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Review and Evaluation of the Influence of Chemicals on the Conductivity of Soil Clays

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REVIEW AND EVALUATION OF THE INFLUENCE OF CHEMICALS ON THE CONDUCTIVITY OF SOIL CLAYS

by

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16. ABSTRACT

A study was undertaken to ascertain the effects of organic solvents on compacted soils. Laboratory measurements showed that clay initially dispersed in water will flocculate as the concentration of organic increases. The hydraulic conductivity typically increased two or three orders of magnitude at concentrations above which the clay flocculated. Laboratory conductivity measurements indicated that elevated gradients caused a significant decrease in conductivity when the permeant was water. No significant changes were found however with organic liquids. The average conductivity of three commercial clays to xylene was significantly greater than corresponding conductivities to water. In addition, the conductivities of two of the three commercial clays to both gasoline and kerosene were also significantly increased. Conductivities measured in the field test cells confirmed the results obtained in the laboratory. All three soils exhibited increased conductivity when exposed to xylene. When exposed to acetone, the soils underwent an initial decrease in conductivity, as was also seen in the laboratory, followed by an increase in conductivity. The overall data indicate that permeants having a dielectric constant below 30 will cause the clay to flocculate, dessicate, crack, and allow the permeant move rapidly through the larger pores which are formed.

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Hazardous Waste Engineering Research Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies programs, and regulations of the Environmental Protection Agency, the permitting and other responsibilities of State and local governments and the needs of both large and small businesses in handling their wastes responsibly and economically.

This report describes the results of studies of the effects of organic solvents and other solutions on compacted clay soils using several chemical and physical techniques. Data collected confirm the effects of desiccating solvents in increasing the fluid-conducting pore spaces in such soils. This leads to increased hydraulic flow when such liquids are ponded on the soil surface. These results have helped to provide a firm basis for the Agency's regulations limiting the types and amounts of liquids which can be safely contained by a clay-lined landfill. For further information, please contact the Land Pollution Control Division of the Hazardous Waste Engineering Research Laboratory.

Thomas R. Hauser, Director
Hazardous Waste Engineering
Research Laboratory

ABSTRACT

A study was undertaken to ascertain the effects of organic solvents on compacted soils. Included were laboratory studies on the flocculation of clays in organic solutions; measurements of the basal spacing of bentonite equilibrated with organic solutions; laboratory measurements of the hydraulic conductivity of compacted soils to water, acetone, and xylene; an evaluation of the influence of hydraulic gradient on the hydraulic conductivity to water, acetone, and xylene; laboratory measurements of the conductivity of commercially available clays to common petroleum products; field measurements of the conductivity of compacted soils to waste acetone and xylene; and micromorphological observations comparing pore space in compacted soils permeated with water and organic liquids.

Laboratory measurements showed that clay initially dispersed in water will flocculate as the concentration of organic or salt increases. Flocculation occurred at dielectric constants in the range of 30 to 50 for water miscible organic liquids or at salt concentrations above 0.1 to 0.5 N for the three tested clays. The hydraulic conductivity typically increased two or three orders of magnitude at concentrations above which the clay flocculated. Volume change measurements indicated that bulk swelling was proportional to the dielectric constant of the permeant. Therefore, above certain concentrations, organics appear to result in flocculation, subsequent shrinkage, and the formation of cracks through which the fluids may rapidly move.

Laboratory conductivity measurements indicated that elevated gradients caused a significant decrease in conductivity when the permeant was water. No significant changes were found, however, with permeants other than water. Average conductivity differences between gradients of 10 and 181 were only 0.38 and 0.22 orders of magnitude for the kaolinitic and micaceous soils, respectively.

The average conductivity of the three commercial clays to xylene was significantly greater than corresponding conductivities to water. In addition, the conductivities of two of the three commercial clays to both gasoline and kerosene were also significantly increased. All three soils showed increased conductivity to diesel fuel and motor oil; however, due to the variability of the results, the increases were not large enough to be statistically significant.

Conductivities measured in the field test cells confirmed the trends seen in the laboratory. All three soils exhibited increased conductivity when exposed to xylene. When exposed to acetone, the soils

underwent an initial decrease in conductivity, as was also seen in the laboratory, followed by an increase in conductivity. The entrance of rainwater through the cap and the resultant decrease in acetone concentration could explain the instances when the behavior differed.

The overall data indicate that permeants having a dielectric constant below 30 will cause the clay to flocculate, desiccate, crack, and allow the permeant to rapidly pass through it.

CONTENTS

FIGURES

Number		Page

TABLES

Number		Page

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SECTION 1

INTRODUCTION

Large volumes of wastes have been and will continue to be disposed of in landfills. In addition to landfills, large amounts of liquid wastes are stored in pits, ponds, and lagoons. There are numerous reports of groundwater contamination from leaking landfills and impoundments. As a result of this, many states and later the federal government required all hazardous waste impoundments to have a clay liner to retard leachate migration to the groundwater. Acceptable clay liners were to be compacted and have a pemeability to water of 1×10^{-7} or less. Despite this effort to prevent environmental damage, reports continued to appear that documented the leaking of concentrated organics from "state of the art" clay lined facilities. One typical case study was described by Daniels (1985) in which a surface impoundment overlaying 15 m of clay with an initial conductivity of 1×10^{-8} to 1×10^{-9} cm sec^{-1} leaked contaminants into the groundwater. Laboratory and field conductivity measurements made after the leakage was discovered showed the conductivity to average 2×10^{-6} (lab) and 1×10^{-4} (field) cm sec^{-1}. The conductivity differences were attributed to seepage paths such as cracks and root holes.

A laboratory study revealed that compacted clays undergo large increases in conductivity when permeated with organic solvents (Brown and Anderson, 1983); however, this study left numerous questions unanswered. Do admixed clays behave the same as the native clays used in the 1983 study? Do clays behave the same in the field as predicted by the fixed wall permeameters used by Brown and Anderson (1983)? What is the effect of dilute organics on the conductivity of clay soils? How did the elevated hydraulic gradients used by Brown and Anderson (1983) affect the measurements? What is the effect of common petroleum products on clay conductivity? If the observed data of Brown and Anderson (1983) is correct, what is the mechanism by which the increased conductivity occurred?

The present study was initiated to provide additional data on the influence of pressure on obtained results, to study the effect of dilutions on the permeability of clay liners, to provide field verification of laboratory results, and to develop a mechanistic explanation for the observed data.

While the laws have changed substantially since this project began, the data are still significant and will be of use in describing what has happened and is likely to happen to many previously installed landfills and impoundments. In addition, the data may help to predict the possible movement of organic wastes that have been injected into deep underground strata and those that are spilled on the surface.

SECTION 2

CONCLUSIONS

1. Exposure of compacted clay soils to concentrated organic solvents results in desiccation of the clay and resultant increased hydraulic conductivity due to the passage of fluids through cracks and channels.

2. The effect of solvents on the conductivity of soils is dependent on the dielectric constant of the fluid. Solutions with a dielectric constant greater than 30 to 40 will behave much like water, while permeants with dielectric constants less than 30 to 40 will act similarly to the concentrated permeant.

3. Concentrated organic solvents, particularly acetone and xylene, will drastically increase the conductivity of compacted soils regardless of their mineralogies.

4. Commonly used petroleum products including gasoline, kerosene, diesel fuel, and motor oil permeate compacted soils one to four orders of magnitude faster than water.

5. The use of elevated pressure to measure the hydraulic conductivity in fixed wall permeameters did cause a significant decrease when water was the permeant; however, no significant effect was observed when other permeants were used.

6. Conductivities of field cells permeated with waste acetone and xylene followed the same patterns and showed similar increases as the laboratory measurements using fixed wall permeameters.

7. Micromorphological measurements and photographs indicated that compacted soils permeated with acetone and xylene contained larger and more continuous pores.

8. Many of the flexible membranes used in the field study leaked.

SECTION 3

RECOMMENDATIONS

1. Concentrated organic solvents should not be placed in clay lined impoundments.

2. Concentrated petroleum products should not be placed in clay lined impoundments.

3. All clay lined impoundments need to be tested to assure their compatability with the materials to be contained.

4. Monitoring efforts should be directed toward clay lined facilities in which organic liquids have been disposed of in the past.

5. All flexible membrane liners should be water tested for possible leaks before use.

SECTION 4

MECHANISM BY WHICH ORGANICS AFFECT SOILS

INTRODUCTION

Previously reported research (Anderson et al., 1985; Brown and Thomas, 1985; Green et al., 1983; and Brown and Thomas, 1984) have indicated that certain organic liquids can rapidly penetrate compacted clay liners. Understanding the mechanism by which this phenomenon occurs is important for extrapolating the present data base to other chemicals, mixtures of chemicals, or other clays that might be candidates for use in soil lined retention facilities.

There are several levels at which one might seek mechanistic explanations for the observed impact of organic chemicals on the hydraulic conductivity of soils. These include a theoretical consideration of the influence of organic chemicals on the thickness of the double layer, the basal spacing of smectitic clays observed by x-ray techniques, the flocculation-dispersion state of clay minerals, and the bulk shrinking-swelling response of clay soils. Evidence on each will be considered in turn.

Double Layer Theoretical Consideration

Double layer theory suggests that the spacing between clay layers should increase as the dielectric constant (D) and the temperature (T) increases and decrease as the concentration of electrolyte in the solution (n), the ionic change (e) and the valence of the primary ion (V) increase, as suggested by Mitchell (1976) where K is the Boltzman constant:

$$H = \sqrt{\frac{DKT}{8\pi n\, e^2\, V^2}}$$

This relationship suggests that if all other things are held constant, a decrease in the dielectric constant should cause a decrease in the basal spacing of primary particles. Since many common organic and inorganic chemicals have dielectric constants lower than water, they would be expected to cause clays to shrink (Maryott and Smith, 1951).

Other factors that may influence the spacing include the size of the hydration shell around the primary ion and the pH. The system is complex and not fully understood; therefore, the above proportionality may not hold for all conditions. The zeta (X) potential of the system may possibly be more directly related to the spacing than the dielectric constant, but sufficient data is not yet available to demonstrate this possibility.

X-Ray Data

The interlayer spacing of Ca saturated montmorillonite is known to be affected by the dielectric constant of the immersion fluid (Brindley et al., 1969). Several researchers have reported that dilute solutions of certain organic chemicals in water result in an increase in basal spacing over that in pure water. More data is available on acetone dilutions than on any other organic. The data of Brindley et al. (1969) plotted on Figure 1 is typical of the available data. Dilute solutions with dielectric constants between 60 and that of water caused swelling in excess of 2.7 nm. Only very low concentrations of acetone are evidently required to cause swelling, but no threshold concentrations have been reported. Thus, the line for acetone (Figure 1) is dashed, since its exact location is not known. Similar data on the swelling of clays exposed to dilute acetone are reported by MacEwan (1948).

Less swelling occurs for calcium montmorillonite with n propanol, ethanol, and a small amount with methanol, as seen in Figure 1. An explanation as to why dilute concentrations of certain organic chemicals cause the increases in basal spacings must be based on something other than the double layer, which predicts that the spacing should be proportional to the square root of the dielectric constant. Mackor (1951) suggests that it may be caused by the adsorption of a monomolecular film of acetone on the surface, which in turn influences the χ potential. Acetone is known to form double-layer complexes with clay minerals (Glaeser, 1948). The adsorption mechanism has been reported by Bykov et al. (1974) to be hydrogen bonding between the OH group on the surface and the carbaryl group of the acetone. At low concentrations, the acetone-water structure surrounding the clay may possibly occupy more volume than the displaced water, thereby causing the basal spacing to increase. In dehydrated systems, the acetone can bond directly to the surface (Parfitt and Mortland, 1968), which should result in a decrease in the basal spacing since the water layers are no longer present.

Brindley et al. (1969) reported on a study of the impact of the dilution of a group of organic chemicals on the basal spacing of a calcium montmorillonite. They plotted their spacing as a function of mole percent of the organic of interest. For all eight organic chemicals they studied, they found abrupt decreases in basal spacing at a different mole fraction for each chemical. Their data (Brindley et

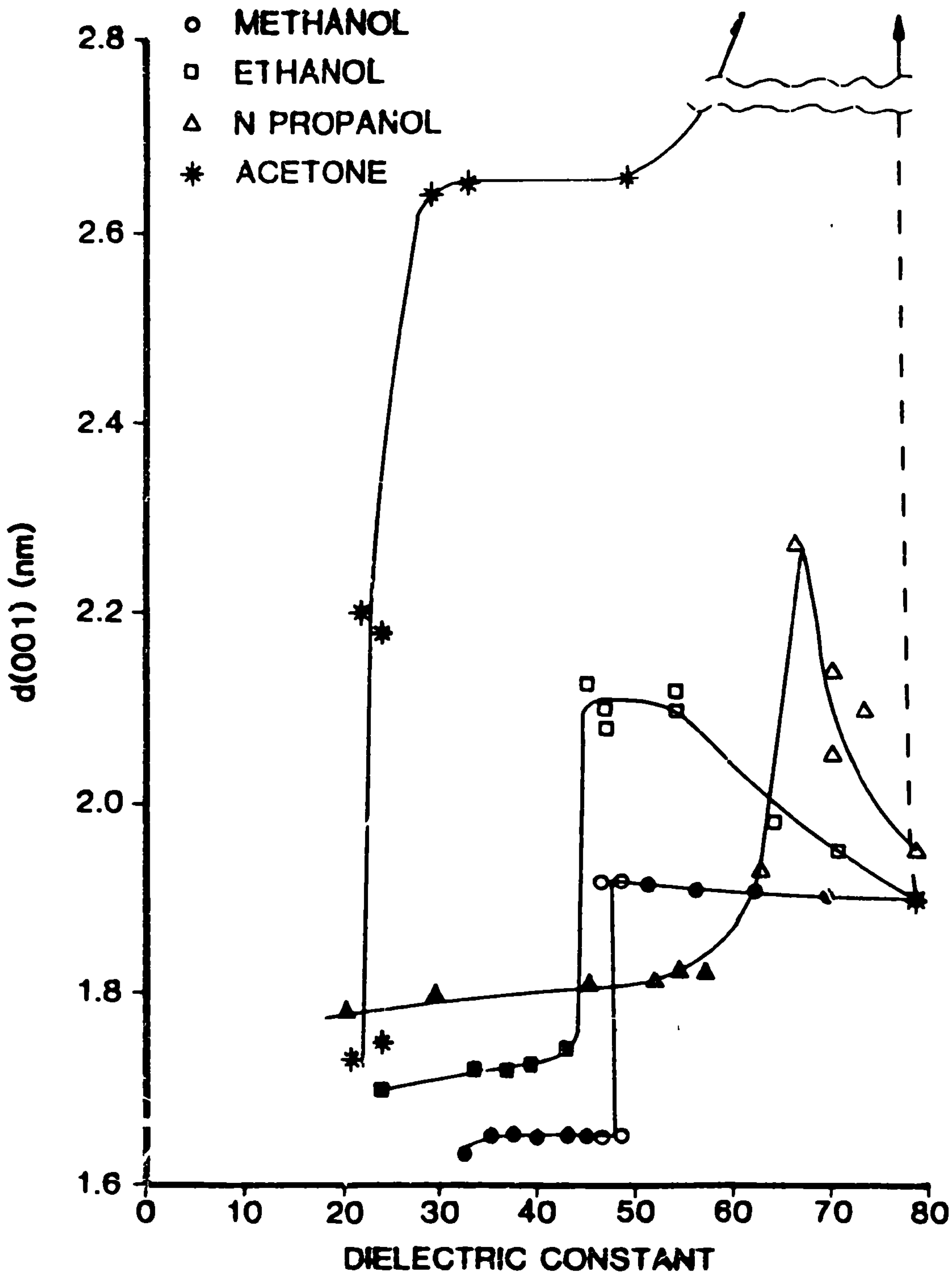

Figure 1. Basal spacing of calcium montmorillonite equilibrated with water dilutions of acetone, methanol, ethanol and n propanol as a function of dielectric constant. (After Brindley et al., 1969).

al., 1969) on dilutions of acetone, methanol, ethanol, and n propanol was replotted as a function of the dielectric constants of their dilutions to determine if there was a unique dielectric constant associated with the abrupt changes in observed spacing. The results shown in Figure 1 indicate abrupt changes in spacing for acetone, methanol, ethanol, and n propanol at dielectric constants of about 23, 47.5, 44, and 65, respectively. There is, thus, apparently no unique dielectric constant for the clay they tested at which the basal spacing changes. This indicates that factors other than or in addition to the dielectric constant are important in regulating the phenomena.

