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THE IMPACT OF WATER-BASED DRILLING MUD DISCHARGES ON THE ENVIRONMENT

An Overview

UNITED NATIONS ENVIRONMENT PROGRAMME

The Impact of Water-Based Drilling Mud Discharges on the Environment

An Overview

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FOREWORD

This overview is based on the following papers presented at the Second Meeting of the UNEP Environmental Consultative Committee on the Petroleum Industry held in Paris, June 2-4, 1981*:

1. "Notification Scheme for the Selection of Chemicals for Use Offshore - the U.K. Approach to the Problem of Monitoring and Regulation of Non-Oil Discharges from Offshore Installations"
(UNEP/IEO/CC/PET. 2/8) by A. D. Read and A. Whitehead

2. "Chemical Components, Functions and Uses of Drilling Fluids"
(UNEP/IEO/CC/PET. 2/10(a)) by H. R. Moseley Jr.

3. "The Fate and Effect of Offshore Drilling Discharges"
(UNEP/IEO/CC/PET. 2/10(b)) by Dr. R. C. Ayers Jr.

4. "Disposal of Drilling Wastes from Onshore Operations"
(UNEP/IEO/CC/PET. 2/10(d)) by W. L. Berry

5. "Disposal of Drilling Wastes from Onshore Operations"
(UNEP/IEO/CC/PET. 2/10(d)) by W. L. Berry

However, some results from more recent research programmes on the fate and effect of drilling discharges which have become available subsequent to preparation of the above papers have been incorporated in this summary document. It should also be noted that the last four papers are based mainly on experience and research in the United States.

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*See Record of the Meeting, Second Meeting of the UNEP Environmental Consultative Committee on the Petroleum Industry, Paris, 2-4 June 1981, United Nations Environment Programme, Industry and Environment Office, Paris, 15 March 1982, UNEP/IEO/CC/PET. 2/4 Final.

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The UNEP officers responsible for this activity were Mr. Nay Htun at the inception and Mr. Takao Hamada, Senior Industry Liaison Officer on the conclusion.

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INTRODUCTION

The first well drilled in the United States was in the year 1859 in the state of Pennsylvania. Since then about 2.7 million onshore wells have been drilled in the U.S. Onshore drilling presently continues at an annual rate exceeding 50,000 wells with total depths ranging from hundreds of feet to greater than 20,000 feet (6,100 metres). In 1981 the average depth of wells drilled onshore was about 4,500 feet (1,370 metres).

The first well drilled over water in the United States was in 1927 in the inland coastal waters of Louisiana. At the turn of the century, some wells were drilled off the California coast, a few hundred or so yards from shore in the Pacific Ocean. However, these were drilled employing conventional land rigs from wooden piers connected to shore. Thus, they are not considered true "over-water" wells. Since 1927, it is estimated that more than 12,000 over-water wells have been drilled in the estuarine areas of Louisiana and Texas. (This is an extremely conservative estimate. An accurate well count is unfortunately not available.)

In 1937, industry moved into the Gulf of Mexico as an extension of exploration and development drilling activities in the coastal wetlands of Louisiana. The first offshore well was drilled one mile from shore in eastern Louisiana. In the ensuing 44-year period through 1981, a total of more than 26,000 offshore wells had been drilled (see Table 1). By far, the majority of the offshore drilling activity (current rate over 1,000 wells a year) has been and continues to be concentrated in the Gulf of Mexico, particularly on the Outer Continental Shelf (OCS)*. However, a number of wells have been drilled in the Pacific Ocean (mainly off Southern California) and Alaskan waters. In the past few years exploratory drilling has been initiated on the Atlantic Coast OCS.

Most of the wells drilled in the United States, both onshore and offshore, have been drilled in temperate and sub-tropic areas using a water-based drilling fluid (mud). In the drilling of practically all of the U.S. wells the used water-based drilling mud and formation cuttings generated by the drilling process are discharged to the environment at the well location. This is done in accordance with the regulations of appropriate state and/or federal governmental agencies. However, in isolated instances such agencies may impose alternate, more stringent, restrictions on these discharges to protect areas of extreme environmental sensitivity.

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* The federally administered OCS waters lie seaward of the state controlled waters of the territorial seas. These state waters extend three miles seaward of the shore in all states except Texas and Western Florida where the limit is three leagues.

TABLE 1

TOTAL OFFSHORE WELLS DRILLED IN THE UNITED STATES
FEDERAL AND STATE LEASES
ALL TIME TO JANUARY 1, 1982

		OIL	GAS	DRY	TOTAL
GULF OF MEXICO					
	State	1,896	828	2,186	4,910
	Federal	6,003	3,638	7,432	17,073
	Total	7,899	4,466	9,618	21,983
PACIFIC OCEAN					
	State	2,880	31	437	3,348
	Federal	330	1	152	456
	Total	3,183	32	589	3,804
ALASKA					
	State	259	19	83	361
	Federal	---	---	19	19
	Total	259	19	102	380
ATLANTIC OCEAN					
	State	---	---	---	---
	Federal	---	---	21	21
	Total			21	21
GRAND TOTAL					
	State	5,035	878	2,706	8,619
	Federal	6,306	3,639	7,624	17,569
	Total	11,341	4,517	10,330	26,188

SOURCE: American Petroleum Institute

The purpose of this overview is three-fold: (1) describe the composition and uses of water-based drilling fluids, (2) review the fate and effect of the discharge of these waste materials to the environment as documented by laboratory tests and field studies, and (3) discuss standard disposal techniques for both the waste mud and cuttings - for offshore wells a discussion of possible alternate disposal techniques is included.

CHEMICAL COMPOSITION AND USES OF DRILLING FLUIDS

FUNCTIONS OF DRILLING FLUIDS

Drilling muds perform the following very important functions:

1. Remove drilled solids (cuttings) from the bottom of the hole and carry them to the surface where they are removed.

2. Lubricate and cool the drill bit and string.

3. Deposit an impermeable wall cake on the well bore wall to seal the formations being drilled so contaminants do not enter the mud and the fluid phase of the mud does not enter the formation.

4. Control downhole pressures.

5. Suspend drill cuttings in the fluid when circulation is interrupted.

6. Support part of the weight of the drill bit and string.

7. Transmit hydraulic horsepower to the bit.

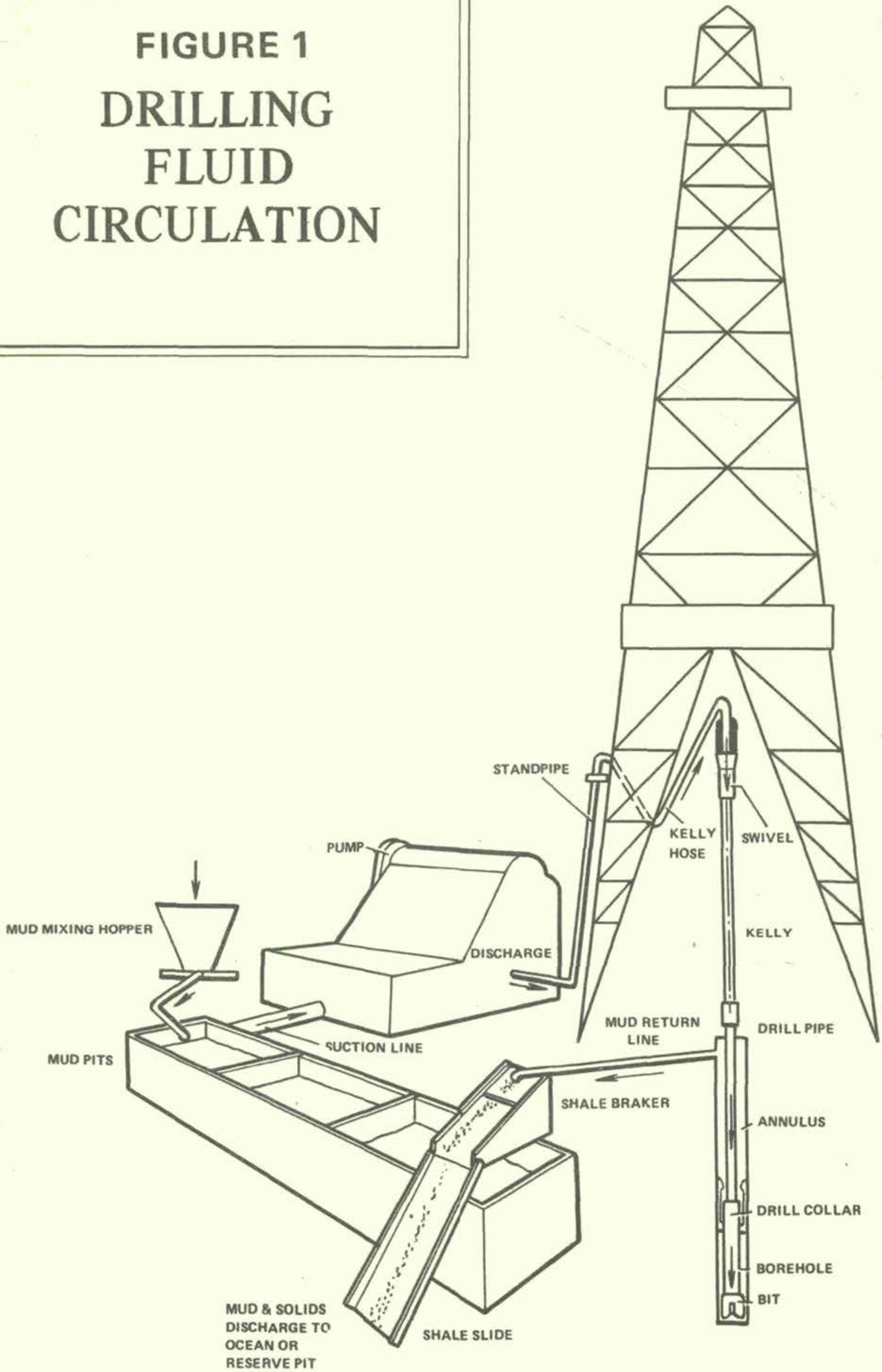
Figure 1 depicts the drilling mud flow path. Mud materials are initially mixed through the mud mixing hopper into the mud tanks (pits). From these tanks the mud is moved through the mud pumps and down the drill pipe via the swivel and kelly. The mud exits the drill pipe through the annulus (space between the well bore wall and the drill pipe). As the mud travels up the annulus, it carries the drill cuttings to the mud return line. The mud is then passed through solids control equipment (shale shakers, hydrocyclones, centrifuges, etc.) to remove the cuttings and is recirculated down the hole.

