Fate and Effects of Whole Drilling Fluids and Fluid Components in Terrestrial and Freshwater Ecosystems: A Literature Review

Battelle Columbus Labs., OH

Prepared for

Environmental Research Lab.
Gulf Breeze, FL

May 81

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
NTIS®

EPA 600/4-81-031
May 1981

PB81-197766

FATE AND EFFECTS OF WHOLE DRILLING FLUIDS AND FLUID COMPONENTS IN TERRESTRIAL AND FRESHWATER ECOSYSTEMS: A LITERATURE REVIEW

to

U.S. ENVIRONMENTAL PROTECTION AGENCY

March 13, 1981

by

John G. Ferrante

BATTELLE
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/4-81-031	2. PROJECT REPORT	3. RECIPII PB81-197766

4. TITLE AND SUBTITLE Fate and Effects of Whole Drilling Fluids and Fluid Components in Terrestrial and Freshwater Ecosystems: A Literature Review	5. REPORT DATE May 1981 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) John G. Ferrante	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO. CAKN1C 11. CONTRACT/GRANT NO. CR-68-02-3169
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency Office of Research and Development Environmental Research Laboratory Gulf Breeze, Florida	13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE EPA/600-04

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Drilling fluids represent an important aspect of offshore and land based drilling operations. The fluids perform a multiplicity of functions, ranging from lubricating to prevention of blowouts when encountering high pressure. Periodically, the fluids must be changed or they become old and the spent fluids are disposed of in on-land facilities. Introduction into the environment of the chemically complex fluids has prompted e-fects research addressing terrestrial and freshwater habitats and their respective biological components.

Studies with terrestrial plants in laboratory and field experiments show that the fluids and some fluid components exhibit phytoxicity properties reducing seed germination, growth and yield. Phytotoxicity in whole drilling fluids is attributed to soluble salt concentrations.

Perference/avoidance reactions were observed in experiments with whole drilling fluids are also collated and discussed. The range of lethal concentrations of fluid components in toxicity studies was from < 1 to 75,000 mg/l and that for whole drilling fluids from 0.29 to 85% by volume. Various reasons for observed toxicity are discussed and recommendations made for future freshwater and terrestrial research with drilling fluids.

17. KEY WORDS AND DOCUMENT ANALYSIS

DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT Release to public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

ABSTRACT

Drilling fluids represent an important aspect of offshore and land based drilling operations. The fluids perform a multiplicity of functions, ranging from lubricating to prevention of blowouts when encountering high pressure. Periodically, the fluids must be changed or they become old and the spent fluids are disposed of in on-land facilities. Introduction into the environment of the chemically complex fluids has prompted effects research addressing terrestrial and freshwater habitats and their respective biological components.

Studies with terrestrial plants in laboratory and field experiments show that the fluids and some fluid components exhibit phytotoxicity properties reducing seed germination, growth and yield. Phytotoxicity in whole drilling fluids is attributed to soluble salt concentrations.

Preference/avoidance reactions were observed in experiments with whole drilling fluids using fish. The toxic properties of fluids components and whole drilling fluids are also collated and discussed. The range of lethal concentrations of fluid components in toxicity studies was from < 1 to 75,000 mg/l and that for whole drilling fluids from 0.29 to 85 % by volume. Various reasons for observed toxicity are discussed and recommendations made for future freshwater and terrestrial research with drilling fluids.

ACKNOWLEDGMENTS

I am indebted to Evan Berchard of Imperial Oil Limited and Dennis G. Wright from the Freshwater Institute, Winnipeg for their assistance in collating studies conducted in Canada. I wish also to thank Jerry Neff from the Battelle Duxbury laboratory for identifying appropriate estuarine and marine drilling fluids studies which were included in the appendix of this report.

This study was funded by the U.S. Environmental Protection Agency and I particularly wish to thank those individuals at the Gulf Breeze Laboratory who aided in the successful completion of this review.

TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

The most modern drilling method is the rotary system which requires a circulation of drilling fluid through the well bore while drilling proceeds. The drilling fluids are pumped from the ground surface through a drill pipe and bit to the bottom of the hole and returned through the annulus between the hole and the drill pipe.

Drilling fluid - mud - is usually a mixture of water, clay, weighting material and variety of chemicals to adjust the properties of the fluid to meet requirements of each well. Drilling fluid is a major factor in the success of the drilling program. It is used in offshore and land based operations and functions:

1. To remove the cuttings from the bottom of the hole and carry them to the surface.
2. To transmit hydraulic horsepower to the drill bit.
3. To cool and lubricate the drill string and bit.
4. To exert sufficient hydrostatic pressure to control fluids and pressure encountered in formations.
5. To minimize settling of cuttings and weight material in suspension when circulation is temporarily stopped. The mud, however, should have properties which allow the cuttings to settle in the surface system.
6. To support and protect the walls of the hole.
7. To reduce to a minimum any harm to the formations penetrated.
8. To insure maximum information about the formations penetrated.

Because of the multiple demands on the fluid it is not surprising that over 600 brand name additives are on the market for use in preparing drilling muds (Shaw 75). These "additives" can be categorized into four main groups, i.e., cooling and lubricating the drills, flotation of rock cuttings, sealing porous layers of the geologic strata, and solving various other problems. Common cooling and lubricating components are the fluid base itself (usually water), sodium saturated bentonite clays, and for high temperatures, diesel oil. Organic polymers, carboxymethyl cellulose and polyacrylates are also sometimes used.

For removing cuttings from the hole a denser (heavier) fluid than water is usually used. The material most widely used is barite (barium sulfate) which has a density of 4. Two other weighting materials that are less frequently used are calcite (calcium carbonate) and siderite (iron carbonate).

As drilling penetrates sandstones or shales drilling fluid may be lost in excessive amounts unless the porous area is sealed. Flocculation of clays and inclusion of fibers of some type is the usual approach to sealing formations. A variety of chemicals and mixtures are used for this purpose some of which are: calcium chloride, calcium sulfate, calcium oxide, calcium lignosulfonate, sodium chloride, sodium silicate, colloidal asphalt, sulfonated asphalt, polyanionic cellulose, gilsonite and aluminum lignosulfonate.

The fourth category "solving other problems" involves controlling four mechanical or physical properties: (1) density, (2) viscosity, (3) gel strength, and (4) filtration. The main specific problems addressed by these properties are:

1. Contamination
2. Abnormal Pressure
3. Corrosion
4. Formation
5. Mud Characteristics
6. Slow Drilling Rate
7. High Temperature
8. Bearing Failure

Each problem is handled by altering the physical nature of (dilution, raise weight, adjust flow properties, etc.) or chemical nature (adjust pH, add chemical additives) of the drilling fluid (IACD 1974).

An entire "science" has developed around drilling fluids and their use in the petroleum industry. This brief introduction is meant only to serve as an indication of the physical and chemical complexities one must be aware of when addressing the fate and effects of drilling fluids (muds) in the environment.

FATE AND EXPOSURE

Disposal Practices

Drilling fluids become contaminated, old or must be replaced because of down-hole conditions, therefore, the fluids are disposed of periodically. On-land when drilling operations are completed the active mud system may be jetted into a reserve pit (pond constructed on-site) and the active pits filled. The reserve pit (which may hold up to 100,000 barrels per site) is allowed to evaporate until it is dry, the retaining walls leveled and the contents of the reserve pit are spread and graded, (Specken 1975, Allred 1980). Although practices vary with geographical location the disposal of drilling wastes is usually by one of the following methods:

1. Dewatering of the reserve pit contents and subsequent backfilling with pit walls (example described above).
2. Landfarming the reserve pit contents into the soils around the drilling location.
3. Removal by trucks to other sites.
4. Pump wastes back down the well annulus.
5. Chemically modify the waste into a dry, inert substance.

The most common practice for fluid disposal is included in the first two options. Unlike offshore marine drilling operations, disposal of offshore drilling fluids from freshwater operations is usually accomplished by transporting the fluids to shore where they are handled as described above.

Surface and Groundwater Contamination

The introduction of drilling fluids into the environment is limited to accidental releases and disposal in terrestrial sites. Although little drilling is presently being done in freshwater lakes, drilling muds and cuttings generated during their operations are usually transported to shore and disposed of on land.

Drilling wastes can be considered pollutants primarily because they contain high concentrations of organic carbon, total nitrogen, phosphorous, solids, chemical oxygen demand, and metals (Bryant et. al. 1974). Shaw and Keeley (1975) discussed the potential for polluting subsurface water supplies through drilling and subsequent contamination and Shaw (1975) outlined sampling and testing methods for toxicity studies with drilling fluids.

The contamination of surface water can be considered from both surface activities and also from contamination of groundwater from the borehole (Campbell and Gray 1975). The contamination of groundwater is important since many surface water habitats have an ultimate hydraulic connection with groundwater aquifers.

Aquifiers can be contaminated from stream runoff, abandoned wells, percolation of spilled muds, discarded materials, and leaching of fluids from earthen pits. One of the worst and widespread problems in drilling is lost circulation and subsequent contamination of aquifers. Lost circulation results from openings in the formation large enough to accept whole mud. While drilling with water seepage may occur into porous, permeable formations exposed to the borehole. Finally, through a blowout uncontrolled entry of fluids into the borehole may force gas into shallow aquifers and cause water wells to be contaminated (Campbell and Gray 1975).

The contamination of soils, surface water and groundwater is a source of impact to both plants and animals. A discussion of adverse impacts of drilling fluid components and whole drilling fluids on plants and animals will be addressed in the following discussion.

Throughout the remainder of the discussion the terminology drilling fluids and drilling muds will be used interchangeably and will refer to the material used during drilling operations. Sump fluids, although composed primarily of drilling muds, may also contain rig wash, fuels, lubricating oils, etc. from rig operations. Studies performed with sump fluids will be so designated.

The toxicity and impact of drilling fluids can only be evaluated on the basis of its availability for reactions with biota. Because drilling muds and sump fluids, containing muds, are often incorporated into the soils adjacent to the well site (Allred 1980), consideration must be given to the bioavailability of potentially toxic components to plant species. Nelson et. al. (1980) addressed this question in laboratory studies with prepared drilling muds one containing barite low in toxic metals and the other having significant levels of Hg, Zn, Pb, Cd, Cu, and As. Their results suggest that the uptake of Cd, Zn, Cu, and Pb and concentration in the leafy portions of plants was directly related to the total amount of these metals in the rooting medium. Mercury found in the muds was not available to the plants. However, this study suggests that some metals (e.g., Cd, Zn, Cu and Pb) present in drilling muds are available for plant uptake and accumulation.