Evidence on the influence of dielectric constant on the basal spacing of calcium montmorillonite was also presented by Murray and Quirk (1982). They plotted data from several sources relating spacing to the dielectric constant of a group of nineteen chemcials. Although there are a few spurious results, their data suggest that the spacing is least at low dielectric constants and increases to values similar to those for water and chemicals with dielectric constants greater than 40. Thus, there is ample evidence which confirms the theoretical suggestion that organic chemicals with dielectric constants lower than water should cause the basal spacing of clays to decrease. While x-ray data can only be used to document interlayer spacing of smetitic clay, it is the double-layer theory that suggests that spacing between adjacent particles of smectitic and other minerals will likely be smaller when chemicals with low dielectric constants replace water on the mineral surfaces.

Bulk Shrinking-Swelling

Physical swelling of illitic clays has been shown to be linearly correlated with the bulk static dielectric constant of the solvent (Murray and Quirk, 1982). Green et al. (1983) found a similar linear relationship between swelling of two kaolinitic soils and the dielectric constant of the solvent.

All the soils on which data are available appear to be subject to increased conductivity when exposed to concentrated organics, although the "active clays", i.e., bentonite, etc., are most affected by changes in soil pore fluid (Acar and Seals, 1984). Decreases in the dielectric constants of the pore fluid are postulated to decrease the thickness of the diffuse double layer, thereby causing shrinkage which results in the formation of cracks or channels that allow increases in conductivity.

Thus, the literature contains data which strongly indicates a potential relationship between solvent dielectric constant, basal spacing of smectitic minerals, bulk volume change, and conductivity. The objective of this study was to document the behavior of three clays when exposed to solutions with a range of dielectric constants.

MATERIALS AND METHODS

Flocculation Study

Three clays, a predominantly kaolinite, a mica, and a bentonite, were selected for use in this study. Twenty-two g of each clay was dispersed by mixing with 50 ml of 0.05 M $Na_4P_2O_7 \cdot 10H_2O$ and 500 ml of water in a mixer at high speed for 5 min. (Day, 1965). The slurry was then air dried and pulverized in a mortar and pestle. The dried clay was mixed with approximately 250 ml of the desired acetone, ethanol, or NaCl solution in a blender (explosion proof laboratory) at high speed for 5 min. This suspension was then transferred to a hydrometer jar and brought to 1130 ml with the liquid being tested. The jar was covered to prevent evaporation and equilibrated overnight in a water bath at 30°C. The following day, solutions were stirred, and 25 ml samples were pipetted from a depth of 10 cm after settling for 6.25 hr. The clay content was calculated from these measurements. The relative clay content (C/Co) in each solution was calculated by dividing the clay content measured in the solution by the clay content measured in water. Dielectric constants of the solutions were estimated by linear extrapolation between dielectric constants of the pure liquids.

Tests were conducted using solutions containing 0, 50, 60, 70, 80, and 100% by volume acetone and 0, 20, 50, 60, 70, 80, 90, and 100% by volume ethanol. In addition, solutions 0.0, 0.05, 0.10, 0.12, 0.15, 0.20, 0.25, 0.30, 0.50, 0.65, 0.75, and 1.0 N NaCl were used. All tests were replicated three times.

Volume Change

Three replications of all three clay soils were packed into volume change apparatus (Soil Test C-290) and exposed to xylene and acetone. Free liquid, approximately 2 cm deep, was applied to the surface and allowed to infiltrate by gravity. Permeant additions were made as needed to maintain a free liquid surface. Measurements of vertical swelling were made and converted to a percentage of the original soil volume.

d-Spacing

Using the pipette method of particle size analysis (Day 1965) the clay fraction of the bentonite soil was isolated, air dried, and ground in a mortar and pestle. Clay slurries were made using solutions containing 0, 20, 40, 60, 80, and 100 percent by volume ethanol and 0, 2, 5, 50, 60, 80, and 100 percent by volume acetone. Each slurry was equilibrated for two days before analysis. One to 2 ml of the slurry to be analyzed was vacuum filtered through a porous tile slide using the procedure of Starkey, et al (1984) to orient the clay particles on the basal configuration (001). To prevent significant evaporation of the organics during orientation, additions of the respective ethanol or acetone solutions were made as needed. The tile slide was removed and placed in the x-ray chamber which had been sealed with clear mylar. Additional pads moistened with the appropriate solutions were placed in the chamber just beneath the slide to minimize evaporation during analysis. The sample was equilibrated three min. in the chamber before analyses. A Philips Electronic Instrument Model XRG 3000 was used. When a slide was too wet to give sufficient peak resolution, it was removed and exposed for one minute to a high intensity heat lamp and the analysis was repeated. This served to remove some of the free standing liquid which interfered with analysis but did not heat the clay sufficiently to remove the adsorbed liquid.

Mobility

The pipette technique for particle size analysis (Day, 1965) was used to separate the clay fraction of each of the soils. The clay fractions were air dried and ground in a mortar and pestle. Two series of dilutions were made containing 0, 10, 20, 50, 65, 80, and 100 percent by volume of acetone and ethanol. Clay was added to each solution at the rate of 500 mg L^{-1} and equilibrated for two days. Preliminary studies showed that electrophoretic mobility was independent of the clay concentration in the range of 100 to 1000 mg L^{-1}.

Movement of individual clay particles under an applied electric field was measured using an instrument similar to that described by Riddick (1961). A 0.03 x 0.3 mm square glass capillary tube was suspended between two glass reservoirs. A stainless steel electrode was placed in each reservoir and connected to a direct current power supply adjusted to provide an output of 30 volts. The apparatus was placed on the stage of a Zeiss binocular microscope and viewed under 200x magnification. The microscope was equipped with a calibrated occular, and measurements were made of the time required for a particle to travel 0.5 mm. Movement of ten particles in each of three replications in each solution concentration were made. Electrophoretic mobility was calculated as µm sec^{-1} per V cm^{-1}. The zeta potential was then calculated by:

$$Z = \frac{\mu (E \cdot E_o)}{n}$$

where Z = zeta potential
µ = electrophoretic mobility
E = dielectric constant
E_o = permittivity of free space ($8.85 \times 10^{-12} C^2/N\,m^2$)
n = viscosity

Solution viscosities and densities were measured, and dielectric constants were estimated by linear interpolation between those of the pure liquids, as suggested by the data of Mashni et al. (1985).

Conductivity Measurements

Clay-sand admixtures that had hydraulic conductivities to water of less than 1 x 10^{-7} cm sec^{-1} were made using each of the clays. Physical characteristics of the soils are given in Table 1. These were compacted in fixed wall permeameters, and the procedures of Anderson et al. (1982) were used to determine conductivities. Three replications of each soil were exposed to solutions of 0, 60, 80, and 100% ethanol; 0, 60, 80, and 100% acetone; and 0.10, 0.20, and 0.30 N NaCl. All tests were conducted at a hydraulic gradient of 181. Leachate volume was measured for determination of the hydraulic conductivity by means of the following equation:

$$K = \frac{V}{ATH}$$

where: V = volume of leachate (cm^3)
A = cross sectional area of the permeameter (cm^2)
T = time (sec)
H = hydraulic gradient calculated as the hydraulic head in cm of water plus the length of the soil core divided by the length of the soil core.

RESULTS AND DISCUSSION

Volume Changes

Within a given soil, the volume change was directly proportional to the solvent dielectric constants (Table 2). Soils swelled least when exposed to xylene (dielectric constant of 2.4) and greatest when exposed to water (dielectric constant of 78). The kaolinitic soil swelled the least amount, the micaceous soil swell was intermediate, while the bentonitic soil exhibited the greatest amount of swell. The greater swelling of the bentonitic clay is likely due primarily to the increased basal d-spacing, while volume changes in the other soils can only be due to changes in spacing betwen particles.

Regression analyses of the data show the bentonitic soil to have a much steeper slope and higher correlation coefficient than that of the other two soils (Figure 2). These data are in general agreement with those of Green et al. (1983), which is plotted in Figure 3. As both of these sets of data contain chemicals with dielectric constants near 2, 20, and 78 and the regression coefficients are large, one could be led to the conclusion that the relationship is nearly linear. This is not likely, however, when one considers the more abrupt changes in

TABLE 1. PHYSICAL PROPERTIES OF THE THREE SOILS BLENDED FOR USE

Clay	USDA Textural Class.	Particle Size distribution Sand	Silt	Clay	Mineralogy	Organic Carbon (%)	pH
		----------- (%)	-----------				
Kaolinite	SCL+	62.8	13.9	24.5	K-1++ M-tr	0.53	7.7
Mica	SCL	60.4	17.6	22.0	Mi-1 K-2 M-3	0.17	8.0
Bentonite	SCL	75.9	3.9	20.2	B-1 Mi-tr	0.29	8.9

\+ SCL = sandy clay loam
\++ K = kaolinite
Mi = mica*
B = bentonite*
M = montmorillonite
1 = dominant mineralogy
2 = 2nd most dominant mineralogy
3 = 3rd most dominant mineralogy
tr = trace quantity

* commercially obtained.

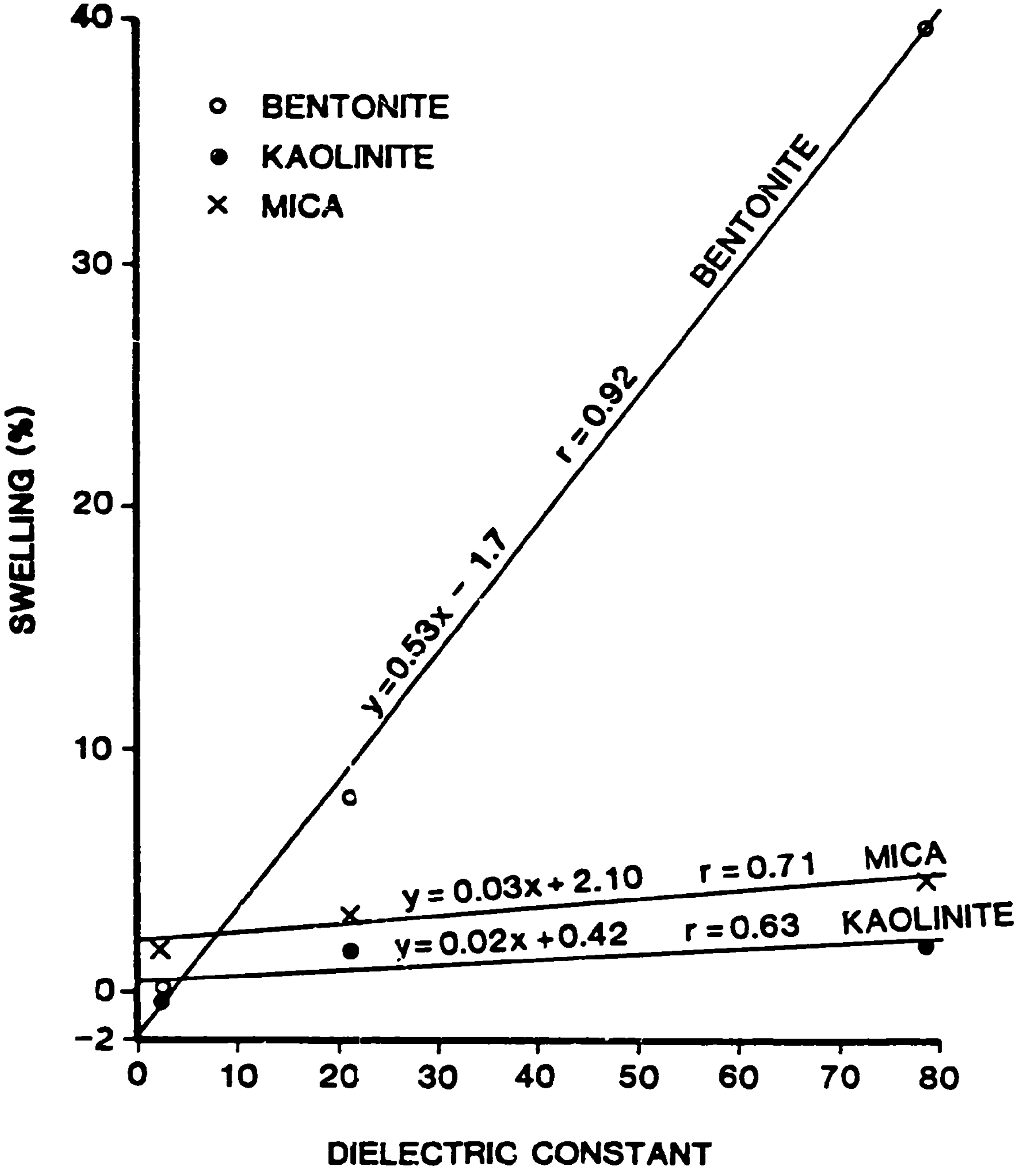

Figure 2. Percent swelling of the three soils used in the present experiment equilibrated with acetone, xylene, and water plotted as a function of dielectric constant.

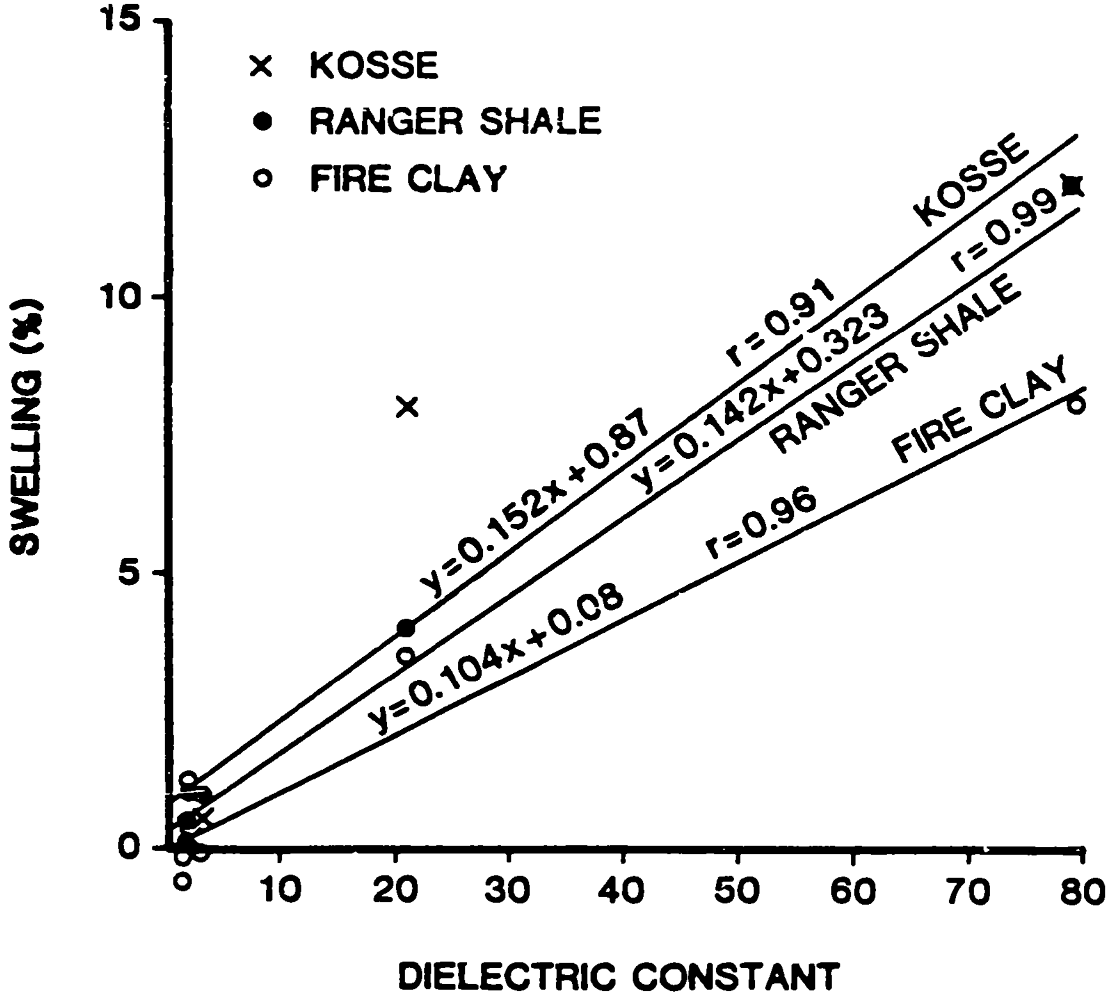

Figure 3. Percent swelling of three soils equilibrated with acetone, xylene and water plotted as a function of dielectric constant. (After Green _et al._, 1983).