NATURE OF DRILLING DISCHARGES

The solids concentration in the solids control equipment discharge ranges from 60-90 per cent by weight. For a typical well, the volume of these wet solids is approximately 3,000-6,000 barrels. Solids control equipment discharges will occur during actual drilling, roughly 50 per cent of the time. The rate of discharge ranges from 1-10 barrels/hour depending on drilling rate.

Even though mud is expensive, there are also times when it is necessary to discharge mud directly. The concentration of colloidal solids (particles too small to be removed by the solids control equipment) can build up and cause the mud to become too viscous. To correct the problem, part of the mud may be discharged and the remainder diluted with water to reduce the overall solids concentration. Also, in the event that a completely different mud system is needed, the old mud is discharged. Finally, in exploratory drilling,

FIGURE 1
DRILLING FLUID CIRCULATION



the remaining mud is discharged after drilling has been concluded. The solids discharged with the mud contain the small cuttings not removed by the solids control equipment plus most of the mud additives (a small portion of the barite is discharged with the solids control equipment). The concentration of solids in the mud discharges ranges from 20-70 per cent. The total volume of mud discharged ranges from 1-30,000 barrels over the life of a well. Mud discharges are only made intermittently and last for a short time at rates ranging from 10-20 barrels/minute.

When drilling a very shallow onshore well, the total volume of mud discharged may be 1,000 barrels or less. However, very deep onshore wells drilled over long periods of time (i.e. one to two years) may generate up to 30,000 barrels of mud. However, total volumes of fluid requiring disposal from such extended operations may be of the order of 100,000 barrels. The reason for this is that an onshore reserve pit collects precipitation through the life of the well which dilutes the waste mud and results in significantly larger volumes of total waste material requiring disposal.

For offshore wells the volume of mud discharged ranges from 1,000 to 5,000 barrels for a typical well (in the Gulf of Mexico). However, discharge volumes up to 30,000 barrels of mud have been experienced in a few situations.

COMPONENTS OF DRILLING FLUIDS

There are several broad categories of drilling muds: water-based fluids (fresh or salt), low solids polymer fluids, oil-based fluids, and oil emulsion fluids. The vast majority of all mud systems used (85 to 90 per cent) are water-based fluids which are the subject of this report.

Drilling muds are usually dense colloidal slurries where the water phase may range from fresh to saturated salt mixtures. Salt waters used may be sea-water, or solutions of sodium chloride, potassium chloride, magnesium chloride, calcium chloride/bromide or zinc chloride/bromide. Generally, all fresh water muds start with water and bentonite and caustic soda, while salt water muds may use attapulgite clay instead of bentonite. These clays are very hydrophilic and form a viscous gel (the basis of drilling mud). As drilling continues, drilled clays (solids) may thicken the mud requiring thinners and dispersants to be added to control rheological properties. The four major thinners used for this purpose are listed in Table 2.

Once a mud has been "built", there is a variety of minerals and chemicals which are added for specific purposes. These requirements and the materials employed are:

TABLE 2

DRILLING MUD THINNERS

Lignosulphonate (some contain chrome, ferro-chrome, iron, calcium, sodium, titanium)

Lignite (sometimes treated with chrome, sodium or potassium hydroxide)

Phosphates (sodium acid pyrophosphate and tetrasodium pyrophosphate)

Plant tannins (quebracho is the most predominant)

Generally, 2.0 to 6.0 lb/bbl of thinner is used. The amount may be increased according to conditions encountered during drilling.

Density

High specific gravity inert materials are sometimes required to control downhole pressures. The major additives are listed in Table 3.

Fluid Loss Control

A properly designed drilling fluid should deposit a filter cake on the well bore wall to retard the passage of the liquid phase into the formation. Bentonite and drilled clays are the prime filter cake builders. In some instances the drilled formations are extremely porous and a fluid loss control additive must also be employed. Major additives are listed in Table 4.

Lubricity

Normally, the drilling mud alone is sufficient to adequately lubricate the drill bit. However, under certain cases of extreme bit loading, a lubricant must be added to improve bit life and performance. Lubricants employed are composed of one or more of the major chemicals in Table 5.

Lost Circulation

Lost circulation is one of the most severe drilling problems. Specifically it is the loss of whole drilling fluid to an extremely porous or cavernous "thief" formation. Lost circulation additives physically plug the holes and/or gaps that allow the mud to enter the formation. These additives are either fibrous, filamentous, or granular/flakes, and are mainly naturally occurring materials. The major products used are listed in Table 6.

Corrosion and Scale Control

Drill pipe corrosion and scaling are serious problems. Through additives to the mud system composed of one or more of the major chemicals found in Table 7, corrosion and scaling can be minimized or eliminated.

Solvents

Some of the chemicals discussed above are liquid blends requiring solvents for fluidity and freezing point depression. The solvents used in certain speciality products are found in Table 8.

Low Solids/Polymer Drilling Muds

There are many areas where drilling with clear water fluids is desirable, such as areas of normal formation pressures with no sloughing or heaving shales. These fluids provide excellent penetration rates. They typically have less than 5 per cent solids and contain mainly water, bentonite, clay and various polymers.

TABLE 3

WEIGHTING AGENTS

Barite (naturally occurring barium sulphate ore)

Ferrophosphate ore

Calcite

Siderite

The amount of weighting agent required is dependent upon the desired mud density, and the specific gravity of the weighting agent used. This amount can range, in the case of barite, from 0 to 700.0 lb/bbl.

TABLE 4

FLUID LOSS ADDITIVES

Bentonite - sodium montmorillonite clay

Starch (corn and potato)

Sodium carboxymethylcellulose, or hydroxyethylcellulose

Sodium polyacrylates

Lignite

Use of fluid loss additives can range from less than 1.0 lb/bbl to 10.0 lb/bbl.

TABLE 5

LUBRICANTS

Asphalts	Lanolin
Calcium oleate	Low order paraffinic solvents
Coconut diethanolamides	Mineral oil
Diesel oil	Sodium alkylsulphates
Ethoxylated alcohol	Sodium asphalt sulphonate
Fatty acid soaps	Sulphonated alcohol ether
Gilsonite	Sulphonated tall oil
Glycerol mono & dioleate	Sulphonated vegetable oil
Glass beads	Triethanolamine
Graphite	Vegetable oils
Wool greases	

The concentration of lubricants added will obviously vary with the problem. However, normal use rates are approximately 0.2 - 6.0 lb./bbl.