The exposure of aquatic biota to toxic chemical components of drilling muds released from offshore drilling operations in freshwater lakes has not been studied in detail. Ferrante et. al. (1980) studied the discharge plume from an offshore rig in Lake Erie. Although only small amounts of mud were discharged during drilling operations, plume dynamics were monitored and particulate discharges tracked. The plume configurations indicated that the fine clay sized particulate remained in the uppermost portion of the water column (0-4 m) and had a tendency to "river"; that is, remain together in a defined plume strung out in a down-current direction from the rig. Additional data from modeling efforts during the study suggested that larger particulates discharged tended to settle out in increasing distances depending upon particle size. Chemical constituents of the discharged fluids were also followed in the plume survey. Dilution of most chemicals was rapid with ambient concentrations being reached within 100 m of the discharge. Exposure to toxic materials may thus be limited to a relatively small area immediately around the rig. However, the behavior of some fish species to turbidity suggests that the discharge plume may act as an attractor (Lawrence and Scherer, 1974). This phenomena needs to be studied in detail before an exposure factor can be determined.

IMPACTS: INDIVIDUAL DRILLING FLUIDS COMPONENTS

Several approaches have been followed by investigators in determining the toxicity of drilling fluids to plant and animal species. Each approach depends on the form of the material which the experimental organism is exposed. The three distinct categories evident in literature are: exposure to individual drilling fluid components, exposure to a prepared (fresh) drilling fluid, and exposure to drilling fluids collected during drilling operations or immediately following (Tables 1 and 2).

Plants

A limited number of studies with drilling fluid components have been performed using terrestrial plants. Initial studies by Miller (1978) on drilling mud components indicated that a number of these components: asbestos, asphalt, a vinyl acetate, maleic anhydride co-polymers, bentonite clay, sodium polyacrylate, an ethoxylated nonyl phenol, a gilsonite paraformaldehyde, Dow-made, shell-supplied polymer, acid pyrophosphate, and sodium carboxymethyl cellulose caused slight reductions in yield or no effect at all when tested on beans and corn. Barite, modified tannin, filming amine, xanthum gum, lignite, modified asphalt and sulfonated tall oil had a more obvious effect reducing yield of experimental plant species.

Using high/excess addition rates of soil-mud , Miller observed significant reductions in yield when modified tannin, a non-fermenting starch, pregelatinized starch, iron chrome lignosulfonate, guar gum and a synthetic and natural plant fiber were tested. The most severe reductions were observed when sodium dichromate, diesel oil, potassium chloride or a mixture of calcium lignosulfonate and lignite were used.

Phytotoxicity studies reported in Miller and Honarvar (1975) and Miller et. al. (1980), showed similar results for 31 drilling mud components. Corn and beans were exposed to high and low rates of applications. The low rate was typical of field concentrations. Of the 31 components tested 10 caused a reduction in growth of both plant species, 1 caused increased plant growth of the beans. Four affected (other than growth) both beans and corn,

TABLE 1. SUMMARY: MAJOR STUDIES OF WHOLE DRILLING FLUIDS, WHOLE SUMP FLUIDS AND DRILLING FLUID COMPONENT EFFECTS ON PLANT AND ANIMAL SPECIES

Authors	Year	Test Organism	Test Fluid	Test Effect	Effect Notation	Test
			<u>Plants</u>			
Honarvar	1975	Beans and sweet corn	Drilling fluids components	Phytotoxicity	% yield	--
Miller and Honarvar	1975	Beans and sweet corn	Drilling fluids components	Phytotoxicity	Relative growth	--
Pesaran	1977	Beans and sweet corn	Drilling fluid mixture	Phytotoxicity	Seed germination/ relative growth	--
Miller and Pesaran	1980	Beans and sweet corn	Whole drilling fluids	Phytotoxicity	% yield	--
Miller et. al.	1980	Beans and sweet corn	Drilling fluids components	Phytotoxicity	Relative growth	--
Yonkin and Johnson	1980	Natural asemblage	Whole drilling and sump fluids	Seed germination and plant productivity	% seed germination and growth	<u>in situ</u>

TABLE 1 (Continued). SUMMARY: MAJOR STUDIES OF WHOLE DRILLING FLUIDS, WHOLE SUMP FLUIDS AND DRILLING FLUID COMPONENT EFFECTS ON PLANT AND ANIMAL SPECIES

Authors	Year	Test Organism	Test Fluid	Test Effect	Effect Notation	Test
Animals						
Falk and Lawrence	1973	9-spine stickleback Lake Chubb	Whole sump fluids	Mortality	96 hour LC50 (% vol.)	Static/ *in situ*
Logan	1973	Rainbow trout	Whole drilling fluids and components	Mortality	96 hour LC50 (% vol. and mg/l)	Static
Lawrence and Scherer	1974	Whitefish and Rainbow trout	Whole drilling fluids and supernatant	Avoidance behavior	Preference/ avoidance	Flow-through
Beak Consultants	1974	Rainbow trout	Whole drilling fluids	Mortality	96 hour LC50 (% vol.)	Static
Didiuk and Wright	1975	Chironomid	Whole sump fluid	Larval survival	% emergence	Static
Weir and Moore	1975	Rainbow trout	Whole drilling fluids	Mortality	96 hour Lc50 (% vol.)	Static
Hollingsworth and Lockhart	1975	Sailfin Molly	Drilling fluids components	Mortality	MTL (ppm)	Static
Moore et. al.	1976	Rainbow trout	Whole drilling fluids	Mortality	96 hour LC50 (% vol.)	Static
Weir et. al.	1976	Rainbow trout	Whole sump fluids	Mortality	96 hour LC50 (% vol.)	Static
Hardin	1976	Phytoplankton amphipods 9-spine stickleback	Whole sump fluids	Mortality	96 hour LC50 (% vol.)	Static

TABLE 1 (Continued). SUMMARY: MAJOR STUDIES OF WHOLE DRILLING FLUIDS, WHOLE SUMP FLUIDS AND DRILLING FLUID COMPONENT EFFECTS ON PLANT AND ANIMAL SPECIES

Authors	Year	Test Organism	Test Fluid	Test Effect	Effect Notation	Test
Sprague and Logan	1976	Rainbow trout	Drilling fluids components	Mortality	96 hour LC50 (% vol. and mg/l)	Static
Beckett et. al.	1976	Rainbow trout	Drilling fluids components	Mortality	96 hour LC50 (mg/l)	Static
Lawrence	1980	Natural Assemblage	Whole sump fluids	Behavior/ mortality	Observations	_In situ_
Logan	1980	Rainbow trout	Whole drilling fluids	Mortaity	96 hour LC50 (% vol.)	Static

TABLE 2. TOXICITY OF DRILLING FLUID COMPONENTS TO RAINBOW TROUT (*Salmo gairdneri*)

Drilling Fluid Component	96 Hour LC50 (mg/L)		
	Beckett et. al. (1976)	Logan et. al. (1973)	Sprague and Logan (1979)
Aluminum stearate	1100		
Barafloc	800		
Barite	Random; >10,000	>7500	76,000
Ben-Ex (polymer)	1300	665	660
Carbonox (lignetic material)	6500		
Cypan (sodium polyacrylates)	1200-1300		
Desco (organic thinner)	1200		
Dextrid (organic polymer)	<1		
DFE-506 normal	250		
neutralized	3500		
Diammonium phosphate	950		
Dowicide-B	0.75		
Drillaid 421	280-550		
Drispac (polyanionic cellulose)	2700-2800		
FLR-100	2200-4000		>1000
Hydrogel (Wyoming bentonite)	7200		
Kelzan XC polymer (xanthum gum biopolymer)	1800-2200	440	420[a]
Kwik-vis	1600		
Mil-Flo	600		
Muriate	2100		
Peltex • normal (ferrochrome lignosulfonate)	560-840		
• neutralized	>3200		
Protectomagic (asphalt)	5000-75,000		
Q Broxin (ferrochrome lignosulfonate)	1500-2000	1530	1500
Rapidril (organic polymer)	550		

TABLE 2. TOXICITY OF DRILLING FLUID COMPONENTS TO RAINBOW TROUT (*Salmo gairdneri*) (Continued)

	96 Hour LC50 (mg/L)		
Drilling Fluid Component	Beckett et. al. (1976)	Logan et. al. (1973)	Sprague and Logan (1979)
Salt mud (attapulgite clay)	23,500		
Sodium acid pyrophosphate	1700		840
Spersene (chrome lignosulfonate)	2500-5000		
Unical (chrome mod. sodium lignosulfonate)	860		
Visbestos (inorganic emulsion mud)	2750		
Walnut shells	2800		
Bentonite clay		>10,500	19,000
Carboxymethyl cellulose		>10,500	>10,000
Torq-Trim (sulphated triglycerides, alephetic and isopropyl alcohols			1300[a]
Sta flo			>1000
SS-100			>1000
Chromolit (potassium chromic sulphate)			750[a]
Metso beads			240[a]
Caustic (NaOH)		105	110
Tri-Cron (dihydroxy-propane and alkyl auryl sulphonates)			75[a]
Capryl alcohol			75[a]
Paraformaldehyde			60
Skot-Free			48
Potassium chloride		2020	
Sodium bicarbonate		7550	
Calcium chloride		>10,500	
B-Free			18

[a] Interpolated

but six others affected only one of the species. Examples of affects observed during testing are reduction in growth, decrease in germination, and dropping of leaves. The most toxic compounds tested, listed in order of severity of affect were: potassium chloride > lignite > calcium lignosulfonate > diesel oil.

Aquatic Animals

The purpose of a number of toxicity studies performed with aquatic animals was to acquire information on the toxicity of drilling fluids components in the aquatic environment (Falk and Lawrence 1973, Hollingsworth and Lockhart 1975, Beckett et. al. 1976, Sprague and Logan 1979, and Logan 1980). Emphasis in these studies was often placed on the toxicity to a sensitive freshwater fish species, usually rainbow trout (Salmo gairdneri). Several of the studies also addressed more specific questions such as: the effect of ageing on the toxicity of the most lethal chemicals (Sprague and Logan 1980), toxicity of specific compounds, e.g., thinning agents (Hollingsworth and Lockhart 1975), and predictability of toxic interactions of chemical components in standard drilling fluids (Sprague and Logan 1979).

Testing protocols varied with 96 hours static testing the "normal" approach although some investigators chose to adjust pH, stir or circulate continuously, and aerate throughout the test. Acute lethal toxicity tests by Logan et. al. (1973) (appendix to Falk and Lawrence 1973) indicated that almost half (13 of 27) of the mud components they tested were toxic with LC50's < 1000 ppm. Of the 13 compounds tested, 7 were very toxic and 6 were moderately toxic. Acute toxicities of 34 drilling fluid components (Table 2) tested with rainbow trout (Beckett et. al. 1976) ranged from < 1 mg/L to > 50,000 mg/L. In general, the organic polymers were extremely viscous and at high viscosities fish apparently were unable to circulate the material past the gills and mortality was due to suffocation. The inert soils such as clay tend to dissociate to some degree and it is possible that this chemical activity may be due to the addition of impurities from the manufacturing process. Observed acute affects with lignosulfonate compounds may be the result of acidic pH. The authors suggest that the acute toxicity of the components fall under two categories, i.e., physical action such as high viscosity and suspended solids, and chemical action such as extreme pH and heavy metals.