TABLE 2. MEAN SWELLING ON SHRINKAGE OF COMPACTED SOILS CONTAINING KAOLINITIC, MICACEOUS OR BENTONITIC CLAYS WHEN EXPOSED TO ORGANIC SOLVENTS AND WATER

Fluid	Dielectric Constant	Soil % Volume Change		
		Kaolinite	Mica	Bentonite
Acetone	20.7	1.8	3.2	8.0
Xylene	2.4	-0.4	1.9	0.3
Water	78.0	1.9	4.7	39.7

basal spacing exhibited in the x-ray analyses of the smectitic minerals shown in Figure 4. Swelling data collected by Murray and Quirk (1982) on nineteen chemicals with a more complete set of dielectric constants is summarized in Figure 5. They also chose to describe the relationship with the dashed line shown in the figure. The solid line which represents an eyeball fit, however, suggests that there is a more abrupt change in the volume dielectric constant relationship, with the volume change occurring near a dielectric constant of 40.

The x-ray data shown in Figure 1 suggests that an abrupt change in basal spacing may take place at dielectric constants between 20 and 50 for different chemicals and soils. Since the impact of other factors were not controlled in these studies, the agreement between the x-ray data and the bulk-swelling data is reasonable.

There is no available data on the swelling of soil exposed to chemicals or dilutions of chemicals with dielectric constants slightly less than that of water, as would be the case for dilute acetone. The x-ray data, however, suggests that swelling greater than that suggested by any of the data presented here may occur when clays are exposed to acetone dilutions with dielectric constants between 60 and 78.

Flocculation

The kaolinitic, micaceous, and bentonitic soils exposed to various concentrations of acetone in water exhibited flocculation below dielectric constants of 35, 35, and 50 for the kaolinitic, micaceous, and bentonitic soils, respectively (Figure 6). When exposed to various strengths of inorganic salt solutions (NaCl), both the kaolinitic and micaceous soils flocculated at 0.15 N NaCl. The dispersed bentonitic soil, however, did not flocculate until the concentration was increased to about 0.45 N NaCl. It is interesting to note that the standard deviations of the data are generally least at the low dielectric constants and high salt concentrations when the soils are flocculated

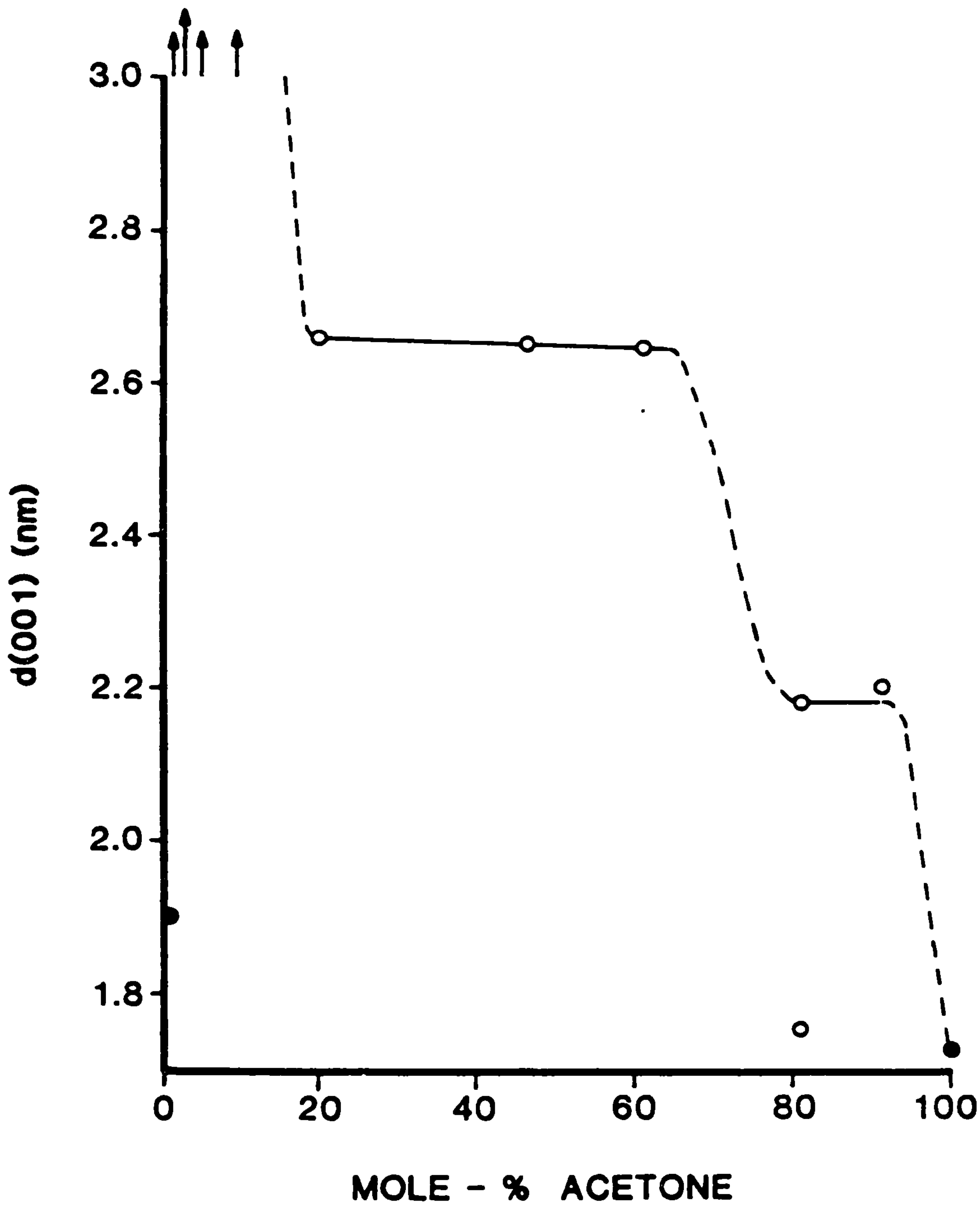

Figure 4. Basal spacing of calcium montmorillonitic equilibrated with water dilutions of acetone. (After Brindley et al., 1969).

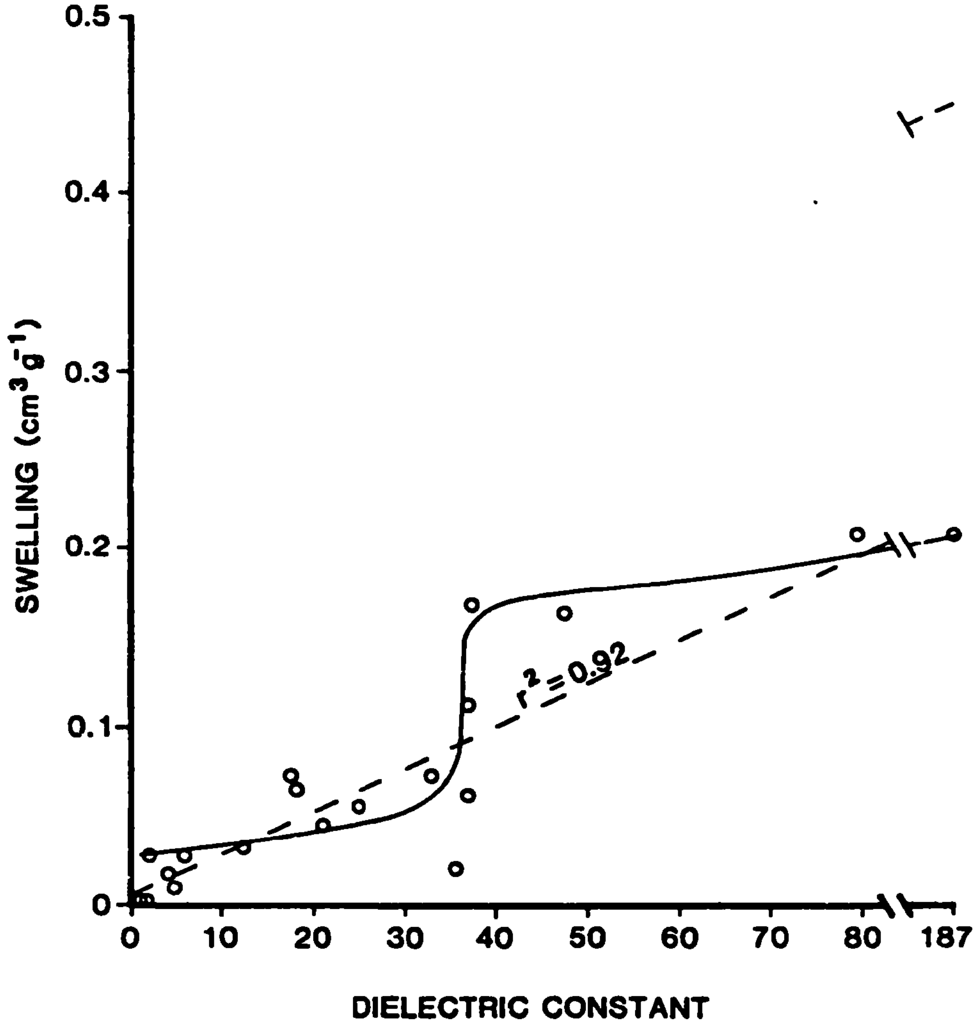

Figure 5. Swelling (cm^3 g^{-1}) of Urrbrae B soil in various organic solvents as a function of dielectric constant. (After Murray and Quirk, 1982).

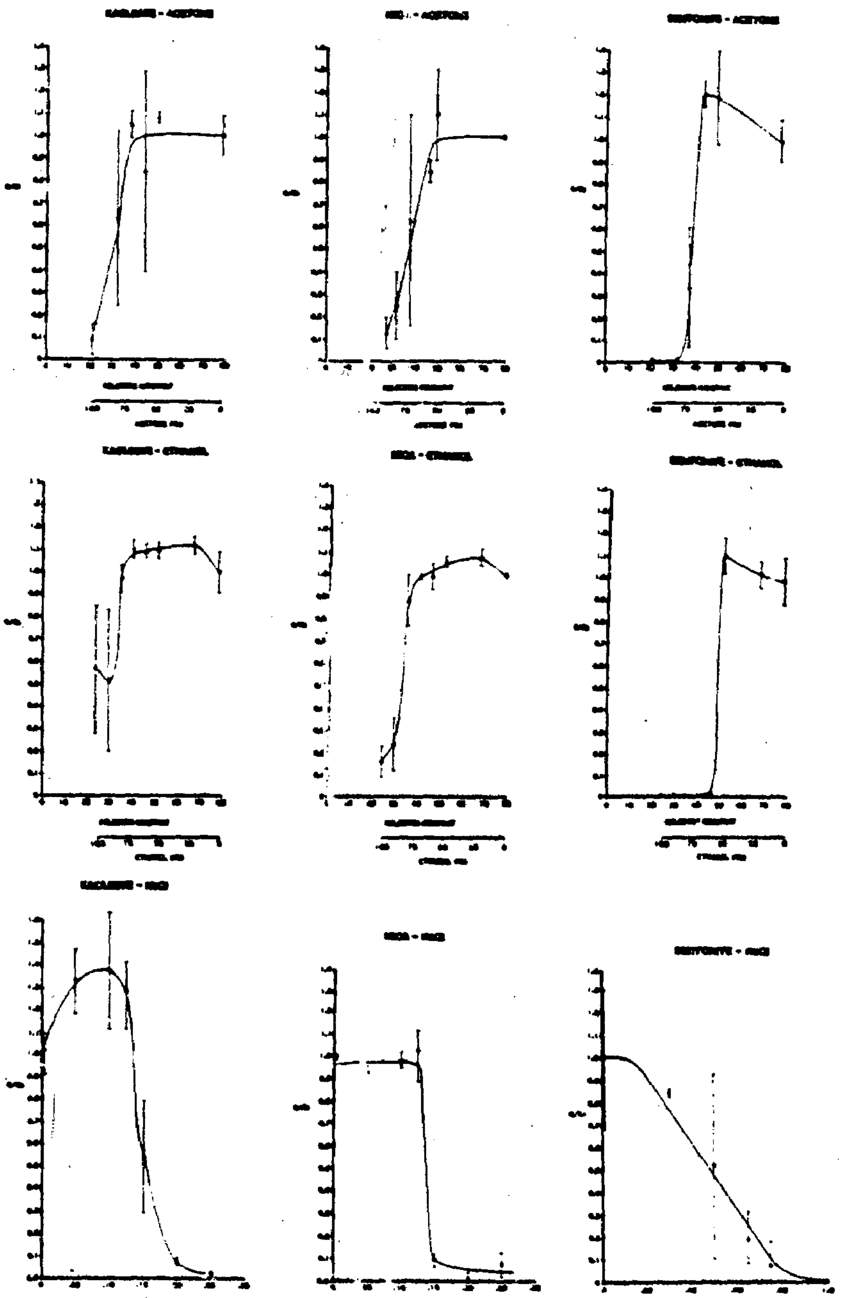

Figure 6. Change in relative clay concentration measured in solutions of various dielectric constants and salt strengths.

and greatest near the transition conditions. While the phenomenon appears to be best characterized as being abrupt, the greatest standard deviations near the conditions where flocculation occurred may indicate that other uncontrolled factors may be influencing the phenomenon or that there are some near threshold conditions.

Flocculation of bentonitic soils at dielectric constants above those required for micaceous and kaolinitic soils is evidence of the increased sensitivity of bentonitic soils to changes in soil pore fluid. The abrupt flocculation of these clays occurring at dielectric constants similar to those at which the basal spacing of the bentonitic clays abruptly changed is further evidence that the tested organic liquids cause the clays to shrink.

d-Spacing

The effect of dielectric constant on the d-spacing of bentonite clay is shown in Figures 7 and 8. As expected, the spacing in bentonite equilibrated with water was about 1.8 nm. When the clay was exposed to dilute concentrations of acetone (2 to 5%) having dielectric constants of 77.3 and 75.6, respectively, the basal spacing increased to 2.0 nm. At a dielectric constant of 49, corresponding to an acetone concentration of 50%, the spacing decreased back to about 1.82 nm and did not differ significantly from that in water. A further decrease in dielectric constant to 43 resulted in a lowering of the spacing to 1.45 nm. Further decreases in dielectric constant did not significantly change the spacing, which remained between 1.45 and 1.55 nm.

When exposed to ethanol, a similar type of response was observed. The spacing increased at dilute ethanol concentrations to 2.3 nm and then decreased to 2.0 nm at a dielectric constant of 57. The spacing remained at 2.0 nm through dielectic constants as low as 35 below which the spacing decreased to about 1.6 nm.

Basal spacings at various NaCl solutions ranging from 0 to 1 M in strength, all remained at the value obtained with water and are not shown.

Thus, the x-ray data for the bentonite suggests that the shrinking-swelling of the interlayer spacing may explain the observed influences of organic solvents on the conductivity of clay soils. The spacing increased at dilute concentrations, which explains the decreased conductivity observed at dilute concentrations of acetone and the initial decrease often observed when clays are wet with concentrated acetone. The later probably occurs because the acetone was initially diluted by the initial water in the sample.