TABLE 6

LOST CIRCULATION ADDITIVES

Ground nut shells

Mica

Diatomaceous earth

Bagasse (cane fibre) and other
vegetable fibres

Cotton seed hulls

Ground or shredded paper

Normal concentrations range from 2.0 - 30.0 lb./bbl.

TABLE 7

CORROSION AND SCALE INHIBITORS

Sodium sulphite	Organically chelated zinc
Ammonium bisulphite	Calcium sulphite
Sodium chromate and dichromate	Sodium and calcium hydroxides
Zinc chromate	Zinc carbonate and zinc oxide
Tall oil	Iron oxide
High molecular weight morpholines	

Normal use concentrations range from 0.25 - 6.0 lb./bbl.

TABLE 8

SOLVENTS

Water	2-ethylhexanol
Isopropanol	Amyl alcohol
N-butanol	Ethylene glycol
Glycerol	Other alcohols (approx. C_3-C_{20})
Naphtha	Ester alcohols
Isobutanol	Diesel oil

There are two types of polymers based on their action as either adsorbants or viscosifiers. Absorbants work on the clay solids while viscosifiers work on the liquid phase, both of which result in increased viscosities. These chemicals are listed in Table 9.

Bactericides

Bactericides are occasionally required in muds subject to bacterial degradation. Under the current regulatory requirements, all bactericides used in drilling fluids in the U.S.A are regulated by EPA under the Federal Insecticide, Fungicide, Rodenticide Act (FIFRA) and specific regulations of the Minerals Management Service. Under FIFRA, registration, labelling, chemical identification, and applic- ation rates are regulated. Currently, only a few products have been approved for in drilling mud use (i.e. paraformaldehyde), and others are consequently not employed.

Typical Drilling Fluid

Table 10 shows the composition of a typical drilling mud utilized for drilling on the OCS. In general, these mud systems are straightforward and do not require major chemical treatment. The average mud volume near total depth ranges between 2,500-3,000 barrels. It must be pointed out that a typical well will use much more than 3,000 barrels. This is due to the continual influx of drilled solids that excessively viscosify the mud requiring certain volumes of mud to be discarded and diluted with water. To put the vast amount of drilling mud additives into perspective, Figure 2 shows the consumption rates of these additives by per cent of use.

It is important to address the presence of heavy metals in some drilling fluids. Chromium enters muds in the form of chromelignosulphonates, chromelignites, and/or sodium chromate salts for corrosion control or lignosulphonate extenders. Chromium exists in the mud system in the trivalent state (Cr^{+3}) regardless of the valence state of the original additive. The source of barium in drilling muds is barite and natural drilled formation solids. Certain sources of low grade barite may contain trace concentrations of many metals. These ore deposits also contain other contaminants (carbonates and sulphides) that adversely affect mud properties. Their use is avoided in both technically difficult wells and in areas of special environmental sensitivity.

TABLE 9

POLYMER ADDITIVES

Polyvinyl acetate - maleic anhydride co-polymer

Co-polymer of acrylamide and acrylic acid

Polyanionic cellulose polymer

Sodium polyacrylates

Hydroxypropyl guar

Sodium polyacrylate and polyacrylamide

Starches (corn, potato)

Carboxymethylcellulose

Hydroxyethylcellulose

TABLE 10

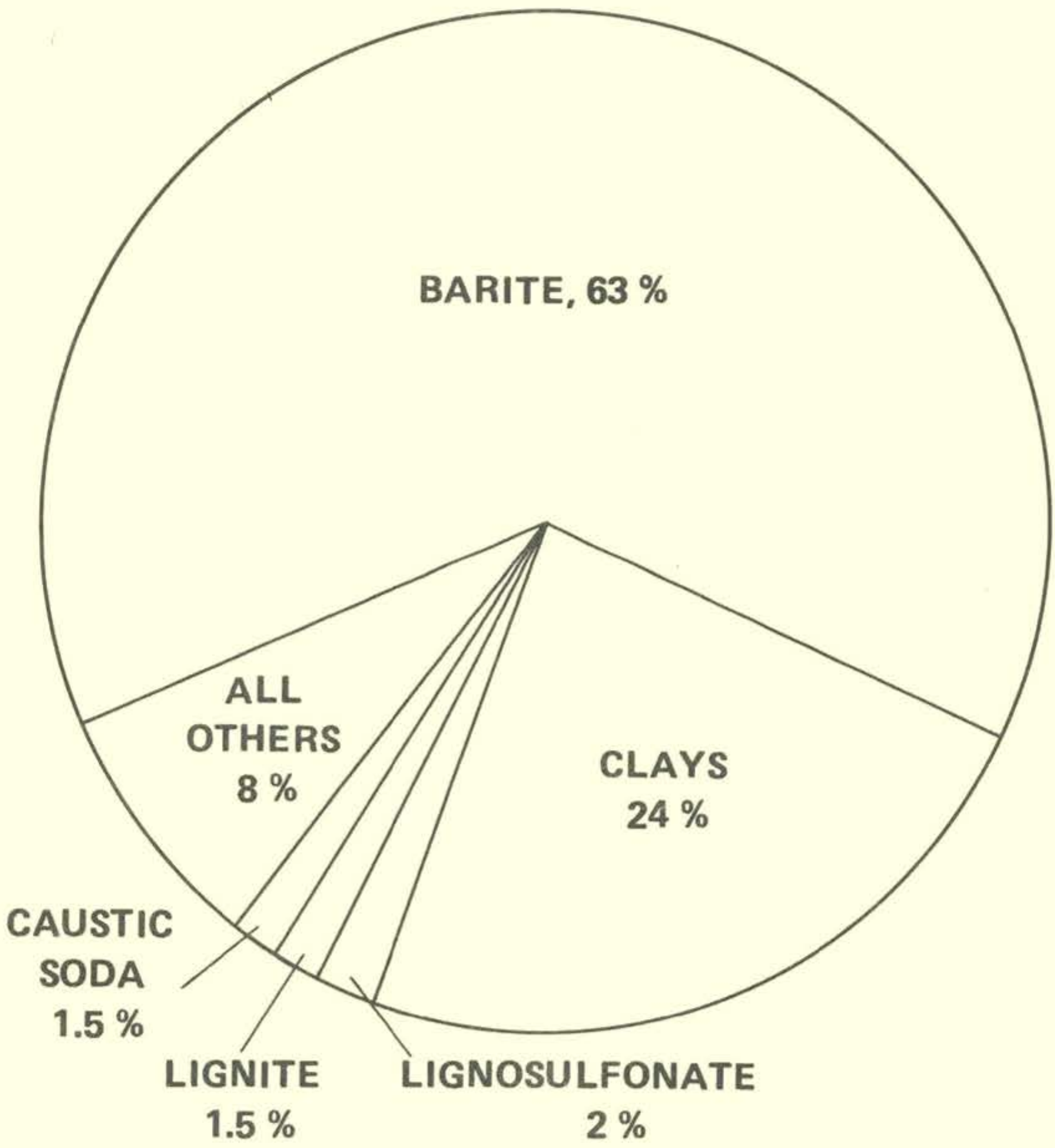
TYPICAL DRILLING MUD COMPOSITION
UNITED STATES OUTER CONTINENTAL SHELF

PRODUCT	CONCENTRATION	
	POUNDS/BARREL (lb/bbl)	kg/m^3*
Water	As needed	As needed
Bentonite	20-25	283.8-354.7
Lignosulphonate	4-8	56.7-113.5
Lignite	4-8	56.7-113.5
Caustic Soda	0.5-2	7-28.4
Barite	0-700	0-9,933
Polymer	1-3	14.2-42.57

* 1 lb/bbl = 14.19 kg/m^3

FIGURE 2

DISTRIBUTION OF U.S. CONSUMPTION RATES OF DRILLING FLUIDS ADDITIVES



ENVIRONMENTAL EFFECTS OF DRILLING DISCHARGES

During the past eight years the petroleum industry in the United States has carried out considerable research to quantify impacts of drilling discharges on the environment. Studies of land disposal effects include determining:

(1) how drilling mud and drill mud components effect growth rates of plants,
(2) the degree of metal uptake in plants growing in mud amended soil, and
(3) if groundwater contamination can occur from drilling mud reserve pits.

Studies concerned with effects in the marine environment include: (1) laboratory studies to determine the toxicity of mud and mud components to marine organisms, (2) field tests to determine actual concentrations of discharge materials in the marine environment, and (3) studies that define impacts to the benthic communities near well sites. Research results are summarized in this section.

ONSHORE EFFECTS

Since 1974 the American Petroleum Institute (API) has been actively researching the environmental effects of drilling mud disposal on plants, soils, and groundwaters. All studies have been conducted by independent researchers at major universities and/or by environmental consulting firms. To date there have been four major studies sponsored by API which are briefly discussed here.

