LAND FARMING RESERVE PIT FLUIDS AND SLUDGES
FATE OF CONTAMINANTS

PROJECT COMPLETION REPORT
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Introduction

The drilling and production of oil and gas in the United States comprises a major portion of the economic base of several states and provides many benefits for society. However, the processes used in the drilling and recovery of the crude material generate contaminants that must be treated and disposed of properly. Chief among these waste products are the drilling fluids or muds which are pumped into the bore holes to aid in the drilling process. Most of these fluids are water base and contain barite, lignite, chrome lignosulfate and sodium hydroxide. Used muds can be removed by vacuum trucks, pumped down the well annulus, allowed to dewater in pits which are then covered with soil or disposed of by land farming. The potential environmental effects resulting from land disposal of drilling fluids have only in recent years been considered. Because of the shortage of available information on drilling muds, EPA has classified them as "special wastes" in the Resource Conservation and Recovery Act (Nelson et al., 1984).

Some of the trace metals of concern found in drilling muds are sodium, arsenic, chromium, cadmium, copper, lead, nickel and zinc. The fates of these pollutants, once incorporated into the soil could be adsorption, ion exchange, precipitation, uptake by plants and the soil microbial population, or the downward transport of the ions into the soil column or groundwater.

Ideally, it would be desirable for the contaminants to be fixed by the soils and not be incorporated into vegetation or transported through the soil. However, many factors govern the fate of pollutants in the subsurface environment. The specific characteristics of the contaminant coupled with the soil type, pH and oxidation-reduction potential will determine the fate and transport of the material.

The purpose of this project was to study the fates of chloride, barium, chromium and zinc in soils as the result of land farming slurried reserve pit wastes. The uptake of these pollutants by bermuda grass, soils, and/or the transport of the ions through the soil column was investigated.

Background Information

The potential for soil, vegetation, and groundwater pollution as the result of land application of drilling wastes definitely exists, and depending on the choice of site, the potential for pollution may be very high. In the past several years, studies of the effects of drilling muds on soils and vegetation have been reported in the literature. Nelson et al.(1984) investigated the effects of three drilling muds on the growth of chard and rye grass. The growth of both plants was depressed, possibly as the result of increased zinc concentrations in the soils. The addition of drilling fluids to the soils studied increased the soil pH, which resulted in decreased availability of metals such as Ba, Hg and Cr. Miller et al. (1980 a and b) conducted a series of studies to ascertain the effects of individual fluid components and complete drilling fluid mixtures on the growth of plants. Depressed growth of both beans and corn was observed.

Tucker (1985) states that sodium and chloride are the two major contaminants in drilling fluids that most adversely affect plant growth. In addition, he reports that case studies of soil farming drilling fluids in Oklahoma indicate that the application of the fluids does not harm soil productivity. In fact, fluids may improve the productivity of some soils.

Lloyd (1985) has reported on the surface disposal of drilling wastes in Alberta. The salt content of the waste was the major controlling factor in determining the waste loading to the soil system.

Deely and Canter (1985) studied the chemical speciation of metals found in drilling fluids to determine how the distribution of the metals varied as a function of pH. Their study is one of a few that discusses the environmental fate of the metals in the drilling wastes. Most of the metals these authors investigated were found to be organically bound or as a carbonate or residual form. As the result of a decrease in the pH, metals in the residual form shifted to the carbonte or organic forms. These authors indicated that metals in drilling fluids were relatively resistant to mobilization. However, at lower pH values, the soluble concentrations of both chromium and lead extracted from the wastes exceeded drinking water standards.

Whether or not metals in drilling fluids disposed of in soils can be mobilized is a function of soil type, pH and the oxidation-reduction potential. Although soil type at a specific site is relatively constant, the pH and redox potential can vary.

Changes in pH could be the result of acid rain, which is lowering the pH and altering the soil chemistry of soil systems across the United States. Increases in soil pH could occur as the result of the addition of the drilling fluids, themselves. Changes in redox potential may occur as the result of heavy rainfall or excessive irrigation. Any alteration of the soil environment, even if it is only temporary, could result in the mobilization and subsequent transport of the metals in the drilling wastes.

Soil type or composition is a very important factor in all heavy metal fixation reactions. Clays are extremely important in adsorption reactions because of their high cation exchange capacity. In addition, soils high in humus or other organic matter also exhibit good exchange capacity.

