Eastern GOM: Discharges not allowed. • California: Discharges not allowed. • Alaska: Discharges allowed except for coastal Cook Inlet subject to the restrictions noted above for Western GOM (except for the &gt;3mi limitation). Allowed for coastal Cook Inlet only if operators are unable to dispose of via injection or onshore disposal.</td>
</tr>
<tr>
<td>Vietnam (EEPVL)</td>
<td>Discharge allowed. • No stipulations on KCl • Toxicity requirements not stipulated concretely. • In general oil content should be lower than 1%. • Any use of drilling fluids, toxic and/or hazardous chemicals must be approved by regulatory agency in advance. • Drilling mud makeup is monitored and reported as drilling mud components in EIA report.</td>
<td>Discharge prohibited &lt; 3 nautical miles. 1% oil limit (possibly extended for certain cases) for areas beyond 3 nautical miles. • Use of diesel-based drilling fluids is totally prohibited.</td>
<td>No stipulations regarding Group III cuttings. May have same restrictions as Group I and II cuttings.</td>
</tr>
</tbody>
</table>

The information in this table is believed to be accurate as of April 2001. However, due to changes in regulatory requirements, operators should determine the current regulatory requirements when operating in any of these countries.
## Appendix D:
### Group II & III based fluid systems & base fluids

<table>
<thead>
<tr>
<th>Company</th>
<th>Type</th>
<th>System name</th>
<th>Base fluid name</th>
<th>Locations used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amoco Chemical</td>
<td>LAO&lt;sup&gt;1&lt;/sup&gt;</td>
<td>AmoDrill 1000</td>
<td>synthetic olefin</td>
<td></td>
</tr>
<tr>
<td>Amoco Chemical</td>
<td>IO&lt;sup&gt;2&lt;/sup&gt;</td>
<td>AmoDrill 1000</td>
<td>synthetic olefin</td>
<td></td>
</tr>
<tr>
<td>Baker Hughes INTEQ</td>
<td>IO</td>
<td>SYN-TEQ</td>
<td>ISO-TEQ</td>
<td>Active - GOM, Australia, Nigeria, UK, China, Indonesia</td>
</tr>
<tr>
<td>Baker Hughes INTEQ</td>
<td>IO/Paraffin Blend</td>
<td>SYN-TEQ</td>
<td>OMNI-BASE</td>
<td>Active - GOM</td>
</tr>
<tr>
<td>Baker Hughes INTEQ</td>
<td>Paraffin</td>
<td>SYN-TEQ (PARA)</td>
<td>PARA-TEQ</td>
<td>Active - Norway, UK, Nigeria</td>
</tr>
<tr>
<td>Baker Hughes INTEQ</td>
<td>LAO</td>
<td>SYN-TEQ (ALPHA)</td>
<td>ALPHA-TEQ</td>
<td>Active - Norway, UK, Angola</td>
</tr>
<tr>
<td>Baker Hughes INTEQ</td>
<td>Ester</td>
<td>BIO-GREEN</td>
<td>BG-5500</td>
<td>Active - Norway, UK, Nigeria, Australia</td>
</tr>
<tr>
<td>Baroid</td>
<td>Ester</td>
<td>PETROFREE</td>
<td>PETROFREE</td>
<td>Gulf of Mexico, UK, Norway, Holland, Australia, Brunei, Nigeria, Malaysia, Mexico</td>
</tr>
<tr>
<td>Baroid</td>
<td>LAO</td>
<td>PETROFREE LE</td>
<td>LE BASE</td>
<td>Venezuela, USA</td>
</tr>
<tr>
<td>Baroid</td>
<td>Linear paraffin</td>
<td>XPO7</td>
<td>XPO7</td>
<td>Australia, UK, Indonesia, Thailand, Eritrea, Brunei, Myanmar, Afghanistan, South Africa, Venezuela, Nigeria, Brazil, Ethiopia, Mexico, USA, Italy</td>
</tr>
<tr>
<td>Baroid</td>
<td>Low Viscosity Ester</td>
<td>PETROFREE LV</td>
<td>PETROFREE LV</td>
<td>Gulf of Mexico</td>
</tr>
<tr>
<td>Baroid</td>
<td>IO</td>
<td>PETROFREE SF</td>
<td>SF BASE</td>
<td>Gulf of Mexico</td>
</tr>
<tr>
<td>Baroid</td>
<td>EMBF&lt;sup&gt;3&lt;/sup&gt;</td>
<td>ENVIROMUL</td>
<td>HDF 2000</td>
<td>USA, UK, Thailand, Colombia, Canada, Egypt, Germany, Norway, Denmark, Netherlands, France, Indonesia, Nigeria, Italy, Angola, Trinidad and Tobago, Australia</td>
</tr>
<tr>
<td>Chevron</td>
<td>IO</td>
<td>GulfTene 14/16/18/20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conoco</td>
<td>EMBF</td>
<td>LV/T-200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dowell</td>
<td>Ester</td>
<td>Finagreen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dowell</td>
<td>LAO</td>
<td>Ultidril</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exxon</td>
<td>EMBF</td>
<td>ESCAID 110</td>
<td></td>
<td>Gulf of Mexico; Offshore California</td>
</tr>
<tr>
<td>Exxon</td>
<td>EMBF</td>
<td>ESCAID 240</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exxon</td>
<td>Paraffin</td>
<td>613DF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exxon</td>
<td>PAO&lt;sup&gt;4&lt;/sup&gt;</td>
<td>EXDRILL S 175</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobil</td>
<td>EMBF</td>
<td>Centrex 67 Special</td>
<td></td>
<td>Equatorial Guinea</td>
</tr>
<tr>
<td>MI</td>
<td>PAO&lt;sup&gt;5&lt;/sup&gt;</td>
<td>Novadril</td>
<td>Novasol II</td>
<td>System name retained but unlikely to be used again</td>
</tr>
<tr>
<td>MI</td>
<td>IO&lt;sup&gt;6&lt;/sup&gt; (IO/SLP blend)&lt;sup&gt;7&lt;/sup&gt;</td>
<td>NOVAPLUS</td>
<td>IO 16/18 predominately</td>
<td>Actiive - GoM, Eastern Canada</td>
</tr>
<tr>
<td>MI</td>
<td>LAO</td>
<td>NOVATEC</td>
<td>LAO C14/16 or C14/16/18</td>
<td>Active - Norway, Nigeria, Caspian</td>
</tr>
<tr>
<td>MI</td>
<td>Paraffin&lt;sup&gt;8&lt;/sup&gt;</td>
<td>PARADRIL</td>
<td></td>
<td>Active - primarily used for offshore applications</td>
</tr>
<tr>
<td>MI</td>
<td>LP with chloride alternative internal phase</td>
<td>PARALAND</td>
<td></td>
<td>Active - primarily used for land drilling operations</td>
</tr>
<tr>
<td>MI</td>
<td>Ester</td>
<td>ECOGREEN</td>
<td></td>
<td>Active</td>
</tr>
<tr>
<td>MI</td>
<td>Acetal</td>
<td>Aquamul</td>
<td>Inactive</td>
<td></td>
</tr>
<tr>
<td>MI</td>
<td>PAO</td>
<td>NOVAPLUS</td>
<td>Inactive</td>
<td></td>
</tr>
<tr>
<td>PetroCanada</td>
<td>Isoparaffin</td>
<td>IA35</td>
<td>Hibernia</td>
<td></td>
</tr>
</tbody>
</table>

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### Environmental aspects of the use and disposal of non-aqueous drilling fluids associated with offshore oil & gas operations

<table>
<thead>
<tr>
<th>Company</th>
<th>Type</th>
<th>System name</th>
<th>Base fluid name</th>
<th>Locations used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schlumberger Dowell</td>
<td>LAO</td>
<td>Ultidrill Mud</td>
<td>Ultidrill</td>
<td></td>
</tr>
<tr>
<td>Shell</td>
<td>LTMBF&lt;sup&gt;7&lt;/sup&gt;</td>
<td>Shellsol DMA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shell</td>
<td>IO</td>
<td></td>
<td>Neodene</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>EMBF</td>
<td></td>
<td>HDF-2000</td>
<td>Congo</td>
</tr>
<tr>
<td>Total</td>
<td>LTMBF</td>
<td></td>
<td>HDF-200</td>
<td>Angola</td>
</tr>
<tr>
<td>Unocal</td>
<td>Synthetic Paraffin</td>
<td>Saraline</td>
<td></td>
<td>Caspian</td>
</tr>
</tbody>
</table>

1. LAO-Linear alpha olefin
2. IO-Internal olefin
3. EMBF-enhanced mineral oil based fluid
4. Synthetic polymerised material made from olefins and fully hydrogenated, similar to PAO
5. PAO-Poly alpha olefin
6. SLP-Synthetic Linear Paraffin
7. LTMBF-low toxicity mineral oil based fluid

† The NOVAPLUS product currently being marketed in the GOM region is a blend of IO C<sub>16</sub>/18 and a synthetic linear paraffin ranging from C<sub>11</sub>-C<sub>16</sub>. As the new EPA Effluent Guidelines come into effect, the NOVAPLUS system used in the GOM will revert to a blend that is predominately IO C<sub>16</sub>/18 but still meets the new EPA Effluent criteria.

‡ Paraffin selection based on local environmental regulation and supply. Options include synthetic or refined, linear or iso-paraffins.
Appendix E: Summary of non-aqueous fluid cuttings discharge field studies

The following are summaries, based on available literature, of non-aqueous fluid (NADF) cuttings discharge field studies. The studies are divided into the following categories:

- Group I NADFs (diesel, mineral oils)
- Group II NADFs (Low Toxicity Mineral Oil Based Fluid (LTMBF))
- Group III NADFs (Enhanced Mineral Oil Based Fluid (EMBF), Synthetic-Based Fluids (SBF))

The conclusions/findings presented are those of the author of the study. In some cases our comments are provided separately following the description of the field programme, findings, and conclusion. The focus is on the Group II, and Group III NADF field studies. Consequently, only one Group I NADF study has been summarised. This report focuses on the long-term recovery of sites where Group I and Group II NADF cuttings have been discharged.

As discussed in Section 3.4.5, there are limitations to how closely these studies can be compared in part due to differences in field survey parameters. Tables D.1 and D.2 summarise some of the field survey parameters and findings of chemical and biological impacts from field studies following Group II and Group III cuttings discharge, respectively. Tables D.3 and D.4 provide additional details on the field study design, discharge details, and location for Group II and Group III studies respectively.

E.1 Group I NADF cuttings discharge field studies

The most comprehensive chemical and biological studies on the impacts of discharging diesel Group I NADF cuttings have been conducted in the UK sector of the North Sea. There is limited information from other sectors of the North Sea, and little to none outside of the North Sea area. Detailed site assessments were conducted at locations in the North Sea where both Group I NADF cuttings and WBFs and cuttings were discharged. Based on these assessments, the Paris Commission Working Group on Oil Pollution published in 1985 a list of “agreed facts” on the impacts of OBF (Group I) cuttings on the marine environment. The main environmental points, as summarised by Davies et al. (1988) are as follows:

1. Discharges of cuttings from water-based or oil-based drilling can have an adverse effect on the seabed biological community. Beneath and in the immediate vicinity of the platform, this is due mainly to physical burial of the natural sediments. However, the extent of the biological effects of oil-based mud cuttings from multiple-well drilling is substantially greater than that with water-based muds.

2. Despite the scale of inputs in all fields studied, the major deleterious biological effects were confined within the 500m safety zone and associated primarily with burial under the mound of cuttings on the seabed. Seabed recovery in this zone is likely to be a long process.

3. Surrounding the area of major impact is a transition zone in which lesser biological effects are detected as community parameters return to normal, generally within 200 to 1,000 metres. The shape and extent of this zone is variable, and is largely determined by the current regime and the scope of the drilling operation. With greater currents and more extensive drilling, this delineation may be extended 2,000 metres in the direction of greatest water movement.