Effects of Drilling Fluids Components and Mixtures on Plants and Soils

The landfarming of drilling muds was first researched at Utah State University.[1,2] The primary focus of the research was to identify and evaluate the effects of drilling muds to plants and soils. The study plan consisted of six different soil types, and seven different drilling mud compositions which utilized thirty-one separate mud components. The drilling muds and components selected represented products and systems most widely used. The following were the major conclusions:

1. Excess soluble salts and high exchangeable sodium percentages were the major inhibiting effects of drilling muds to plants and soils.

2. Elimination of these effects can be accomplished by the addition of salts of calcium, magnesium, potassium, or ammonium with subsequent water leaching to move the salts into the deeper less productive soil layers.

3. Detrimental effects of diesel oil appear to be less severe and long-lived than the effects of salts and/or exchangeable sodium.

4. Drilling muds are least detrimental to acid, highly organic, and sandy soils and more detrimental to alkaline loam and high clay content soils. This is due to the alkaline nature of drilling muds.

5. Most drilling muds caused soil dispersion resulting in surface crusting. However, proper treatment can minimize or eliminate these effects as stated in item 2 above.

6. Arid regions (less than 20 inches or about 50 centimetres of precipitation annually) have a higher potential for adverse effects than do regions with wetter climates. When employing this method of disposal it is highly desirable to have a final soil:mud ratio of at least 4:1. A higher soil:mud ratio will result in a more efficient disposal process and decreased potential for adverse effects. Care should be taken to ensure an even spreading of the mud/cuttings slurry over the intended landfarming area.

Plant Uptake and Accumulation of Metals Derived from Drilling Fluids

As an extension of the Utah State University programme, API is sponsoring additional work at Purdue University[3] on the uptake and accumulation of metals in plants from drilling fluid amended soils. The overall study plan consists of two phases:

Phase one - a greenhouse study evaluating the effects of applying three water-based drilling fluids to two fertile soils on the yield and metal content of two plants - swiss chard and ryegrass.

Phase two - a field study investigating plant yields and metal contents to several actual drilling mud pits that have been reclaimed using landfarming techniques.

Phase one is complete and the final report is published.[4] Phase two was initiated in the spring of 1981 and completed in 1982[5,3].

In Phase one, two heat treated lab muds were prepared using barites with very low levels of trace metals, and one mud was prepared using an extremely low grade mixed barite to represent a worst case situation. All muds were mixed with the soils using the same soil:mud ratio employed in the Utah State study.

Plant cuttings of each species were collected at monthly intervals after seed germination and emergence. Total concentrations of various metals in drilling muds, soil-mud mixtures, soils and plant materials were determined. Plant available metals were also determined in drilling mud, soil-mud mixtures, and soils.

The conclusions of the first phase of the programme are:

1. Soil:mud ratios of 1:1 resulted in plant yield reductions. The mud components causing these reductions are probably excess soluble salts, exchangeable sodium, and heavy metals. Soil:mud ratios of 4:1 using high grade barites did not result in decreased plant yields.

2. Cd, Zn, Cu, As, Pb present in the drilling muds were partially available for plant uptake. The uptake was directly related to the concentrations in the soil:mud and mixtures.

3. Hg, Cr, and Ba present in the drilling muds were not available for uptake.

Drilling Mud Land Spreading and Site Reclamation

The second major landfarming research study was a co-operative effort between the United States Bureau of Land Management in Wyoming and API.(6) Due to a large number of open reserve pits in Wyoming, as well as other arid regions, an accelerated method of drying and reclaiming these pits is desirable. It was believed that the high water retention capacity of bentonite base drilling muds could be utilized to speed the reclamation and revegetation of certain coarse textured soils native to the area.

A land spreading test site was established near Cody, Wyoming and fresh water-based drilling muds were spread using three different application rates and a control. The muds were mulched, disked into the soil and seeded with indigenous grasses. The soils and drilling muds were tested to evaluate any movement of heavy metals and salts. Major conclusions are:

1. No environmental harm occurred from disposing of drilling mud (low application rate) on the soil types studied.

2. The water holding capacity of the soils increased in all cases.

3. The lowest drilling mud application rate area studied showed increased vegetative production when compared to the virgin or control sub-areas.

4. Even at the highest level of drilling mud application studied, no heavy metal problems were found.

5. No heavy metal movement was found in any of the drilling mud application areas.

6. Even though the levels of total chromium in the soil slightly increased, the concentration was still well within levels typically found in Wyoming soils.

7. The chromium existed in its most stable state (Cr^{+3}) and was, therefore, unavailable for plant uptake.

8. The concentration of manganese at the site increased slightly but was well within the levels found in typical Wyoming soils.

9. No significant heavy metal accumulations were found in plants. Therefore, no adverse impact to livestock grazing would be expected.

10. Sodium levels in the high and medium application areas were above optimum for plant growth, but can be offset by applications of appropriate amounts of gypsum or sulphur.

Reserve Pit Study

The API has funded a study by an independent environmental/hydrogeologic consulting firm to investigate the environmental impact to surface/groundwaters, soils, and vegetation from closed drilling mud pits. The basic objective of the project is to test impoundments utilized in drilling operations to determine if any constituents in drilling mud will leach out in sufficient quantities to present a significant hazard to human health or the environment.

In all, six mud pits were investigated throughout the continental United States. One pit was tested first as a pilot study to ensure a sound experimental design. In an effort to test the most important oil and gas regions of the continental United States, pits in the following five hydrogeologic regimes were evaluated: Alluvium-wet, Carbonate-dry, Tilted and Sedimentary Basins-wet, Tilted and Sedimentary Basins-dry, and Coastal-wet. In conjunction with the hydrogeology, several other siting parameters were considered: drilling mud composition, site accessibility, age of the site, soil types, land use, groundwater depth, well workover and chemical history, well depth, and climate.

The result of the study was published in 1982.(7)

OFFSHORE EFFECTS

Prior to 1977 there was little research information available on the fate and effects of drilling discharges in the marine environment. A great deal of historical information was available. At that time 23,000 wells had been drilled in United States waters in the Gulf of Mexico and offshore California over a period of several decades with no noticeable impact on fisheries. However, little confirming research results were available to answer questions posed by concerned regulators as industry moved into frontier areas where drilling had not previously occurred. Since 1977 a large body of research information has been developed by both Government and industry. Research is continuing. However, as discussed here, a great deal has already been learned regarding both the nature of the discharges and their impact.

Laboratory Studies

Most of the work to date has been directed toward determining acute toxicity. In these tests, organisms are subjected to different concentrations of mud (or liquid phases of mud) for a set time, usually 96 hours. Then by observing mortality rates and by calculation, the concentration required to kill 50 per cent of the test organisms in 96 hours is determined. This is called the 96-hour LC_{50}. Such a test is useful because it is comparatively rapid and inexpensive and produces a single number to help make a judgement concerning toxicity. Chronic tests are similar to acute tests except that the organisms are exposed to lower concentrations for longer periods of time - days to months.

In addition to the mortality tests several studies have addressed sublethal effects. For example, investigators have measured concentrations where changes in reproduction, growth rates and respiration occur. In community studies, mud solids or mud components are either layered on or mixed with natural sediment and then unfiltered sea-water passed through the aquaria. Comparisons are made between these and aquaria containing only natural sediment to learn how changes in the substrate can alter recruitment of settling planktonic larvae and the biological community that develops. Estimates of drilling mud metals bioavailability are made by exposing organisms to various concentrations of mud or mud components for several days. After an appropriate depuration period the metals concentrations in the test organisms are determined and the results compared with concentrations in control organisms.

Detailed reviews of the laboratory research results are presented in References 8 and 9. Only a brief summary is presented here.

Table 11 shows typical 96-hour LC_{50} results for major mud components, and drilling mud. Barite and bentonite are essentially non-toxic while lignite and lignosulphonate respectively would be classified as practically non-toxic and slightly toxic (see Table 12). Of course muds, not components, are discharged in the drilling process. Thus, the toxicity of the mud itself is of primary importance. Clay-chromelignosulphonate muds, the basic composition of which is shown in Table 10, are used in over 95 per cent of the offshore wells drilled in the U.S. Test results have been summarized from 40 different muds, primarily of this type, using 48 species of marine organisms representing several classes of various growth stages from the Gulf of Mexico, Atlantic, Pacific, Beaufort Sea and Cook Inlet.(9) The vast majority (90 per cent) of the muds tested have LC_{50}'s that fall into the practically non-toxic range, 10,000-100,000 ppm. This is true even though many different species of test organisms in various life stages have been tested. Some species are more sensitive than others and juveniles are normally more sensitive than adults. These differences though are normally too small to cause the LC_{50} results to fall outside the 10,000-100,000 ppm range. Test results are available on muds that produced LC_{50} values falling below this range. Test results are available on muds that produced LC_{50} values falling below this range. However, most of these muds were obtained from drilling locations on land and contained significant amounts of oil which are not typical of water-based drilling fluids.