Sprague and Logan (1979) observed in their studies that many of the organic materials (CMC, Ben-Ex, Kelzan-XC, SS-100, FLR-100 and Staflo) had relatively low toxicity and used in small quantities would not contribute to a serious environmental problem. However, paraformaldehyde, capryl alcohol and 5 of the 7 surfactants tested were fairly toxic with LC50 values < 100 mg/L.

In an additional aspect of their study, Sprague and Logan found no single pattern of joint action (calculated on the asumption that toxicities of individual components were additive). The additive action was approximately one half the results for single components. Less than additive toxicity was shown for 7 components in simulated drilling fluid and antagonism was demonstrated in 9 of 21 bioassays with single components added to simulated fluids.

In studies by Logan (1976, 1980) rainbow trout were tested in bioassays with ferrochrome lignosulfonate, torq-trim, sodium acid pyrophosphate, chromolet, Ben-Ex, Helzon-XC, caustic, capryl alcohol, Tri-Con, paraformaldehyde, Scot-Free, and B-Free. Five components: capryl alcohol, Tri-Con, paraformaldehyde, Scot-Free and B-Free had 96 hour LC50 values < 100 mg/L. The remaining chemicals had 96 hour LC50 values between 105-2270 mg/L.

Ageing of the various chemical components for 16 days eliminated or substantially reduced the toxicity of 5 of these 6 chemicals. The exception was B-Free where the median effective time (ET 50) was reduced to 4.6 hours from 930 hours.

In a more specific study, Hollingsworth and Lockhart (1975) studied the toxicity of thinning agents on sailfin molly (Mollienesia latipinna). Because of the importance and extensive use in the drilling industry lignosulfonates were tested along with phosphates, tannins, and lignites. Of the compounds tested the tannin class had considerably lower median tolerance limits than any of the other products. An example of a widely used tannin is quebracho. The suspected cause of the toxic response to this class is the oxygen scavenging characteristics of tannin. It is interesting to note that chrome lignosulfonate and ferrochrome lignosulfonate were the least toxic in freshwater and marine experiments. Lignosulfonate compounds are the most widely used thinning agents today. For a more detailed discussion of the effects of selected components, see Land (1974).

IMPACTS: WHOLE DRILLING FLUIDS

Plants

Few studies have been published on the effects of whole drilling fluids on plant growth or changes in natural vegetation as a result of exposure to drilling fluids, although brief observations have been recorded at disposal sites or adjacent to drilling sumps (Smith and James 1980). Most information about the effects of drilling fluids on plants has been deduced from studies other than those using the fluids themselves. Bryant and Hrudey (1976) discussed the toxicity of drilling mud components based on chemistry derived from the literature.

Two master's theses from Utah State University, Honarvar (1975) and Pesaran (1977b), and a study by Miller and Pesaran (1980) provide the majority of useful information about the effect of drilling fluid mixtures on plants. The conclusions of the three investigations are similar indicating that fluids containing specific chemical components inhibit plant growth.

In general, the major inhibiting effect of drilling fluids which reduced plant growth is the result of excess soluble salt and exchangeable sodium. Large amounts of potassium chloride, in potassium chloride muds, is a good example and sodium salts (sodium-dichromate and sodium hydroxide) added in lesser amounts also reduced growth. Pesaran (1977b) also found that muds that contained diesel oil inhibited growth, however, he observed this effect to be temporary.

Six of the seven muds tested by Miller and Pesaran (1980) contained sodium hydroxide in appreciable amounts. The inhibitory effects of these muds was attributed to the destruction of soil aggregation by the excess sodium. The muds rendered the soils impermeable or slowly permeable which were poorly aerated when wet and hard and structureless when dry.

The effects of drilling muds depends on the soil type. Drilling muds will be least detrimental on acidic, leached soils high in organic matter and most detrimental on alkaline loam to claying soils (Pesaran 1977a). When drilling muds which have alkaline pH values are added to strongly acid soils, there may be a beneficial effect on plant growth because of increased soil pH (Miller and Pesaran 1980).

The impact of waste drilling fluids (sump fluids) on soils and vegetation was studied in field plots of natural plant assemblages (Yonkin and Johnson 1980). In this investigation, field studies were conducted using the three basic drilling fluids used in Alberta, Canada, ie., potassium chloride, dispersed water gel and flocculated water gel.

Sump fluids derived from potassium chloride water-polymer muds had the highest salt concentration (up to 33,000 ppm anions and cations) and were most potentially harmful to soils and vegetation. Additional laboratory studies with these fluids also showed a significant reduction in seed germination. Fluids from freshwater gel drilling muds contained considerably lower concentrations of salt (up to 2055 ppm anions and cations) and exhibited significantly lower effects. The authors suggest that plant damage was related to direct contact and uptake of fluid components. Salt content of the sump fluids was most damaging to plant growth followed by diesel fuel. These results agree with those of Pesaran (1977b) and Miller and Pesaran (1980) and provide the added dimension of being conducted in the field with natural assemblages of vegetation.

Aquatic Animals

Freshwater amphipods, insects and fish have been used to study the toxicological properties of whole drilling fluids. Qualitative investigations such as Granthum and Sloan (1975), Hardin (1976), Shaw (1975), and Zitko (1975) offer insight into general effects of drilling and sump fluids on aquatic species.

A number of studies have been conducted to define the lethal threshold beyond which the normal functions of an organism, as well as its survival, are adversely affected. A range of responses has been observed from behavioral studies with individual species (Lawrence and Scherer 1974), community response to drilling fluid discharge in a body of water (Lawrence 1980), survival and emergence of chironomid (Didiuk 1975, Didiuk and Wright 1976) to lethality (Logan 1980, Moore et. al. 1976, Beak Consultants 1974, Weir et. al. 1976, Weir and Moore 1975, Logan 1973, and Falk and Lawrence 1973).

Sublethal responses of whitefish and rainbow trout to drilling fluids and the supernatant fraction showed that whitefish were attracted to suspensions with increasing concentration over the concentration range tested (1-1000 μl/l). Visual perceived turbidity was speculated as one causal element in attracting this species (Lawrence and Scherer 1974). Rainbow trout exposed to the same range of mud suspension exhibited somewhat of a different response. Up to concentrations of 100 μl/l the fish showed a neutral response, however, at concentrations of 1000 μl/l, the trout shifted to a preference response. Drilling fluid supernatant elicited a biphasic response in both species, i.e., an initial attraction followed by avoidance at higher concentrations.

It has been shown by Herbert and Merkens (1961) that irritation of gell epithelium by suspended solids may not lead to a lethal stage in fish within 4 days (96 hours). However, mortality can occur abruptly after a long latency. This raises the question: Will whitefish and rainbow trout maintain their preference for mud suspensions at concentrations between 1000 μl/l and "lethal levels" (LC50 whitefish - 25,000 μl/l, rainbow trout 75,000 μl/l) and in essence be living in a "death trap"?

In a field study of some effects of drilling wastes on a small subarctic lake, Lawrence (1980) found no mortality to whitefish or nine spine sticklebacks that could be attributed to the sump fluid disposal. In fact, the author suggested that the movement of fish in and out of the lake was unchanged even though he measured an increase in turbidity, conductivity, alkalinity, total hardness, total iron, aluminum, chloride and sulfate ions. Although Lawrence observed a decrease in benthic biomass throughout the study the response was not uniform. For example, chironomid larvae decreased in abundance within 25 m of the outfall while nematodes and oligochaetes increased in abundance.

The decrease in chironomid larvae in response to drilling fluids, observed by Lawrence (1980), is consistant with observations by Didiuk and Wright (1976). Their study focused on the effects of deposition of thin (1, 3 and 7 mm) layers of drilling wastes on the survival of larvae of the chironomid, Chironomus titans, using emergence of adults as an index of survival. The authors found an inverse relationship between the thickness of mud and the percent emergence, i.e., control 84%, 1 mm - 61%, 3 mm - 47% and 12 mm - 12%. These results suggest that the mud represents a physical barrier to burrow construction and perturbation of feeding mechanisms. In addition, the authors postulated that delays in growth may result from large amounts of energy used for food gathering that could have been used for growth.

Qualitative studies are usually non-specific and can be compared in general terms, however, lethality studies are quantitative in nature and are usually defined by LC50, LD50 or TLM values. Table 3 lists ranges of 96 hour LC50 values of whole drilling muds on rainbow trout. The six studies cited provide values that range from very toxic (0.29 % fluid by volume) to relatively non toxic (85 % by volume). The studies by Moore et. al. (1976) and Weir and Moore (1975) indicate a wide range, 0.29-85 % and 9-70 % (by volume), respectively. In both studies drilling fluid was collected at various depths during drilling operations. In both studies the toxicity was related to changes in fluid composition from addition of components, in response to drilling conditions at various depths, and downhole contamination. The acute toxicity of the drilling fluids tested was directly related to the type of mud system used. Weir and Moore (1975) found that the toxicity of the drilling fluids collected while drilling near the surface (3000 feet) to be very high with LC50 values approximately 10 % by volume. The authors speculate that the toxicity was due to high chloride, calcium and conductivity from the potassium chloride-gel-polymer mud being used. From 4000-9000 feet, the fluids (unweighted gel-polymer mud) were moderately toxic, 5-6 fold decrease below that for the 3000 feet mud. The third mud system (weighted gel-barite system) used from 10,000-13,000 feet exhibited an increase in acute toxicity, LC50 9-16 % by volume.

A similar relationship was observed by Beak Consultants (1974) with LC50 values varying with depth of fluid collection, 4000 feet - 9.8 %, 6000 feet - 5.0 %, 7000 feet - 26 % and 8000 feet - 25 %. Along with the relation-

TABLE 3. TOXICITY OF WHOLE DRILLING FLUIDS TO RAINBOW TROUT (*Salmo gairdneri*)

Study	96 Hour LC50 (% by volume)
Moore et. al. (1976)	85 - 0.29[a]
Weir et. al. (1976)	59 - 3.23
Weir and Moore (1975)	70 - 9[b]
Lawrence and Scherer (1974)	7.5 - 4.2[c]
Beak Consultants (1974)	25 - 5
Logan et. al. (1973)	5.3 - 83

[a] Wide range due to changes in components used during drilling specific formations.

[b] Toxicity dependent upon depth of hole when sample collected.

[c] Calculated using the factor μl/l x 10^{-4}

ship of depth (fluid chemistry) and toxicity, the authors also concluded that the toxicity was due to mud components, drilled solids did not effect the toxicity as much as components added. They also suggest that the toxicity resulted from metallic ions the source of which was barite and lignosulfonate.

The drilling fluid studies conducted by Falk and Lawrence (1973) were used to acquire information on the nature and amounts of drilling fluid compounds used, the efficiency of waste containment facilities and the toxicity of drilling fluids. Test animals (on site - lake chub and rainbow trout, laboratory - 9-spine stickleback) were exposed to sump fluids, composite sump fluids and drilling fluids. Drilling fluids were found to be acutely toxic with 96 hour LC50 values of 0.83 to 12.0 % by volume for lake chubb and rainbow trout. Sump fluids were comparatively less toxic with one sump yielding 96 hour LC50 of 22.5 and 81 % (by volume) for composite and surface sump fluids, respectively.