The relationship between soil type and heavy metal retention has been closely examined in the literature. Zinc adsorption by calcareous soils has been studied by Udo et al. (1970) using ten calcareous Arizona soils and dilute zinc sulfate. Zinc adsorption at low Zn concentrations could be described by the Langmuir adsorption equation. At higher zinc concentrations, where zinc was added in excess of the adsorption maximum, the concentration of zinc was governed by the solubilities of zinc hydroxide or zinc carbonate. Leeper (1952) and Jurinak and Bauer (1956) have also investigated the behavior of zinc in calcareous soils and have concluded that zinc adsorption by carbonates is probably responsible for the unavailability of zinc noted in some soils. Zinc precipitation as a carbonate or hydroxide may also account for the lack of available zinc for crops.

The organic matter content and the clay fraction of a soil also affect zinc retention. The reaction with the soil organics may be by chelation (Jones et al., 1936). In a study conducted by Udo et al. (1970), it was concluded that the soil zinc content was most highly correlated with the organic fractions of the soils investigated. Zinc is also retained by clays; however it is not retained equally by all clays or by the same mechanism.

Chromium (III) and chromium (VI) are the two major forms of chromium in the environment. According to Ross et al. (1981), chromium III is not mobile in soils in the inorganic form. Chromium (VI), however, is a very mobile ion, and if not reduced to chromium (III), will migrate through soil columns. Chromium (VI) can be retained by soils as the result of anion adsorption, precipitation, or as the result of reduction to a lower solubiity form (James and Bartlett, 1983).

Chromium concentrations in soils are dependent on the solubility of the metal, the soil type, the presence of competing elements and the chemical bonding of the metal (Korte et al, 1976). The organic matter content of the soil appears to be largely responsible for chromium fixation; however, some sorption may take place on iron and manganese oxides. In a study of chromium uptake by lake and river sediments, Huggins (1977) determined that lake sediments composed primarily of clay, silt and organic matter fixed more chromium than sandy river sediments low in organic content.

Barium may also be adsorbed by and then desorbed from various soil components. Barium is more readily sorbed by some soil components than calcium and magnesium. The uptake and release of barium, magnesium, calcium and potassium under various conditions has been investigated. The normal order of retention of the ions was found to be Mg > Ba > Ca >K. However, when phosphate was added to the soil, barium became the most readily fixed ion. The stability of barium in soils is largely determined by the anion with which it is associated. Barium sulfate is very insoluble and therefore barium bound to sulfate will not be highly mobile in a soil column. Barium chloride, however, is very soluble and could be transported through soils.

pH plays a very important róle in the retention and mobility of metals in soil columns (Korte et al., 1976; Zimdahl and Skogerboe, 1977). pH controls sorption-desorption reactions and precipitation-solubilization reactions. In addition, the cation exchange capacity of soils generally increases with an increase in pH. Even with a soil that has a high affinity for a specific metal, the degree to which the metal is fixed is a function of pH. In general heavy metals form insoluble or slightly soluble precipitates in neutral or high pH ranges. The pH range of maximum solubility of metals is dependent on the soil type.

Zinc fixation by H-montmorillonite is characterized by adsoprtion as long as the pH of the system is below 5.0 to 6.5. At higher pH values and when the cation exchange capacity of the clay has been exceeded, zinc is precipitated as zinc hydroxide (Bingham et al., 1964). In addition, Misra and Tiwari (1966) also indicate that high zinc retention is governed by pH and the presence of soluble and insoluble carbonates. While carbonates and hydroxides reduce the solubility of zinc in high pH soils, zinc is relatively mobile in acid soils. Melton et al. (1973)

observed that the diffusion coefficient for zinc in a calcareous soil was 50 times less than that observed in an acidic soil.

With respect to the effects of pH on chromium, Bartlett and Kimble (1976) found that organo-chromium complexes are soluble and stable at a pH of 5.5. At pH values greater than 6, chromium may precipitate as chromium hydroxide (Grove and Ellis, 1980). Under acidic conditions, however, chromates may dissolve as the result of the conversion of chromate to dichromate. In a study of the effects of pH on the adsorption of chromium on a kaolinitic clay, Griffin et al. (1977) observed that soluble chromium decreased when the pH of the suspension decreased. As solution pH was raised above pH 4, the solubility of chromium (III) decreased. Complete precipitation of chromium (VI) occurs at a pH of 5.5 (Bartlett and Kimble, 1976; Jones and Bartlett, 1980). Chromium (VI) is almost completely insoluble in the pH range of 6-8. Above or below this range, the solubility greatly increases. Desorption of chromium (VI) under alkaline conditions, particularly in the range of 10-11 has been observed. One of the various forms of chromium will be available for transport in most pH ranges.