4. Elevated hydrocarbon concentrations attributable to OBF were observed beyond the areas of biological effects. These elevated hydrocarbon concentrations have been measured out to as far as 4000 metres in the direction of the prevailing current.

It should also be noted that these points were based on operations where multiple wells were drilled in the UK portion of the North Sea and may not apply to single well exploration sites, or areas with different depths, and stronger current regimes. In addition, Points 2 and 3 above do not reflect the current state of knowledge about the effects discharges from drilling with WBFs.

Several years following the development of the agreed facts, more recent (post-1983) North Sea survey data were examined to determine whether the agreed facts still held and to fill in initial knowledge gaps (Davies et al, 1988). Consequently, three sets of studies were examined: (1) those that involved continuing monitoring around the existing platforms, (2) those involving new installations particularly in the UK sector of the North Sea (in 1985 the effects of OBF cuttings discharge had not been clearly defined in the higher energy southern North Sea), and (3)
those involving single well exploration sites (as the original facts were developed based on development well drilling).

The results of this further research on the effects of OBF cuttings discharges (Davies et al, 1988) were qualitatively consistent with the zones-of-influence concept described above. Consequently the postulated zones-of-influence were amended to include impacts from single well drilling. A summary of these zones is provided below in Table E.1.

Studies of fields where drilling discharges have ceased indicate that recovery and re-colonisation of the transition zone begins within 1-2 years, accompanied by base fluid degradation. The transition zone begins to move inwards, despite the potential outward distribution of base fluid-laden sediments (Davies et al, 1988).

In regard to long-term impacts, Olsgard and Gray, 1995 reviewed 24 field surveys of 14 oil fields on the Norwegian continental shelf to examine long-term impacts of and recovery from OBF cuttings discharge. They found that the areal extent and magnitude of effects of OBF cuttings discharge on benthic biological communities was highly variable. For three fields that were extensively studied, the areal extent of sediments with elevated base fluid and metal (primarily barium) content, ranged from 10km² to over 100km². Over a period of six to nine years after termination of cuttings discharge, the sediment contamination spread so that nearly all stations two to six km from the drill site showed evidence of elevated base fluid/metals levels. There was evidence of oil biodegradation in sediments following cessation of discharge; however, effects on benthos persisted longer than the elevated base fluids, suggesting that metals or some other cuttings component were contributing to the long-term effects of the discharges.

### Table E.1 The zones of effect of OBF (group 1) cuttings discharge

<table>
<thead>
<tr>
<th>Zone</th>
<th>Maximum extent within range</th>
<th>Chemistry</th>
<th>Biology</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0-500m development wells</td>
<td>High base fluid levels 1000x background; sediments largely anaerobic</td>
<td>Impoverished and highly modified benthic community (beneath and close to platform the seabed can comprise cuttings with no benthic fauna)</td>
</tr>
<tr>
<td>II Transition</td>
<td>200-1000/2000m development wells, out to 500m single wells</td>
<td>Base fluid levels 10-700x background</td>
<td>Transition zone in benthic diversity and community structure</td>
</tr>
<tr>
<td>III</td>
<td>800-4000m development wells, out to 1000m single wells</td>
<td>Base fluid levels return to background 1-10x background</td>
<td>No benthic effects detected</td>
</tr>
<tr>
<td>IV Background</td>
<td></td>
<td>No elevation of base fluids</td>
<td>No benthic effects</td>
</tr>
</tbody>
</table>

Daan and Mulder (1996) examined some of the long-term impacts of Group I NADF cuttings discharges in the Dutch North Sea. The results of their studies of drill sites in the Dutch Sector of the North Sea indicated elevated base fluids in sediments up to 750 to 1000 metres from the well site during the first year after drilling. At distances greater than 500 metres from the well site, hydrocarbon concentrations tended to decrease to natural background levels within a few years. Base fluid concentrations remained well above background levels for at least eight years at some stations within a few hundred metres of the well site. The highest concentrations were found 25-30 cm below the sediment surface. Benthic impacts were initially observed out to 1000m, with the number of species affected and the severity of effects increasing with decreasing distance from the well site. Within a few years, recovery was evident at locations more than 500 metres from the well sites. Benthic communities near the well site were still adversely affected eight years after drilling terminated. More detail on this study is provided below.

A similar summary by Daan and Scholten (Smith, 1999) of the results of a 1985-1995 Dutch North Sea monitoring programme indicated that localised hydrocarbon contamination and biological effects were detectable in the Dutch North Sea as long as eight years after drilling, although the general trend is towards recovery with time. Categorisation of sites according to water depth and potential for sediment erosion is a key feature of the Dutch monitoring programme. The Dutch sector of the North Sea consists of waters of mostly less than 50-metres depth. Sites in the southern part of this sector are considered to be in the erosion zone. In this area, waters are less than 20 metres in depth, bottom currents are strong, and the sea bottom comprises coarse sand. Sites in the northern part of this sector are considered to be in the sedimentation zone, where waters are deeper and slower bottom currents lead to more silty sediment conditions. In between these extremes, there is a transition zone of sites at intermediate
depths. The results of the monitoring programme were organised according to the type of site: sedimentation, transition, or erosion. The erosion-type sites had the smallest zones of base fluid contamination and biological effects. Gradients in sediment hydrocarbon concentration were detectable up to eight years after the cessation of discharges. The gradients are gradually weakening with time, indicating that base fluids either are being redistributed by currents or are biodegrading. Biological effects can still be detected at relatively low (<1000mg/kg) base fluid concentrations at some of the monitoring sites. Consequently, although conditions in the Dutch North Sea are favourable for preventing the formation of cuttings piles, benthic biological effects can be detected very close to the discharge site as long as eight years after discharges have stopped.

It is of interest to note that the monitoring results showed that the character of sediment hydrocarbons changes with distance from the source. Close to the source (100 metres), gas chromatography-mass spectrometry (GC-MS) evidence shows that the sediment hydrocarbons are clearly related to Group I NADFs. At large distances (5000 metres) from discharge sites, the character of the hydrocarbons indicates that their source is something other than Group I NADF cuttings discharges. Possible sources could be hydrocarbons from shipping discharges or shore-based runoff.

**Dutch sector of the North Sea (Daan and Mulder, 1993)**

A field study was undertaken in 1992 in the Dutch Sector of the North Sea at the K12a platform. The aim of this study was to examine the long-term impacts of discharging diesel and LTMBF cuttings eight years earlier. Previous studies had been conducted every year from 1985-1988. Bottom stations were sampled primarily along a transect in the residual current direction at distances ranging from 100 to 7500 metres. One station was sampled at 250 metres in a direction perpendicular to the primary transect.

**The findings were as follows:**

- The highest hydrocarbon concentrations were found in subsurface sediments at 25-30 cm;
- Substantially elevated hydrocarbon levels were found to 250 metres in the residual current direction; concentrations at 100 metres were still within the range of levels observed between 1985-1990; there is little evidence for biodegradation of the oil since it was discharged in 1984; if there were any decrease in concentration, it is masked by spatial patchiness
- Hydrocarbon contents of samples collected at 500 metres and further away did not exceed background; however, traces of oil were visible at stations up to 1000 metres
- The benthic fauna were impoverished at 100 metres; at 250 metres only the absence or reduced abundance of some sensitive species indicated a persistent effect. The absence of the opportunistic species Capitella capitata at the 100-metre station and the reappearance of E. cordatum points to stabilisation of sediment conditions. No significant effects could be detected at 500 metres and further away.

**The following conclusions were reached:**

- There is little horizontal redistribution of discharged material. In the long-term components of the drilling mud appeared to be stored in the deeper sediment layers;
- Initially contaminated sediments were buried under freshly sedimented material; biodegradation may have occurred only at the sediment water interface;
- Hydrocarbon levels may have decreased in samples beyond 500 metres; however, it is not clear whether this is a result of biodegradation or the fact that most cases only the upper 10 cm of sediment was sampled;
- The benthos were still impoverished 100 metres from the platform; however the absence of opportunistic species indicates stabilisation;
- From 250 metres and outwards the surficial sediments appear to have allowed settlement of juveniles.
E.2 Group II NADF cuttings discharge field studies

Southern North Sea (Davies et al., 1988)
Field studies were conducted at the Vulcan field in the Southern North Sea to determine the impacts of discharging LTMBF (Group II) cuttings from 8 wells. Surveys included a baseline study in March of 1986, and one at the cessation of drilling in July of 1987. Two samples each were taken at 200, 500, 800, 1200, 2500, and 5000 metres from the platform.

The findings were as follows:
• Immediately following drilling, hydrocarbon levels were elevated at the 200-metre site (average 11347 µg/g dry wt), with low levels measured at 500 metres (8.5 µg/g), and extremely low levels measured from 800-1200 metres (2.6-3.4), possibly also at 2500 metres (2.2 µg/g). Levels at 5000 metres were at background levels (1.1 µg/g);
• Despite a high hydrocarbon level at 200 metres, there was not a marked depression of the diversity index; additional analyses indicated that a normal population was present at the 1200-metre site.

Comment:
It was difficult to interpret the data on number of individuals, species, and diversity indices. The fauna in this area are known to be sparser, less diverse and more variable than those in the northern North Sea. Also, the baseline study was conducted in March, and the post-drill study in July. Consequently, differences between values collected from the two studies could reflect seasonal differences.

Central North Sea (Davies et al., 1988)
Seabed surveys were conducted to determine the impacts of LTMBF and OBF cuttings from the two exploration wells 16/28H and 16/28I located in 100 metres of water in the Central North Sea. Both wells had 17 1/2” sections drilled using a low toxicity oil-based mud, and 16/28H also had the 12 1/4” section drilled using OBF. Surveys were conducted before drilling and immediately upon completion of drilling. Samples were taken at 50, 100, 250, 500, 800, 1200, 2500, and 5000 metres to the south of the drill site, and 50 and 100 metres to the north. Samples were taken only for hydrocarbon content.

The findings were as follows:
• Elevated hydrocarbon levels could be detected out to 800 metres at site I, but concentrations were not highly elevated above background beyond 500 metres. Levels of hydrocarbons up to 100x background were restricted to distances within 250 metres and 100 metres of the drill site for sites I and H respectively;
• Close to the discharge source, hydrocarbon concentrations appeared similar to those found at multi-well sites (for well H, ~5000 mg/kg at 50 metres; for well I, ~2000 mg/kg at 50 metres);
• Hydrocarbon levels dropped off rapidly to not much greater than 10-100 x background within 500-1000 metres of the discharge location.

Central North Sea (Davies et al., 1988)
Seabed surveys were conducted at three single well sites in the Central North Sea, in order to assess the long-term impact of seabed sediment hydrocarbons and biological recovery. Of these three wells, one, 16/27, discharged ~85 tonnes of Group II NADF six years prior to the survey, another, water based mud 7 years prior (well 14/11), and the other 181 tonnes of diesel oil 5 years prior (well 21/12). Samples were taken at 50 metres, north, and 50, 100, 200, 500, 800, 1200, and 2500 metres south of the well site. A reference station was located 6000 metres to the east. Samples were taken for hydrocarbon and macrofaunal biological analysis.
Environmental aspects of the use and disposal of non aqueous drilling fluids associated with offshore oil & gas operations

The findings were as follows:

- Elevated hydrocarbons were detected to 2500 metres at the diesel oil site, but were detected only to 750 metres at the Group II NADF site. No hydrocarbon concentrations above background were detected for the water-based mud site;
- At the Group I NADF site, there was a marked reduction in species diversity between 50 and 500 metres (compared to reference and 500 metres and beyond); at the Group II NADF site the reduction in diversity occurred between 50 and 200 metres (compared to reference and 200 metres and beyond); there was no observable effect on benthos for the WBF site.