Finally, Moore et. al. (1976) concluded that both fluid components used <u>and</u> the formation drilled contributed to the overall toxicity of the mud samples tested. A great amount of variability in toxicity was related to the individual areas drilled, company and rig practices and conditions encountered. Four major sources of toxicity were identified; metal chlorides (e.g., potassium chloride), solids (e.g., barite), viscosity and speciality products (e.g., bactericides, rust inhibitors, crosslinking agents, alcohol defoamers, etc.). The only pattern which emerged from the data collected was that the overall toxicity of each sample was a result of the components in use at that particular time and the formation being drilled.

It is recognized that additional data may be found in large comprehensive reports which contain bioasay investigations as a small part of an overall assessment. No attempt was made to collate this data into the present report since most of the experiments were focused on very specific needs and would not add significantly to this report. In addition, it is also recognized that many petroleum companies and drilling fluid manufacturing companies have toxicity data, however, most of this information is proprietory and not available to the open literature.

SUMMARY

Drilling fluids are used in rotary drilling offshore and in land based operations. The fluids serve in a multiplicity of functions from lubrication to aiding in well logging operations. because of this wide range of functions drilling fluids are required to perform under extreme conditions yet must be sufficiently stable to maintain fluid integrity. Over 600 drilling fluids components are presently available for use in adjusting fluid characteristics to meet the needs of each drilling operation.

Drilling fluids get old and requirements change during the drilling of a well, thus, spent fluids are usually disposed of in a reserve pit on-site or in a designated disposal area. Both offshore (freshwater) and land based drilling operations dispose of spent drilling wastes in on-land facilities.

The introduction of these spent drilling fluids into the environment is a result of drilling mishaps and migration of liquid wastes from disposal sites. The resulting concern for environmental perturbation prompted effects research on drilling fluids components, whole drilling fluids and sump wastes.

Drilling fluids move through the environment in stream runoff, percolation through soils and groundwater aquifers. Metal uptake from drilling fluids, by plants has been shown to have a direct relationship with the concentration of the metals in rooting medium. The movement of discharged material in a lake from offshore drilling operations suggests that dilution is rapid and exposure to potentially toxic concentrations of chemicals is probably limited to a relatively small area adjacent to rig.

In terrestrial studies drilling fluid components, whole fluids and sump wastes have been shown to decrease seed germination, reduce growth and yields. In whole fluid experiments, the toxic component in each of the plant studies was postulated to be the salt content of the fluids.

Investigations involving fluids and aquatic organisms show a variety of toxicities depending on the component tested. In general, however, testing with rainbow trout showed some consistancy between investigations with a range of LC50 values from < 1 to 75,000 mg/l. Whole drilling fluids also showed a wide range of variability (0.29 to 85 mg/l) which was attributed in some

studies to the changing fluid composition purposefully altered to meet fluid requirements at various depths during drilling.

Preference/avoidance behavior has been observed with several fish species under varying concentrations of whole drilling fluids and fluid supernatant. The results of these studies suggest a preference by the fish for high suspended solids.

Several authors, Beckett et. al. (1976) and Beak Consultants (1974) differ in their causual evaluation of toxic effects of fluids on rainbow trout. The former attributing effects to physical and chemical characteristics of experimental fluids, the later indicating little effect from suspended solids. The potential impact of suspended solids was speculated that these solids (turbidity) may represent a "death trap" since they attract some species but potentially may cause latent mortality from gill damage (Falk and Lawrence 1973).

In general, studies with drilling fluid components and whole drilling fluids show a consistancy in toxicity testing. All of the studies show that some drilling components and whole drilling fluids are toxic to plant or animal species.

CRITIQUE AND RECOMMENDATIONS

In general, the data generated on the effects of drilling fluids and fluid components represents a good base for assessments of potential environmental perturbation. However, comparisons between data bases is somewhat questionable since in some studies pre-alteration of the test material (e.g., adjusting the pH) took place while in others unaltered fluids and components were used. Several bioassay studies were performed where aeration or resuspension of the fluids was accomplished throughout the study. The effect of this on the results, when compared to strictly static experiments, is unknown.

A problem one faces in evaluating toxicity data is the lack in uniformity of specific testing protocols, the variety of test organisms used, and the dimensions used in expressing toxicity values. The latter presents difficult problems when comparing test results by independent researchers, even though the compounds used are the same. This problem is even more exaggerated in the testing of whole muds and mud mixtures.

Interpolation of whole fluids toxicity from individual component studies has also been shown to be highly questionable, thus, making whole drilling fluids the prefered method. Confusion between some toxicity results is a function of interpretation of the data and should be scrutinized closely and compared with the corresponding data.

A hazard assessment for drilling fluids must include both effects and exposure components. Most of the data collected thus far has been on effects; the exposure component has been sadly neglected in freshwater and terrestrial research. The role that preference/avoidance behavior has in toxicity testing must be determined before extrapolation of _in vitro_ testing results can be made into the field with any confidence.

Additional _in situ_ studies are needed to determine community response to drilling wastes. We have seemingly generated sufficient toxicological information to say that drilling fluids and sump wastes represent a toxic pollutant in the environment. Toxicity data indicates that the obvious follow-up would be to conduct _in situ_ studies in freshwater and terrestrial habitats to determine the overall effect of these materials on the habitat and endemic biota. These studies integrate exposure, toxicity, behavior, and endemic species under exact environmental conditions. It seems unwise to rely so heavily on so few field studies and a number of laboratory experiments with components, the toxicity of which may not be additive, for decision making.

LITERATURE CITED

Allred, R. B. 1975. The handling and treating of water-based drilling muds. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. pp 491-502. U.S. EPA. EPA-560/1-75-004.

Beak Consultants. 1974. Disposal of Waste Drilling Fluids in the Canadian Arctic-Project C6006. Reports submitted to Imperial Oil Ltd., Edmonton, Alberta, Canada. pp 170.

Beckett, A., B. Moore, and R. H. Weir. 1976. Acute toxicity of drilling fluid components to rainbow trout. In: Industry/Government Working Group in Disposal Waste Fluids from Exploratory Drilling in the Canadian North. Yellowknife, N.W.T., Canada. Dept. of the Environment, Environmental Protection Service. Vol. 9, pp 88.

Bryant, W. J., J. Goldburn, and S. E. Hrudey. 1974. Water pollution aspects from waste drilling mud disposal in Canada's arctic. In: Proc. 1974 Offshore Technology Conf., pp 95-102. OTC. 2044 Houston, Tx.

Bryant, W. J. and S. E. Hrudey. 1976. Water pollution characteristics of drilling operations. In: Industry/Government Working Group in Disposal Waste Fluids from Petroleum Exploratory Drilling in the Canadian North. Yellowknife, N.W.T.; Canada. Dept. of the Environment, Environmental Protection Service. Vol. 3.

Campbell, M. D. and G. R. Gray. 1975. Mobility of well-drilling additives in the ground-water system. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. pp 261-284. U.S. EPA. EPA-560/1-75-004.

Didiuk, A. 1975. The effect of a drilling waste on the survival and emergence of the chronomid chironomus tentans (fabricius). Canada Fisheries and Marine Service. Tech. Rep. 586:pp 26.

Didiuk, A. and D. G. Wright. 1976. The effect of a drilling waste on the survival and emergence of the chironomid, chironomus tentans (fabriciues). Vol. 12. In: Industry/Government Working Group in Disposal Waste Fluids from Petroleum Exploratory Drilling in the Canadian North. Yellowknife, N.W.T., Canada. Dept. of the Environment, Environment Protection Service. Vol. 12. pp 19.

Falk, M. R. and M. J. Lawrence. 1973. Acute Toxicity of Petrochemical Drilling Fluids Components and Wastes to Fish. Tech. Rep. No. CENT-73-1. Fisheries and Marine Service, Freshwater Institute, Winnipeg, Manitoba, Canada. pp 108.

Ferrante, J. G., E. H. Dettman, and J. I. Parker. 1980. Natural Gas in Lake Erie: A Reconnassance Survey of Discharges From on Offshore Drilling Reg. ANL/ES-85, Argonne National Laboratory, Argonne, Il. pp 61.

Granthum, C. K. and J. P. Sloan. 1975. Toxicity study. Drilling fluid chemicals on aquatic life. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. pp 103-110. U.S. EPA. EPA-560/1-75-004.

Hardin, M. J. 1976. A preliminary study of the effects of oil well drilling sump fluid on some aquatic organisms of the Mackenzie Delta. In: Industry/ Government Working Group in Disposal Waste Fluids from Petroleum Exploratory Drilling in the Canadian North. Yellowknife, N.W.T., Canada. Dept. of the Environment, Environmental Protection Service. Vol. 11. pp 65.

Herbert, D.W.M. and J. C. Merkens. 1961. The effect of suspended mineral solids on the survival of trout. Air Water Pollut. 5:46-55.

Hollingsworth, J. W. and R. A. Lockhart. 1975. Fish toxicity of dispersed clay drilling mud deflocculants. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. pp 113-123. U.S. EPA. EPA-560/1/75-004.

Honarvar, S. 1975. Effect of drilling fluid components and mixtures on plants and soils. M.S. Thesis. U.S.U., Logan, Utah. pp 133

IADC. 1974. Drilling Manual. 9th edition. International Association of Drilling Contractors.

Land, B. 1974. The toxicity of drilling fluid components to aquatic biological systems. Canada Department of Environment. Fish Marine Service. Tech. Rep. No. 487. pp 33.

Lawrence, M. J. 1980. A study of some effects of drilling wastes on a small sub-arctic lake. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. (Abstract). Jan. 21-24. Lake Buena Vista, Fla.

Lawrence, M. and E. Scherer. 1974. Behavioral response of whitefish and rainbow trout to drilling fluids. Tech. Rep. No. 502. Fisheries and Marine Services. Freshwater Institute. Winnipeg, Maritoba, Canada. pp 47.

Logan, W. J. 1976. The toxicity of drilling fluids and their component chemicals to rainbow trout. M.S. Thesis. U. of Guilph. Guilph, Canada.

Logan, W. J. 1980. The toxicity of drilling fluids and their component chemicals to rainbow trout. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. (Abstract). Jan. 21-24, 1980. Lake Buena Vista, Fla.

Logan, W. F., J. B. Sprague, and B. D. Hicks. 1973. Acute lethal toxicity to trout of drilling fluids and their constituent chemicals as used in the Northwest Territories. pp 43-108. In: Falk, M. R. and M. J. Lawrence. Acute toxicity of petrochemical drilling fluid components and wastes to fish. Canada Dept. of Environment. Resource Management Branch. Technical Report No. CENT-73-1.

Miller, R. W. 1978. Effects of drilling fluid components and mixtures on plants and soils. Summary Report 1974-1977. Utah Agricultural Experiment Station. Logan, Utah. pp 39.