Sublethal tests are more sensitive than acute toxicity tests, but they are also more difficult to interpret. In many cases it is not clear if the observed effect is truly adverse (pathologic) or not (compensatory). Sublethal effects are usually noted at concentrations one to two orders of magnitude lower than the 96-hour LC_{50} values. That is, most investigators have not noted sublethal effects at concentrations below the 100-1,000 ppm range for muds discharged offshore.

Studies have shown that marine organisms can accumulate mud-associated metals. However, under realistic exposure conditions accumulation has not been shown to occur to a degree sufficient to cause a toxic effect in the accumulating organism.(8) Drilling mud metals have only limited bioavailability because of the form the metals are in (insoluble salts, chemically bound to high molecular weight organic molecules, or adsorbed on clays).

Another issue of concern is whether or not accumulated metals are bioconcentrated in prey organisms and a direct threat to human health. This is extremely unlikely since studies of other pollutants indicate that organic mercury and selenium (not found in drilling mud) are perhaps the only metals having bioconcentration potential. In any case, an API research project is currently addressing the possible problem.

TABLE 11

TYPICAL BIOSSAY RESULTS* ON DRILLING FLUIDS AND MAJOR COMPONENTS

MATERIAL	96-HOUR LC_{50} (ppm)
Barite	>100,000
Bentonite	>100,000
Lignite	15,000 - 25,000
Chrome Lignosulphonate	500 - 10,000
Clay-Chrome Lignosulphonate Mud	10,000 - 100,000

*Sublethal effects usually noted at concentrations 1-2 order of magnitude less than LC_{50} value.

TABLE 12

CLASSIFICATION OF TOXICITY GRADES

TOXICANT CLASSIFICATION	LC_{50} VALUE mg/l
Practically non-toxic	>10,000
Slightly toxic	1,000-10,000
Moderately toxic	100-1,000
Toxic	1-100
Very toxic	< 1

Field Studies

During the past five years major field studies have been conducted in the Beaufort Sea, the Lower Cook Inlet, Offshore California, the Gulf of Mexico and in the Atlantic[10]. These studies addressed either one or both of these questions: (1) What is the fate of the discharged material, i.e. how rapidly is it dispersed to concentrations approaching background levels? (2) What is the nature and extent of effects on the biological community?

Water Column Effects - When drilling mud is discharged to the ocean most of the solids settle rapidly in the vicinity of the well site. Settling is much more rapid than would be predicted from the mud particle size distribution[11]. The finely divided clay particles owe their stability in the mud system to the electrical charge between the particles and the presence of lignosulphonate which serves as a deflocculant. When the mud contacts sea-water these particles are destabilized by the decrease in lignosulphonate concentration and by the high concentration of electrolytes present in sea-water. This leads to agglomeration of particles and rapid settling. Only a small fraction of the particles (less than 10 per cent) escape extensive initial flocculation and remain in the water column for more than a few minutes. The rapid decrease in the concentration of suspended solids in the water column with distance is illustrated by the data shown in Table 13, taken from a field test in the Gulf of Mexico.[12]

Table 13 shows suspended solids concentration and transmittance as a function of distance from the discharge source for both tests. Values shown are the maximum suspended solids concentration and minimum transmittance numbers measured at the noted distance. Suspended solids concentration dropped quickly with distance from the source due to settling and dispersion.

The greatest decrease in concentration occurred in the first 50 metres. Suspended solids concentrations reached background levels around 500 metres and 1,000 metres for the 275 barrel per hour and 1,000 barrel per hour test respectively. Transmittance values did not reach background as quickly as suspended solids. During the 1,000 barrel per hour test transmittance values reached background around 1,500 metres downcurrent from the discharge source. Transmittance was the only hydrographic variable affected by the discharge. All other hydrographic variables (temperature, salinity, dissolved oxygen) remained unchanged from ambient conditions within the monitored interval (40-1,500 metres from the discharge point). Transmittance values take longer to reach background due to the large number of colloidal particles present in the plume. These particles continue to scatter light effectively even when present in concentrations too low to significantly contribute to the weight of suspended solids.

TABLE 13

SUSPENDED SOLIDS CONCENTRATION AND TRANSMITTANCE VERSUS DISTANCE DURING HIGH RATE DISCHARGES

DISTANCE FROM SOURCE (metres)	SOLIDS CONCENTRATION (mg/l*)	TRANSMITTANCE (%*)
275 BARREL/HOUR - 250 BARRELS DISCHARGED		
0	1,430,000	-
6	14,800	-
45	34	2
138	8.5	56
250	7.0	48
364	1.2	37
625	0.9	71
Background	0.3 - 1.9	76 - 85
1,000 BARREL/HOUR - 389 BARRELS DISCHARGED		
0	1,430,000	-
45	855	0
51	727	0
152	50.5	2
375	24.1	4
498	8.6	23
777	4.1	21
878	1.2	71
1,470	2.2	82
1,550	1.1	82
Background	0.4 - 1.1	80 - 87

*Maximum concentration and minimum transmittance measured at noted distance.

The transmittance and suspended solids data were used to estimate the maximum quantity of solids present in the water column during both discharges. This is the quantity present in the water column immediately after discharge ceases, about 5 per cent of the discharged solids during the 275 barrel per hour test and 7 per cent during the 1,000 barrel per hour test. The quantity of solids present in the upper plume continues to decrease after discharge ceases since settling continues as the plume drifts.

In addition to the solid particles, drilling mud may contain low concentrations of soluble components. An estimate of the dilution ratio for any soluble materials present was made by using the ratio of the volume of the plume in the water column to the volume of liquid phase discharged. After a time of one hour the dispersion ratio for soluble components was estimated to be about two orders of magnitude less than that for solids, due to the fact that almost all of the solids settle quite rapidly.

In addition to the Gulf of Mexico study there have been several other similar tests in other OCS areas.[11,13,14,15,16,17] Even though the tests have been conducted under a variety of environmental conditions, using different sampling techniques, the results have been similar in every case.

Benthic Effects - The degree of impact that can occur on the benthos depends on environmental factors (current regime, water depth) that dictate how long the settled material remains concentrated at the well site. The type of impact is illustrated by the results obtained in a monitoring programme conducted on the mid-Atlantic Outer Continental Shelf.[11,18,19]

The overall study objective was to determine what effect drilling discharges have on ambient water quality, bottom sediments, and benthic community during exploratory drilling in the mid-Atlantic. The well site was located approximately 156 kilometres east of Atlantic City, New Jersey in an approximate water depth of 120 metres. Bottom currents here are weak and the sea floor can be characterized as a low energy environment. The study consisted of monitoring the environment around the well site before the rig moved on location (Pre-Drilling Survey) while the rig was on location (Drilling Survey), after the rig moved off location (First Post-Drilling Survey), and one year after the rig was moved off location (Second Post-Drilling Survey).

The Pre-Drilling Survey was carried out in July 1978. The Drilling Survey lasted from the time the rig arrived at the well site on January 4, 1979 until it moved off location on July 15, 1979. During the drilling operation, mud and solids control equipment discharges and ocean currents were monitored. Also, two discharge tests (500 barrels per hour and 275 barrels per hour), similar to those conducted in the Gulf of Mexico study mentioned earlier, were carried out to determine effects on water quality. The First and Second Post-Drilling Surveys were conducted in late July 1979 and 1980, respectively.

The behaviour of discharged mud during the dispersion tests was similar to that observed in the Gulf of Mexico study. It was concluded that the drilling discharges had a negligible effect on the water quality of the area.

The drilling discharges did have an effect on the benthic community. In the First Post-Drilling Survey a zone of visible drilling discharge accumulations (primarily formation clays) was observed in the immediate vicinity of the well site. Megabenthos (demersal fish and crabs) increased substantially in the immediate vicinity of the well site and over the general study area south of the well site. The cuttings piles were still present in the Second Post-Drilling Survey. Megabenthic abundance was still elevated over the pre-drilling level but reduced from that observed in the First Post-Drilling Survey.