The oxidation-reduction or redox potential of a soil is a very important in determining which species of an element is available for sorption, precipitation or complexation. In fact, Phillips et al.(1976) state that the redox potential is one of the most critical mechanisms associated with heavy metal retention. In general, the reduced forms of a metal are more soluble than the oxidized forms. The redox potential of a soil system is usually altered through biological activity, and a change in redox potential is many times correlated with changes in pH. Reducing conditions may be associated with a low pH resulting from the formation of carbon dioxide and organic acids from the microbial degradation of organic matter. Reducing conditions in soils which would enhance metal mobility can also be induced by heavy rainfall or excessive irrigation or land application of wastewater effluent.

Chloride is a very mobile anion and once applied to soil surfaces is readily transported through the soil column. The high mobility is attributed to the phenomena of anion exclusion. Both field and laboratory studies indicate that anions can move faster through a soil column than water (Dyer, 1965; Thomas and Swoboda, 1970). The greater velocity of the anions is the result of the fact that they are excluded from the immediate vicinity of negatively charged soil particles and narrow pores. In both locations, water movement is relatively slow or virtually nonexistent. Therefore, when leaching occurs, the anions move at a greater rate than if they were associated with the water.

Although chloride is mobile, it can be adsorbed to some extent by various soil constituents. Fields and Schofield (1960) reported the sorption of chloride onto volcanic ash, and Wada and Ataka (1951) studied the adsorption of chloride on Pembroke silt loam. Gebhardt and Coleman (1974) studied uptake of chloride by goethite. Chloride adsorption is dependent on pH with fixation increasing with a decrease in pH.

Materials and Methods

Reserve pit fluids were obtained from a drilling site east of Stillwater, Oklahoma. The wastes were returned to the laboratory and stored in the refrigerator until used. Samples of the drilling fluids were analyzed for barium, chloride, chromium and zinc. In addition, the dry weight expressed in ppm was also determined.

Two types of soils were taken from the Sand Springs, Oklahoma area. The soils were returned to the laboratory where they were air dried and thoroughly mixed to obtain a homogenous sample. The soil characteristics were determined by the School of Civil Engineering Soils Lab. The chemical analyses performed on the soils included total barium, chromium, and zinc and a chloride analysis. In addition a known weight of each soil was shaken with distilled deionized water for a period of 24 hours to determine what fraction of the metals in the soils could be extracted with water.

For each soil, three columns were prepared. The columns were were composed of clear plastic. The were 24 inches high and had a diameter of 4 inches. A sampling port was placed in the bottom of each column. The six columns were placed in a wooden stand that also supported fluorescent lights about 12 inches above the tops of the columns. For each soil, there was column containing only soil which served as a soil control, a column containing soil and reserve pit fluids, and a column contaimining soil, reserve pit fluids, and bermuda grass. Like amounts of dry soil (5.8 kg) were placed in each column. One hundred milliters of reserve pit fluids or 0.5 inches were mixed with the top four inches of soil prior to being placed in the columns. This gave an 8:1 ratio of soil to reserve pit fluid. Bermuda grass seed was planted in one column for each soil. Due to poor germination, bermuda grass sprigs were later used. In addition to using bermuda grass in the columns, bermuda grass was also grown on each soil and soil-reserve pit mixture in 6 inch diameter flower pots.

One hundred milliters of tap water or 0.5 inches was added to each column daily for a period of 84 days. The chloride, chromium, barium and zinc content of the tap water was experimentally determined. Samples were collected daily from the bottom of each column. The volume of each sample was determined and the samples then analyzed for barium, chromium, zinc and chloride.

At the end of the experimental period, the addition of water ceased and the columns were allowed to dry for four days before cores were taken. The cores were divided into three fractions. The fractions were allowed to dry and then were analyzed for barium, chromium, zinc and chloride.