Miller, R. C., R. P. Britch, and R. V. Shafer. 1980. Physical aspects of disposal of drilling fluids and cuttings in shallow ice covered arctic seas. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 670-689. Jan. 21-24, 1980. Lake Buena Vista, Fla.

Miller, R. W. and S. Honarvar. 1975. Effect of drilling fluid component mixtures on plants and soils. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. pp 125-143. U.S. EPA. EPA-560/1-75-004.

Miller, R. W. and P. Pesaran. 1980. Effects of drilling fluids on soils and plants. II. Complete fluid mixtures. J. Environ. Qual. Vol. 9, No. 4. pp 552-556.

Moore, B., A. Beckett, and R. H. Weir. 1976. Acute toxicity of drilling fluids to rainbow trout. In: Industry/Government Working Grouup in Disposal Waste Fluids from Petroleum Exploratory Drilling in the Canadian North. Yellowknife, N.W.T., Canada. Dept. of the Environment. Environmental Protection Service. Vol. 8. pp 93.

Nelson, D. W., S. Liki, and L. E. Sommers. 1980. Plant uptake of toxic metals present in drilling fluids. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 114-138. Jan. 21-24, 1980. Lake Buena Visa, Fla.

Pesaran (Djavan), P. 1977a. Effects of drilling fluids on soils and plants. 69th Annual Meeting Amer. Soc. of Agronomy/Crop Sci. Soc. of Amer/Soil Sci. Soc. of Amer. Los Angeles, Ca. 13-18 Nov., 1977.

Pesaran (Djavan), P. 1977b. Effect of drilling fluid components and mixtures on plants and soils. Masters Thesis. Utah State University. Soil Science and Biometeorology (Soil Science). pp 134.

Shaw, D. R. 1975. The toxicity of drilling fluids, their testing and disposal. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. pp 463-471. U.S. EPA. EPA-560/1-75-004.

Shaw, D. C. and J. W. Keeley. 1975. Ground-water problems associated with well-drilling additives. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. pp 223-230. U.S. EPA. EPA-560/1-75-004.

Smith, D. W. and T.D.W. James. 1980. Vegetation changes resulting from sump waste spillage in the Canadian arctic. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 166-184. Jan. 21-24, 1980. Lake Buena Vista, Fla.

Specken, G. A. 1975. Treatment and disposal of waste fluids from onshore drilling sites. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. pp 451-462. U.S. EPA. EPA-560/1-75-004.

Sprague, J. B. and W. J. Logan. 1979. Separate and joint toxicity to rainbow trout of substances used in drilling fluids for oil exploration. Environ. Pollut. 19(4):269-281.

Weir, R. H. and B. Moore. 1975. Acute toxicity of well-drilling muds to rainbow trout, Salmo gairdneri (Richardson). In: Environmental Aspects of Chemical Use in Well-Drilling Operations. pp 169-182. U.S. EPA. EPA-560/1-75-004.

Weir, R. H., W. H. Lake, and B. T. Thakeray. 1976. Acute toxicity of discharged drilling muds from emmerk B-48. Beaufort Sea to rainbow trout, Salmo gairdneri. In: Industry/Government Working Group in Disposal Waste Fluids from Exploratory Drilling in the Canadian North. Yellowknife, N.W.T., Canada. Vol. 6. pp 37.

Yonkin, W. E. and D. L. Johnson. 1980. The impact of waste drilling fluids on soils and vegetation in Alberta. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 98-113. Jan. 21-24, 1980. Lake Buena Vista, Fla.

Zitko, V. 1975. Toxicity and environmental properties of chemicals used in well-drilling operations. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. pp 322-326. U.S. EPA. EPA-560/1-75-004.

APPENDIX: FATE AND EFFECTS REFERENCES FOR TERRESTRIAL, FRESHWATER AND MARINE STUDIES

Allred, R. B. 1975. The handling and treating of water-based drilling muds. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. pp 491-502. U.S. EPA. EPA-560/1-75-004.

Atema, J., L. Ashkeras, and E. Beale. 1979. Effects of drilling muds on lobster behavior. Progress Report 1 January- 1 October, 1979. Marine Bio. Lab., Woods Hole. pp 107

Ayers, R. C., Jr., T. C. Sauer, Jr., R. P. Meek, and G. Bowers. 1980. An environmental monitoring study to assess the impact of drilling discharges in the mid-Atlantic. I. Quantity and fate of discharges. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 382-391. Jan. 21-24, 1980. Lake Buena Vista, Fla.

Ayers, R.C., Jr., R. P. Meek, T. C. Sauer, Jr., and D. O. Stuebner. 1980. An environmental study to assess the effect of drilling fluids on water quality parameters during high rate, high volume discharges to the ocean. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 351-361. Jan. 21-24, 1980. Lake Buena Vista, Fla.

Ayers, R. C., Jr., T. C. Sauer, Jr., R. P. Meek and G. Boniers. 1980. An environmental study to assess the impact of drilling discharges in the Mid-Atlantic. I. Quantity and fate of discharges. Prepared by Exxon Production Research Company, Ecomar, Inc. and E. G & G. Environmental Consultants for Mid-Atlantic Operators. 22 pages and appendices.

Bachman, W. A. 1979. Solid waste law becomes threat to oil. Jour. Oil and Gas. 77(6):26

Baker, R. 1978. A study of environmental concerns: Offshore oil and gas drilling production. Fisheries and Env. Canada Report, EPS 2-EC-78-1. Env. Canada Env. Protection Ser.

Bascom, W., A. J. Mearns, and M. D. Moore. 1976. A biological survey of oil platforms in the Santa Barbara Channel. J. Petrol. Technol. 1280-1284.

Beak Consultants. 1974. Disposal of Waste Drilling Fluids in the Canadian Arctic-Project C6006. Reports submitted to Imperial Oil Ltd., Edmonton, Alberta, Canada. pp 170.

Beckett, A., B. Moore, and R. H. Weir. 1976. Acute toxicity of drilling fluid components to rainbow trout. In: Industry/Government Working Group in Disposal Waste Fluids from Exploratory Drilling in the Canadian North. Yellowknife, N.W.T., Canada. Dept. of the Environment, Environmental Protection Service. Vol. 9, pp 88.

Benech, S., R. Bowker, and B. Pimentel. 1980. Chronic effects of drilling fluids exposure to fouling community composition on a semi-submersible exploratory drilling vessel. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 611-631. Jan. 21-24, 1980. Lake Buena Vista, Fla.

Bohum, D. 1974. Long term effects of mud sump toxicity on vegetation. Indian and Northern Affairs, Ottawa. June 7 report.

Brandsma, M. G., L. R. Davis, R. C. Ayers, Jr., and T. C. Sauer, Jr. 1980. A compter model to predict the short-term fate of drilling discharges in the marine environment. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 588-608. Jan 21-24, 1980. Lake Buena Vista, Fla.

Brannon, A. C. and P. J. Conklin. 1978. Effect of sodium pentachlorophenate on exoskeletal calcium in the grass shrimp, Palaemonetes pugio. In: Pentachlorophenol. pp 205-211. Plenum Pub. Corp. New York, N.Y.

Brannon, A. C. and K. R. Rao. 1979. Barium, strontium and calcium levels in the exoskeleton, hepatopancreas and abdominal muscle of the grass shrimp. Palaemonetes pugio: relation to molting and exposure to barite. Comp. Biochem. Physiol. 63A:261-274.

Bryant, W. J., J. Goldburn, and S. E. Hrudey. 1974. Water pollution aspects from waste drilling mud disposal in Canada's arctic. In: Proc. 1974 Offshore Technology Conf., pp 95-102. OTC. 2044 Houston, Tx.

Bryant, W. J. and S. E. Hrudey. 1976. Water pollution characteristics of drilling operations. In: Industry/Government Working Group in Disposal Waste Fluids from Petroleum Exploratory Drilling in the Canadian North. Yellowknife, N.W.T.; Canada. Dept. of the Environment, Environmental Protection Service. Vol. 3.

Cabrera, J. 1971. Survival of the oyster Crassostrea virginica (Gmelin) in the laboratory under the effects of oil drilling fluids spilled in the Laguna de Tamiahua, Mexico. Gulf. Res. Repts. 3:197-213.

Campbell, M. D. and G. R. Gray. 1975. Mobility of well-drilling additives in the ground-water system. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. pp 261-284. U.S. EPA. EPA-560/1-75-004.

Cantelmo, A. C., P. J. Conklin, F. R. Fox, and K. R. Rao. 1978. Effects of sodium pentachlorophenate and 2,3-Dinitrophenol on respiration in crustaceans. In: Pentachlorophenol. pp 251-263. Plenum Pub. Corp. New York, N.Y.

Cantelmo, F. R. and K. R. Rao. 1978. Effects of pentachlorophenol on the meiobenthic nematocytes in an experimental system. In: Pentachlorophenol. pp 165-174. Plenum Pub. Corp. New York, N.Y.

Cantelmo, F. R., M. E. Tagatz, and K. R. Rao. 1979. Effect of barite on meiofauna in a flow-through experimental system. Mar. Environ. Res. 2:301-309.

Cantelmo, A. C. and K. R. Rao. 1978. The effects of pentachlorophenol (PCP) and 2,4-Dinitrophenol (DNP) on the oxygen consumption of tissues from the blue crab, Callinectes sapidus, under different osmotic conditions. Comparative Biochemistry and Physiology. 60C. pp 215-219.

Carney, L. L. and L. Harris. 1975. Thermal degradation of drilling mud additives. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. pp 203-218. U.S. EPA. EPA-560/1-75-004.

Carr, R. S., W. L. McCulloch, and J. M. Neff. 1980. Bioavailability of chromium from a used chrome lignosulfonate drilling mud to five species of marine invertebrates. Mar. Environ. Res. (in press).

Carr, R. S., L. A. Reitsema and J. M. Neff. 1980. Influence of a used chrome lignosulfonate drilling mud on the survival, respiration, growth, and feeding activity of the opossum shrimp Mysidopsis almyra. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 944-960. Jan. 21-24, 1980. Lake Buena Vista, Fla.

Chambers Consultants and Planners. 1979. Underwater survey of the marine life associated with oil platform Emmy. Report prepared for Aminoil USA, Inc., Huntington Beach, California. 92648.

Charlton, D., C. P. Falls, R. C. Miller, J. P. Houghton, and D. L. Beyer. 1978. The environmental impact of discharging drilling fluids, Cook Inlet, Alaska. Proc. Energy/Environment '78 Symposium. Assoc. of Petroleum Industry Biologists. 22-24 August 1978. Los Angeles, California

Chesser, B. F. and W. H. McKenzie. 1975. Use of bioassay test in evaluating the toxicity of drilling fluid additives on Galveston Bay shrimp. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. pp 153-168. U.S. EPA. EPA-560/1-75-004.

Chow, T. J. 1976. Barium in Southern California coastal waters: a potential indicator of marine drilling contamination. Science 193:57-58.