The decrease in d-spacing at dielectric constants less than 35 to volumes below those observed when the clay is in equilibrium with water may explain the increases in conductivity observed when concentrated

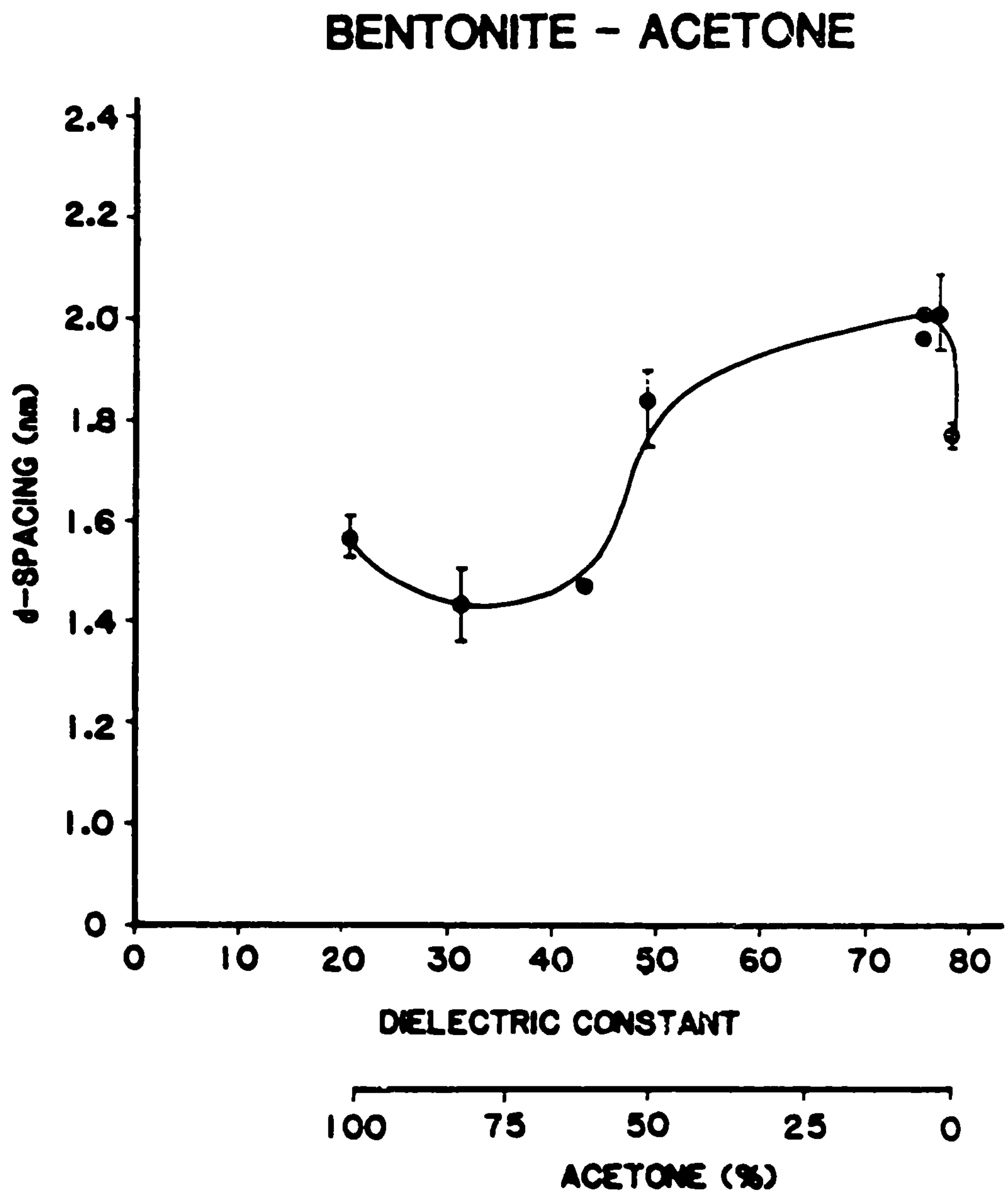

Figure 7. Basal spacing of bentonite clay equilibrated with acetone solutions of various concentrations and dielecrric constants.

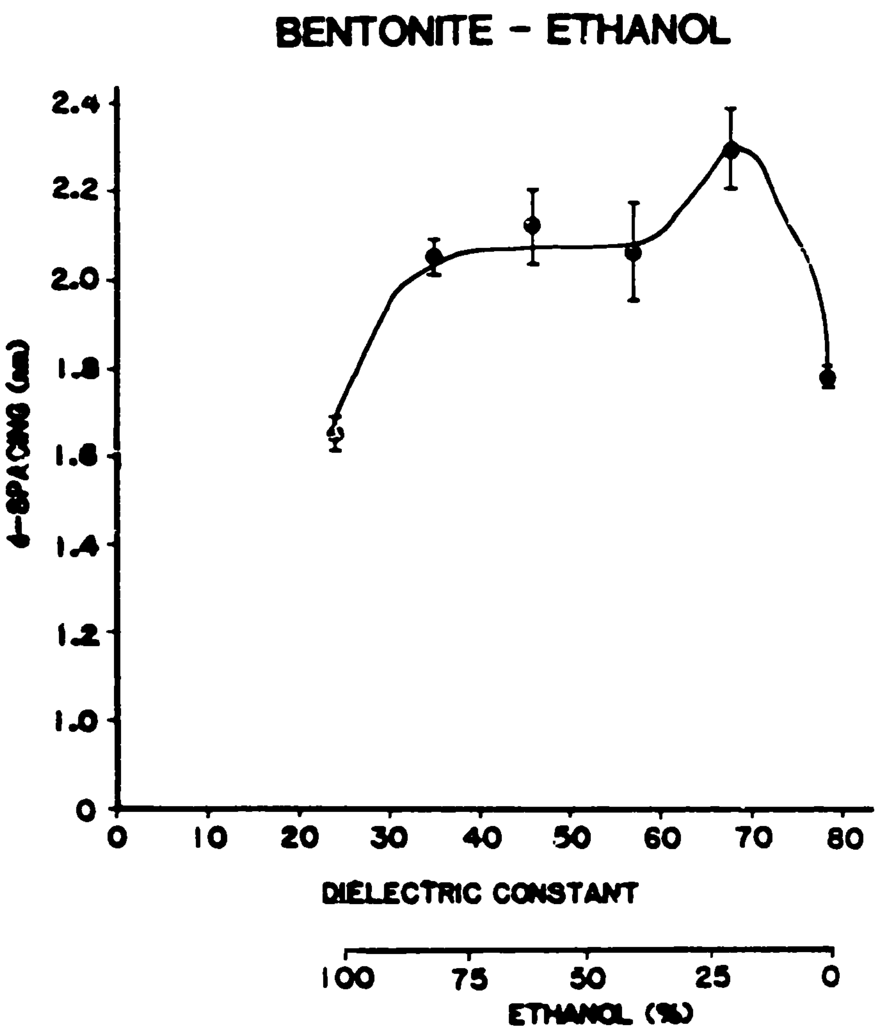

Figure 8. Basal spacing of bentonite clay equilibrated with ethanol solutions of various concentrations and dielectric constants.

organic liquids permeated the clay. Changes in d-spacing are not possible in the kaolinitic and micaceous clays, suggesting the possibility that the shrinking-swelling necessary to explain the changes in conductivity observed in these clays may be a result of changes in the space between, rather than within, the clay particles.

Mobility

The electrophoretic mobility and zeta potential of the three clays in acetone and ethanol solutions are given in Figures 9 and 10, respectively. The kaolinite soil exhibited a sharp linear decrease in mobility as the dielectric constant decreased. The mica clay decreased in mobility as the dielectric constants moved between 80 to 70. The mobility was nearly constant between a dielectric constant of 70 to 30, below which the mobility dropped to zero. The bentonite clay behaved similar to the mica except that the clay exhibited zero mobility at dielectric constants less than 40.

The decrease in mobility to zero for all three clays in both dilutions of acetone and ethanol correlate well with the flocculation of clays at and below similar dielectric constants in the Flocculation Dispersion Study.

Conductivity Measurements

The conductivity of the kaolinitic soil to acetone solutions increased significantly at a dielectric constant of 40 (Figure 11). This is equivalent to approximately 70% acetone by volume and indicates that solutions less concentrated than this will behave much like water, while solutions in excess of 70% acetone will behave like concentrated acetone. When exposed to varying concentrations of ethanol, the kaolinitic soil exhibited higher conductivities with solutions having dielectric constants of 45 or less. The increase in conductivity caused by these solutions was 2.5 to 3 orders of magnitude. The micaceous soil exhibited some conductivity increase below a dielectric constant of 45, but the increase was only about 0.5 orders of magnitude and was not significant. The kaolinitic soil responded to salt solutions as it did to organic solutions. A two order of magnitude increase in conductivity was observed as the NaCl concentration increased to 0.2 N. The micaceous soil exhibited a similar increase in conductivity between 0.2 and 0.3 N NaCl concentrations.

Thus, as either the organic or inorganic solution strengths increase, there is a point beyond which the conductivity increases significantly. Visual observations of clay patterns in the soils removed from the permeameter indicated that the organic liquids moved through cracks in the soil. There is, thus, evidence at several levels to suggest the mechanisms by which organic liquids influence the permeability of compacted clay. Double-layer theory predicts that the spacing between clay particles should decrease as water is displaced by

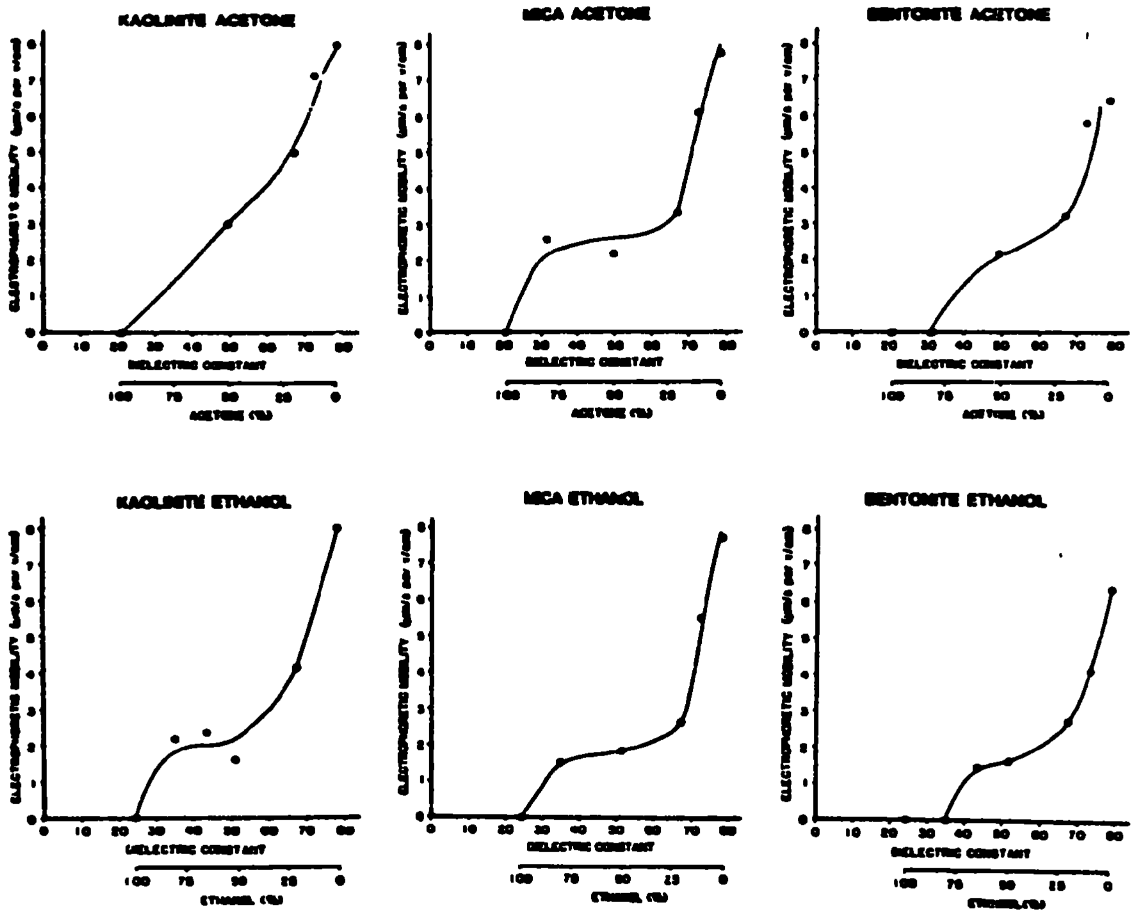

Figure 9. Electrophoretic mobility of three clays in water acetone and water ethanol solutions as a function of dielectric constants.

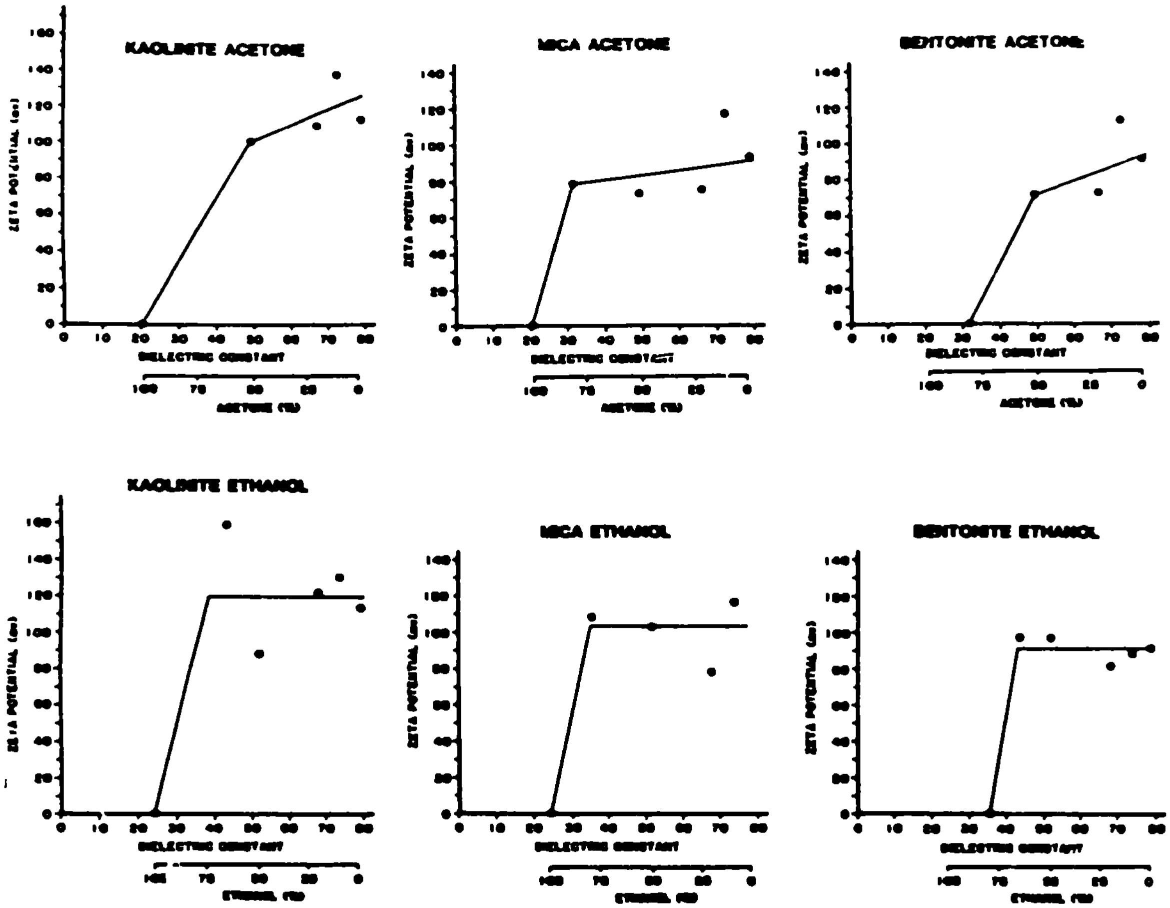

Figure 10. Zeta potential of three clays in water acetone and water ethanol solutions as a function of dielectric constants.