Australia-Wanaea 6 (Oliver and Fischer, 1999)

A long-term seabed study was conducted in 80 metres of water on the North West Australian Shelf to study the impacts of discharging drill cuttings coated with 44 tonnes of Group II NADF from one well, Wanaea 6. A baseline survey was conducted in 10/93 in the vicinity of Wanaea 3 (where WBF and cuttings had been previously discharged), thirteen months prior to drilling Wanaea 6 (11/94). Follow up surveys were conducted at 11 months (11/95; physical and chemical only), and approximately 36 months (9/97) after cessation of drilling at Wanaea 6. Additional samples were taken immediately under the point of cuttings discharge at approximately 16 months (4/96). Samples from the first post-drilling survey were tested only for physical (grain size) and chemical (TPH, metals, TOC, SiO$_2$, CaCO$_3$) characteristics. During the initial baseline and final sampling survey, samples were taken for physical, chemical, and biological analyses. Samples from the intermediate survey were used only for chemical analyses.

Meteorological and oceanographic conditions in the region (Northwest Shelf) are as follows:

- The predominant current direction oscillates between NW and SE under the influence of semi-diurnal tides
- Peak spring and neap tidal currents measured are 0.65m/s and 0.3m/s respectively
- The Northwest Shelf is influence by tropical storms between November and April and receives an average of 10.7 days of cyclone activity per annum.
- Wind speeds can reach > 60m/s
- Significant wave heights> 10 metres
- Sediment distribution is influenced by cyclones, also action of long-period internal waves breaking in mid-shelf depths
- Near bottom seawater temperatures range from 24°C in summer to 22°C in winter.

The findings were as follows:

- The baseline survey indicated that trace metals (Ba, Pb, Cr) were elevated above background levels at Wanaea 3 - likely to be residual effects of water-based mud discharges;
- Eleven months following drilling, hydrocarbons concentrations <200mg/kg were measured near the Wanaea 6 drill-site, with levels reducing to less than 1mg/kg within 200 metres of the discharge point;
- Samples taken at 16 months showed the same. Barium was found to be elevated 400 metres from the well-head;
- Approximately 3 years after drilling at Wanaea 6, there was no evidence of acute impacts on species richness and abundance (such as those sometimes found immediately below the discharge point as discussed in the following study on North Rankin A)
- Reduced abundance and richness (both in comparison to other stations and to the 1993 baseline) at a station 80m from the #6 well can likely be attributed to persistent effects of drilling discharges.
- Richness was also reduced at the station where the cuttings pile originally formed, however, abundance was similar to other stations, likely due to the number of hydrocarbon tolerant species such as Capitella.
The following conclusions were reached:

- Eleven months following drilling, the transition between affected and unaffected sediment hydrocarbons occurred between 200 and 400 metres in the direction of the prevailing current; at right angles to this direction the transition occurs between 100 and 200 metres. The highest concentrations were restricted to within 50 metres of the cuttings discharge point (178 and 181mg/kg in the cuttings pile, and 129mg/kg at approximately 50 metres);
- Approximately three years following drilling, TPH concentrations within 200-400 metres of the well site were higher in some directions than recorded at 11 months, with the maximum levels measured at 50m (860mg/kg) and in the cuttings pile (274mg/kg). TPH levels above those of the control site (<0.01mg/kg) were found out to 1200 metres;
- TPH concentrations were still elevated in the cuttings pile (ranging from 2.1-274mg/kg dry weight)-in four out of five samples, levels were less than those taken eleven months post-drilling;
- Three years after drilling, the TPH transition zone between contaminated and uncontaminated sediment is beyond 1200 metres;
- The persistence of hydrocarbons at this location (particularly as contrasted with the Lynx site) is attributed partly to differences in local sediment dynamics. At Wanaea, the installation of sub-sea installations could have redistributed sediments, including burying contaminated sediments. In addition, sub-sea installations could also contribute to entrapment.

Comments:

Lower detection limits for hydrocarbon analysis methods used on samples collected three years following drilling allowed more refined definition of zones of impacts than did data from eleven months post drilling.

**Australia-North Rankin A (Oliver and Fischer, 1999)**

Seabed surveys were conducted at the North Rankin A platform in Northwestern Australia to determine the impacts from discharging Group II NADF cuttings from production drilling. During the period from 1983-1991, 23 wells were drilled, the first 12 using WBF, and the other 11 using variable amount of WBF and Group II NADFs. An estimated 1297 tonnes of Group II NADF adhering to cuttings were discharged into 125 metres of water. In 10/91 shortly after the cessation of drilling, samples were collected along two transects, one up to 10 km in the direction of the current (NW-at the platform site, 100, 200, 400, 800, 1200, 1600, 2000, 3000, 5000, and 10000 metres), the other along a perpendicular transect up to 1.2km (NE at 200,400, 800, and 1200 metres). A single sample was also taken at 800 metres in the direction of the prevailing current in 1992, 1993, and 1997, and from the cuttings pile directly under the cuttings chute in 12/94.

**Meteorological/oceanographic conditions in the region (Northwest Shelf) are as follows:**

- The predominant current direction oscillates between NW and SE under the influence of semi-diurnal tides
- Peak spring and neap tidal currents measured are 0.65m/s and 0.3m/s respectively
- The Northwest Shelf is influenced by tropical storms between November and April and receives an average of 10.7 days of cyclone activity per annum.
- Wind speeds can reach > 60m/s
- Significant wave heights> 10m
- Sediment distribution is influence by cyclones, also action of long-period internal waves breaking in mid-shelf depths
- Near bottom seawater temperatures range from 24°C in summer to 22°C in winter.

**The findings were as follows:**

- Upon completion of drilling, TPH concentrations underneath the cuttings discharge chute were 75000mg/kg (dry weight of sediment); hydrocarbon concentrations decreased rapidly with increasing distance from the platform in the direction of the current (40mg/kg at 800 metres; 2mg/kg at 2000 metres); trace levels were detected
as far as 3km in the direction of the current. Hydrocarbons displayed an increasingly weathered signature with increasing distance from the cuttings chute; metal concentrations also decreased rapidly with increasing distance from the platform. (Authors conclude that as the distance from the cuttings pile increase, the depth of cuttings layer decreases exposing a greater proportion of hydrocarbons to the more favourable weathering condition near the sediment surface);

• Upon completion of drilling, species richness was depressed near the cuttings pile. The only species represented within 100 metres in the direction of the current was a polychaete worm *Neanthus nr. Cricognatha*. No species were in the sample collected from within the cuttings pile itself. Acute effects are evident within the cuttings pile and at the 100 and 200 metre stations in the direction of the predominant current, species richness and abundance were depressed out until 400 metres; along the NE transect species richness and abundance increased rapidly at a distance less than 400 metres from the platform;

• Comparison of samples taken at 800 metres indicated TPH concentrations reduced with an approximate half-life of one year for the first three years ('91: 37mg/kg, '92: 15mg/kg, '93: 9mg/kg); TPHs were not detectable in the 1997 sample. Samples collected in '91, '92, and '93 showed increasing amounts of weathering;

• Three years after drilling was complete, relatively un-weathered hydrocarbons were still detectable at 5cm in the cuttings pile.

(There appears to be no benthic data after the first post-drilling survey)

The following conclusions drawn by the authors, and pertain to immediate post-drilling effects:

• For TPHs, the zone of transition between affected and unaffected areas was between <1km up to several in the direction of the currents (NW), and approximately 200 metres at right angles to this direction (NE);

• For metals, the transition zone in the direction of the current in which values are above background, extends between 1600-3000 metres; background levels are reached at 200-400 metres at right angles to this direction;

• The transition zone for benthic species richness and abundance starts at 400 metres along the NW transect and may extend out to 3000 metres. Along the NE transect, it is difficult to discern a trend.

Other Applicable Studies E&P Forum, 1996

A laboratory and controlled field study was conducted to determine the environmental impacts of drill cuttings with different low toxicity oil based fluid concentrations. The study examined the physical characteristics of the cuttings, their deposition on the seabed, and possible impacts on seabed fauna and fish. Cuttings were collected from a North Sea development well drilled with Group II NADFs. Cuttings were treated by a variety of techniques, resulting in oil contents of 15.8% for unprocessed cuttings, 1.5% for light hydrocarbon solvent extracted samples, and 0.3% for thermally treated cuttings. Ground rock was used to simulate uncontaminated cuttings.

Potential biological effects of deposited cuttings were examined in two settings: natural faunal field experiments and laboratory mesocosms. Impacts on the benthic faunal community were investigated by placing enclosures (1m², 23cm deep) dosed with cuttings on the seabed. The benthic fauna was sampled for species composition and abundance after 1 week, 4 months, and 8 months. The effect of cuttings on larval recruitment was also examined in separate enclosures by examining the species composition and abundance of settled organisms sampled after 3 and 7 months. Laboratory mesocosms were used to examine the impacts of cuttings on three sediment dwelling species, a cockle inhabiting the upper 3 cm of sediment, a bivalve mollusc living at depths of 5-7 cm, and a polychaete worm which burrows to depths up to 35 cm. Cuttings impacts on fish were examined by measuring levels of detoxifying enzyme activity, also the uptake of hydrocarbons into tissues.

The study also included computer modelling to examine depositional patterns of cuttings and estimated hydrocarbon distributions around a platform under a variety of oceanographic conditions at sites ranging in depth from 30 to 150 metres.
The findings of these studies were as follows:

- Cuttings behaviour: At high oil concentrations a large cuttings pile is deposited in the immediate vicinity of the drilling operations; at lower oil concentrations lower cuttings piles will result, but will be spread over a wider area. Untreated cuttings have the most rapid fall velocities;

- Field-benthic impact:
  - within 4 months, the number of individuals in the untreated cuttings enclosure (Case 2) had increased significantly with the presence of the opportunistic species *Capitella capitata*; however, there was a decrease in the number of species present.
  - the enclosure with 1.5% oil cuttings (Case 5) showed an increase in numbers of *Capitella capitata* but not as much so as for the untreated cuttings;
  - the thermally treated cuttings showed no difference from the controls,
  - after 8 months, the number of species in Case 2 had declined by 50%; there was some evidence of recovery for Case 5 as both the species and number of individuals had increased relative to those found after 4 months.

- Field impact-settling:
  - after 3 months, few species had settled in the enclosure exposed to untreated cuttings, however the number of individuals was similar to the other enclosures,
  - after 7 months, both the untreated (Case 2) and Case 5 had fewer species and individuals than the control plots.

- Laboratory Mesocosms:
  - there was significant bioturbation in all cases due to the high density of individuals; bioturbation resulted in the greatest concentration of oil being found at depths between 5 and 25 cm;
  - the species living closest to the surface were less affected by the various cuttings samples than were those living deeper in the sediment; nevertheless, mortality was up to 3× greater for the untreated cuttings case than for the control. The mollusc (living at 5-7cm) showed the greatest mortality. None survived the case 2 conditions. There were also mortalities of the polychaete worm. In all cases there were also mortalities associated with the 0% oil cuttings. Effects were less evident at lower oil concentrations.

- Fish: concentrations of hydrocarbons in tissues were up to 2-3 times those found in the controls but there was no corresponding elevation in enzyme activity.