Chow, T. J., J. L. Earl, J. H. Reed, N. Hansen, and V. Orphan. 1978. Barium content of marine sediments near drilling sites. A potential pollutant indicator. Mar. Pollut. Bull. 9:97-99.

Cole, J., R. Greene, B. Bowman, and P. Friedman. 1979. Programmatic Environmental Impact Statement for DOE's Enhanced Oil Recovery RD & D Program. Printed: DOE Enhanced Oil and Gas Recovery & Improved Drilling Technology. 5th Sym. Tulsa, Ok. Aug. 22-24, 1979. Vol. 3, PE-3(13).

Collins, A. G. 1971. Oil and gas wells--potential polluters of the environment. J. Wat. Pollut. Contr. Fed. 43:2383-2393.

Collins, A. G. 1975. Chemical applications in oil- and gas-well-drilling and completion operations. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. pp 231-256. U.S. EPA. EPA-560/1-75-004.

Collins, A. G. 1975. Possible contamination of ground water by oil- and gas-well-drilling and completion fluids. In: Environmental Aspects of Chemical Use In Well-Drilling Operations. U.S. EPA. pp 231-256. U.S. EPA-560/1-75-004.

Conklin, P. J., D. G. Doughtie, and K. R. Rao. 1980. Effects of barite and used drilling muds on crustaceans, with particular reference to the grass shrimp, Palaemonetes pugio. In: Symposium - Research and Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 912-940. Jan 21-24, 1980. Lake Buena Vista, Fla.

Conklin, R. J. and F. R. Fox. 1978. Environmental impact of pentachlorophenol and its products--a round table discussion. In: Pentachlorophenol. pp 389-394. Plenum Pub. Corp. New York, N.Y.

Conklin, P. J. and K. R. Rao. 1978. Toxicity of sodium pentachlorophenate to the grass shrimp Palaemonetes pugio, in relation to the molt cycle. In: Pentachlorophenol. pp 181-192. Plenum Pub. Corp. New York, N.Y.

Conklin, P. J. and K. R. Rao. 1978. Toxicity of sodium pentachlorophenate (NaPCP) to the grass shrimp Palaemonetes pugio at different stages of the molt cycle. Bull. Environ. Contam. Toxicol. 20:275-279.

Connor, M. S. and R. W. Howarth. 1977. Potential effects of oil production on Georges Bank communities: a review of the draft environmental impact statement for outer continental shelf oil and gas lease sale No. 42. Technical rept. Woods Hole Oceanographic Institution, Woods Hole, Ma. No. WHOI-77i-1. pp 41.

Continental Shelf Associates, Inc. 1975. East Flower Garden Bank environmental survey. Rept. No. 1. Pre-drilling environmental assessment. Vol. I, II. Rept. No. 2. Monitoring program and post-drilling environmental assessment Vol. I, II, III, IV. Reports submitted to Mobil Oil Corp. for lease OCS-G2759.

Continental Shelf Associates, Inc. 1976. Pre-drilling survey report. Results of gravity core sediment sampling and analysis of barium. Post-drilling survey report. Results of gravity core sediment sampling and analysis for barium. Block A-502, High Island Area, South Addition. Reports submitted to Burmah Oil and Gas Co.

Continental Shelf Associates, Inc. 1976. Pre-drilling survey report. Results of gravity core sediment sampling and analysis for barium. Post-drilling survey report. Results of gravity core sediment sampling and analysis for barium. Block A-85, Mustang Island Area, East Addition. Reports submitted to Continental Oil Co.

Controlling corrosion in petroleum drilling and in packer fluids. In: Bush and Nathan (ed.). Corrosion Inhibitors. National Assoc. of Corrosion Eng. pp 284.

Crippen, R., G. Greene and S. L. Hood. 1980. Metal levels in water, sediment and benthos resulting from a drilling fluid discharge in the Beaufort Sea. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 636-664. Jan 21-24, 1980. Lake Buena Vista, Fla.

Dames and Moore, Inc. 1978. Drilling fluid dispersion and biological effects study for the lower Cook Inlet C.O.S.T. well. Report submitted to Atlantic Richfield Co. pp 309. Dames and Moore, Ankorage, Ak.

Daugherty, F. W. 1950. Effects of some chemicals used in oil well drilling on marine animals. Sewage Indust. Wastes. 23:1282-1287.

Dickey, T. D. and M. D. Fortin. 1980. A numerical model of dispersion of drilling discharges in the marine environment. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings (Abstracts). Jan. 21-24, 1980. Lake Buena Vista, Fla.

Didiuk, A. 1975. The effect of a drilling waste on the survival and emergence of the chronomid chironomus tentans (fabricius). Canada Fisheries and Marine Service. Tech. Rep. 586:pp 26.

Didiuk, A. and D. G. Wright. 1976. The effect of a drilling waste on the survival and emergence of the chironomid, chironomus tentans (fabriciues). Vol. 12. In: Industry/Government Working Group in Disposal Waste Fluids from Petroleum Exploratory Drilling in the Canadian North. Yellowknife, N.W.T., Canada. Dept. of the Environment, Environment Protection Service. Vol. 12. pp 19.

Ecomar, Inc. 1978. Tanner Bank mud and cutting study. Conducted for Shell Oil Company. January through March 1977. Ecomar, Inc., Goleta, California. pp 495.

EG & G Environmental Consultants. 1976. Compliance with ocean dumping final regulations and criteria of proposed discharges from exploratory drilling rigs on the mid-Atlantic outer continental shelf. Report submitted to Shell Oil Co.

EG & G Environmental Consultants. 1980. Monitoring Program for Exxon's Block 564, Jacksonville OCS Area (Lease OCS-G 3705). EG & G Environmental Consultants, Walthan, Ma. pp 29 with appendices.

EG & G Environmental Consultants. 1980. Water Quality Monitoring, NPDES Permit Requirement Mid-Atlantic Outer Continental Shelf Area. EG & G Environmental Consultants, Walthan, Ma. pp 237.

Estuarine Research Federation. 1975. Marine environmental implications of offshore oil and gas development in the Baltimore Canyon region of the mid-Atlantic coast. Proceedings of the estuarine Research Federation Outer Continental Shelf Conference and Workshop. December 1974. Chemical oceanography workshop report. pp 375-376. ERF, Wachaprigue, Va.

Falk, M. R. and M. J. Lawrence. 1973. Acute Toxicity of Petrochemical Drilling Fluids Components and Wastes to Fish. Tech. Rep. No. CENT-73-1. Fisheries and Marine Service, Freshwater Institute, Winnipeg, Manitoba, Canada. pp 108.

Farrel, D. 1975. Benthic communities in the vicinity of producing oil wells in Timbalies Bay, La. Report to Gulf Universities Research Consortium (GURC). Offshore Ecology Investigation.

Ferrante, J. G., E. H. Dettman, and J. I. Parker. 1980. Natural Gas in Lake Erie: A Reconnassance Survey of Discharges From on Offshore Drilling Reg. ANL/ES-85, Argonne National Laboratory, Argonne, Il. pp 61.

Fox, F. R. and K. R. Rao. 1978. Effects of sodium pentachlorophenate and 2,4-Dinitrophenol on hepatopancreatic enzymes in the blue crab, Callinectes sapidus. In: Pentachlorophenol. pp 265-275. Plenum Pub. Corp. New York, N.Y.

French, H. M. 1978. Terrain and environmental problems of Canadian arctic oil and gas exploration. Musk-Ox. 21:11-17.

French, H. M. 1980. Terrain, land use and drilling fluid disposal problems, Arctic Canada. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. (Abstracts). Jan. 21-24, 1980. Lake Buena Vista, Fla.

French, H. M. and M. W. Smith. 1980. Geothermal disturbance remitting from sump construction and use in permafrost terrain, Arctic Canada. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 139-164. Jan. 21-24, 1980. Lake Buena Vista, Fla.

Friesen, G. 1980. Drilling fluids and disposal methods employed by Esso Resources Canada Ltd. to drill in the Canadian arctic. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 53-68. Jan. 21-24, 1980. Lake Buena Vista, Fla.

George, R. Y. 1975. Potential effects of oil drilling and dumping activities on marine biota. In: Environmental Aspects of Cemical Use in Well-Drilling Operations. pp 333-355. U.S. EPA. EPA-560/1-75-004.

Gerber, R. P., E. S. Gilfillan, B. T. Page, D. S. Page, and J. B. Hotham. 1980. Short and long term effects of used drilling fluids on marine organisms. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 882-909. Jan. 21-24, 1980. Lake Buena Vista, Fla.

Gettleson, D. A. 1978. Ecological impact of exploratory drilling: a case study. In: Energy/Environment '78. Soc. of Petroleum Industry Biologists Symposium. 22-24 August, 1978. Los Angeles, California. pp 23.

Gettleson, D. A. and C. E. Laird. 1980. Barium as an indicator of the short-term fate of discharged drilling fluids. In: Symposium - Research on Envirionmental Fate and Effects of Drilling Fluids and Cuttings. pp 739-785. Jan. 21-24, 1980. Lake Buena Vista, Fla.

Gilfillan, E. S., R. P. Gerber, S. A. Hanson, D. S. Page, and J. B. Hotham. 1980. Effects of used drilling muds on recruitment of soft bottom benthic communities. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Jan. 21-24, 1980. Lake Buena Vista, Fla.

Granthum, C. K. and J. P. Sloan. 1975. Toxicity study. Drilling fluid chemicals on aquatic life. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. pp 103-110. U.S. EPA. EPA-560/1-75-004.

Hardin, M. J. 1976. A preliminary study of the effects of oil well drilling sump fluid on some aquatic organisms of the Mackenzie Delta. In: Industry/ Government Working Group in Disposal Waste Fluids from Petroleum Exploratory Drilling in the Canadian North. Yellowknife, N.W.T., Canada. Dept. of the Environment, Environmental Protection Service. Vol. 11. pp 65.

Herbert, D.W.M. and J. C. Merkens. 1961. The effect of suspended mineral solids on the survival of trout. Air Water Pollut. 5:46-55.

Herbert, D.W.M. and A. C. Wakeford. 1962. The effect of calcium sulfate on the survival of rainbow trout. Wat. Waste Treat. J. Vol. 8. pp 608-609.

Hollingsworth, J. W. and R. A. Lockhart. 1975. Fish toxicity of dispersed clay drilling mud deflocculants. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. pp 113-123. U.S. EPA. EPA-560/1/75-004.

Holmes, C. W. and S. S. Barnes. 1977. Trace metal and mineralogical analyses of suspended and bottom sediment. In: Environmental Studies, South Texas Outer Continental Shelf, Biology and Chemistry. R. D. Groover, ed. pp 6.1-6.18. Final report submitted to U.S. Dept. of Interior, Bureau of Land Management, Outer Continental Shelf Office. Washington, D.C.

Honarvar, S. 1975. Effect of drilling fluid components and mixtures on plants and soils. M.S. Thesis. U.S.U., Logan, Utah. pp 133

Houghton, J. P. 1979. Drilling fluid dispersion effects studies at an Alaskan continental offshore stratigraphic test well. Amer. Inst. Chem. Eng. 87th Nat. Meeting. Boston, Ma. 19-22 Aug. 1979.