Analytical methods used were taken from the 15th Edition of Standard Methods for the Examination of Water and Wasteweater (1980) or from the Hach Chemical Company Water Analysis Handbook (1982). All soil samples were acid digested using reagent grade concentrated nitric acid. Vegetation samples were washed thoroughly with distilled deionized water to remove any soil clinging to the roots. The were then air dried, weighed and acid digested using reagent grade concentrated nitric acid. All aqueous samples and digested soil and vegetation samples were analyzed for the metals using a Perkin Elmer Atomic Absorption 5000 equipped with a HGA 400 graphite furnace. Chloride was determined in the aqueous samples using the diphenylcarbozone method (Hach, 1982). Chloride was extracted from the soil samples by mixing a known weight of dried soil with 100 milliters of distilled water for an hour (Page et al. 1982). After the soil was removed by filtration, chloride was determined using the diphenylcarbozone method.

Results

Several problems were encountered in the experimental segment of the study. A 4:1 ratio of reserve pit fluids to soil was originally used in the columns. However the columns containing the reserve pit fluids were relatively impermeable to the tap water which was added daily. As a result, the columns were emptied and repacked with soil and a 8:1 mixture of soil and reserve pit fluids.

The columns which were to be used for grass growth were seeded with bermuda grass seed which was then replaced with bermuda grass sprigs after poor germination of the seed became evident. The daily addition of 100 ml of tap water to the columns provided an environment too wet for the grass which subsequently died. The columns containing the grass were discarded and the effects of the reserve pit fluids on grass were determined using pots of grass, soil and reserve pit fluids and pots of grass and soil only for control. The grass in the pots was watered as needed for growth.

The results from the physical analyses of the soils used are shown in Table I. Table II shows the chemical composition of the soils, reserve pit fluids, and tap water with respect to barium, chromium, zinc and chloride. No barium, chromium, or zinc was leached from either soil during the 24 hour leaching study.

Table I. Soil Composition (%)

Soil	Clay	Sand	Silt	Organic Matter
Silty Loam	15.5	30.3	52.2	6.2
Sand	----	91.7	8.3	1.1

Table II. Chemical Composition of Soils, Reserve Pit Fluids, and Tap Water

Soil	Barium	Chromium	Zinc	Chloride
Silty Loam	52.6 ppm	74 ppm	49 ppm	19.8 ppm
Sand	20 ppm	13 ppm	16 ppm	24.5 ppm
Reserve Pit	199 ppm	85 ppm	115 ppm	273.6 ppm
Tap Water	0.07 mg/1	ND *	0.21 mg/1	149 mg/1

* ND---None Detected

Table III indicates the amount of each pollutant in each column as the result of the addition of the soil, the reserve pit fluid and the total amount of tap water added throughout the study. Columns C-1 and C-2 represent the columns containing the silty loam and the reserve pit fluid and the column containing silt loam only; whereas columns S-1 and S-2 represent the columns containing sand and reserve pit fluid and the control column for the sandy soil respectively.

Table III. Amount of Metal or Chloride in Each Column

Column	Barium	Chromium	Zinc	Chloride
C-1				
Soil	308 mg	429 mg	285 mg	115 mg
RPF*	4 mg	1.7 mg	2.3 mg	274 mg
TW**	0.6 mg	-----	1.8 mg	1252 mg
C-2				
Soil	308 mg	429 mg	285 mg	115 mg
TW **	0.6 mg	-----	1.8 mg	1252 mg
S-1				
Soil	116 mg	76 mg	93 mg	142 mg
RPF*	3.9 mg	1.7 mg	2.3 mg	274 mg
TW**	0.6 mg	-----	1.8 mg	1252 mg
S-2				
Soil	116 mg	76 mg	93 mg	142 mg
TW**	0.6 mg	-----	1.8 mg	1252 mg

* RPF---Reserve Pit Fluid
** TW---Tap Water

Table IV represents the total mass in mg of each pollutant leached through each column during the 84 day study period.

Table IV. Amount of Pollutant Leached Through Columns

Column	Barium	Chromium	Zinc	Chloride
C-1	0.88 mg	ND	0.38 mg	1437 mg
C-2	0.67 mg	ND	0.37 mg	918 mg
S-1	1.25 mg	ND	0.85 mg	1422 mg
S-2	1.03 mg	ND	0.34 mg	1066 mg

Table V shows the results from the analyses of the core fractions taken from each column. The numbers represent the percentage of the total amount of metal or chloride recovered found in each fraction. The percentages were rounded off to the nearest whole number.