In the First Post-Drilling Survey sessile macrobenthos were subjected to burial by drill cuttings within the immediate vicinity of the well site. However, little change in species diversity accompanied the decreased abundance.

Reductions in abundance of macrobenthos beyond the immediate vicinity of the well site occurred in those areas south-west of the site where elevated levels of clays were detected. The reduction was attributed in part to increased predation by fish and crabs and in part to diminished recruitment of larvae to the area due to substrate alteration. In the Second Post-Drilling Survey macrobenthic abundance at the well site was no different from other sites in the study area with the exception of the brittle star _Amphioplus macilentus_ which remained in low abundance near the well site.

Barium concentrations in the sediment were increased in both post-drilling surveys. Concentrations 10-30 times background were observed near the well site. All other metals and extractable hydrocarbons were unchanged from pre-drilling levels.

No relationships were detected between macrobenthic abundance and the barium content of sediments (which were elevated near the well site in both post-drilling surveys) or the barium content in tissues of organisms although elevated levels of barium were detected between the Pre- and Post-Drilling Surveys.

The impact observed in this study might be considered as a "worst case", as far as discharge in the open ocean is concerned. In addition to being a low energy area, natural sedimentation rates are low and the area can be considered non-depositional.

The effect of these environmental factors is illustrated in Table 14 for three areas where studies have been conducted, including the one discussed above.(10) The energy of the areas is indicated by the maximum measured bottom currents. In the Cook Inlet, an area subjected to strong diurnal tidal currents, bottom currents were 99 centimetres per second. It is an extremely energetic area. The Tanner Bank is offshore California. Here the maximum bottom currents measured were 36 centimetres per second. The mid-Atlantic study was conducted in a relatively calm area where infrequent maximum bottom currents of 18 centimetres per second were observed. Water depth is also a consideration since storm waves have a greater effect on resuspension and bottom transport of mud solids and sediment in shallow water depths. In the Cook Inlet and Tanner Bank the water depths were 62 and 55 metres respectively while in the mid-Atlantic the water depth was 120 metres.

Table 14 shows some of the results that were noted in the different areas. First, visual evidence of discharged material (observed by bottom TV or submarine) at the rig site immediately after drilling. In the Cook Inlet, there was no visual evidence of drilling immediately after the rig was moved off location. In the Tanner Bank, there was also no visual evidence of the discharged material. In the mid-Atlantic even one year after the rig had moved off location, cuttings piles were still visible in the well site area.

The second parameter shown is increased barium levels in the sediment surrounding the well site immediately after drilling. Due to the high concentration of barite in most muds, barium is a sensitive tracer for drilling discharges. In the Cook Inlet there was no increase in barium levels in the well site area sediment because the barite particles were rapidly swept away by the current. In the Tanner Bank study, barium concentrations in the sediment were increased at the well site. In the low energy mid-Atlantic area increased barium levels were observed in the sediment around the well site even one year after drilling.

The third parameter is the impact on the benthic community. In the Cook Inlet there were no measurable impacts. Benthic effects were not studied at Tanner Bank. The impacts observed in the mid-Atlantic study have already been discussed. It is clear that the extent of the effect and how long it lasts depends on how dynamic the bottom environment is.

TABLE 14

EFFECT OF ENVIRONMENTAL FACTORS ON STUDY RESULTS

	COOK INLET	TANNER BANK	MID-ATLANTIC
ENVIRONMENTAL FACTORS			
Maximum Bottom Current, cm/sec	99	36	18
Water Depth, metres	62	55	120
STUDY RESULTS			
Visual Evidence of Discharged Material Immediately after Drilling	NO	NO	YES
Increased Barium Levels in Sediment Immediately after Drilling	NO	YES	YES
Benthic Impacts in Study Area	NO	---	YES

Future Research Trends

The vast majority of laboratory and field research projects to date have addressed short-term impacts. These have been extensively studied and are fairly well understood. Today, there is a definite trend in the direction of studying long-term fate and effects. This is being done both in the laboratory and field. In the field the emphasis is on monitoring sediment and biota throughout a pristine area for several years during exploratory drilling activities to determine if any significant long-term impacts occur. Laboratory studies are concentrating on sublethal effects associated with long exposure times to low concentrations of mud-sediment mixtures.

Another area of prime importance is improving predictive capability. A model is being developed which will satisfactorily predict the short-term fate of drilling discharges.[20] Attempts are also under way to develop models which consider resuspension and bottom transport in order to predict the long-term fate. However, this problem is more difficult and experimental models are presently only useful in a qualitative sense. Models predicting effects are also being developed, but so far the available models are extremely simplistic and are useful only in a very gross qualitative sense at present.

DISPOSAL PRACTICES

ONSHORE

Considerable attention is currently focused on the disposal practices for wastes generated in drilling onshore wells, i.e. water-based drilling fluids and drilled solids. Onshore a reserve pit (sump) is normally used to store the drilling mud and cuttings and usually to serve as the means for final disposal. Prior to the rig moving on location, a reserve pit is excavated directly adjacent to the area where the rig and mud equipment will be sited. The pit is typically deeper near the rig and associated mud processing (solids control) equipment to allow the heavy mud solids to settle out. The pit is sized according to the projected well depth and the planned volume of drilling mud to be used. The walls of the reserve pit must be high enough to provide 3-5 feet (1-1.5 metres) of native topsoils on top of the mud and cuttings after backfilling (if this is the method of disposal chosen). If space at the drilling location is adequate, it is preferable to have a larger, more shallow reserve pit, because the final disposal will be achieved more quickly and efficiently.

In certain areas, Government regulations and/or unique geographical and/or environmental considerations required the use of an impervious liner in the reserve pit. In many cases where a liner is employed, the resulting waste drilling mud and cuttings are hauled off the location to a designated disposal site by the use of vacuum trucks. However, in some cases, disposal will take place with the liner in place.

Once the well has either been completed or abandoned and the drilling equipment moved off location, the reserve pit wastes are ready for final disposal. There are three major methods of disposal listed here in their order of prevalence:

1. Dewatering the pit wastes with subsequent backfilling using the pit walls.

2. Landfarming the wastes into the surrounding soils.

3. Vacuum truck removal to an approved disposal site.

The last method is specific to unique circumstances. Therefore, only the first two are discussed in detail, because they comprise the vast majority of all reserve pit disposal on land.

Whatever disposal method is chosen, it is beneficial to explore all methods and act quickly. The longer a reserve pit exists, there is a proportionately larger volume of waste to be handled during ultimate disposal due to precipitation.

Backfilling

Backfilling a reserve pit is by far the most common method employed. It results in a dried mud lens some 3-5 feet (1-1.5 metres) below the surface. Before the backfilling operation can begin, it is first necessary to remove the top aqueous layer. In some cases there may be free oil on top of the aqueous layer originating from diesel rig washings or used lubricating oil. If it is excessive, the oil is removed by skilling. The need to remove the oil is dictated more by the fact that the aqueous layer must be removed than the fact that the oil is harmful. Indigenous bacteria in soils can biodegrade large quantities of oil in a relatively short period of time.[21]

After the oil is skimmed, the aqueous layer can be clarified by mixing or broadcasting the pit area with organic flocculants such as polyacrylamide, or inorganics such as gypsum. Flocculation should be as complete as possible. This results in a denser colloidal slurry, which decreases the volume of waste and increases the efficiency of the dewatering process.

Once the clarification process is complete, the aqueous layer is removed. Sometimes it is allowed to evaporate, which can take considerable time, up to a year. In some cases the wall of the pit dike is cut and the fluid drained out. If this is done certain chemical and/or biological analyses are conducted to ensure that the released water meets guidelines established by the Environmental Protection Agency and/or appropriate state regulatory agencies. The aqueous layer can also be removed by vacuum truck and injected: (1) into the well that was drilled (if it is plugged and abandoned), (2) into the drilled well's annulus (if it is completed as a producing well), or (3) be transported to a nearby injection well.

After the aqueous layer has been removed, the actual backfilling of the reserve pit is performed. Care is taken to ensure that the process is uniform around the reserve pit perimeter to return the area to original contours and replace the topsoils evenly. In addition, the method also allows ample time for the remaining slurry to undergo further dewatering. The dry subsoils of the reserve pit walls also aid in the final dewatering as they are slowly moved over and mixed with the waste muds and cuttings. When the closure process is complete the area is ready for return to its original use.