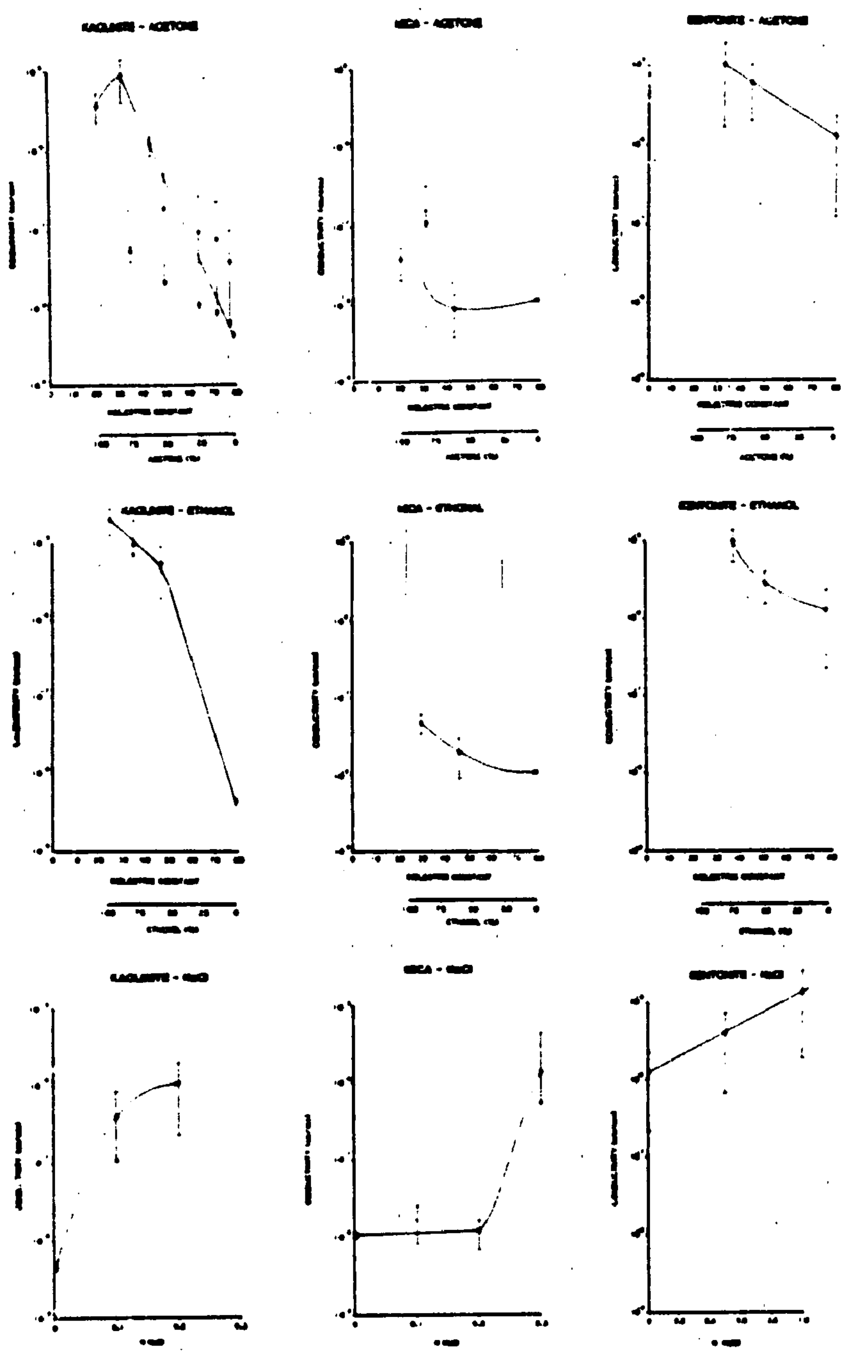

Figure 11. Average conductivity of compacted soils as a function of dielectric constant and salt strength.

organic chemicals with low dielectric constants. This is confirmed by x-ray data on smectitic soils and flocculation, mobility, and zeta potential data on soils with clays representative of the three most common mineralogies (Table 3). In general, the dielectric constants at

TABLE 3. DIELECTRIC CONSTANTS AT WHICH THE APPARENT CLAY CONCENTRATIONS REACHED 0.5, THE d-SPACING DROPPED BELOW 1.5 NM, THE ELECTROPHORETIC MOBILITY WAS MIDWAY BETWEEN ZERO AND THE PLATEAU, AND THE ZETA POTENTIAL WAS MIDWAY BETWEEN ZERO AND THE PLATEAU.

		Apparent Clay Content	Basal d-Spacing	Electrophoretic Mobility	Zeta Potential	Average
Acetone	K	31		31	35	32
	M	37		26	26	30
	B	38	47	37	41	41
Ethanol	K	30		28	31.5	30
	M	33		31	30	31
	B	49	28	38	39	39
Na Cl	K	.16				
	M	.14				
	B	.48				

which each of these parameters are affected by organics are quite similar within a given soil. The average dielectric constants at which the kaolinite soil was affected by acetone and ethanol were 32 and 30, respectively. The dielectric constants with acetone and ethanol were 30 and 31, respectively, for the mica soil and 41 and 39, respectively, for the bentonite soil. Comparison of these average values to the conductivities shown in Figure 11 indicate that solutions with dielectric constants less than the averages in Table 3 will result in increased conductivities. For the mica and bentonite soils, one can be reasonably assured that solutions with dielectric constants greater than the averages in Table 3 will have conductivities similar to those with water as the permeant. The kaolinite soil, however, will require a dielectric constant of 50 or above before the conductivity will be similar to that of water.

The differential volume changes when bulk soils are exposed to organic liquids also suggests that soils swell more when equilibrated to water than when equilibrated with organic liquids. The inverse of this is also likely, i.e., soil in equilibrium with water will likely shrink when the water is displaced with organic liquids. As the soil shrinks, cracks develop causing channels through which the liquids can move more freely. This, in turn, is expressed as increased saturated conductivity.

SECTION 5

MICROMORPHOLOGICAL OBSERVATIONS

INTRODUCTION

Interactions between soil barriers and leachate components may cause deterioration of the liquid retention properties of a barrier. Two important soil barrier properties that may be affected by interactions with leachate are as follows:

1. Effective pore volume -- the fraction of the total pore space that transmits most of the leachate percolating through a soil barrier; and

2. Conductivity - the rate at which leachate percolates through a soil barrier at a given hydraulic gradient.

A redistribution of soil pores toward larger, more conductive pores causes an increase in both the effective pore volume and the conductivity of a soil barrier. An increase in effective pore volume occurs if a soil shrinks and cracks. The leachate preferentially moves through the cracks instead of through the soil matrix, which results in leachate breaching the soil barrier more quickly.

Clay liners are sometimes compacted to artificially induced bulk densities. Although this compaction reduces the total volume of pores, planes that allow the flow of fluids can be created, i.e., between lifts (layers of compacted soils) and along shear planes. Two basic methods are used to depict these preferential flow paths. The soil structure and obvious planes of weakness can be observed without magnification; the macropore flow paths or macromorphology can be described by this method. The flow paths in the finer pores can be estimated by using micromorphometric techniques with a light microscope. In addition, soil components and pores can be examined by scanning electron microscopy (SEM) at magnifications far greater than is possible with the petrographic light microscope. When the SEM is used in the backscatter mode, images can be obtained in the form of photomicrographs of the pores and pore patterns of soil thin sections.

Backscattered electrons are produced when a beam of high energy electrons strikes a sample which produces an image of the surface topography of the soil thin section. When used in the compositional mode, they reflect approximate atomic number in that the atoms of heavier elements, which have stronger fields than lighter elements, also possess higher backscattering properties. These images have been qualified and quantified by measurements made on the Quantiment (Bisdom and Thiel, 1981). The photomicrographs must have significant contrast and clarity for this combination to give reliable porosity measurements.

Dyes have been used by several researchers to give direct visual evidence of the pathways of water movement in the soil (Kissel et al., 1973; Anderson and Bouma, 1973; Bouma et al., 1977; Bouma et al., 1979; Omoti and Wild, 1979; and Smettem and Trudgill, 1983). After infiltration of water containing a visual dye, disection of the soil can indicate pathways of movement and depth of penetration by the permeating fluid and solute. Most of the dyes used by prior investigators have been cationic and fluorescent. These dyes are highly water soluble and have an affinity for negatively charged mineral surfaces. There is little or no evidence on the surface of the soil as to the infiltration ports (entry points) of the fluid and dye tracer. Bulk sampling and subsequent chemical analysis done for the quantitative determination of the tracer are unsatisfactory because "average" results often have little indicative value. Large numbers of samples taken randomly over several replicate experimental units will give better estimates of flow path qualification and quantification (Brewer, 1976).

The literature found on effective porosity investigative techniques has concentrated on saturated flow in soils. Two fluorescent dyes and three nonfluorescent dyes were compared by Smettem and Trudgill (1983) for use in the identification of water transmission routes in structured soils. Transmission routes identified in field soils were found to be associated with structural features readily recognized by routine soil survey techniques. In the laboratory comparison, the most desirable properties of the tested dyes included stability over a wide pH range, anionic character, and high molecular weight. The fluorescent dye lessamine yellow FF was found to be the most suitable for tracing rapidly moving water under field conditions.

Flow patterns of two undisturbed swelling clay soils with different microstructures were studied by Bouma and Wosten (1979) using methylene blue cationic visual dye. They reported that the pores effective in conducting water constituted less than one percent of the entire soil mass. Most of these dyed pores had a diameter greater than 500 µm.

Fluid flow patterns through a compacted soil with a high clay content and high bulk density were also studied using a methylene blue as the dye tracer by Bouma and Dekker (1978). Their data showed that the tracer moved very rapidly through large continuous voids, and the soil solution was only slightly displaced from the finer water-filled pores. Bouma and Dekker (1978) called this phenomenon "short circuiting."

The small volume of conductive pores in the soils can be characterized best by an extension of the dye tracer concept to the micromorphological scale. Although constituting a small percent of the total volume, these pores contribute significantly to the hydraulic conductivity of soils. Measurements of pore size distribution in terms of the volumes of selected size classes is, therefore, more relevant than measurements of the total pore volume. Horton et al. (1985) determined the percent of the total porosity which was effective in conducting fluid faster than the average pore-water velocity. For the three soils studied, the percent of the total pore volume which was found to meet their definition of effective porosity was 13.8, 17.4, and 20 percent.

The portion of the total porosity, which was between 10 and 200 μm of each of the ten soils studied by Olson (1985), ranged between 0.07 and 23.3 percent, with most falling below 13.5 percent. They suggest that these larger pores are primarily responsible for the flow of fluids under saturated conditions.

No information is currently available on the impact of organic chemicals on the pore size distribution or the effective porosity of clay soils. This study was, thus, undertaken to develop data on the pore size distribution and effective porosity of soils permeated with water and selected organic chemicals.

MATERIALS AND METHODS

Each soil liner type and permeant treatment combination was examined in several ways. These included: a) visual inspection for planes of weakness, liquid permeation as evidenced by the presence of dye, and any abnormalities witnessed within the soil core; b) petrographic light microscopy for fabric orientation; c) epifluorescent microscopy for the qualification and quantification of pores effective in transmitting the liquid treatments; and d) scanning electron microscopy-backscatter mode for the examination of the total porosity of a section for each liquid treatment type. Examination techniques "a to c" were conducted in a minimum of three replications for each soil-permeant combination in both the field and the laboratory. The soil cores were examined after permeation was complete, as defined in the conductivity studies. Examination technique "d" was done only c. one 7.9 cm^3 block of impregnated soil, which included the top two centimeters of an internal compacted lift per soil-permeant type.

Samples of the compacted soils permeated with the test fluids were collected by random sampling from both laboratory permeameters and field cells. Air-dired oriented clods were vacuum impregnated (Cady et al., 1984) using the apparatus shown in Figure 12 with EPO-TECH 301-2 epoxy resin. Samples were set for one to two days under a vent hood and placed in a 45^{o}C oven for several days, after which the temperature

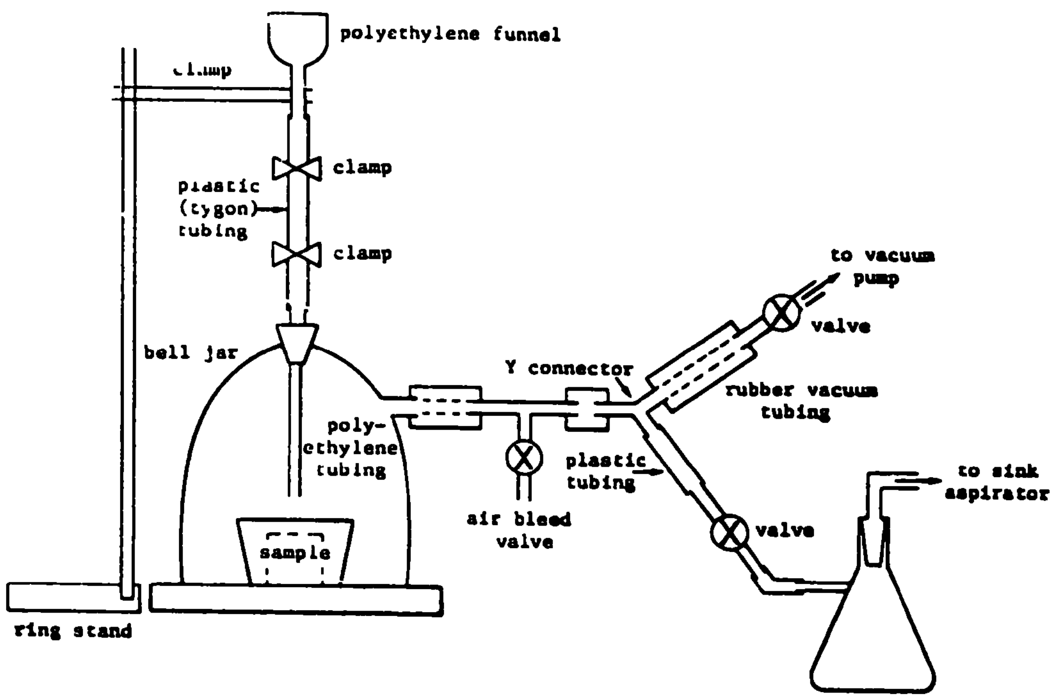

Figure 12. Schematic diagram of vacuum impregnation apparatus used to impregnate soil samples for micromorphological analysis.

was raised to 65°C for two days to complete the hardening process. A minimum of three slabs were then cut from each treatment, polished on a lapidary wheel, and mounted on frosted glass slides with EPO-TECH 301-1 epoxy resin. Thin sections were then cut, ground, and polished to approximately 30 μm. Horizontal and vertical thin-sections were cut from various positions in the soil cores. The vertical thin-sections were cut across the interface of soil lifts. The number of sections varied from core to core, as the impregnation of the epoxy resin was not always uniform throughout all cores. The variation in the compaction within the soil liner and the lamination or preferred orientation of the soil fabric was evident in the vertical cuts. The horizontal cuts showed the cross-cut pattern of the vertical flow paths. These thin sections were then analyzed by petrographic and epifluorescent microscopy.

The petrographic analysis was performed by using a Zeiss polarizing microscope at 160X magnification. All thin-section slides were analyzed by random transect to identify the fabric.

A Zeiss Universal Research Microscope equipped with a IIIRS epi-illuminator system and a 100W mercury arc lamp was used with a magnification of 160X to evaluate fluorescing pores. The excitation filter (trans - max 365 nm) and the barrier filter (trans - max > 418 nm) were used to assist in examination of the fluorescing pores.

A ribbon traverse method (Brewer, 1976) was used to estimate effective porosity using a point-counting microscope stage coupled with a micrometer eyepiece. The point-counting stage was moved incrementally while the soil pores were counted and classified according to the system of Brewer (1976). Information on the size of fluorescing pores was gathered in an effort to identify the pathways by which the fluids penetrated the soils.

The pores in each field of vision were measured and classified according to the following system:

A. micropores (5μm - 30 μm), radius
B. mesopores (30 μm - 75 μm), radius
C. macropores (> 75 μm), radius

Planar voids (a. <100 μm; b. 100-300 μm; and c. >300 μm).

The calculations used to estimate the porosity were as follows:

For circular pores, $\% \text{ voids} = 100 \times \frac{N \pi r^2}{A}$

Where N is the number of pores in a given class, r is the average radius of the pore class, and A is the area of the section analyzed. The value of r was taken as 10, 49, and 100 for the micropores, mesopores, and macropores, respectively.

For the planar voids, the porosity was calculated as follows:

$$\% \text{ voids} = 100 \times \frac{N\ D\ W}{A}$$

Where N is the number of pores, D is the width of the void, and W is the width of the field of vision. For pores with widths <100 µm, D was taken as 85; for those with widths between 100 and 300 µm, D was taken as 200; and for those with widths >300 µm, D was taken as 400 µm. These will be referred to as planar void groups a, b, and c, respectively. The percent effective porosity was calcuated as the sum of all the dyed pores in the above groups.