Conclusions:

- Observed impacts correlate with hydrocarbon concentration and REDOX potential. Effects appear to be minimised where REDOX potential values remain positive, which correlates inversely with oil concentration;
- Statistical analyses indicate that there was no significant impact on benthos from treatment with thermally processed cuttings in the field or laboratory;
- The solvent extracted cuttings had an initial low level impact with recovery evident within the time frame of the experiment;
- The untreated cuttings had a significant impact on the benthos, and the observed depositional behaviour was consistent with field observations;
- At oil concentrations of ~1000mg/kg, biological impact is minimal and recovery is rapid;
- Solvent extraction and thermal processing of oily cuttings and their subsequent discharge at single well sites appear to offer environmental acceptable options for the continued use of Group II NADFs.
E.3 Group III NADF cuttings discharge field studies

**Australia-Lynx 1a (Oliver and Fischer, 1999)**

Sea-bed surveys were conducted on the North West Australian Shelf to study the impacts of discharging 160 tonnes of a paraffin-based fluid (XP-07) cuttings from a single well-Lynx 1a-in 79 metres of water. Two surveys were conducted, one several weeks following cessation of drilling (October 1996) and the other 10 months following drilling (August 1997). Thirteen stations were sampled with an ROV, one at the drill site/cuttings pile, 8 on a 50-metre radius, 3 on a 100-metre radius, and one at 200 metres in the direction of the prevailing current. Two additional locations, at 400 and 1200 metres downstream, were sampled for the 1997 survey. Samples were taken for TPH and metals analyses.

**Meteorological/oceanographic conditions in the region (Northwest Shelf) are as follows:**
- The predominant current direction oscillates between NW and SE under the influence of semi-diurnal tides
- Peak spring and neap tidal currents measured are 0.65m/s and 0.3m/s respectively
- The Northwest Shelf is influenced by tropical storms between November and April and receives an average of 10.7 days of cyclone activity per annum.
  - Wind speeds can reach >60m/s
  - Significant wave heights >10m
- Sediment distribution is influenced by cyclones, also action of long-period internal waves breaking in mid-shelf depths
- Near bottom seawater temperatures range from 24°C in summer to 22°C in winter.

**The findings were as follows:**
- Immediately following drilling, there was a 1.5-2.0 metre high, 10-15 metre diameter cuttings mound; base fluid levels were high (up to 40400mg/kg) in and adjacent to the cuttings pile and decreased rapidly with increasing distance from the well (levels at 100m were approximately 10% those at the well-site). Base fluid concentrations were highest in the upper 5cm of the sediment with levels 2-3 times lower in sediments at 10-15cm. Drill cuttings were dispersed primarily in the direction of the prevailing current;
- Ten months following drilling, the cuttings pile no longer existed, but cuttings were still visible in sediment samples; faunal elements were present in the sediments obtained at the drill-site;
- There were significant reductions in TPH and barium 10 months following drilling; these reductions have been attributed to sediment dispersal mechanisms. Rapid biodegradation of the paraffin-based mud was expected, however, concurrent reduction in barium can only be explained by sediment dispersal mechanisms. Analysis of sediments from a 50-cm core taken under the point of discharge did not reveal significantly high hydrocarbons or barium concentrations.

Studies of impacts from discharges of Group III - EMBF cuttings (XP-07, Versaplus, Ecosol) in the North Sea have been conducted. Most of these studies are limited in scope and have focussed on the chemical persistence of hydrocarbons from the base fluids.

**Bass Strait Australia (Terrens et al., 1998)**

A seabed-monitoring programme was undertaken in the Bass Strait, Australia, to determine the changes in seabed hydrocarbon concentration and biological impacts over time resulting from the discharge of ester-based (‘Petrofree’) cuttings during development drilling of 7 wells. A total of 18 wells were drilled from October 1994-September 1996. For the first year, only WBFs were used; synthetic fluids were used on 7 well sections for the second year of drilling. In total, approximately 20000m³ of WBF, 5000m³ of cuttings and 2000m³ of synthetic fluid (adhered to cuttings) were discharged. A total of 5 seabed surveys were conducted; before [survey #1] (but following 9.5 months of WBF drilling), during [survey #2] (5 months into discharge) and after [surveys #3, #4, #5; immediately following completion of drilling, 4, and 11 months after] the period of cuttings discharge. Samples were collected at distances of...
100 metres, 500 metres, 1 km, and 2 km from the platform site along a transect following the predominant ocean current. An additional sampling site was located at a distance of 100 metres in the direction of the prevailing seabed current. Three reference sites were selected in equivalent (70 metre) water depths. Samples were analysed for sediment chemistry (ester and barium), grain size and macrobenthic parameters (diversity, abundance). In addition, underwater video footage was taken following the end of cuttings discharge.

The Bass Strait is characterised by high wave and current energy.

**The findings were as follows:**

- chemical analyses indicate that ester concentrations were detected over the widest area for samples taken during drilling (survey #2), with esters detectable up to 2 km from the platform;
- the highest measured ester concentrations were from samples taken following completion of drilling (survey #3). Ester concentrations were highest 100 metres from the platform (average 6900 mg/kg) along the main current direction, but were not detectable (<0.2 mg/kg) at any site beyond 100 metres;
- four months following drilling (survey #4) ester concentrations at 100 metres had declined to an average of 230 mg/kg; esters were also detected (average 16 mg/kg) at 100 metres along the direction of the bottom current, indicating possible redistribution of sediment. Eleven months following drilling (survey #5) esters were not detected (<0.1 mg/kg);
- immediately following drilling, visual examination of the same sediment samples indicated the presence of anaerobic conditions (black iron sulphide patches); 11 months after drilling completion when esters were no longer detectable, samples retrieved within 100 metres from the platform retained evidence of anaerobic conditions in the sub-surface layers;
- macrofaunal analyses results indicate some initial impact, largely a reduction in abundance of two classes and possibly a decline in the number of taxa and total number of individuals; the significant effect was confined to the 100-metre sample, consistent with the observed ester concentration distribution; effects disappeared four months after cessation of drilling; *C. Capitella* increased in abundance in the disturbed areas;
- underwater video footage following cessation of discharge showed evidence of cuttings as a thin layer of grey/black material covering the sandy substrate, aligned primarily in the direction of the current. Cuttings appeared densest up to 75 metres from the platform in the SW direction; patches decreased in size beyond 100 metres and were not observed beyond 200 metres from the platform;
- elevated sediment barium concentrations were detected up to 1 km from the platform, but increased concentrations beyond 100 metres were transient; sediment barium concentrations persisted beyond the period of hydrocarbon degradation and period of presence of finer particles in the sediment.

**Conclusions:**

- While impacts on benthic infauna are detectable at a high taxonomic grouping, they are not substantial and are localised in area (100 metres from the platform) and duration (four months); risks of long term alteration of benthic infauna from the use of ester fluids in this environment is minor;
- Ester concentrations increase in sediments during drilling discharge, then rapidly decrease after completion of discharge to undetectable levels after 11 months;
- Ester biodegradation has continued rapidly even under anaerobic conditions; residence time in sediments appears to be less than one year;
- The retention of barium and the existence of anoxic conditions in subsurface sediments suggest that the Group III NADF cuttings discharges have resulted in a patchy residual cohesion of the subsurface sand grains, minimising normal grain mobility and potentially reducing oxygen penetration.

**Dutch Sector of the North Sea (Daan et al., 1995)**

Field surveys were conducted in the Dutch sector of the North Sea to determine the impact from the discharge of ester-based cuttings from one exploration well. Approximately 180 tonnes of ester (as part of 477 tonnes of EBF) and 248.7 tonnes of WBF were discharged in 30 metres of water at 5 metres above the seafloor over a three-week period.
Surveys included a baseline study and sampling 1, 4, and 11 months following drilling. Samples were taken at 75, 125 (post-drill only), 200, 500 (baseline and +4 and +11 month surveys), and 1000 metres from the platform with reference samples at 3000 metres. Ester concentrations were determined for the three post-drill surveys. Macrofauna analyses were made for the baseline and second and third post-drill surveys.

Oceanographic conditions in the region are not provided in this paper. (These are expected to be similar to the regime described above in Section D.1)

The findings were as follows:

• A limited number of samples taken 1 month following drilling indicated spatial variability in ester levels (from 10.8 to 701.1 mg/kg) in samples taken at 125 metres;

• Four months following drilling, ester concentrations in sediments were consistently detected within 200 metres of the discharge point, ranging from 2 to 4700 mg/kg dry sediment; traces were detectable up to 3000 metres. Ester concentrations were consistently higher by a factor ranging from 1.2 to 3 than those measured for the first post-drill survey; this increase is most likely due to sediment redistribution. Samples showed evidence of drill cuttings and anaerobic conditions (eg large part of the samples were black covered and frequently a H₂S smell was observed) out to 200 metres, with no evidence of cuttings beyond this distance and only a little evidence of anaerobic conditions at 500 metres. Impacts on macrofauna could be detected up to 200 metres. The species Echinocardium cordatum was absent up to 500 metres, and the presence of exoskeleton remains indicates some mortality. Most benthic species showed reduced abundance, and there appeared to be an overall reduction in species richness, total faunal abundance, and relative faunal abundance. A few species showed reduced abundance up to 500 or 1000 metres. Elevated numbers of Capitella capitata (opportunistic species characteristic of organically enriched sediments) were found within 200 metres;

• Eleven months following drilling, esters were still detected within 200 metres, but concentrations were lower than at four months. At distances greater than or equal to 500 metres, concentrations were below detection level. All samples at =200 metres looked more or less anaerobic. Inspection of a vertical sediment profile indicated the anaerobic conditions occurred particularly about 3-5 cm below the sediment surface. Macrofauna impacts at the individual and community level were still detected within 200 metres of the discharge. At the species level, more than 50% of the abundant species occurred in reduced abundance at 75 metres compared to the reference station. At the community level, relatively low numbers of species per sample, low overall fauna abundance, and significantly reduced relative fauna abundance were observed at 75 metres. Effects were less pronounced at 125 and 200 metres than at 75 metres. Within 200 metres, the sediment was recolonised by several species, indicating the onset of natural recovery. At distances greater than or equal to 500 metres, persistent effects could no longer be demonstrated;

• Examination of the ratio of ester concentrations relative to the concentration of the C₁₂ ester for the original ester mixture, indicates that by the third survey, lower molecular weight esters were depleted relative to the higher molecular weight esters;

• A mean half-life for ester degradation was estimated to be 133 days.

Conclusions:

• Over the 11 month-study period, hydrocarbon levels decreased significantly but were still detectable within 200 metres;

• Macrofaunal impacts were limited in extent to 200 metres; there were signs of natural recovery in this zone after 11 months;

• There were similar initial effects to those observed with Group I cuttings discharges—a pattern of overall decreasing faunal density near the well site, and the decrease in frequency of occurrence of sensitive species (ie Echinocardium cordatum). These similarities likely result from the organic enrichment and oxygen depletion in the sediment.
Comments:

It should be noted that the orientation of the post-drilling sampling transect was changed from that of the baseline survey. Consequently there is accurate baseline data, and reference sites were taken to provide baseline values.

Central North Sea - Ula well 7/12-9 (Smith and May, 1991)

Field studies were conducted at the Ula well-site 7/12-9 in the Central North Sea to determine the impact of the discharge of ester-based Petrofree fluid cuttings from one well. Approximately 749 tonnes of cuttings containing 96.5 tonnes of esters were discharged in 67 metres of water from February to May of 1990. Surveys were conducted two days after drilling stopped and one year later. Sampling was along two transects, one to the SW (in the direction of the flood tide) and the other to the SE, with sampling at distances of 50, 100, 200, 500, 800, 1200, 2500, and 5000 metres to the SW and 100, 200, 500, and 1200 metres to the SE. Samples were also taken at 100, 200, and 500 metres perpendicular to the direction of the tidal flow (the residual current direction). The reference station was located 6000 metres to the NW. Samples were taken for esters, THC, metals, grain size and biological analyses.

The findings were as follows:

- Immediately following drilling there was a distinct impact zone within 100 metres of the well. In this zone, concentration of esters, THC and heavy metals were all elevated. Highest ester concentrations (85300 mg/kg) were measured at 50 metres;
- Immediately following drilling, benthic infauna were impacted to a distance of 100 metres from the well site as indicated by low species diversity, low species abundance and high numbers of the opportunistic polychaete worm Capiella capitata;
- Immediately following drilling, there were mainly drill cuttings with little natural sediment close to the well;
- One year after drilling, ester, THC, and barium concentrations in general were dramatically reduced over those immediately following drilling; ester concentrations at 50 metres were 360 mg/kg benthic communities showed signs of significant recovery (increases in number of taxa and individuals); black spots and oily smell were found in sediments out to 200 metres;
- One year following drilling, the cuttings and mud solids distribution on the seabed was patchy; samples taken at 500 metres showed mixed faunal communities. Of five samples taken at 500 metres, two contained cuttings and smelled of the ester;
- One year following drilling the cuttings pile was largely dispersed.