Landfarming

The second major disposal method utilizes landfarming techniques. Landfarming essentially consists of spreading the contents of the reserve pit evenly over the drilling location with subsequent incorporation into the soil using basic soil tilling equipment. In some instances the water phase is first removed as discussed above under "Backfilling". Landfarming is especially useful for wells that will be producing hydrocarbons as the production and ancillary equipment will be sited on location.[22]

Prior to selecting landfarming as a disposal method, the disposal location must first be fully characterized as follows:

1. Soil chemistry - pH, conductivity, sodium, calcium and potassium contents, and per cent of clay.

2. Climatic conditions - annual precipitation.

3. Complete chemical and physical characteristics of the reserve pit contents.

4. Presence of nearby surface waters and surface terrains.

5. Original or intended land use of the landfarming area.

6. Location and depth of usable groundwaters.

If the characterization of the area proves favourable for landfarming and surface waters are in the immediate proximity, the drainage gradient should be slightly bermed to prevent rainwater run-off from entering the surface water.

Vacuum Truck Removal

In certain cases the contents of the reserve pit are not suitable for landfarming or the locality is not conducive to backfilling. Should these situations occur, the other viable disposal technique is required - removal of the pit contents by vacuum truck with disposal at some other disposal site.

Both the aqueous and the solid phases of the reserve pit are pumped to trucks while dirt moving equipment "squeezes" the pit dikes together. This method results in a completely backfilled reserve pit when the last portion of mud is removed. It is very costly and should be utilized only when all other methods have been exhausted.

OFFSHORE

As discussed earlier, water-based drilling fluids and cuttings generated in drilling most of the 37,000 plus "over-water" wells in the United States waters were discharged directly to the marine environment, and with no significant detrimental environmental impacts during a period of over 50 years. These discharges are made in compliance with applicable governmental rules and regulations. Such regulations are administered by the Minerals Management Service and the Environmental Protection Agency in the federal OCS waters and by EPA and/or appropriate state regulatory bodies in state offshore waters and inland coastal waters. Practices followed by the United Kingdom Department of Energy in the North Sea are given in Appendix A.

In isolated instances, the appropriate regulatory body may impose alternate, more stringent restrictions on these discharges to protect areas of extreme environmental sensitivity. Also, other methods have been proposed from time to time for such sensitive areas as possible alternates to direct overboard disposal. This has been done even though there is usually inadequate justification to require utilization of these techniques. All of these alternate disposal techniques are reviewed here. In the following discussion, the different disposal techniques are categorized as shown in Table 15.

Feasible Alternates

Shunting - The term "shunt" means to release the drilling mud and cuttings through a pipe extending below the surface of the water (usually near to the sea floor). Theoretically, shunting minimizes the physical transport of the wastes and the chance for environmental damage. However, because of the rapid dilution once the materials enter the water, it is debatable if shunting actually improves the situation. Shunt systems cost less than $100,000. With proper care they can be used on many wells, and are easily stored when not required. Shunting is viewed as a feasible alternate method to dispose of mud and cuttings.

Impractical Alternates

Transporting to an ocean dump site - Hauling drilling mud and cuttings to an authorized ocean dump site is a widely discussed alternate disposal technique.

Due to weight and space limitations common to all drilling units, and buoyancy constraints of semi-submersible drilling rigs, storage capacity to accumulate used mud and cuttings for periodic offloading is limited. Thus, on most rigs sea conditions would dictate whether or not drilling could proceed safely while a barge or boat stands by continually to accept these materials. If towed barges are used to collect effluents, seas as low as 5 feet (1.5 plus metres) will prevent safely tying up to a rig. If self-propelled boats are employed, 10-foot (3 plus metres) seas are the practical upper limit. To maintain normal drilling activities on a continuous basis, it would also be necessary to employ two barges, or boats.

TABLE 15

CLASSIFICATION OF ALTERNATE TECHNIQUES FOR OVERBOARD DISCHARGE OF OFFSHORE DRILLING WASTES

Feasible Alternates - Those which are technically possible, and which can be accomplished in a safe manner at a reasonable cost.

Impractical Alternates - Those which, because of potential safety and/or technical problems and excessive costs, cannot be considered as viable means to dispose of mud and cuttings.

Completely Impractical Alternates - Those which are technically impossible. Also, included in this category are those methods which, because of technical problems and/or the fact that they do not dispose of all of the muds and cuttings generated, must be considered completely impractical means to dispose of offshore drilling wastes. Included in this category are: incineration, injection and complete recycling. Such approaches have been investigated and found not to be worth pursuing because of cost, unreliability or major technical problems. Thus, they are not discussed further in this report.

While it is technically possible to handle the disposal of drilling wastes in this manner, it has seldom been done, and then only in relatively calm waters near-shore. Therefore, a fully safe and reliable method to retrofit existing rigs, boats and barges to handle large volumes of used slurries and solid materials is not available. There are also a number of other safety problems associated with such hauling even within the above specified sea state limitations. In addition, it is quite expensive, i.e. from about $500,000 for a typical Gulf of Mexico well up to $6 million for a deep well in the North Atlantic.

For all of these reasons, safety and technical problems coupled with extremely high costs, hauling mud and cuttings to an authorized ocean dump site is not a practical alternate disposal technique.

Transporting to a land disposal area - The technical and safety problems associated with hauling the spent mud and formation cuttings to a land disposal area are the same as for transporting to an approved ocean dumping site. Costs are also estimated to be comparable.

The conclusion is the same as for transporting to an approved ocean dump site, i.e. hauling to a land disposal area is not a viable alternate to overboard discharge of mud and cuttings.

Offloading via a SPM buoy and/or transporting to an ocean dump site or land disposal area - The use of a single point mooring (SPM) buoy has been suggested to provide a mooring point away from a rig. This would allow offloading mud and cuttings to a barge/boat system in a manner minimizing the safety problems discussed above associated with tying vessels directly to a rig. The waste materials would then be taken to an ocean dump site or land disposal area as above.

The initial capital cost of such a system employing a 500-foot (152 metres plus) long pipeline would be in excess of $9 million. The cost to reinstall an existing buoy at each new drilling location would be in excess of $1 million. To these figures must be added the previously discussed costs for disposing of the mud and cuttings generated at each well. Additionally, technical problems associated with pumping a high solid content fluid must also be considered (see next discussion "Pipelining to another area"). All factors considered, this technique cannot be viewed as a practical alternate disposal method.

Pipelining to another area - Utilization of a pipeline to move discharged mud and cuttings away from an environmentally sensitive area has also been considered as an alternate to direct overboard disposal. In addition to a pipeline, pumping equipment to move the material through the pipe would have to be installed, as would mechanisms to prepare the drilling fluids and cuttings prior to pumping. Other systems, such as constant sea-water pumping and/or pigging would be necessary to prevent the pipeline from plugging. Should the line plug or break (which are likely possibilities handling a high solid content fluid), drilling would have to cease while repairs were effected. Cost estimates for a nine-nautical mile (16.7 kilometres), 10-inch diameter pipeline system which has been suggested by EPA as a possible disposal mechanism near unique coral reef areas are:

1.	Pipeline and connection to initial well	\$5.9 million
2.	Each additional well tie-in - maximum two-mile length (3.2 kilometres)	\$1.3 million
3.	Ultimate pipeline removal	\$3.3 million

In addition to excessive capital costs enumerated above, high operating and maintenance costs would be incurred. Also, the potential environmental impact on the benthic community and water column organisms during installation and recovery of the pipeline and at the discharge point during operation must be considered. These would be a result of the excessive turbidity created and would probably greatly exceed any disturbances from the normal overboard discharge of mud and cuttings. Therefore, pipelining to another area cannot be considered a practical alternate disposal method.

SUMMARY AND CONCLUSIONS

Since 1859 about 2.7 million wells have been drilled on land in the United States. Onshore drilling continues at an annual rate exceeding 50,000 wells. In 1927 the first well was drilled over water. A total of over 37,000 offshore wells have now been drilled. The number is constantly increased by the drilling of more than 1,000 wells each year, mainly on the Outer Continental Shelf (OCS). Practically all U.S. wells, both onshore and offshore, have been drilled in temperate and sub-tropic areas.

The vast majority of the wells have been drilled using water-based drilling fluid (mud)*. Water-based drilling mud is mainly a suspension of clay in water. It usually contains barite for density (weight) control and low concentrations of speciality chemicals to control viscosity, fluid loss, corrosion and other mud properties. In addition, the drilled solids or "cuttings" (small pieces of formation material that are produced by the crushing action of the drill bit) also comprise a significant constituent in drilling muds.