Impregnated polished blocks of the soils cut from the interface of the second and third lift were selected for additional investigation for pore structure and distribution using the backscatter mode of the scanning electron microscope (SEM) as described by Bisdom (1981).

Backscatter electron images were examined using a JEOLCO JSM-35U scanning electron microscope with dual, automated, wavelength - dispersive x-ray spectrometer, an automated energy-dispersive x-ray spectrometer, with X and Y stage automation, digital beam control, and compositional contrast. The SEM operated at 35 KeV accelerating voltage, 39 mm working distance, 140 µm objective aperture, and a column vacuum of approximately 2×10^{-6} torr. Photomicrographs were taken on the block surfaces normal to the lift surface and spanning the small area between lifts. All 3.3 cm diagonal block samples were sputter coated with approximately 5 nm of Au-Pd. Pore size and pore configurations were evaluated from images recorded on Kada Tri-X film. Enlargements (20 cm x 25.5 cm) were made from negatives, and estimates of the total porosity of each soil sample were made using a planimeter outlining the pore area of each picture in the series. One replication each of bentonitic, micaceous, and kaolinitic soils permeated with aqueous 0.01N $CaSO_4$, acetone, and xylene were studied.

Because the SEM photomicrographs show all pores and not just those that were permeated with the liquid treatments, the total porosity seen by this technique is expected to give greater porosity estimates than other techniques, which account for only the pores permeated by the dyed fluids.

RESULTS AND DISCUSSION

Visual Examination

The laboratory soil cores were extruded from the rigid wall permeameters by slowly forcing the steel permeameter down over a wooden block the size of the inside dimensions of the permeameter. The cores were inspected after extrusion to find any evidence of side-wall flow. No evidence on any cores was seen for side-wall flow, as indicated by the lack of dye along the edges of the cores. When the cores treated with concentrated organics labeled with dye were cut open, traces of dye were typically found in the upper one to two cm of the soil and in the soil within one to two cm above the lift interfaces. When cores were broken open, traces of dye were often observed in the cracks that formed, particularly in soil treated with the pigmented xylene paint solvent waste.

Visual inspection of the field cell soil liners revealed that there were occasional areas near the edge of the test cell walls that were not compacted as well as the rest of the liner. These areas extended 10 to 15 cm inward on all sides and were crumbly in the lower 50 percent of each lift. Observation of the tracer dye, however, indicated that the flap extending into the soil liner between lifts appeared to have prevented side flow and lessened the impact of the poorly compacted soil edges. The remainder of each soil liner exhibited uniform compaction with the bottom three to four cm or less of each lift showing the structure of the original soil peds.

Soil core porosities from the laboratory and the field cells varied within each core as a function of position in lift. The top of each lift, i.e., the compactive surface, had greater density and less total porosity than within the lift. The increase in porosity was gradual, with the bottom of a lift having the greatest porosity. As the density of the soil matrix decreased in the lower portion of the soil liner lift, the flow was more random but generally occurred in pores that were greater than 75 µm. All the soils appeared to have the same dense massive structure with few planar voids. Even after prolonged exposure to either acetone or xylene, the bentonitic soil had fewer planar pores than the micaceous or kaolinitic soil.

Crossections of all three soils collected from field test cells permeated with xylene showed that the xylene flowed through relatively large cracks and pores between structural units rather than passing through the soil as a uniform wetting front. This was evident because vertical cleavage planes were coated with dye and paint pigments, while the surfaces of the soil cut during excavation were not stained. While the dyes were harder to see in the soils from test cells permeated with acetone because of the absence of the paint pigment that was present in the xylene waste, all indications are that the acetone movement was similar to that of the xylene. Because acetone is miscible with water, it is likely that more acetone penetrated into the soil mass than did xylene; however, there was dye evidence of flow through cracks and larger pores.

Platy structure was found in the upper portion of the compacted kaolinitic soil exposed to acetone for two years. The platy structure is characterized by horizontal units in the upper soil, while the structure at depths greater than five cm is massive. The compactive effort is postulated to have initially oriented the clays immediately below the surface, and as the acetone dessicated the clays it caused them to collapse into platy structural units.

Petrographic Microscopy

The plasmic structure of all analyzed soil thin-sections was skel-masepic fabric. This structure is characterized by part of the plasma having flecked orientation pattern, with plasma separations occurring as zones within the s-matrix. Separations apparently are associated with the surfaces of skeleton grains and not with the walls of the voids. The original materials were mixed in a pugmill, and the resulting soil fabric had a random mixture of soil separates. Primarily, the compaction effort and secondarily, the permeation of the test fluids are likely responsible for the development of the skel-masepic fabric.

The observed stress pressure faces were associated with skeleton grains and were orientated parallel to compaction surfaces, with some at approximately 45^{o} angles to the surface. Most of the horizontal planar voids were at the lift interfaces. A few weakly oriented argillans were observed on planar voids. These voids were metavoids, where evidence of differential movement under pressure caused elongated crests and depressions on the plane surfaces.

Epifluorescent Microscopy

Results of the effective pore-size distribution calculations for each soil and permeant combination are given as mean percent porosity in Tables 4 through 6. Total porosity, as measured in the laboratory using the scanning electron microscope, ranged from 11.6 to 14.5%, while that calculated from the bulk density measurements assuming a particle density of 2.65 g cm^{-3} ranged from 25.3 to 35.8% (Table 4). The calculated porosity was 1.9 to 2.5 times greater than measured with the least difference in the mica soil and the greatest difference in the bentonite.

The effective porosity for the kaolinite and mica soils permeated with water was 1.3 and 1.7%, respectively, and did not change appreciably when acetone was the permeant. When permeated with xylene, however, the effective porosity dropped to 1.2 and 1.1% for the kaolinite and mica soils, respectively. The bentonite soil had a higher effective porosity to water (3.2%), which decreased to 2.9% when permeated with acetone and 2.2% when permeated with xylene. For all three soils studied, only 3.2% or less of the volume was active in rapid fluid movement. This effective porosity was greatest with water and decreased when acetone and xylene were the permeants.

TABLE 4. TOTAL AND EFFECTIVE POROSITY OF ALL THREE SOILS PERMEATED WITH WATER, ACETONE, AND XYLENE IN LABORATORY

	Kaolinite	Mica	Bentonite
	(%)		
Total Porosity			
Measured (SEM)	11.6	13.2	14.5
Calculated	28.7	25.3	35.8
Effective porosity when permeated with:			
Water	1.8	1.7	3.2
Acetone	1.8	1.5	2.9
Xylene	1.2	1.1	2.2

The total number of voids per cm^2 for all soils exhibited similar trends. From 257 to 504, voids were counted per cm^2 in the soils permeated with water, while 210 to 382 and 86 to 151 voids per cm^2 were counted in the acetone and xylene permeated soils, respectively. The low number of voids in the xylene permeated soils is likely the cause of the reduced effective porosity in Table 4. While the observed microvoids are the most numerous (Table 5), they comprise the least volume (Table 5). Approximately one-quarter to one-half of the void volume is comprised of mesovoids, with the majority of the remaining volume distributed between round and planar macrovoids. This pore distribution is in general agreement with the data of Bisdom and Ducloux (1983), who reported that at least two-thirds of the total porosity was in the micropore and ultramicropore range. While water and acetone can permeate into these pore sizes, xylene would need to displace the structural water already in these pores before entering. Thus, xylene is preferentially excluded from micropores and ultramicropores in the soil.

The length of time the soil is inundated with a permeant will determine the kind of effective porosity one can expect to find within a soil. The porosity study included soils which were inundated for periods ranging from a few weeks to many months. The smallest detectable pore diameter was 5 µm and did not include much of the soil porosity. The rapid breakthrough of 100% xylene concentrations from the field cells (Table 14) is further evidence that the chemicals bypassed the small pores.

According to Poiseuille's equation, volumetric flow through porous media increases with the fourth power of pore diameter. For instance, where all other factors are held constant, a 100 µm diameter pore will conduct volumetric flow 10,000 times that of a 10 µm diameter pore.

TABLE 5. NUMBER OF DIFFERENT SIZE VOIDS PER CM^2 IN EACH OF THE THREE SOILS PERMEATED WITH WATER, ACETONE, AND XYLENE IN LABORATORY

Permeant	Void Size	Kaolinite	Mica	Bentonite
Water	microvoids	181	320	348
	mesovoids	38	56	100
	macrovoids	15	7	22
	macrovoids planar a	8	14	16
	macrovoids planar b	11	5	10
	macrovoids planar c	3	2	8
	Total	257	405	504
Acetone	microvoids	138	238	185
	mesovoids	28	66	155
	macrovoids	24	6	20
	macrovoids planar a	11	16	12
	macrovoids planar b	5	4	7
	macrovoids planar c	3	1	3
	Total	210	330	382
Xylene	microvoids	62	47	60
	mesovoids	12	13	45
	macrovoids	7	9	13
	macrovoids planar a	6	7	10
	macrovoids planar b	10	8	16
	macrovoids planar c	4	2	7
	Total	101	86	151

The tortuosity of micro- and mesopores is generally greater than that of macropores within the soil matrix. Flow tends to follow the path of least resistance, i.e., the path with the least tortuosity and the larger diameter pores.

The total effective pore volume (EPV), as measured in this study, was greatly dependent upon the number of macropores that were stained with dye. The number of microvoids can change an order of magnitude while the total EPV may change only one percent. The number of macropores effective in transmitting the permeants differed greatly between treatments; therefore, large differences occurred in the means of macropores in the various soil-permeant combinations. This difference shows up as changes in conductivity values. The counts of micro- and mesopores of acetone and water were much larger than for the xylene permeated soils (Table 5). Acetone permeated soils, especially the bentonitic soils, had higher mean counts in the mesopores and macropores (most <100 µm in diameter) than found in the water or xylene

TABLE 6. AVERAGE EFFECTIVE PORE SPACE EXPRESSED AS PERCENT OF TOTAL SOIL VOLUME FOR EACH OF THE THREE SOILS PERMEATED WITH WATER, ACETONE AND XYLENE IN LABORATORY

Permeant	Pore Size	Kaolinite	Mica	Bentonite
		(%)		
Water	microvoids	0.17	0.31	0.33
	mesovoids	0.33	0.48	0.87
	macrovoids	0.48	0.21	0.69
	macrovoids planar a	0.13	0.24	0.27
	macrovoids planar b	0.44	0.22	0.39
	macrovoids planar c	0.21	0.19	0.61
	Total	1.77	1.66	3.16
Acetone	microvoids	0.13	0.23	0.18
	mesovoids	0.24	0.58	1.34
	macrovoids	0.76	0.18	0.64
	macrovoids planar a	0.19	0.27	0.20
	macrovoids planar b	0.22	0.15	0.30
	macrovoids planar c	0.25	0.06	0.27
	Total	1.79	1.47	2.93
Xylene	microvoids	0.06	0.04	0.06
	mesovoids	0.10	0.11	0.39
	macrovoids	0.22	0.29	0.42
	macrovoids planar a	0.10	0.12	0.18
	macrovoids planar b	0.41	0.33	0.65
	macrovoids planar c	0.31	0.17	0.54
	Total	1.20	1.06	2.24

permeated soils. One reason for this was the bentonitic soil had a lower bulk density than the micaceous or kaolinitic soils (1.7 g cm^{-2} vs 1.95 - 2.0 g cm^{2}) and was compacted less tightly. Also, the higher volume of the smaller pores can relate back to the properties of acetone, e.g., miscible with water, dielectric constant one-third that of water, and a tendency to flocculate dispersed clays when in high concentrations. The acetone had been applied in concentrations greater than 80 percent in both the laboratory and outdoor test cells. The cumulative pore volume of permeant collected over time periods ranging from a few weeks to over a year were between one and two PV. This was a sufficient concentration and time duration to expect to see molecular diffusion into the small pores (<75 μm) and, also, to expect some alignment by flocculation of the colloidal sized particles in the immediate vicinity of the pores.

SECTION 6

EFFECTS OF PETROCHEMICALS AND ORGANIC SOLVENTS ON COMMERCIAL CLAYS

INTRODUCTION

Land disposed hazardous wastes found in industrial disposal facilities generally fall into four physical classes, i.e., aqueous inorganic, aqueous organic, organic, and sludges (EPA, 1974). Cheremisonoff et al. (1979) estimated that 90%, by weight, of industrial hazardous wastes are produced as liquids that contain solutes in the ratio of 40% inorganic to 60% organic. Although testing with pure chemicals (Anderson, 1981; Anderson et al., 1982; and Brown and Anderson, 1983) has been conducted, the effects of commonly used complex petroleum products, e.g., kerosene, diesel fuel, gasoline, and motor oil, on the conductivity of compacted clays has not been researched to date.

Anderson (1981) evaluated four native clay rich soils with diverse mineralogical and chemical properties; however, little data is currently available on clays that are prepared and sold for sealing and lining impoundments. Therefore, this study was conducted to measure and document the effects of common petroleum products on the conductivity of three commercially available clay-sand admixtures.

MATERIALS AND METHODS

Three clays were obtained from commercial sources. Each clay was mixed with sand to obtain a conductivity to water of about 1×10^{-8} cm sec^{-1}. Clay:sand mixtures were 9:91, 15:85, and 25:75 (v:v) for CC1, CC2, and CC3, respectively. The dry materials were mixed by hand in quantities of about 12 l at a time until they were homogenous. The physical and chemical properties of the clay-sand mixtures, hereafter referred to as soils, are described in Table 7. The dominant mineral in the materials identified as Soils CC1 and CC2 was smectite, while that in CC3 was of a mica clay. All soils had a pH of 8.0 or greater and hydraulic conductivities between 1.6 and 3.6 x 10^{-8} cm sec^{-1}. The soils were brought to their optimum moisture contents (Table 7) and allowed to equilibrate overnight. The soils were compacted in 10 cm diameter, 11.6 cm tall fixed wall molds using a mechanical compactor as described in ASTM Procedure 698-70. After compaction, the test permeant

TABLE 7. PHYSICAL AND CHEMICAL PROPERTIES OF THE THREE SOILS

Soil	Sand	Silt (%)	Clay	USDA Texture	Dominant Mineralogy	Common Name	pH	Optimum Moisture (%)
CC1	89.6	0.4	10.0	LS*	smectite	blue bentonite	8.5-9.5	14.5-15.5
CC2	84.0	5.5	10.5	LS	smectite	synthetically treated bentonite	8.5-10.0	14.5-15.5
CC3	60.4	17.6	22.0	SCL	mica	Ranger Yellow	8.0	11-12

*LS = loamy sand.

SCL = sandy clay loam.

was placed in the chamber above the clay, and the chamber was sealed and allowed to set for a 24 hr period. A pressure of 15 psi (equal to a hydraulic gradient of 91) was then applied to the liquid surface, and leachate volumes were collected periodically. The volumes were used to calculate the conductivity which was then plotted as a function of the pore volume. Three replications of all treatments were run except for two cases in which only duplicates were run.

The evaluated permeants included 0.01 N $CaSO_4$, hereafter referred to as water; two organic solvents, acetone and xylene; and four petroleum products, kerosene, diesel fuel, gasoline, and used motor oil. The physical and chemical properties of the permeants are given in Table 8 for comparison. After permeation, all cores were disassembled and carefully examined for evidence of the presence of the permeant in the core.

TABLE 8. PHYSICAL AND CHEMICAL PROPERTIES OF PERMEANTS*

Liquid	Viscosity (Centistokes)	Density ($g\ cm^{-3}$)	Surface Tension ($dynes\ cm^{-1}$ @ 85°C)
Acetone	0.42	0.79	21.1
Xylene	0.97	0.87	28.9
Gasoline	0.7	0.70-0.75	24.4-25.8
Kerosene	0.7-0.9	0.79-0.82	30.7-31.2
Diesel Fuel	1.4-2.5	0.87	
Motor Oil	0.9-13	0.81-0.90	36.0-37.5

*Values from Leslie, 1923; Deere & Co., 1970; Spiers, 1952 Gruse, 1967; and Weast et al., 1964.

Statistical analysis of the conductivity data was accomplished for each permeant by using a one-way analysis of variance. Means were separated using a Duncan's Multiple Range test at a significance level of $P = 0.05$.