Comments:

It should be noted that samples for this study were positioned using radar rather than the more accurate positioning of Differential Geographic Positioning System (DGPS). Consequently, samples taken in different surveys would be less likely to be taken in the same position than had DGPS been used. Consequently, some reviewers have attributed this study’s findings in relation to the lack of benthic impact after one year, to positioning errors.

North Sea (BP, 1996 - summarised in EPA, 1999b)

Field studies were conducted at the BP 15/20b-12 well site located in the North Sea to determine the impact of the discharge of ester-based cuttings (Petrofree) from one well. Approximately 304 tonnes of esters (adhered to cuttings) were discharged in 142 metres of water. Surveys were conducted five months and fifteen months after drilling stopped. Sampling was along seven transects, one to the south (downstream) with sampling sites 25-5000 metres, one to the north with sites 25-200 metres, and stations to the east, west, northeast, northwest and southwest with sampling sites 25-100 metres. Samples were taken for esters (in 0-2, 2-5, and 5-10cm), barium, redox, and biota. Sidescan sonar surveys were done to determine cuttings pile depths.

The findings were as follows:

- Five months following drilling, the highest ester concentrations (1055-8389 mg/kg) were found in the 0-2cm sample, within 25 metres of the platform; concentrations in subsurface layers were lower, but elevated levels (up
to 1081mg/kg) were still detectable 10-15cm below the sediment surface. Barium concentrations ranged from 70100mg/kg at the drill site, to 661mg/kg 1200 metres south of the drill-site. Benthic indices (the number of species, evenness, and diversity) were statistically significant in relation to Petrofree concentration and distance from the point of discharge;

• Fifteen months after drilling, ester concentrations in most surface sediments had decreased and ranged from 133.1-1785mg/kg in the 25-metre range. Esters were detectable (at 0.1mg/kg) out to a distance of 500 metres. Barium concentrations were lower than those from the first survey (22,000mg/kg at the drill-site and 572mg/kg at 1200 metres to the south). Redox readings indicated anaerobic conditions within 200 metres of the platform. Biota measurements indicated clear impacts at 50 metres, with transition communities developing 100 and 300 metres. (The authors indicated that benthic communities at 1200 metres showed impacts associated with industrial activity and trace amounts of Petrofree measured at this location).

**Gulf of Mexico (Candler et al, 1995)**

A seabed study was conducted in 39 metres of water in the Gulf of Mexico to determine the impacts from discharging 354bbls (approximately 45 tonnes) of polyalphaolefin (PAO) from one exploratory well over a nine-day period. Sampling was conducted 9 days, 8 months, and 24 months following drilling. Baseline levels were established for each sampling cruise by averaging results from the reference stations. Samples were taken on north to south and east to west transects at 25, 50, 100, and 200 metres from the discharge point with reference samples at 2000 metres. Analyses for oil and grease (including GC/MS), TPH, Barium, and grain size were conducted on the top two centimetres of samples from all three surveys. Biological analyses were conducted on only the samples taken 24 months following drilling.

**Oceanographic conditions in the region are as follows:**

• A net SW flow along the shelf characterises predominant conditions from autumn to early spring
• Surface waters undergo seasonal temperature fluctuations of 20-28°C and may have reduced salinity
• Bottom waters have salinity greater than 34
• Measurements taken in June 1992 show temperatures ranging from 27°C at the surface to 21.5°C at 39 metres. Salinity ranged from 35.2 on surface to 36 at 39 metres.

**The findings were as follows:**

• Mass balance calculations of barium levels indicate that nine days following discharge, more than 50% of the cuttings were deposited within 200 metres of the discharge point;
• GC/MS scans on samples from each of the three surveys did not change significantly from the baseline scan for the PAO-base oil;
• Immediately following drilling, hydrocarbons were distributed primarily in the north-south direction, with the highest levels 100 metres north (39470mg/kg) and 50 metres south (134428mg/kg) of the discharge point. Concentrations above 1000mg/kg were found out to 200 metres in some directions;
• Eight months following discharge, hydrocarbon concentrations, as measured by TPH, showed significant (60-98%) decreases from the first to second survey at all but the 25-metre stations. TPH values at 25 metres increased with the highest values being 25747mg/kg to the east and 7283mg/kg to the west. Levels of TPH above 1000mg/kg were found only within 50 metres. The drift of sediment appeared to be to the southwest. The most significant change in area of high hydrocarbon concentrations occurred within the first 8 months;
• Two years following discharge, hydrocarbon levels decreased at two of the 25-metre sites and increased at the other two. Maximum levels were at 25 metres south (19110mg/kg) and 25 metres west (8330mg/kg). Levels of TPH above 1000mg/kg were found only within 50 metres. TPH levels remained more or less the same as at 8 months with some stations showing slight increases and other decreases. Macrobenthic indices (richness, diversity, evenness) at three sites (25 and 50 metres south, and 25 metres west) were markedly different from those at the other sites. These three sites also showed the highest levels of TPH. Eight sites with biological indices similar to background had TPH levels ranging from 87 to 1080mg/kg.
The author’s conclusions were as follows:

- Macrobenthic indices similar to background can occur in the presence of PAO up to 1000mg/kg, suggesting recovery can occur before degradation is complete;
- Compared to Group I, the concentration of PAO required to impact the macrobenthic indicators adversely is significantly higher; consequently, there would be a smaller transition zone of biologic impacts;
- The macrobenthic impact zone is limited to within 50 metres of the discharge point;
- Compared to WBF a higher percentage of NADF cuttings is deposited on the seafloor within 200 metres of the discharge point;
- Areas of heavy (>10,000mg/kg) and moderate (>1000mg/kg) TPH levels were reduced (by 86% each) over a two-year period; this contrasts with North Sea studies following diesel cuttings discharge which show little TPH reduction over the same or longer period.

Comment:
The authors seem to have overlooked or have failed to mention the increase or lack of change in TPH concentration at 10 out of 16 of the stations within 200m of the discharge. Consequently, although not highlighted by the authors, PAO does seem to persist in the sediments within 200 metres, for at least two years following drilling.

Deep water Gulf of Mexico (Fechelm et al, 1999)

Two surveys were conducted in the deep water Gulf of Mexico to determine the impacts of discharging Petrofree LE (90% LAO, 10% ester) associated with 7 development wells. During the period from October 1995 to March 1997, 7 wells were drilled in 565 metres of water using both water-based fluids (WBFs) and Group III NADFs. During this period, 6263 bbls of Petrofree were discharged (adhered to cuttings). An additional well was drilled in February-March 1998, discharging an additional 1486 bbls. A total of 7659 bbls was discharged between March 1996 and March 1998. Remotely Operated Vehicle (ROV) surveys were conducted in July of 1997 (four months following discharge), and March of 1998 (immediately following drilling of the additional well). Baseline conditions had been documented previously in Minerals Management Service (MMS) regional surveys (Gallaway 1988, Gallaway et al, 1988). Samples were taken at 25, 50, 75, and 90 metres in a transect paralleling the direction of the predominant bottom current. Cross-current samples were also taken at 25 and 50 metres. Samples to determine Petrofree LE were taken at all locations during both surveys. Macrofauna samples were taken only in the downstream direction in the 1997 survey, and at both up and down current sites in 1998. Video transects along each of the four bearings of the sampling grid were conducted to record the species and numbers of ‘megafauna’ encountered for each of the two surveys as well as to look for cutting piles.

The findings were as follows:

- cuttings were dispersed over the bottom in a patchy fashion-in some areas cuttings were as thick as 20-25cm; no piles were observed in either survey; thicker deposits of cuttings may result from the ‘riserless’ drilling phase;
- four months after completion of drilling (in 1997), the seafloor sediment appeared dark, interspersed by white-coloured mats and small patches of an orange-mat like gelatinous material;
- chemical analyses indicated that most of the LE was observed along the transect in the direction of the surface and mid-level currents (north-east), rather than in the direction of the bottom currents;
- highest LE concentrations for both surveys were observed at 75 metres from the discharge point in the north-east direction (165051mg/kg for 1997 and 198320mg/kg for 1998); values are higher in the surficial sediments (0-2cm) than for the subsurface sediment (2-5cm);
- results of the 1998 benthic survey indicate increased densities of some benthic macrofauna (for polychaetes-40× and gastropods-3000×) over MMS background data.
**Gulf of Mexico (CSA, 1998)**

A seabed survey was conducted at three sites in the Gulf of Mexico where Group III NADF cuttings had been discharged from wells drilled with internal olefins (IO) and linear alpha olefins (LAO). Discharge information is provided in the following table:

<table>
<thead>
<tr>
<th>Location/Platform</th>
<th>Water depth (m)</th>
<th>Group III type</th>
<th>Period of Group III Drilling</th>
<th>Months Since Cessation</th>
<th>Number of Group III Wells</th>
<th>Cuttings Discharge (bbl)</th>
<th>Group III NADF adhered to Cuttings (bbls)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grand Isle 95A (GI)</td>
<td>61</td>
<td>IO</td>
<td>1995</td>
<td>25</td>
<td>5</td>
<td>1394</td>
<td>1315</td>
</tr>
<tr>
<td>South Marsh Island 57C (SMI)</td>
<td>39</td>
<td>LAO/IO</td>
<td>1996-1997</td>
<td>11</td>
<td>2</td>
<td>376</td>
<td>94</td>
</tr>
<tr>
<td>South Timbalier 148E-3 (ST)</td>
<td>33</td>
<td>IO</td>
<td>1996</td>
<td>10</td>
<td>1</td>
<td>782</td>
<td>2390</td>
</tr>
</tbody>
</table>

Only one survey was conducted at each site. The duration of time between the survey and the end of drilling discharges for each well is indicated in the above table. Sampling was in a radial grid pattern with stations located at distances of 50 and 150 metres from the platform along transects aligned with the local bathymetry. Two additional stations, 100 metres from the platform, were sampled at two of the sites (GI and SMI). Reference samples were taken at 2000 metres. At each station, samples were collected for hydrocarbon analysis (HC), polycyclic aromatic hydrocarbons (PAHs), grain size, presence of drill cuttings, odour, and visual characteristics. Several samples were also collected for toxicity testing.

The findings were as follows:

- Concentrations of hydrocarbons greater than detection limits were restricted to the vicinity of the platforms. The highest concentrations (1900, 6500, 23000 mg/kg dry sediment, respectively for the ST, SMI and GI installations) were found within 50 metres of the platform. However, concentrations at these levels were found only in one of 8 grabs (four samples at 50-metres distance, two replicates each) at each site. The most distant station at which hydrocarbons were detected (41 mg/kg dry sediment) was at 100 metres from SMI;
- An H$_2$S odour was detected in at least one of the 50-metre samples at each site; H$_2$S odour was also noted in one sample at 100 metres (at SMI) and in two at 150 metres (GI);
- Black streaks in the subsurface sediments, likely indicative of anaerobic conditions, were noted in approximately 70% of the samples taken within 150 metres of GI and SMI and in 33% of those at ST;
- No cuttings piles were detected.

**Conclusion:**

Elevated concentrations of Group III NADF-associated hydrocarbons were scattered around the platform rather than being in a continuous pattern.

**Eastern Canada-Nova Scotia (JWEL, 2000a)**

The Sable Offshore Energy Inc (SOEI) environmental effects monitoring (EEM) programme is monitoring the effects of operations, including the discharge of WBF, WBF cuttings, and SBF (Novaplus - an IO) cuttings from drilling at the Venture, Thebaud and North Triumph wells. Venture and Thebaud are in relatively shallow water (20-22 metres) and North Triumph is in deeper water (80 metres).