During drilling the mud is circulated down the drill pipe and through the bit to remove and transport the drilled solids up the annulus to the surface. At the surface, the formation cuttings are removed by mechanical separation and the drilling fluid is recirculated. Much effort is spent on this treatment to reduce net mud consumption and discharge. While drilling a well, it is necessary to discharge both drilled solids and mud. The solids are discharged as they are separated from the mud stream. Small quantities of mud adhering to the solids are also released with the solids discharge. Mud is discharged when a change in the type of drilling fluid is needed, when the mud properties have deteriorated, or when the well is completed and the drilling fluid must be discharged before moving off location.

In the drilling of practically all land and over-water wells, the water-based drilling mud and formation solids are discharged to the environment at the location. While there are alternate methods to dispose of these drilling wastes, they are neither cost-effective nor necessary to protect the environment.

The following general conclusions can be made concerning the environmental impact of water-based drilling discharges on the environment:

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* The use, environmental impacts and disposal of oil-based drilling mud are not addressed in this report.

ONSHORE

The used mud and drilled solids are usually discharged to earthen sumps (called reserve pits) excavated adjacent to the well site. After appropriate treatment, if necessary, to remove the water phase, the mud and cuttings are incorporated into the soil. Experience through the years and recent research indicate no significant environmental impact: neither significant surface or groundwater contamination nor uptake of and accumulation of metals into plants occur.

OFFSHORE

In recent years extensive studies have been conducted by both U.S. Government and industry to evaluate the effect of drilling discharges on the marine environment. These studies, which include laboratory toxicity tests and field assessment studies, indicate that:

1. Drilling discharges per se are not very toxic. Typically, 96-hour LC_{50}'s are in the 10,000-100,000 ppm range.

2. Due to rapid settling and dilution, drilling discharges have no significant adverse effect on the open-ocean water column. Concentrations reached are orders of magnitude below the 96-hour LC_{50} values within metres of the discharge source. Background levels are usually achieved within 1,000 metres downstream of the drill site.

3. Drilling discharges may adversely affect the benthic community near the well site. The effect is often temporary and physical rather than toxic in nature. The only significant adverse effect noted is burial of the sessile organisms within 100-200 metres of the well site.

GOVERNMENT REGULATIONS

Mud and cuttings discharges are regulated by the appropriate federal and/or state governmental bodies. As there are no permanent demonstrated adverse environmental impacts, these agencies normally allow such wastes to be discharged on location with minimal restrictions. For example, onshore, normally the aqueous phase in the reserve pit must be properly clarified prior to release. In offshore drilling only the amount of oil discharged is usually restricted. However, in infrequent instances more stringent requirements may be imposed to protect unique environmentally sensitive areas. Onshore, for wells drilled in very pristine wildlife refuges, it is possible that it would be necessary to transport the mud and cuttings to an approved disposal site. Offshore this could be both a prohibition of drilling and discharging wastes immediately on top of unusual coral reefs, or when drilling near such natural phenomena, releasing the mud and cuttings near the ocean floor, rather than at the surface (normal practice).

Drilling discharges from onshore wells and those drilled in state waters are controlled by the state regulatory agencies through various laws and/or the U.S. Environmental Protection Agency (EPA) through the mechanism of National Pollutant Discharge Elimination System (NPDES) permits authorized by the Clean Water Act (CWA). Drilling discharges on the OCS are regulated by two agencies: Minerals Management Service (MMS - formerly the Bureau of Land Management and the U.S. Geologic Survey) and the EPA. MMS exercises its authority through: (a) stipulations in OCS lease agreements (which must be followed by the successful bidders purchasing such leases) and (b) Operating Orders. EPA regulates these discharges through the previously mentioned NPDES permits.

For offshore operations in the United Kingdom, the Department of Energy employs a voluntary reporting scheme under which advice is given on the types of chemicals whose use is to be avoided wherever possible, and information is made available to users and Government on the chemical type and toxicity of the various products in use. The scheme is discussed in Appendix A. The vast majority of the materials employed are either inert solids, or non-toxic derivatives of natural products. The use of some fairly toxic chemicals has been identified but the amounts involved do not cause concern.

APPENDIX A

NOTIFICATION SCHEME FOR THE SELECTION OF CHEMICALS FOR USE OFFSHORE IN THE UNITED KINGDOM

INTRODUCTION

A wide range of chemicals are used offshore - some in small, some in large quantities. While the composition of many is well known, many more are sold under trade names, and their composition is not known by their users, and sometimes not even by the suppliers. Most of these chemicals will ultimately reach the sea either in continuous discharges or during intermittent dumping operations. The monitoring of each and every discharge or dumping operation would be a formidable task and no authority has attempted to exercise such controls for offshore oil and gas operations.

However, since some of the chemicals that could be used for particular applications, particularly the corrosion inhibitors and biocides, could be environmentally harmful, the United Kingdom Government decided to give guidance to operators on the selection of chemicals for use offshore and to monitor the situation to establish whether further intervention was necessary.

The UK Notification Scheme for the Selection of Chemicals for Use Offshore

Following consultations within Government and with representatives of the United Kingdom Offshore Operators Association, the Petroleum Industry Advisory Committee, the Confederation of British Industry and the Chemical Industries Association, a non-statutory "Notification Scheme for the Selection of Chemicals for Use Offshore" was introduced on February 1, 1979.

The objectives of the scheme are as follows:

1. To provide guidance to operators and suppliers on the types of chemicals whose use is to be avoided wherever possible for applications which result in discharges to the sea.

2. To enable operators to take environmental factors into consideration when selecting chemicals for particular applications, by making the necessary information available to them.

3. To establish consultative procedures with Government scientists for any large scale discharges.

4. To inform Government of the types of discharges that are occurring to enable it to identify any possible problem areas and take the necessary action.

During the past two years information has been provided by most of the active operators on the U.K. Continental Shelf in respect of the nature of many of the chemicals being employed and their scale of use. Further information on the chemical composition and toxicity has been provided by 20 of the chemical suppliers. This provides full information on 95 products and partial information on a further 175. More information from these sources has been promised.

Although full data has not yet been provided by all operators or all suppliers, it has proved possible to draw a number of general conclusions:

1. Predictions that large amounts of persistent biocides are used have not been confirmed. Although hypochlorite is widely used to treat cooling water, other large scale uses of biocides which result in discharges to the sea have not been identified.

2. The largest uses of chemicals offshore appear to be associated with drilling fluids. Discharges associated with other activities appear to be of a much lower order.

3. While a number of the larger suppliers have toxicity data on all or some of their products relating to fresh water species, few had much on marine species at the beginning, more have so now.

It has proved possible from the information generated by the scheme to estimate the scale of use and discharge of drilling mud chemicals from U.K. installations during 1980.

Some 152 wells were drilled during that year and details have been supplied by operators on the mud components used in over half of these. The figures given on Table A-1 were obtained by extrapolating the data received to the full 152 wells. The procedures adopted may have yielded erroneous totals for some of the minor components involved, but the overall picture should be reasonably accurate.

It is apparent from an examination of the data contained on Table A-1:

1. Most of the components in the discharges are either inert or non-toxic

2. The principal product containing heavy metal cations found to be in use on a significant scale is ferrochrome lignosulphonate. Zinc chloride was reported as a component in certain corrosion inhibitors but the amounts used for these applications were fairly small.

The future of the scheme

The establishment of the scheme has provided both suppliers and users with guidance on the types of chemicals which they should avoid wherever possible, for applications which involve discharges to the sea. It has also helped to establish a data base on the environmental properties of the chemicals involved which will be of continuing value both to operators and Government in identifying and advising on the best environmental solutions to particular problems. The same data base might usefully be used elsewhere since many of the chemicals involved are marketed world-wide.

The scheme has not so far generated any alarming information regarding widespread uses of highly toxic substances. It has rather indicated that most of the substances used offshore are fairly innocuous, but that there is a minority in use on a small scale which are relatively toxic. The U.K. Department of Energy intends to use the scheme to continue to monitor the situation and will request that operators keep it informed when it is proposed to use these particular chemicals in quantities higher than certain specified threshold levels. The Government will then be in a position to intervene should discharges of any of these chemicals appear likely to rise to worrying levels anywhere on the U.K. Continental Shelf.

TABLE A-1

ESTIMATED QUANTITIES OF CHEMICALS USED ON U.K. CONTINENTAL SHELF DURING 1980

	Tons
Weighting Agents and Inorganic Gelling Products	120,000
Inorganic Chemicals	16,200
Lost Circulation Materials	650
Lignosulphonates, lignites, etc.	2,070
Polymeric Viscosifiers and Filtrate Reducers	4,430
Asphalts and Asphalt-based products	550
Defoamers, Biocides, Corrosion Inhibitors, etc.	1,650
TOTAL	145,550

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