Table V. Percentage of Each Pollutant Found in Each Soil Fraction

Column	Fraction	Barium	Chromium	Zinc	Chloride
C-1	1	28	41	50	36
	2	45	30	28	22
	3	27	29	22	42
C-2	1	34	33	35	24
	2	32	34	33	29
	3	34	33	32	47
S-1	1	34	31	30	39
	2	34	52	29	26
	3	32	17	41	34
S-2	1	31	32	20	44
	2	35	33	18	22
	3	34	35	19	34

Table VI shows the amounts of chromiun and zinc found in the bermuda grass grown on the silt loam soil, the silt loam with reserve pit fluids, the sandy soil and the sandy soil with reserve pit fluids.

Table VI. Zinc and Chromium Contents in Bermuda Grass

Sample	Zinc	Chromium
Silty Loam	36.1 ppm	4.28 ppm
Silty Loam & Reserve Pit Fluids	37.9 ppm	4.96 ppm
Sand	68.6 ppm	10.97 ppm
Sand and Reserve Pit Fluid	82.12 ppm	9.20 ppm

Discussion

Barium

According to Table VI, small amounts of barium were leached through both the sandy and the silt loam soil columns containing the reserve pit fluids. The total amounts of barium found in the leachates of both columns exceeded the mass of barium found in the leachates of the control columns. The distribution of barium in the soil fractions taken from column C-1 (Table V) shows that the barium was transported from the top fraction to the middle fraction. Forty four percent of the barium was found in the middle fraction whereas only 28 % was in the top fraction and 27 % in the bottom fraction. The distribution of barium in the control column was similar in each fraction. The distribution of barium in columns S-1 containing the reserve pit fluids and the sand and in the control column for the sandy soil are essentially the same (Table V). The acutally mass of barium found in the fractions from the column containing the reserve pit fluids and the sandy soil are three time larger than the mass of barium found in the fractions from the control column. The barium was obviously redistributed through the column during the leaching studies.

The transport of barium through the columns and the redistribution of the barium in the soils was probably the result of the high solubility of barium chloride as compared to other chemical forms of barium. The reserve pit fluids, themselves, contained high levels of chloride and additional chloride was added daily with the addition of tap water.

Chromium

Throughout the 84 day study period, no chromium was detected in any of the leachate samples collected from any of the columns. Table V shows that for column C-1 containing the silt loam and the reserve pit fluids, the majority of the chromium remained in the top fraction where the reserve pit fluids had been initially mixed with the soils. However, for the sandy soil column (S-1), the chromium was transported from the top fraction to the middle fraction. The percentage of chromium found in the top, middle and bottom fractions for this column were 30.8 %, 51.7 % and 17.4 % respectively. Although chromium did not appear in the leachate from column S-1, it was being transported through the column at the time the study was terminated and may have appeared in the leachate had the study been contiuned for a longer period of time.

There was no significant uptake of chromium by bermuda grass grown on either of the two soils as can be seen in Table VI. The levels of chromium in grass samples taken from the controls as well from the pots with the reserve pit fluids are very similar.

Zinc

As can be seen from Table IV, zinc was not transported through the columns containing the silt loam soil. The total mass of zinc collected from the silt loam column with the reserve pit fluids (C-1) and the control column for the silt loam are not significantly different. Zinc, however was transported through the sandy soil. The total amount of zinc in mg found in the leachate for the column containing the sandy soil and the reserve pit fluids was 0.85 mg whereas the total mass of zinc found in the leachates from the control column was 0.34 mg. The transport of the zinc through the column occurred in the first 22 days of the study period. After that time, only minimal concentrations of zinc were found in the leachate collected and analyzed daily. In many cases, the zinc in the leachate was below the detection level of the atomic absorption utilized in the study.

Even though zinc was transported through the column containing the sandy soil and the reserve pit fluids, the total amount transported was low comapred to the amount added in the reserve pit fluids and the tap water. The amount of zinc added to the column as can be seen in Table III was 4.1 mg. The 0.85 mg recovered represents only 20.7 % of the mass added.

In reviewing the results obtained from analyzing various soil fractions from each column (Table V), it can be readily seen that for the silt loam column containing the reserve pit fluid that the majority of the zinc stayed at the top of the column where it had been initially added with the reserve pit fluids. Fifty percent of the zinc in the column was found in the top fraction. For the column containing the sandy soil and the reserve pit fluids (S-1), the reverse is true. The majority of the zinc (41.2%) was found in the bottom fraction clearly indicating that the zinc was transported through the column. The zinc distribution in the fractions of the two control columns are essentially the same for each fraction which would be expected.