RESULTS AND DISCUSSION

Addition of acetone to Soil CC1 resulted in final conductivities of 2.3×10^{-5} to 1.0×10^{-4} cm sec^{-1}, which is three to four orders of magnitude greater than the corresponding conductivity to water (Figure 13). Individual data are presented in Appendix B. The effect of acetone on CC2 was less. Replication 1 showed a two order of magnitude rise in conductivity while Replications 2 and 3 showed an increase of only 1 to 1.5 orders of magnitude. In the case of Soil CC3, the conductivity increased 0.5 to 2.0 orders of magnitude. Soil CC1, the

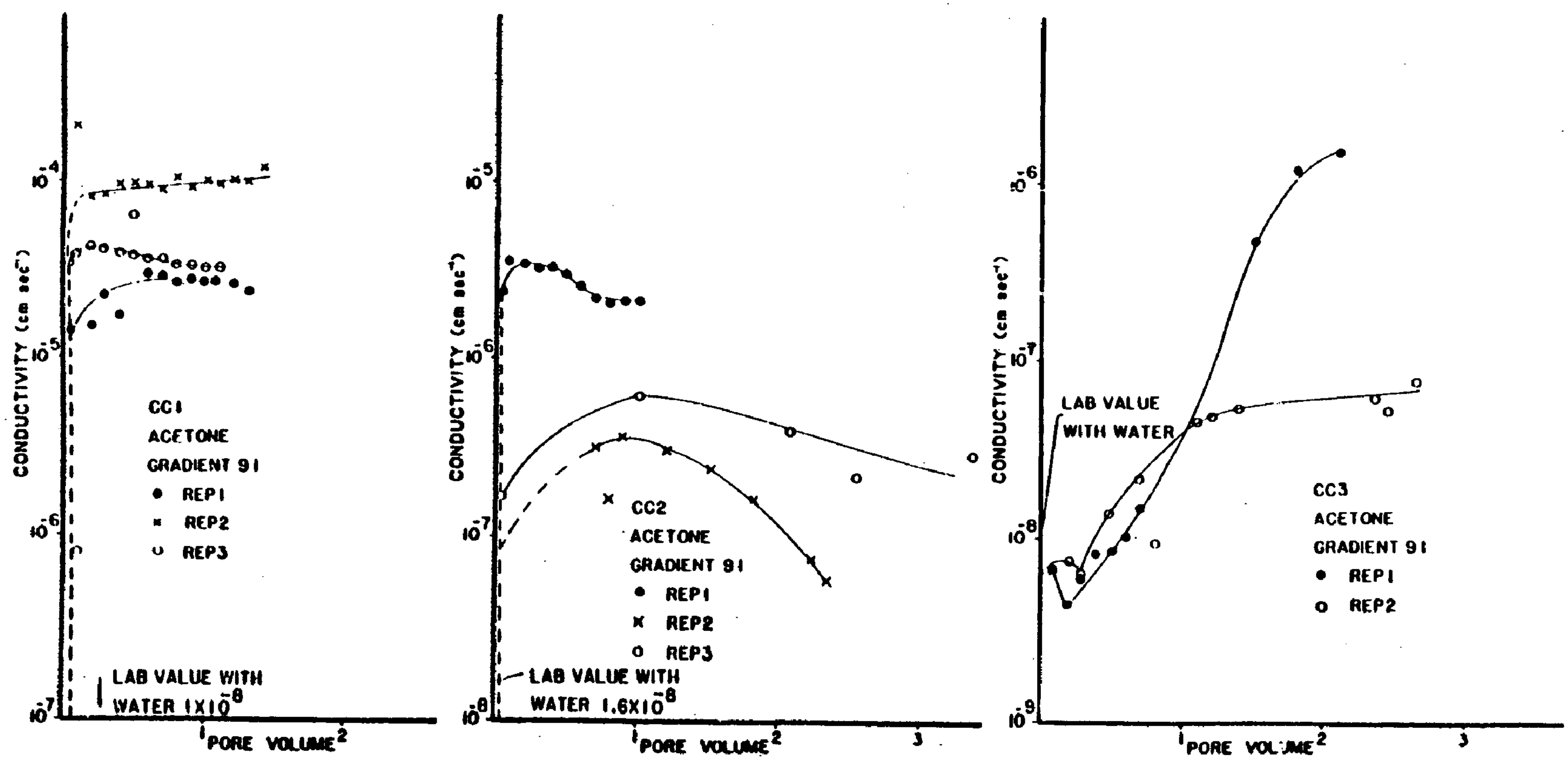

Figure 13. Conductivity of three soils to acetone.

untreated bentonite, was the most subject to volume change and, as expected, had the greatest conductivity increase in response to acetone. Similarly, Soil CC3 is a non-swelling micaceous clay and would be the least subject to large volume changes. When averaged over all replications, the mean conductivity of Soils CC1, CC2, and CC3 to acetone were 5.05×10^{-5}, 1.41×10^{-6}, and 2.51×10^{-7} cm sec^{-1}, respectively. Even though these values represent conductivity increases of 1 to 3 orders of magnitude, they did not differ significantly from water (Table 9). Addition of xylene to CC1 resulted in conductivity increases of three to four orders of magnitude (Figure 14). Replications 1 and 2 had an equilibrium conductivity of about 2.5×10^{-4} cm sec^{-1}, while Replication 3 only increased to 1×10^{-5} cm sec^{-1}. The effect of xylene on CC2 was similar with Replications 1 and 3 and attained conductivities near 1×10^{-3} cm sec^{-1}. Replication 2, however, only rose as high as 1×10^{-5} and plateaued at 6×10^{-6} cm sec^{-1}. Conductivity increases for xylene through CC2 were 2.5 to 5 orders of magnitude. Soil CC3 was similarly affected by xylene and had a four order of magnitude rise in conductivity from 1×10^{-8} to about 1×10^{-4} cm sec^{-1}. Statistical analysis of the data showed a significantly higher conductivity for xylene through all three soils as compared to water (Table 9). Thus, xylene equally affected all three clays.

TABLE 9. MEAN CONDUCTIVITY OF EACH SOIL TO EACH FLUID TESTED

Fluid	CC1	CC2	CC3
Water	3.61×10^{-8}b*	2.58×10^{-8}b	1.57×10^{-8}b
Acetone	5.05×10^{-5}b	1.41×10^{-6}b	2.51×10^{-7}b
Xylene	1.76×10^{-4}a	7.28×10^{-4}a	1.00×10^{-4}a
Gasoline	1.96×10^{-4}a	9.07×10^{-5}a	6.19×10^{-5}b
Kerosene	1.49×10^{-4}a	9.10×10^{-5}a	5.68×10^{-5}b
Diesel Fuel	5.17×10^{-5}b	4.53×10^{-5}ab	6.29×10^{-7}b
Motor Oil	6.13×10^{-6}b	2.13×10^{-6}b	9.48×10^{-7}b

* Values in a given column followed by the same letter do not differ significantly (P = 0.05).

The conductivity of CC1 to gasoline was four orders of magnitude greater than the conductivity to water (Figure 15). The three replications ranged from 9×10^{-5} to 3×10^{-4} cm sec^{-1}. Two replications of CC2 permeated with gasoline also had equilibrium conductivities of 1.4×10^{-4} cm sec^{-1}, and the third replication

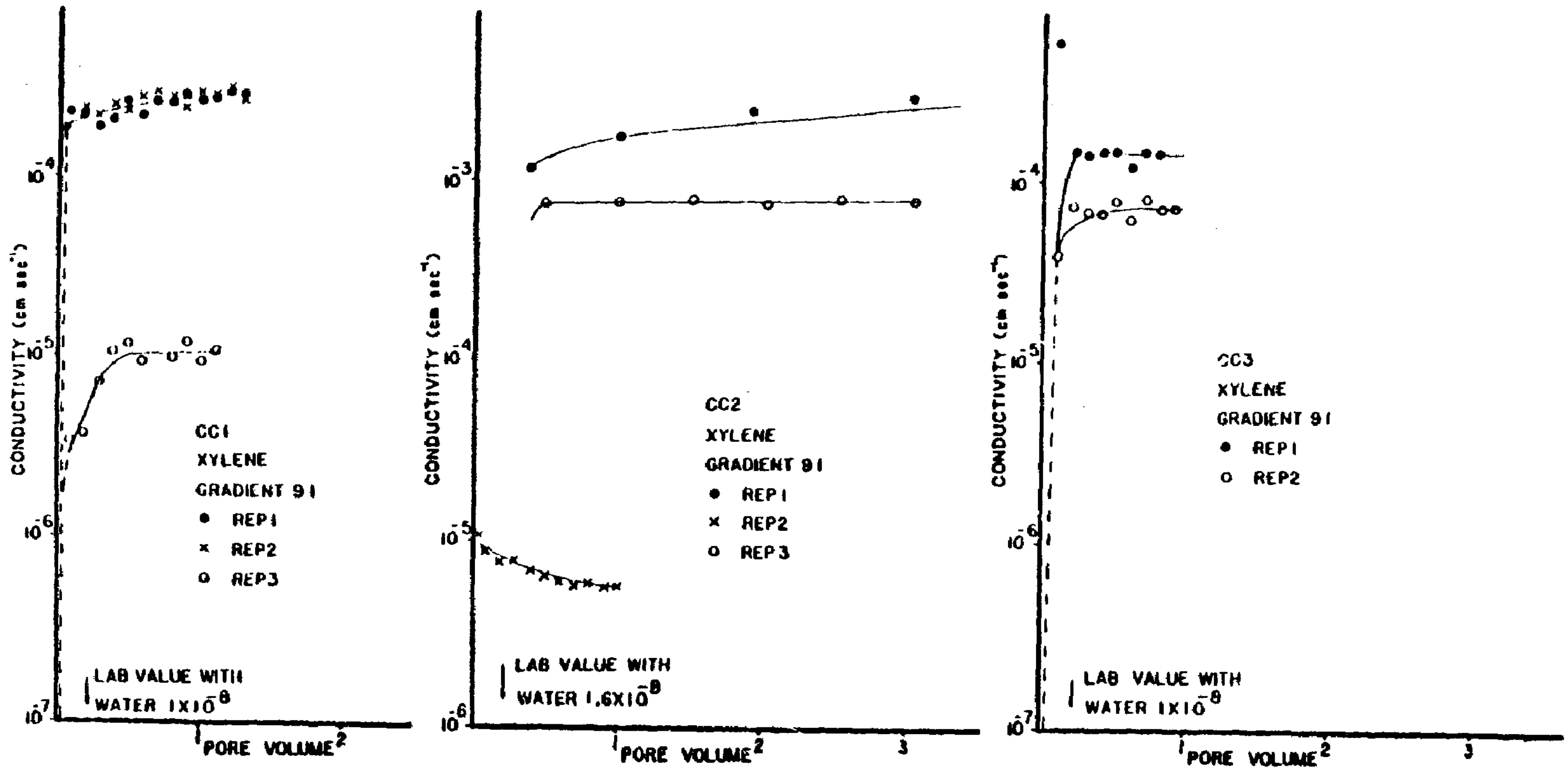

Figure 14. Conductivity of three soils to xylene.

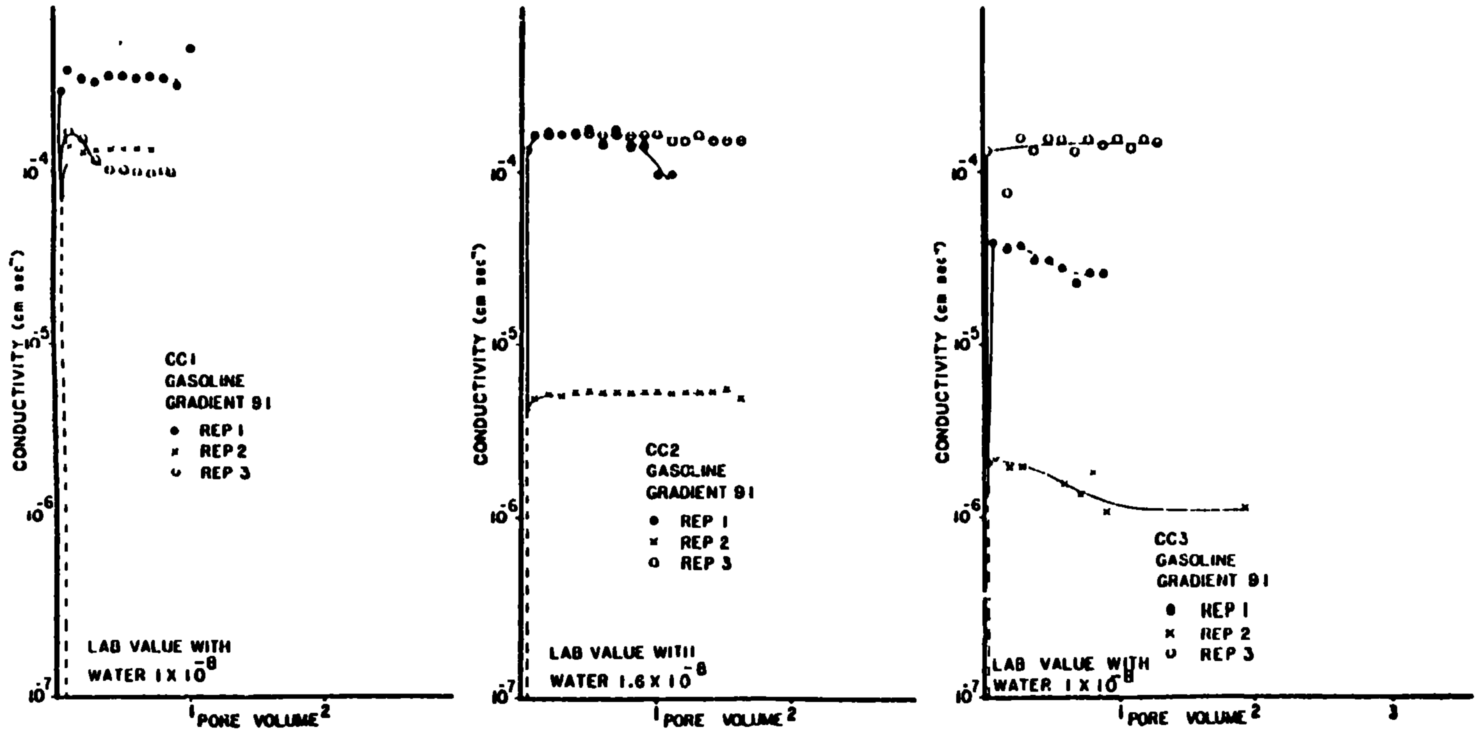

Figure 15. Conductivity of three soils to gasoline.

equilibrated at 5.2×10^{-6} cm sec^{-1}. The conductivities of both CC1 and CC2 soils to gasoline were significantly greater than corresponding conductivities to water. The micaceous soil, CC3, was somewhat more variable in its response to gasoline. The three replications equilibrated at 1.2×10^{-6}, 2.4×10^{-5}, and 1.3×10^{-4} cm sec^{-1}, which represented increases of two to four orders of magnitude over the conductivity to water. Due to the greater variability, the increase in conductivity for CC3 was not found to be significant.

The addition of kerosene to all three compacted soils resulted in dramatic increases in conductivity (Figure 16). The final conductivity of all three soils to kerosene ranged from 1×10^{-5} to 1.7×10^{-4} cm sec^{-1}. This represents a conductivity increase of three to four orders of magnitude over the corresponding conductivities to water. In all replications except Rep 3 of CC3, the permeability had plateaued after the passage of only 0.25 pore volume of leachate. Conductivities measured for CC1 and CC2 permeated with kerosene were significantly greater than corresponding conductivities to water (Table 9). Variability in the replications of CC3 was sufficient to preclude a significant difference in CC3.

Addition of diesel fuel to CC1 and CC2 resulted in equilibrium conductivities in the range of 1.8×10^{-5} to 1×10^{-4} cm sec^{-1} (Figure 17). This represents an increase of three to four orders of magnitude over corresponding conductivities to water. Diesel fuel had less effect on CC3 and resulted in a conductivity increase of only one to two orders of magnitude. Although these differences were not significant at the 5% level, they do represent a large increase in the rate at which fluid will move through these soils.