As of the end of 1999, five wells had been drilled at the Venture field discharging more than 1800 m$^3$ of adhering IO fluid. Average percentage retention on cuttings (ROC) per well ranged from 9.25 to 9.98 on a dry weight basis. At the Thebaud field, five wells were drilled, one with only WBF, and approximately 1800 m$^3$ of fluid discharged. Average percentage ROC ranged from 5.84 to 9.08%. At North Triumph, only one well was drilled and 194.1 m$^3$ of IO discharged with cuttings; the average ROC was 9.5%.

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Venture and Thebaud baseline surveys were conducted in June-July 1998. At the Venture field, one baseline and three during drilling surveys (November 1998, June 1999, and November 1999) were conducted. At Venture, the baseline surveys coincided with the drilling and discharging of WBF at the Venture 1 and Venture 5 wells. The November 1998 survey was immediately following IO discharges at the Venture 1 well. The June 1999 survey coincided with IO cuttings discharges from the Venture 4 well while the November 1999 survey coincided with IO cuttings discharges from the Venture 5 well. Consequently, none of these surveys can be truly considered as ‘post drilling’.

At the Thebaud field, one baseline (June 1998) and two drilling surveys (June 1999 and November 1999) were conducted. The June 1999 sampling occurred following WBF discharges from Thebaud well 1 and IO discharges from Wells 2 and 3. The November 1999 survey followed completion of all discharges except for that of IO at Well 5.

For the North Triumph field, two baseline surveys (autumn 1998; June 1999) and one post drilling survey (autumn 1999) were conducted. In addition stations adjacent to the Gully, a protected area nearby on the Scotian Shelf, were sampled at each of the sampling periods.

Parameters measured as part of this programme are the following: water quality; suspended particulate matter (SPM) in the benthic boundary layer; sediment quality (chemistry and toxicity); benthic habitat and megafaunal community structure; shellfish body burden and taint; marine mammals; and seabirds. At each field, samples were taken along eight radials at distances from the platform at distances ranging from 250 metres to 20km. Mussel moorings were set at 500 metres, 1km, 2km, 4km, 10km, 13km, and 30km from the Venture platform. Scallops were collected from natural beds at three test areas (north of Venture, south of Thebaud, and west of North Triumph) and a reference area.

**The study findings were as follows (JWEL, 2000a):**

- Drill cuttings piles were considerably smaller than predicted by models. This may be due, in part, to lower volumes being discharged from Venture than originally modelled, however, Thebaud discharges were close to predicted, and the cuttings pile was approximately half the predicted radius.
- At Venture, the maximum observable radius of the cuttings pile (1cm or greater thickness) was approximately 66 metres; the pile edge is abrupt (measured at 20-30cm high) with little evidence of smothering beyond.
- At Thebaud, the maximum observable radius of the cuttings pile ranged from 45-47 metres, approximately half the radius of that estimated from modelling.
- There are no ROV data available from North Triumph.
- Drill cuttings piles were visible within 70 metres of the discharge point at Venture and Thebaud.
- Elevated levels of TPH and barium were found at both 250 and 500 metres from the drilling platforms and were intermittent. Dispersion or burial appeared to occur within a six-month period and is likely attributed to sediment transport. Biodegradation of the SBM may also be a contributing factor.
- At Venture, there were no large-scale differences between near- and far-field that could be attributed to drilling. Within the near field there was some indication of increase in Ba over time. Although TPH concentrations at 250 metres may have increased over time from baseline, levels decreased over time from November 1998 (75.2mg/kg) to June 1999 (37.4 and 29.3mg/kg), to November 1999 (15.2mg/kg).
- At Thebaud, concentrations of barium and TPH were significantly higher during the June 1999 survey than at other times, and were higher overall at 250 metres than at other distances. Barium concentrations up to 760mg/kg were detected at 250 metres in June 1999, however they returned to background range (100 to 300mg/kg) by November 1999. During June 1999, TPH concentration of 1546mg/kg was detected at 250 metres; levels were also elevated at 500 metres (324mg/kg) and at 1000 metres (35.5mg/kg). Concentrations returned to background levels by the November 1999 survey.
- At North Triumph, there were higher concentrations of barium and TPH during the November 1999 survey. Barium concentrations were elevated (1900mg/kg and 1,200mg/kg) on two of the 8 sampling points at 250 metres. A sampling point at 500 metres on only one of the axes was slightly elevated (580mg/kg) over background (250mg/kg). TPH concentrations were observed to be as high as 2440mg/kg and were elevated at that distance on two other sampling axes. TPH concentration of 613mg/kg and 52.7mg/kg were observed at the 500 and 1000 metres along one axis.
Water samples collected on transect out from the drilling platform and along the axis of the prevailing current did not contain detectable levels of hydrocarbons during drilling phase surveys.

Benthic boundary layer sampling showed no significant differences (from baseline) in suspended particulate matter (SPM) or barium concentrations around the three drilling platforms that can be attributed to drilling activities. Bentonite was not present as a component of the SPM.

No effect on the benthic communities outside the areas of cuttings accumulation could be detected but high natural variability at the site made detection of effects very difficult.

Amphipod toxicity results were variable between the different sites. No effect on amphipod survival was found at either the Venture or Gully sites in any of the four rounds of the EEM. Two of four samples taken at 250 metres from Thebaud showed an effect on amphipod survival. These samples also showed elevated TPH and barium concentrations compared to baseline values. A similar effect was not exhibited in samples tested from the same location several months later and TPH and barium levels were no longer elevated. Sediments taken from the North Triumph site showed toxicity in the baseline survey (for the 20km sample) and in 3 of 4 of the samples taken at 250 metres immediately following discharges of SBM cuttings; two of these samples also had elevated barium and TPH levels.

Samples taken at all sites for Microtox™ analysis, during all rounds of the programme did not show a toxic response.

Mussels moored at the Venture site revealed no obvious taint or odour that was different from the controls at any other mooring site. Aliphatic hydrocarbons were detected in tissues; only samples at collect at 500 metres appeared to have hydrocarbons concentrated in the range of the synthetic base oil. Aliphatic hydrocarbons may result naturally from filtering of phytoplankton. To put the levels detected at 500m into perspective, 3.04mg/l were detected in the mussels 500m from the Venture platform. Whereas, concentrations in mussels 50 metres from Cohasset-Panuke were 44.5mg/l (Zhou et al, 1996).

No taint was reported in sensory evaluations of scallops collected from natural beds in the project area. Low levels of aliphatic hydrocarbons were detected in scallops collected in both baseline and drilling phase surveys. Tissues of scallops collected near Thebaud did show evidence of hydrocarbons from petroleum sources however, the source of hydrocarbons is unknown. The gas chromatographic signature of these hydrocarbons has not been matched to the drilling fluid, diesel fuel, and gas condensate from Thebaud. Nor was there a match with the gas condensate from Cohasset-Panuke. The source of hydrocarbons may be from natural seepage (JWEL, 2000a).

The SOEI EEM results up to December 1999, confirm that the combination of low discharge volumes, high-energy sea floor conditions, and environmentally benign fluid characteristics resulted in low impacts and rapid recovery of the sea floor.

Fluid characteristics resulted in low impacts and rapid recovery of the sea floor.

**Eastern Canada-Newfoundland (JWEL, 2000b)**

The Hibernia EEM programme is studying the effects of operations at the Hibernia platform. Over the life of the project, an estimated 83 development wells will be drilled from a single fixed platform located in 80 metres of water. WBF has been used to drill the upper portions of all wells and an isoparaffin-based mud (IPAR-3 also known as Puredrill or IA-35) will be used for the lower sections of the wells. Until April 2001, associated WBF and WBF and IPAR-3 cuttings have been discharged overboard. Two wells were drilled in 1997, 7 in 1998, and 3 in 1999 as of the August 1999 survey.

Baseline surveys were conducted in August-September 1994 (sediment) and December 1994 (biology). Follow-up surveys have been conducted in August-September 1998 (sediment) and December 1998 (biology), late June-early July 1999 (biology) and August 1999. Surveys were also conducted in 2000, however results are not yet available.

Sediment sampling is based on a sample net design consisting of a series of eight radii and concentric rings on a geometric progression outward from the point source. For the baseline and 1998 surveys, samples were taken along four radii at 250, 750, 1500, 2500 and 4000 metres. Along the other 4 radii samples were taken at 500, 2000, 3000, 6000, and 8000 metres. Starting with the 1999 survey, coverage within 1000 metres was expanded so that
samples were taken at 500, 750, and 1000 metres along all radii. Two reference sampling points were established at 16 km to the North and 16 km to the West for a total of 58 sampling points (baseline and 1998 surveys). At each of the 44 primary monitoring sites samples were taken in triplicate. Reference samples were collected in duplicate. Samples collected represented the upper 5 cm.

The following parameters were analysed: sediment total extractable hydrocarbons (TEH: C_{11}-C_{32}; C_{11}-C_{20}; C_{21}-C_{32}); PAH; grain size, trace metals, organic/inorganic carbon, sediment toxicity (bacterial bio-luminescence (Microtox^®)), amphipod survival, juvenile polychaete growth and survival; biological sampling of American Plaice (body burden, trace metals, hydrocarbons, PAH, total extractable hydrocarbons, moisture, taint).

The EEM results collected to date indicate the following:

- The average 1998 the values ranged from 0.965mg/kg at 16km to 223mg/kg at one of the 250-metre stations; the 1999 average values ranged from 3.3mg/kg at 16km to 279.3mg/kg at 250 metres; the baseline values were all below the level of quantification;
- The average 1994 baseline barium concentration (weak acid leach) ranged from 73mg/kg at 16000 metres, to 373mg/kg at 3000 metres. The average 1998 concentration ranged from 55mg/kg at station at 8000 metres to 643mg/kg at 250 metres. The 1999 concentrations ranged from 68mg/kg at stations at 6000 metres to 568mg/kg at the 250-metre station. The increases in Ba concentrations from 1998 to 1999 were confined to near field and mid-field, with far-field concentrations at baseline concentrations;
- There is no indication of taint in American Plaice collected near the Hibernia platform;
- There were differences in body burden data between 1998 and 1999, however, these data need to be considered with caution due to possible seasonal effects due to the change in sampling period;
- There were statistically significant increases in concentrations of hydrocarbons and barium in the 1999 samples compared to those of 1998 and baseline studies. Measured concentrations are similar to those and often less than those found at similar distances from the drilling discharge location of other offshore producing fields. In addition, the levels measured are not known to cause ecological or biological effects;
- Individual PAH concentrations in sediments and fish tissues are less than the level of quantification (<0.05mg/kg);
- None of the samples collected indicated a toxic response in the Amphipod or polychaete bioassay;
- Although some of the 1999 samples indicated a toxic response in Microtox^® testing, this response does not appear to be correlated to drilling discharges (there was no correlation with barium and hydrocarbon concentrations). In addition, grain-size analysis indicated that the samples for which a response was found were dissimilar to other samples for which no response was found;
- Drilling wastes appear to have been transported further from the well site than originally predicted from the fate and effects model. However, this modelling did not account for the severe storms that move through the area and which are believed to contribute to sediment transport.