Zinc was taken up by the bermuda grass. Table VI shows an increased zinc level for the bermuda grass grown on the sandy soil containing the reserve pit fluids over the bermuda grass grown on the control for the sandy soil. Zinc, however, was not taken up by the bermuda grass grown on the silt loam containing the reserve pit fluids. The amounts of zinc found on the bermuda grass samples taken from the pots containing the silt loam and the reserve pit fluids and the samples taken from the silt loam control are essentially the same.

Chloride

Chloride is an extremely mobile anion and as expected, it appeared in the leachates from all of the columns. Chloride in the leachates from the control columns resulted from the daily addition of 100 ml of tap water which contained 14.9 mg of chloride. For the control columns for each of the two soils, the amount of chloride in the daily leachate fractions ranged from 13 to 18 mg daily, indicating that the chloride added from the tap water was rapidly transported through each column.

Leachates from columns C-1 and S-1 which contained the reserve pit fluids, had higher chloride contents than samples from the control columns as seen from Table IV. The chloride which was added in the reserve pit fluids moved rapidly through the columns. The leachate fractions taken later in the study period contained amounts of chloride similar to those added daily with the tap water. For column C-1 which contained the silt loam and reserve pit fluids, the majority of the chloride moved through the column from day 13 to day 24. For the column containing the sandy soil (column S-1), the chloride moved through the column from day 7 to day 14. Chloride movement through the column was obviously faster in the column containing the sandy soil than in the column containing the silt loam. Little chloride was detected in the leachate samples taken before day 13 for the silt loam and day 7 for the sandy soil.

Summary and Conclusions

As reported earlier in the background information, soil type has a significant affect on pollutant retention. This is clearly evident from the results of this study. Ths silt loam was a finer textured soil than the sand and contained a clay fraction. As would be expected, the silt loam had a higher retention capacity for the metals than the sand. Zinc was not leached through the silt loam and did not move significantly from the upper part of the column where it had initially been mixed with the soil. Chromium, also, did not move from the upper faction of the column. In the sandy soil, zinc was detected in the leachate samples and analyses of soil fractions from the column indicated that zinc had moved from the top fraction of the column to the bottom fraction. Although no chromium appeared in the leachate samples taken from the sandy soil column containing the reserve pit fluids, the analyses of the various soil fractions showed that chromium was being transported through the column at the time the study was concluded.

Additional evidence indicating that the metals were more tightly bound in the silt loam than the sand comes from a review of the uptake of the metals by the bermuda grass. Although no chromium was taken up by the grass grown on either soil, the levels of zinc in the grass grown on the sandy soil did increase over the levels in the control. Zinc was more tightly bound to the silt loam and was not as readily available for bermuda grass uptake. In the sandy soil, however, zinc was not as tightly bound and was taken up by the grass.

Barium and chloride were found in the leachates from both soils. The mobility of the barium may possibly be attributed to the presence of chloride in the reserve pit fluids and the soils and the subsequent formation of chloride compleses. The behavior of the chloride in the columns was not unexpected. As reported earlier, chloride is a very mobile ion and is rapidly transported through soils. It is interesting to note that chloride movement was faster through the sandy soil than through the silt loam. Chloride was detected sooner in the leachate samples from the sandy soil than from the silt loam. In addition, the load of chloride added with the addition of the reserve pit fluids moved through the sand column in 7 days whereas it took 11 days for it to move through the silt loam column.

The results from this study clearly show that contaminants added to soils from the land farming of reserve pit fluids may be taken up by vegetation and/or transported through the soil column. The extent of transport of zinc and chromium appeared to be function of soil type whereas the mobility of barium was probably affected by the presence of chloride. Chloride added to soils by land farming reserve pit fluids is readily transported through the soils with the rate of transport being controlled by soil type.

This study provided preliminary information on the behavior of four contaminants added to soils as the result of land farming reserve pit fluids. There was no attempt to correlate pH and oxidation-reduction potential on pollutant mobility and transport. Obviously, these environmental conditions would have an effect on metal transport. Additional studies should be performed to determine the effects of the soil environment with respect to pH and redox potential on contaminant mobility. In addition the behavior of metals other than zinc, chromium and barium should be characterized.

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