Houghton, J. P., D. L. Beyer and E. D. Thielk. 1980. Effects of oil well drilling fluids on several important Alaskan marine organisms. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 1017-1041. Jan. 21-24, 1980. Lake Buena Vista, Fla.

Hrudey, S. E. 1979. Sources and characteristics of liquid process wastes from Arctic offshore hydrocarbon exploration. Arctic. 32:3-21.

Hrudey, S. E. and J. D. McMullen. 1976. *Monitoring of two exploratory drilling sites in the shallow regions of MacKenzie Bay.* Vol. 4. In: Industry/Government Working Group in Disposal Waste Fluids from Petroleum Exploratory Drilling in the Canadian North. Yellowknife, N.W.T., Canada. Dept. of the Environment, Environmental Protection Service. Vol. 4.

Hrudey, S. E. 1980. Surface and groundwater quality implications of waste drilling fluid sump abandonment in permafront regions. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 191-192. Jan. 21-24, 1980. Lake Buena Vista, Fla.

Hrudey, S. E., J. Michalchuk, and J. D. McMullen. 1976. A preliminary assessment of water pollution from abandoned oil and gas drilling sumps in the N.W.T., Canada. In: Industry/Government Working Group in Disposal Waste Fluids from Petroleum Exploratory Drilling in the Canadian North. Yellowknife, N.W.T., Canada. Vol. 2. pp 42.

Hudson, J. H. and D. M. Robbin. 1980. Effects of drilling mud on the growth rate of the reef-building coral, Montastrea annularis. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 1101-1119. Jan. 21-24, 1980. Lake Buena Vista, Fla.

Jessen, F. W. and C. A. Johnson. 1963. The mechanism of adsorption of lignosulfonates on clay suspensions. Soc. Petrol. Eng. J. 3:267-273.

IADC. 1974. Drilling Manual. 9th edition. International Association of Drilling Contractors.

Kaufman, D. and J. W. Rogers. 1972. Toxicity to fish of drilling mud components and mixtures. Shell Summary Report. Project No. 32-26617. Bellaire Res. Cent. Houston, Texas (cited through Beckett et. al. 1976).

Kelly, J. 1964. What Mobil research revealed about: how lignosulfonate muds behave at high temperatures. Oil and Gas J. 62:112-119.

Kennedy, K. 1979. The environmental impacts of energy extraction. Env. Views. April-May, 1979. V2, Ni, P3 (6).

Knox, F. 1976. The behavior of ferrochrome lignosulfonate in natural waters. Masters Thesis. Mass. Inst. Technol. Cambridge, Ma. pp 62.

Kojola, W. H., G. R. Brenniman, and B. W. Carnow. 1979. Review of environmental characteristics and health effects of barium in public water supplies. Rev. Environ. Hlth. 3:79-95.

Krone, M. A. and D. C. Biggs. 1980. Sublethal metabolic responses of the hermatypic coral Madracis decatus exposed to drilling mud enriched with ferrochrome lignosulfonate. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 1079-1096. Jan. 21-24, 1980. Lake Buena Vista, Fla.

Land, B. 1974. The toxicity of drilling fluid components to aquatic biological systems. *Canada Department of Environment.* Fish Marine Service. Tech. Rep. No. 487. pp 33.

Lawrence, M. J. 1980. A study of some effects of drilling wastes on a small sub-arctic lake. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. (Abstract). Jan. 21-24. Lake Buena Vista, Fla.

Lawrence, M. and E. Scherer. 1974. Behavioral response of whitefish and rainbow trout to drilling fluids. Tech. Rep. No. 502. Fisheries and Marine Services. Freshwater Institute. Winnipeg, Maritoba, Canada. pp 47.

Liss, R. G., F. Knox, D. Wayne and T. R. Gilbert. 1980. Availability of trace elements in drilling fluids to the marine environment. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 691-719. Jan. 21-24, 1980. Lake Buena Vista, Fla.

Logan, W. J. 1976. The toxicity of drilling fluids and their component chemicals to rainbow trout. M.S. Thesis. U. of Guilph. Guilph, Canada.

Logan, W. J. 1980. The toxicity of drilling fluids and their component chemicals to rainbow trout. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. (Abstract). Jan. 21-24, 1980. Lake Buena Vista, Fla.

Logan, W. F., J. B. Sprague, and B. D. Hicks. 1973. Acute lethal toxicity to trout of drilling fluids and their constituent chemicals as used in the Northwest Territories. pp 43-108. In: Falk, M. R. and M. J. Lawrence. Acute toxicity of petrochemical drilling fluid components and wastes to fish. Canada Dept. of Environment. Resource Management Branch. Technical Report No. CENT-73-1.

Louden, L. R. and R. E. McGlothlin. 1975. Waste water base drilling fluid disposal. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. pp 575-522. U.S. EPA. EPA-560/1-75-004.

Ludke, J. L. and R. A. Schoettger. 1979. Hazardous substances: A threat to aquatic resources. USDI Columbia North Fishery Res. Lab., Mo. Presented at US F & W Service Pollution Response Conf. St. Petersburg, Mo. May 8-10, 1979. pp 73(6).

Mariani, G. M. and L. V. Sick. 1980. An environmental monitoring study to assess the impact of drilling discharges in the mid-Atlantic. III. Chemical and physical alterations in the benthic environment. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 438-495. Jan. 21-24, 1980. Lake Buena Vista, Fla.

Mariani, G. M., L. V. Sick, and C. C. Johnson. 1980. An environmental study to assess the impact of drilling discharges in the Mid-Atlantic. III. Chemical and physical alterations in the benthic environment. Prepared by EG & G Environmental Consultants and University of Delaware College of Marine Studies for Mid-Atlantic Operators. pp 31 and appendices.

Marine Technical Consulting Services. 1977. Ecological assessment of drilling activities. Well No. 1. Block 384. High Island, East Addition, South Extension. Report submitted to Union Oil Co. of California.

McAtee, J. L. and N. R. Smith. 1969. Ferrochrome lignosulfonates. I. X-ray adsorption edge fine structure spectroscopy. II. Interation with ion exchange resin and clays. J. Colloid Interface Sci. 29:389-398.

McAuliffe, C. D. and L. L. Palmer. 1976. Environmental aspects of offshore disposal of drilling fluids and cuttings. Soc. Petrol. Engrs. AIME, paper No. SPE 5864. pp 8.

McCulloch, W. L., J. M. Neff, and R. S. Carr. 1980. Bioavailability of heavy metals from used offshore drilling muds to the clam Rangia cuneata and the oyster Crassostrea gigas. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 964-982. Jan. 21-24, 1980. Lake Buena Vista,, Fla.

McDermott-Ehrlick, D., D. R. Young, G. V. Alexander, T. K. Jan, and G. P. Hershelman. 1978. Chemical studies of offshore oil platforms in the Santa Barbara Channel. Proc. Energy/Environment '78 Symposium. pp 133-144. Assoc. Petroleum Industry Biologists. 22-24 August, 1978. Los Angeles, California.

McGuire, W. J. 1975. Disposal of drilling fluids and drilled-up solids in offshore drilling operations. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. pp 523-530. U.S. EPA. EPA-560/1-75-004.

McLeay, D. J. 1976. Marine toxicity studies on drilling fluid wastes. In: Industry/Government Working Group in Disposal Waste Fluids from Petroleum Exploratory Drilling in the Canadian Arctic. Yellowknife, N.W.T., Canada. Dept. of the Environment. Environmental Protection Service. Vol. 10, pp 17.

McDerott-Erlich, D., D. R. Young, G. V. Alexander, T. K. Jan, and G. P. Hershelman. 1978. Chemical studies of offshore oil platforms in the Santa Barbara channel. J. Linstedt - Siva, ed. Proc., Energy/Environment '78: a symposium on energy development impacts. August 22-24, 1978. Los Angeles, California. pp 133-134.

McLeod, G. C., T. R. Gilbert, R. Stone, and N. Riser. 1980. Indices of sublethal stress in bivalve molluscs exposed to drilling muds: an overview. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. (Abstract). Jan. 21-24, 1980. Lake Buena Vista, Fla.

Meek, R. P. and J. P. Ray. 1980. Induced sedimentation, accumulation, and transport resulting from exploratory drilling discharges of drilling fluids and cuttings. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 259-280. Jan. 21-24, 1980. Lake Buena Vista, Fla.

Menzie, C. A., D. Maurer, and W. A. Leathem. 1980. An environmental monitoring study to assess the impact of drilling discharges in the mid-Atlantic. IV. The effects of drilling discharges on the benthic community. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 499-536. Jan. 21-24, 1980. Lake Buena Vista, Fla.

Menzie, C. A., D. Maurer and W. A. Leathem. 1980. An environmental study to assess the impact of drilling discharges in the Mid-Atlantic. IV. The effects of drilling discharges on the benthic community. Prepared by EG & G Environmental Consultants and University of Delaware College of Marine Studies for Mid-Atlantic Operators. pp 40 and appendices.

Miller, R. W. 1978. Effects of drilling fluid components and mixtures on plants and soils. Summary Report 1974-1977. Utah Agricultural Experiment Station. Logan, Utah. pp 39.

Miller, R. C., R. P. Britch, and R. V. Shafer. 1980. Physical aspects of disposal of drilling fluids and cuttings in shallow ice covered arctic seas. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 670-689. Jan. 21-24, 1980. Lake Buena Vista, Fla.

Miller, R. W. and S. Honarvar. 1975. Effect of drilling fluid component mixtures on plants and soils. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. pp 125-143. U.S. EPA. EPA-560/1-75-004.

Miller, R. W. and P. Pesaran. 1980. Effects of drilling fluids on soils and plants. II. Complete fluid mixtures. J. Environ. Qual. Vol. 9, No. 4. pp 552-556.

Monaghan, P. H., C. D. McAuliffe, and F. T. Weiss. 1977. Environmental aspects of drilling muds and cuttings from oil and gas extraction operations in offshore and coastal waters. Proc. 9th Offshore Technol. Conf. Houston, Texas. OTC paper No. 2755. pp 251-256.

Moore, B., A. Beckett, and R. H. Weir. 1976. Acute toxicity of drilling fluids to rainbow trout. In: Industry/Government Working Grouup in Disposal Waste Fluids from Petroleum Exploratory Drilling in the Canadian North. Yellowknife, N.W.T., Canada. Dept. of the Environment. Environmental Protection Service. Vol. 8. pp 93.

Montalvo, J. G., Jr. and M. M. McKown. 1975. Environmental implications of sediment bulk analysis techniques for trace metals in offshore well-drilling operations. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. pp 357-383. U.S. EPA. EPA-560/1-75-004.

Moseley, H. R. 1980. Drilling fluids and cuttings disposal. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 43-52. Jan. 21-24, 1980. Lake Buena Vista, Fla.