Although the results of the Hibernia EEM are not atypical of what might be expected where large volumes of Type III fluids have been discharged, there are some differences from the results observed at Hibernia versus those at SOEI. These differences likely result from a number of factors. Firstly, hydrodynamic conditions at Sable Island are more energetic than they are at Hibernia, which means that accumulations of discharged materials are less likely to persist at SOEI than at Hibernia. Also, drilling volumes and conditions were different between the two areas. At Hibernia, there has been continuous discharge of drill cuttings from a single location, whereas at SOEI, lower total volumes of cuttings were discharged, and cuttings were discharged from different locations.
### Table E.2
Field survey parameters/chemical and biological impacts for Group II NADF cuttings discharge field studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Depth of Sampling-Chemistry Samples</th>
<th>Depth of Sampling-Biology Samples</th>
<th>Timing of first Post-drill survey</th>
<th>Timing of final survey relative to drilling cessation</th>
<th>Distance of first/second sampling points from well-site</th>
<th>NADF: Distance and level detected first post drilling survey</th>
<th>NADF: Distance and level detected Final Survey</th>
<th>Benthos: Distance and level detected first post drilling survey</th>
<th>Benthos: Distance and level detected final survey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Davies et al., 1988-S. North Sea</td>
<td>?</td>
<td>?</td>
<td>Immediate</td>
<td>None</td>
<td>200/500</td>
<td>Levels elevated out to 5000 m; highest levels at 200m [avg. 11347µg/g]</td>
<td>NA</td>
<td>?</td>
<td>NA</td>
</tr>
<tr>
<td>Davies et al., 1988-Central North Sea</td>
<td>?</td>
<td>?</td>
<td>Immediate</td>
<td>None</td>
<td>50/100</td>
<td>Hydrocarbon levels of 100x background restricted to within 100-250m; at 50m concentrations were 2000-5000mg/kg</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Davies et al., 1988-Central North Sea</td>
<td>?</td>
<td>?</td>
<td>-</td>
<td>+ 6 years</td>
<td>50/100</td>
<td>NA</td>
<td>+5-6 years (HC elevated out to 750m for Group II; out to 2000m for Group I - diesel</td>
<td>NA</td>
<td>Group II site, benthic diversity reduced between 50-250m; Group I - diesel site, reduction in diversity between 50-500m</td>
</tr>
<tr>
<td>Oliver and Fischer, 1999; Northwest Australia/ Wanaea</td>
<td>?-grab sample (50cm core in cuttings pile)</td>
<td>?</td>
<td>11 months</td>
<td>+ 3 years</td>
<td>200/400m</td>
<td>Under discharge chute; 100/200m</td>
<td>Highest cons within 50m; 3 years post, concs still elevated in cuttings pile (2.1-274mg/kg)</td>
<td>NA</td>
<td>Three years after drilling, evidence of benthic impacts at discharge site and at 80m</td>
</tr>
<tr>
<td>Oliver and Fischer, 1999; Northwest Australia/ North Rankin A</td>
<td>0-10cm; 0-1cm, 4-5cm, 5-6cm, 6-10cm</td>
<td>0-10cm?</td>
<td>Immediate</td>
<td>+ 6 years</td>
<td>Under discharge chute; 200/400m</td>
<td>TPH concentrations of 75,000mg/kg in cuttings pile; decrease with distance-trace detectable at 3km</td>
<td>TPH concentrations at 800m reduced with an approximate half-life of one year for the first three years; six years following drilling. TPHs were not detectable in sediments at 800m</td>
<td>Species richness depressed near cuttings pile; richness and abundance depressed out to 400m</td>
<td></td>
</tr>
<tr>
<td>Study</td>
<td>Depth of Sampling-Chemistry Samples</td>
<td>Depth of Sampling-Biology Samples</td>
<td>Timing of first Post-drill survey</td>
<td>Timing of final survey relative to drilling cessation</td>
<td>Distance of first/second sampling points from well-site</td>
<td>NADF: Distance and level detected first post drilling survey</td>
<td>NADF: Distance and level detected Final Survey</td>
<td>Benthos: Distance and level detected first post drilling survey</td>
<td>Benthos: Distance and level detected Final Survey</td>
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</tr>
<tr>
<td>Terrens et al, 1998/Bass Strait Australia</td>
<td>2cm</td>
<td>10cm</td>
<td>Immediate</td>
<td>+11 months</td>
<td>100/500m</td>
<td>100m (6900mg/kg); not detected beyond</td>
<td>No ester detected after 11 months</td>
<td>100m; impact at the class level</td>
<td>No impact (after 4 months)</td>
</tr>
<tr>
<td>Daan et al, 1993/North Sea</td>
<td>10 cm</td>
<td>10 cm?</td>
<td>+1 month (limited) +4 more comprehensive</td>
<td>+11 months</td>
<td>75/125m</td>
<td>Conc. within 200m- traces at 3000m (at +4 months)</td>
<td>Esters still elevated within 200m</td>
<td>+1 no analyses +4-impacts within 200m</td>
<td>Impacts at community and individual level within 200m; signs of recovery within 200m (11 months)</td>
</tr>
<tr>
<td>Smith and May, 1991/North Sea</td>
<td>1cm</td>
<td>10cm</td>
<td>2 days</td>
<td>+1 year (?)</td>
<td>50/100m</td>
<td>100m (ester conc. 85300mg/kg)</td>
<td>Elevated within 50m (ester conc. 360mg/kg)</td>
<td>100m; low species diversity and abundance, high numbers opportunistic species</td>
<td>Significant signs of recovery</td>
</tr>
<tr>
<td>Neff et al, 2000/North Sea/UK Sector</td>
<td>NK</td>
<td>NK</td>
<td>Shortly after completion of drilling</td>
<td>None</td>
<td>NK</td>
<td>Maximum conc. (1600mg/kg) at 70m</td>
<td>NA</td>
<td>Distance information not available; decrease in number of individuals at conc. In excess of 500mg/kg</td>
<td>NA</td>
</tr>
<tr>
<td>Neff et al, 20000/North Sea/UK Sector</td>
<td>NK</td>
<td>NK</td>
<td>Shortly after completion of drilling</td>
<td>None</td>
<td>NK</td>
<td>Maximum conc. (28000mg/kg) at 210m</td>
<td>NA</td>
<td>Distance information not available; Number of individuals highest at concentrations of 15000-28000mg/kg; number of taxa low</td>
<td>NA</td>
</tr>
<tr>
<td>BP Exploration, 1996/North Sea</td>
<td>0-2cm, 2-5cm, 5-10cm</td>
<td>?</td>
<td>5 months</td>
<td>+15 months</td>
<td>25/50m (?)</td>
<td>Highest conc. at 25m (1055-8389mg/kg) (+5 months)</td>
<td>Detectable to 500m (0.1mg/kg)</td>
<td>?</td>
<td>Impacted at 50m; transitional communities at 100-300m</td>
</tr>
<tr>
<td>Candler et al, 1995/Gulf of Mexico</td>
<td>0-2cm</td>
<td>25cm</td>
<td>9 days</td>
<td>+24 months</td>
<td>25/50m</td>
<td>Highest TPH conc. at 50-100m (39000-134,000mg/kg); &gt;1000mg/kg out to 200m</td>
<td>Max. levels at 25m (~8000 and 19000mg/kg); conc. &gt;1000mg/kg out to 200m</td>
<td>No samples</td>
<td>Macrobenthic indices depressed at three sites (two at 25m and one at 50m)</td>
</tr>
<tr>
<td>Study</td>
<td>Depth of Sampling-Chemistry Samples</td>
<td>Depth of Sampling-Biology Samples</td>
<td>Timing of first Post-drill survey</td>
<td>Timing of final survey relative to drilling cessation</td>
<td>Distance of first/second sampling points from well-site</td>
<td>NADF: Distance and level detected first post drilling survey</td>
<td>NADF: Distance and level detected Final Survey</td>
<td>NADF: Distance and level detected First Survey</td>
<td>Benthos: Distance and level detected Final Survey</td>
</tr>
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<td>-----------------------------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>JWEL 2000a/ Eastern Canada/ SOEi</td>
<td>NK</td>
<td></td>
<td>All during</td>
<td>NA</td>
<td>250/500m</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JWEL 2000b/ Eastern Canada/ Hibernia</td>
<td>0-5cm</td>
<td>NA-no benthic samples</td>
<td>All during</td>
<td>NA</td>
<td>250/500m</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fechelm et al 1999/Gulf of Mexico</td>
<td>0-2cm</td>
<td>0-2cm</td>
<td>Immediate</td>
<td>None</td>
<td>25/50m</td>
<td>Highest LE concentration at 75m (165,051mg/kg)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>CSA, 1998/ Gulf of Mexico</td>
<td>0-5cm</td>
<td>Up to 15cm?</td>
<td>10-25 months</td>
<td>None</td>
<td>50/150m</td>
<td>NA</td>
<td>Highest HC measured were within 50m (1900-23000mg/kg); patchy distribution</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Oliver and Fischer, 1999/ Australia/ Lynx</td>
<td>15cm</td>
<td>15cm</td>
<td>Immediate</td>
<td>+10 months</td>
<td>Cuttings pile; TPH concentrations of 40,400mg/kg in and adjacent to the 1.5-2.0m high cuttings mound; concentrated in upper 5cm; levels decreased rapidly with increasing distance from the well (levels at 100m were 10% of those at the well-site)</td>
<td>Signficant reductions in TPH and barium 10 months following drilling; no cuttings piles; TPH levels (where detectable) ranged from 0.02-0.125mg/kg</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
</tbody>
</table>

NK: not known
NA: not available
### Table E.3  Summary of Group II NADF cuttings discharge field studies

<table>
<thead>
<tr>
<th>Source</th>
<th>Fluid type (specific/generic)</th>
<th>Location (field)</th>
<th>Physical environment/bottom type</th>
<th>Number of wells</th>
<th>Drilling period/discharge period</th>
<th>Volume discharged</th>
<th>Water depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Davies et al, 1988</td>
<td>Group II NADF (16/28H also OBF section)</td>
<td>Central North Sea-16/28H and 16/28I</td>
<td></td>
<td>2</td>
<td></td>
<td>?</td>
<td>100</td>
</tr>
<tr>
<td>Davies et al, 1988</td>
<td>Group II NADF/ WBF/ Diesel Group I</td>
<td>Central North Sea-16/27, 14/11, 21/12</td>
<td></td>
<td>3</td>
<td>16/27-85 tonnes Group II; 14/11-Group I; 21/12-181 tonnes diesel Group I</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Oliver and Fischer, 1999</td>
<td>Shellsol DMA/Group II NADF</td>
<td>NW Australia-Wanaea 6</td>
<td>Silty carbonate sands</td>
<td>1</td>
<td>November 1994</td>
<td>44 tonnes</td>
<td>80</td>
</tr>
<tr>
<td>Oliver and Fischer, 1999</td>
<td>LTO</td>
<td>NW Australia-North Rankin A</td>
<td>Silty carbonate sands</td>
<td>11 (preceded by 12 WBF)</td>
<td>1983-1991</td>
<td>1297 tonnes</td>
<td>125</td>
</tr>
<tr>
<td>Sampling programme (total number of surveys)</td>
<td>Parameters</td>
<td>#Sampling stations/replicates/controls</td>
<td>Sample distances</td>
<td>Sampling design</td>
<td>Sampling protocol</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Baseline; immediately post-drill</td>
<td>TPH; benthic indices</td>
<td>6/2/7</td>
<td>200,500,800,1200,2500, 5000m from the platform</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline; immediately post-drill</td>
<td>TPH</td>
<td>10/7/7</td>
<td>50,100,250,500,800,1200,2500, and 5000 to the south of the drill-site; 50 and 100m to the north</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One survey; 6 years post Group II well drilling; 7 yrs post WBF; 5 yrs post Group I</td>
<td>TPH; benthic indices</td>
<td>8/7/1</td>
<td>50m north; 50,100,200,500,800,1200, and 2500m south of the drill-site; reference station 6000m east</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline, +11 months, +3 years</td>
<td>Biota, TPH, metals, grain size, TOC, SiO₂, CaCO₃</td>
<td>8/5:2:2</td>
<td>#1 survey-at well # site, 100,200,400,1200m downcurrent; 100,200,400 perpendicular to current; also references at 4 and 7km #2 survey—additional stations at well # 6 site, at cuttings discharge point, at 100, 200m downcurrent from well-site; and 100, 200m perpendicular to prevailing current</td>
<td>Transects aligned in current direction and perpendicular to current</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>End of drilling; +1, +2, +6 years at 800m; at pile +3 years</td>
<td>Platform, 200, 400,800,1200,1600,2000, 3000,5000,10000 downcurrent; 200, 400, 800, 1200 @90 degrees to current</td>
<td></td>
<td>Transects aligned in current direction and perpendicular to current</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Drill-site, 50 and 100m radii, and 200m downcurrent; 400 and 1200 for 1997 survey DGPS with ROV</td>
<td></td>
<td>Grab sample penetrated ~15 cm into seabed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Source</td>
<td>Fluid type (specific/generic)</td>
<td>Location (field)</td>
<td>Physical environment/bottom type</td>
<td>Number of wells</td>
<td>Drilling period/discharge period</td>
<td>Volume discharged</td>
<td>Water depth (m)</td>
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</tr>
<tr>
<td>Terrens et al. 1998</td>
<td>Petrofree/Ester</td>
<td>Australia-Bass Strait (Fortescue)</td>
<td>High energy seabed-winter storms; medium to coarse sand</td>
<td>7 (Dv/itm)</td>
<td>1 year</td>
<td>5000m³ cuttings; 2000m³ SBF on cuttings</td>
<td>70</td>
</tr>
<tr>
<td>Daan et al. 1995</td>
<td>Ester</td>
<td>Dutch sector of N. Sea (K14/13)</td>
<td>Strong bottom currents; Fine sand with some silt</td>
<td>1</td>
<td>3 weeks? (mid Aug-begin Sept)</td>
<td>361m³ (477.2 tonnes EBF; 180 tonnes of Ester-38%)</td>
<td>30m</td>
</tr>
<tr>
<td>BP Exploration Operating Co. Ltd. 1996</td>
<td>Petrofree/Ester</td>
<td>North Sea 15/20b-12</td>
<td></td>
<td>1</td>
<td></td>
<td>304 tonnes</td>
<td>142</td>
</tr>
<tr>
<td>Candler et al. 1995</td>
<td>NOVADRIL-Polyaliphaolefin (PAO)</td>
<td>Gulf of Mexico-North Padre Island Block 895 (NPI-895)</td>
<td>Silty clay</td>
<td>1</td>
<td>Discharged over a 9 day period</td>
<td>441 bbl cuttings; 354 bbl SBF (45 tonnes olefins)</td>
<td>39</td>
</tr>
<tr>
<td>Parameters</td>
<td>#Sampling stations/replicates/controls</td>
<td>Sample distances</td>
<td>Sampling design</td>
<td>limitations</td>
<td>Sampling protocol</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Biota, TPH, esters, grain size, barium</td>
<td>5/2/3 * Four replicates taken = two tested</td>
<td>0.1, 0.5, 1.0, 2.0 km in alignment with current; one sample at 0.1 km in alignment with bottom current; references in same water depth @ 10, 15, and 20 km</td>
<td>Transect following predominant ocean current; also one site in direction of bottom current</td>
<td>Samples 10cm thick with Smith MacIntyre; upper 2cm for sediment chemistry; chem and bio from same grab?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ester, Biota</td>
<td>Baseline 6/Post+1-4 st (8 reps each + 8 box cores at 125m) Post +4 mo-10 st (8 reps each + 8 box cores at 125m) Post+1mo-10 st * Reference- 3000m</td>
<td>BL+75,200,500,1000,3000 @45deg; 75m @225deg; +1mo+75,125,200 @0deg;75@45deg; +4&amp;1mo-75,125,200,50 0,1000,3000@0deg;75, 125,200@45deg; DGPS positioned</td>
<td>BL-supposed to follow current; post surveys along depth contour</td>
<td>Grab sampled to 15-20 cm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ester, THC, metals, grain size, biota</td>
<td>13 stations including reference</td>
<td>50, 100, 200, 500, 800, 1200, 2500, 5000 to the SW; 100, 200, 500, 1200 to the SE; references at 6000 m to the NW radar positioned samples</td>
<td>Two transects; one to the SW one to the SE</td>
<td>Only 0-1 cm sampled for esters; 0-10 for biology</td>
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</tr>
<tr>
<td>Ester for 0-2 cm, 2-5 cm, 5-10cm, Barium, Redox measurements at 2 and 4 cm; biota; Sidescan for cuttings piles depths</td>
<td>25-5,000m downcurrent (south); 25-200m upcurrent (north); 25-100m east, west, ne, nw, and sw</td>
<td>N/S; E/W transects-25m,50,100,200,2000 ref=2000m - DGPS positioning on samples</td>
<td>N/S; E/W transects</td>
<td>Chemistry-upper 2cm; (instead of deeper) Bio-top 25 cm; no baseline only previous regional studies</td>
<td></td>
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<tr>
<td>(Oil and grease; TPH:-to measure level of organic compounds); GC/MS; Barium; grain size; biota for third survey + 9 days-chemistry + 8 months-chemistry +24 months-chem+bio</td>
<td>20 stations +9 days-1 box core/station +8 months-1 box core/station +24 months-1 box core/station</td>
<td>N/S; E/W transects-25m,50,100,200,2000 ref=2000m - DGPS positioning on samples</td>
<td>N/S; E/W transects</td>
<td>Chemistry-upper 2cm; upper 3cm; bio samples-upper 2cm</td>
<td></td>
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<tr>
<td>Sampling by ROV Petrofree LE analysis: 1997-down, up, and cross current samples in 1997 Macrofauna: 1997 downstream; 1998 upstream at 50, 75, 90 m; Video transects to identify fish and large invertebrates</td>
<td>16 stations 1 sample per station No reference sites</td>
<td>-Samples at 25, 50, 75, 90 m following predominant current direction -at 25, 50m cross current -at four template corners</td>
<td>Transect following predominant bottom current direction</td>
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</tr>
<tr>
<td>Source</td>
<td>Fluid type (specific/generic)</td>
<td>Location (Field)</td>
<td>Physical environment/ bottom type</td>
<td>Number of wells</td>
<td>Drilling period/discharge period</td>
<td>Volume discharged</td>
<td>Water depth (m)</td>
</tr>
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<tr>
<td>CSA</td>
<td>GI-IO SMI-LAO/IO ST-IO</td>
<td>Gulf of Mexico</td>
<td>GI-fine grained; sandy silty clay SMI-coarser silty-sand/sandy silt ST-fine grained; sandy silty clay/sandy clayey silt</td>
<td>GI-5 SMI-2</td>
<td>ST-1</td>
<td>GI-1394 bbl cuttings/ 1315bbls Group III; SMI-376 cuttings-94 Group III; ST-782 cuttings; 2390 Group III</td>
<td>GI-61m; SM-39m ST-33m</td>
</tr>
<tr>
<td>JWEL, 2000a</td>
<td>IO/</td>
<td>Eastern Canada-Sable Island</td>
<td>High Energy, V and T-sand NT-sand with minor silt and clay</td>
<td>V-5 T-5</td>
<td>NT-1</td>
<td>V 1821.4m; T 1832.8m; NT 194.1m²</td>
<td>V 20-22m, NT 80m,</td>
</tr>
<tr>
<td>JWEL 2000b</td>
<td>IPAR-3; isoparaffin</td>
<td>Eastern Canada-Hibernia</td>
<td>Moderate to high energy; sands; winter storm influence</td>
<td>Multiple 1997-2 1998-7 1999-3 by August 1999, three more underway</td>
<td>NK</td>
<td>80m</td>
<td>All to be considered during drilling as new wells have been continued to be drilled and associated cuttings discharge. By 1999 survey cuttings had been discharged from a total of 12 wells</td>
</tr>
<tr>
<td>Oliver and Fischer, 1999</td>
<td>XPO7/linear paraffin</td>
<td>NW Australia-Lynx 1a</td>
<td>Silty carbonate sands</td>
<td>1</td>
<td>July-August 1996</td>
<td>160 tonnes</td>
<td>78</td>
</tr>
</tbody>
</table>

GI-Grand Isle 95A
LAC-Linear Alpha Olefin-T-Thebaud
IO-Internal Olefin
ST-South Timbalier mg/kg 148E-3
NT-North Triumph
SMI-South Marsh Island 57C
<table>
<thead>
<tr>
<th>Parameters</th>
<th>#Sampling stations/replicates/controls</th>
<th>Sample distances</th>
<th>Sampling design</th>
<th>limitations</th>
<th>Sampling protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total organic hydrocarbons (TOC); TPH; PAHs; grain size, presence of drill cuttings, odour, visual char, redox; macrofauna, side-scan sonar, Video; visual observations include location and thickness of redox potential discontinuity layer; water column profiles; sediment toxicity samples at select locations</td>
<td>GI-10/2/4 SM-10/2/4 ST-8/2/4</td>
<td></td>
<td>At each field, samples were taken along eight radials at distances from the platform at distances ranging from 250 m to 20 km. Mussel moorings were set at 500m, 1km, 2km, 4km, 10km, 13km, and 30km from the Venture platform. Scallop were collected from natural beds at three test areas (north of Venture, south of Thebaud, and west of North Triumph) and a reference area.</td>
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<tr>
<td>Water quality; suspended particulate matter (SPM) in the benthic boundary layer (BBL); metals, TPH, total organic carbon, total inorganic carbon, grain size, and toxicity; benthic habitat, and megafaunal community; shellfish body burden and taint; marine mammals; and seabirds.</td>
<td>At each field, samples were taken along eight radials at distances from the platform at distances ranging from 250 m to 20 km. Mussel moorings were set at 500m, 1km, 2km, 4km, 10km, 13km, and 30km from the Venture platform. Scallop were collected from natural beds at three test areas (north of Venture, south of Thebaud, and west of North Triumph) and a reference area.</td>
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<tr>
<td>Sediment total extractable hydrocarbons (TEH: C11-C32; C11-C20; C21-C32); PAH; grain size; trace metals, organic/inorganic carbon, sediment toxicity (bacterial bioluminescence, amphipod survival, juvenile polychaete growth and survival; biologic sampling of American Plaice (body burden, trace metals, hydrocarbons, PAH; total extractable hydrocarbons, moisture, taint).</td>
<td>GI-10/2/4 SM-10/2/4 ST-8/2/4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TPH, metals (video observations, sonar)</td>
<td>13-15/1/2 One grab per location</td>
<td>50m, 150m, 2000m (ref) GI and SM-also 100m</td>
<td>Transects aligned with bathymetry</td>
<td>Side scan Sonar-ROV</td>
<td>Upper 5 cm for organic, grain size and microscopic analyses.</td>
</tr>
</tbody>
</table>
What is OGP?

The International Association of Oil & Gas Producers encompasses the world’s leading private and state-owned oil & gas companies, their national and regional associations, and major upstream contractors and suppliers.

Vision

• To work on behalf of all the world’s upstream companies to promote responsible and profitable operations.

Mission

• To represent the interests of the upstream industry to international regulatory and legislative bodies.
• To achieve continuous improvement in safety, health and environmental performance and in the engineering and operation of upstream ventures.
• To promote awareness of Corporate Social Responsibility issues within the industry and among stakeholders.

Objectives

• To improve understanding of the upstream oil and gas industry, its achievements and challenges and its views on pertinent issues.
• To encourage international regulators and other parties to take account of the industry’s views in developing proposals that are effective and workable.
• To become a more visible, accessible and effective source of information about the global industry, both externally and within member organisations.
• To develop and disseminate best practices in safety, health and environmental performance and the engineering and operation of upstream ventures.
• To improve the collection, analysis and dissemination of safety, health and environmental performance data.
• To provide a forum for sharing experience and debating emerging issues.
• To enhance the industry’s ability to influence by increasing the size and diversity of the membership.
• To liaise with other industry associations to ensure consistent and effective approaches to common issues.