NALCO Environmental Sciences. 1976. Physical and toxicity bioassay studies in Cook Inlet, Alaska during drilling operations. Report submitted to Union Oil Co. of California.

Neff, J. M., R. S. Carr and W. L. McCulloch. 1980. Acute toxicity of a used chrome lignosulfonate drilling mud to several species of marine invertebrates. Mar. Environ. Res. (in press).

Neff, J. M., W. L. McCulloch, R. S. Carr, and K. A. Retzer. 1980.. Comparative toxicity of four used offshore drilling muds to several species of marine animals from the Gulf of Mexico. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 866-880. Jan. 21-24, 1980. Lake Buena Vista, Fla.

Nelson, D. W., S. Liki, and L. E. Sommers. 1980. Plant uptake of toxic metals present in drilling fluids. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 114-138. Jan. 21-24, 1980. Lake Buena Visa, Fla.

Newbury, T. K. 1979. Possible accumulation of heavy metals around offshore oil production facilities in the Beaufort Sea. Arctic. 32:42-45.

OECS Corporation. 1977a. Barium investigation, post-drilling survey well #2, pre-drilling survey well #3. Mustang Island area, Block A-86. Report submitted to Marathon Oil Company.

OECS Corporation. 1977b. Barium investigation, post-drilling survey well #3, pre-drilling survey well #4. Mustang Island area, Block A-86. Report submitted to Marathon Oil Company.

Offshore Operators Committee. 1978. Comments on U.S. Environmental Protection Agency Draft Document, "Permit Conditions for NPDES permits at the Flower Garden Reefs, Gulf of Mexico, Outer Continental Shelf. August 1978". Report submitted to U.S. EPA, Region VI.

Page, D. S., B. T Page, J. R. Hotham, E. S. Gilfillan, and R. R. Gerber. 1980. Bioavailability of toxic constituents of used drilling muds. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 984-993. Jan. 21-24, 1980. Lake Buena Vista, Fla.

Palmer, L. L. 1976. Environmental aspects of offshore disposal of drilling fluids and cuttings. Society of Petroleum Engineers of AIME SPE 5864. pp 16.

Pesaran (Djavan), P. 1977a. Effects of drilling fluids on soils and plants. 69th Annual Meeting Amer. Soc. of Agronomy/Crop Sci. Soc. of Amer/Soil Sci. Soc. of Amer. Los Angeles, Ca. 13-18 Nov., 1977.

Pesaran (Djavan), P. 1977b. Effect of drilling fluid components and mixtures on plants and soils. Masters Thesis. Utah State University. Soil Science and Biometeorology (Soil Science). pp 134.

Rao, K. R., P. J. Conklin, and A. C. Brannon. 1978. Inhibition of limb regeneration in the grass shrimp. Palaemonetes pugio, by sodium pentachlorophenate. Pentachlorophenol. pp 193-203. Plenum Pub. Corp. New York, N.Y.

Ray, J. P. 1978. Drilling mud toxicity: laboratory and real world tests. Ocean Resources Eng. 12:8-12.

Ray, J. P. 1979. Offshore discharge of drill muds and cuttings. In: Proc. of the OCS Frontier Technology Symposium. Dec. 6, 1979. Washington, D.C.

Ray, J. P. and R. P. Meek. 1980. Water column characterization of drilling fluids dispersion from an offshore exploratory well on Tanner Bank. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 223-252. Jan. 21-24, 1980. Lake Buena Vista, Fla.

Ray, J. P. and E. A. Shinn. 1975. Environmental effects of drilling muds and cuttings. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. pp 533-534. U.S. EPA. EPA-560/1-75-004.

Reish, D. J., S. G. Appan, M. E. Bender, T. L. Linton, C. H. Ward, and J. M. Sharp. 1980. Long-term cumulative effects of petroleum drilling on benthic polychaete community structure. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. (Abstracts). Jan. 21-24, 1980. Lake Buena Vista, Fla.

Richards, N. L. 1979. Effects of chemicals used in oil and gas well-drilling operations in aquatic environments. In: Fourth National Conference. Interagency Energy/Environment R & D Program. June 7-8, 1979. Washington, D.C. ERL-Gulf Breeze Contrib. No. 392. pp 12.

Robichaux, T. J. 1975. Bactericides used in drilling and completion operations. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. pp 183-191. U.S. EPA. EPA-560/1-75-004.

RPC, Inc. 1979. Analysis of ecolological effects of geopressured-geothermal resource development. Geopressured-geothermal technical paper no. 4. RPC, Inc. Austin, Tx (DOE-Wash., D.C.) pp 137.

Robson, D. S., C. A. Menzie, and H. F. Mulligan. 1980. An environmental monitoring study to assess the impact of drilling discharges in the mid-Atlantic. II. An experimental design and statistical methods to evaluate impacts on the benthic environment. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 419-436. Jan. 21-24, 1980. Lake Buena Vista, Fla.

Rubinstein, N. and R. Rigby. 1980. Effect of drilling fluids on representative estuarine organisms and developing benthic communities. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. (Abstracts). Jan. 21-24, 1980. Lake Buena Vista, Fla.

Shaw, D. R. 1975. The toxicity of drilling fluids, their testing and disposal. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. pp 463-471. U.S. EPA. EPA-560/1-75-004.

Shaw, D. C. and J. W. Keeley. 1975. Ground-water problems associated with well-drilling additives. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. pp 223-230. U.S. EPA. EPA-560/1-75-004.

Shinn, E. A. 1974. Effects of oil field brine, drilling mud, cuttings, and oil platforms on the offshore environment. Proc. Estuarine Research Federation, Outer Continental Shelf Conference and Workshop. U.S. Dept. of Commerce, Bureau of Land Management. Washington, D.C. pp 10.

Shinn, E. A., J. H. Hudson, D. M. Robbin, and C. K. Lee. 1980. Drilling mud plumes from offshore drilling operations: implications for coral survival. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. (Abstracts). Jan. 21-24, 1980. Lake Buena Vista, Fla.

Skelly, W. G. and D. E. Dieball. 1969. Behavior of chromate in drilling fluids containing chromate. Proc. 44th Ann. Meeting Society of Petroleum Engineers of AIME paper No. SPE 2539. pp 6.

Skelly, W. G. and J. A. Kjellstrand. 1966. The thermal degradation of modified lignosulfonates in drilling mud. Presented at API Spring Meeting, Southern District, Division of Production. Houston Tx. March 2-4, 1966.

Smith, J. E. 1975. Regulation of onshore and offshore oilfield waste disposal. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. pp 579-584. U.S. EPA. EPA-560/1-75-004.

Smith, D. W. and T.D.W. James. 1980. Vegetation changes resulting from sump waste spillage in the Canadian arctic. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 166-184. Jan. 21-24, 1980. Lake Buena Vista, Fla.

Specken, G. A. 1975. Treatment and disposal of waste fluids from onshore drilling sites. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. pp 451-462. U.S. EPA. EPA-560/1-75-004.

Sprague, J. B. and W. J. Logan. 1979. Separate and joint toxicity to rainbow trout of substances used in drilling fluids for oil exploration. Environ. Pollut. 19(4):269-281.

Strosher, M. T. 1980. Characterization of organic constituents in waste drilling fluids. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 70-97. Jan. 21-24, 1980. Lake Buena Vista, Fla.

Strosher, M. T., W. E. Youskin, and D. L. Johnson. 1979. Environmental Assessment of the Terrestrial Disposal of Waste Drilling Muds in Alberta: Chemistry of Sump Fluids and Effects on Vegetation and Soils. Report to Canadian Petroleum Association. In Press.

Suter, G. W., II. 1978. Topical Briefs: Fish and wildlife resources and electric power generation. No. 6. Effects of geothermal energy development on fish and wildlife. National Power Plant Team. Ann Arbor, Mi. pp 27.

Tagatz, M. E., J. M. Ivey, H. K. Lehman, and J. L. Oglesby. 1978. Effects of lignosulfonate-type drilling mud on development of experimental estuarine macrobenthic communities. Northeast Gulf Sci. 2:35-42.

Tagatz, M. E., J. M. Ivey, H. K. Lehman, M. Tobia, and J. L. Oglesby. 1980. Effects of drilling fluid on development of experimental estuarine macrobenthic communities. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 847-861. Jan. 21-24, 1980. Lake Buena Vista, Fla.

Tagatz, M. E., J. M. Ivey, and M. Tobia. 1978. Effects of Dowicide G-ST on development of experimental estuarine macrobenthic communities. In: K. R. Rao (ed.), Pentachlorophenol. pp 157-163. Plenum Pub. Corp. New York, N.Y.

Tagatz, M. E. and M. Tobia. 1978. Effect of barite ($BaSO_4$) on development of estuarine communities. Estuar. Cstl. Mar. Sci. 7:401-407.

Thompson, J. H. 1979. Effects of an offshore drilling mud on selected corals. Amer. Assoc. Petro. Geo/Society of Econ. Paleont. and Mineralogists Annual Conv. Houston, Tx. April 1-4, 1979.

Thompson, J. H., Jr. 1979. Effects of drilling mud on seven species of reef-building corals as measured in field and laboratory. Final Rept. to U.S. Geological Survey, Conservation Division, Grant No. 14-08-001-1627. pp 29.

Thompson, J. H. and T. J. Bright. 1977. Effects of drill mud on sediment clearing rate of certain hermatypic corals. Proc. 1977 Oil Spill Conference. pp 495-498. American Petroleum Institute. Washington, D.C.

Thompson, J. H., Jr. and T. J. Bright. 1980. Effects of an offshore drilling mud on selected corals. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 1044-1076. Jan. 21-24, 1980. Lake Buena Vista, Fla.

Tillery, J. B. 1980. Long term fate and effects of heavy metal contamination from petroleum production in the Gulf of Mexico. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. (Abstracts). Jan. 21-24, 1980. Lake Buena Vista, Fla.

Tornberg, L., E. D. Thielk, R. E. Nakatoni, R. C. Miller, and S. O. Hillman. 1980. Toxicity of drilling fluids to marine organisms in the Beaufort Sea, Alaska. In: Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp 997-1013. Jan. 21-24, 1980. Lake Buena Vista, Fla.

Turner, C. H. 1967. California Dept. of Fish and Game's study of offshore oil drilling and its effect on the marine environment. Calif. Dept. Fish and Game. MRO Ref. No. 67-29.

Turner, C. H., J. G. Carlisle, and E. E. Ebert. 1971. Offshore oil drilling, its effects upon the marine environment. Calif. Dept. Fish and Game, Marine Resources Operations. In: EIS PB-198979-F. Aug. 26, 1971. pp 108-145. U.S. Geological Survey. Washington, D.C.

Ward, C. H., M. E. Bender and D. J. Reish (eds.). 1980. The Offshore Ecology Investigation. Effects of Oil Drilling and Production in a Coastal Environment. Rice University Studies, Rice University. Houston, Tx. pp 600.

Watkins, S. H. 1970. Bacterial degradation of lignosulfonates and related model compounds. J. Wat. Pollut. Contr. Fed. 42:R47-R56.