Conductivity of CC1 to motor oil ranged from 1.5×10^{-6} to 4×10^{-6} cm sec^{-1} (Figure 18). The conductivity increased slowly between 0.25 and 2.0 pore volumes. All three replications of CC2 attained a conductivity near 6×10^{-6} cm sec^{-1}. Thus, both CC1 and CC2 exhibited a conductivity increase of two orders of magnitude when exposed to motor oil. The micaceous soil, CC3, showed a conductivity increase of one to two orders of magnitude. Again, the conductivity appeared to increase steadily as more liquid permeated the soil. Conductivities of all three soils to motor oil did not differ at the 5% level from corresponding conductivities to water.

Both solvents and all four petroleum products resulted in dramatic increases in conductivity over the corresponding permeabilities to water. Increases ranged from one to five orders of magnitude. Generally the increase in CC3 was 1 order of magnitude less than that of CC1 and CC2. Brown et al. (1983) postulated that xylene moved through preferential pathways, e.g., along cracks and ped faces, in the soil. This movement may have possibly occurred through the removal of some of the structural water (Yale and Ritchie, 1980). Visual observations revealed the presence of organic liquids on ped faces

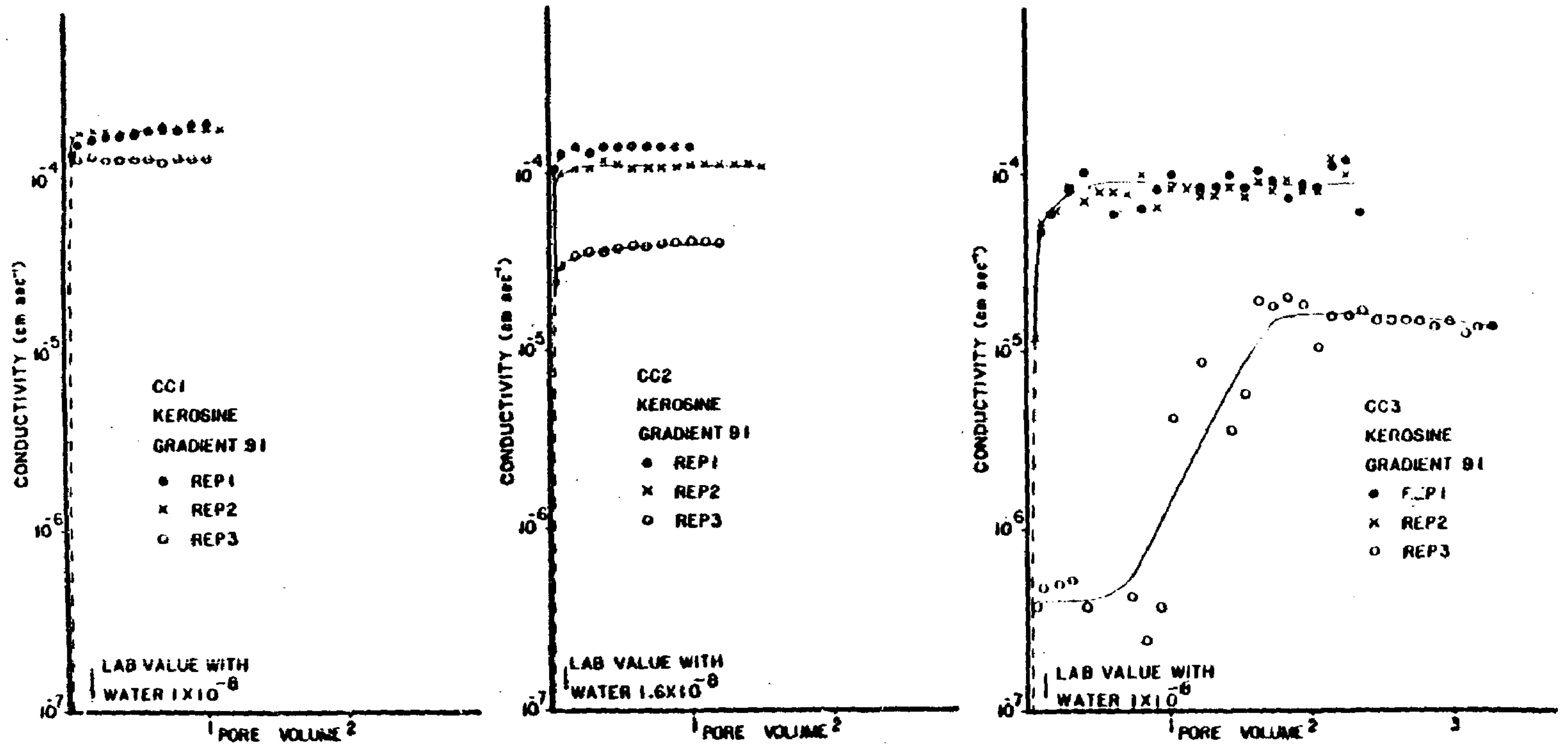

Figure 16. Conductivity of three soils to kerosine.

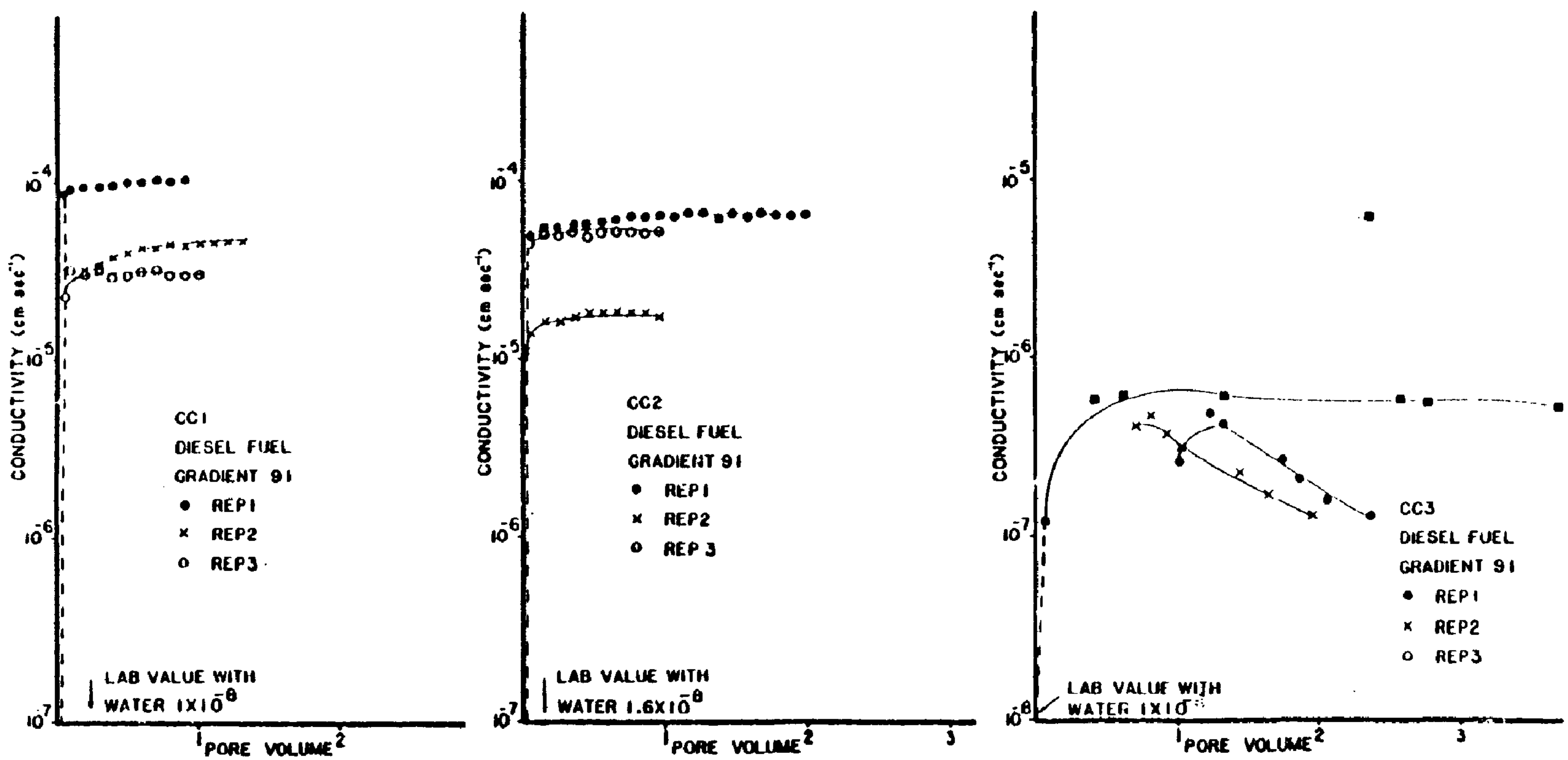

Figure 17. Conductivity of three soils to diesel fuel.

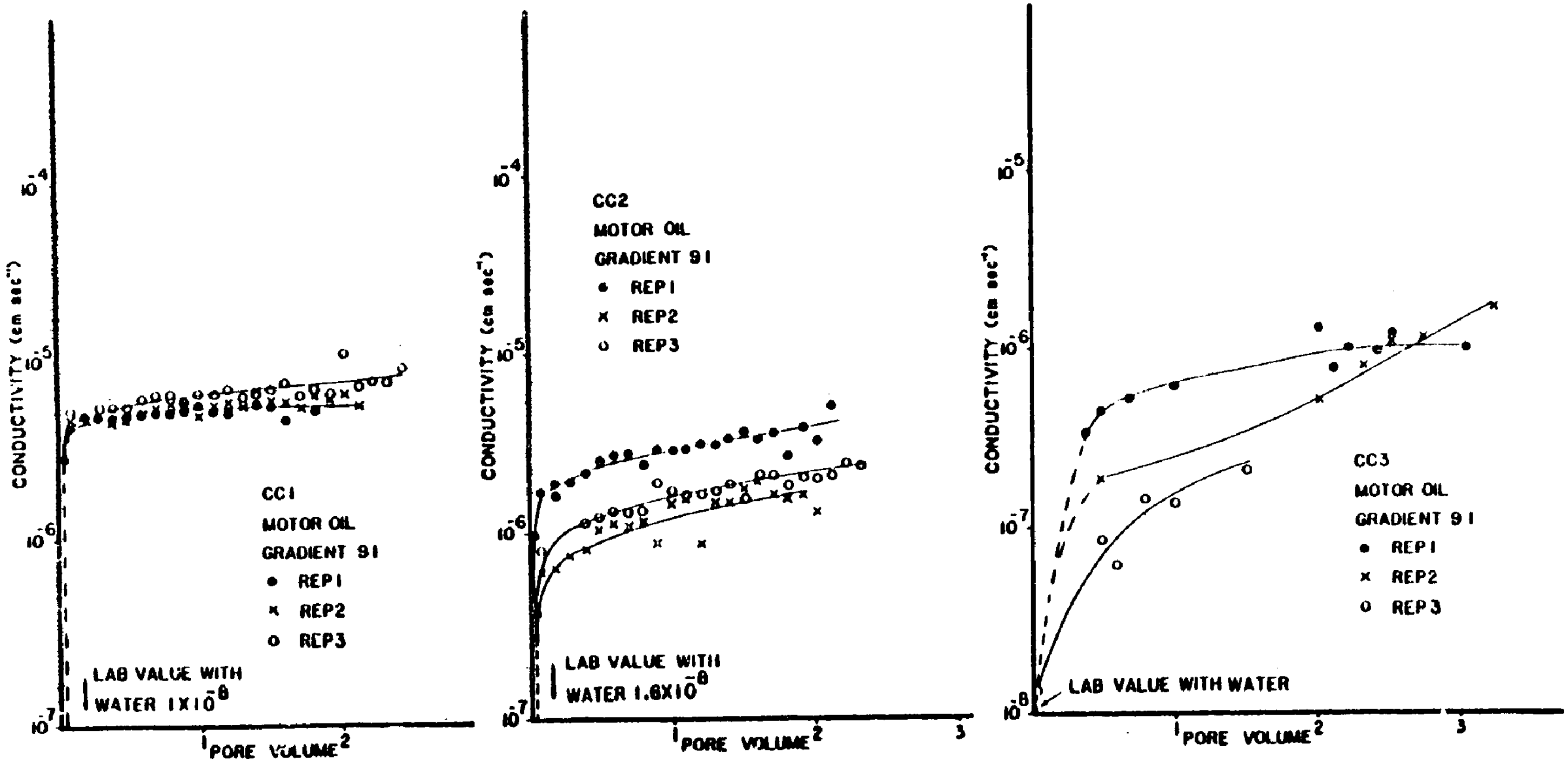

Figure 18. Conductivity of three soils to motor oil.

throughout the soil, indicating that the permeants moved through the soil rather than through cracks between the core and side wall. If the organic permeants caused shrinkage that resulted in greater spacing between peds in the soil as suggested by Acar and Seals (1984), the observed increases in conductivity would not be unreasonable. As the micaceous soil is the least subject to shrinkage, it should also be less affected by the permeants, as was the observed occurrence. Much of the variability between replications within a given soil-permeant treatment may be due to the size and number of channels formed in response to the organic liquid. The data indicate that clay-soil lined impoundments will not be suitable for holding concentrated organic solvents or petroleum products. They also indicate that the permeability of native soil to spilled solvents or petroleum products may be much greater than that which would be expected based on the conductivity to water.

SECTION 7

THE INFLUENCE OF APPLIED PRESSURE ON HYDRAULIC CONDUCTIVITY

INTRODUCTION

Compacted clay soils have long been used to line waste storage and disposal facilities, i.e., waste piles, surface impoundments, and landfills. Design specifications have in the past been developed using only water as the permeant liquid. Such installations have generally been successful when the primary liquid to be retained was relatively pure water.

When smectite clay is subjected to some organic chemicals, it has long been known to exhibit smaller spacing between adjacent crystalline layers than when exposed to water (Barshad, 1952). Only recently, however, have measurements been made of the impact of organic liquids on the permeability of recompacted clay soils. Previous reports by Anderson _et al_. (1982) and Brown and Anderson (1983) evaluating the impact of concentrated organic liquids on the permeability of four native clay soils indicated that the permeabilities may be two to three orders of magnitude greater than those measured with water. Observations of the permeated soil cores indicated physical changes in the soil structure.

Since the previous testing was done at elevated pressures equivalent to hydraulic gradients of 61.1 and 361.6, further tests were deemed necessary to evaluate the effects of hydraulic gradient on the measured conductivity.

MATERIALS AND METHODS

Soil

Three clay soils were used in the laboratory and field cell study of hydraulic gradients and solvents. Each of the three clay soils was blended with a predetermined amount of sandy loam soil to attain water conductivities in the range of 1×10^{-8} to 1×10^{-9} cm sec^{-1}. These three blends were selected to represent the range of materials most widely available and used for the construction of land disposal facility clay liners. In all the following discussion, the clay soil blends will be referred to by their dominant mineralogies, i.e., kaolinite, mica, and bentonite. The textures and mineralogies of the blends are given in Table 10, and the chemical properties are given in Table 11. Engineering properties of the three clay soils are given in Table 12.

TABLE 10. PHYSICAL PROPERTIES OF THE THREE CLAY SOILS BLENDED FOR USE.

Clay	USDA Textural Class	Particle Size Distribution Sand	Silt	Clay	Mineralogy	Organic Carbon (%)	pH (1:1 Soil: H_2O)
		------- (%) ------					
Kaolinite	SCL[†]	62.8	13.6	24.5	K-1 M-tr[††]	0.53	7.7
Mica	SCL	60.4	17.6	22.0	Mi-1 K-2 M-3	0.17	8.0
Bentonite	SCL	75.9	3.9	20.2	B-1 Mi-tr	0.29	8.9

† SCL = sandy clay loam
†† K = kaolinite*
Mi = mica*
B = bentonite*
M = montmorillonite
1 = dominant mineralogy
2 = 2nd most dominant mineralogy
3 = 3rd most dominant mineralogy
tr = trace quantity
* = commercially obtained

Laboratory Procedures

Soils were compacted in fixed wall permeameters using a mechanical compactor (ASTM 698-70), as described in previous reports by Anderson et al. (1982) and Brown and Anderson (1983). Compaction was to at least 90% Proctor density; hydraulic conductivity measurements were conducted with soils slightly wet of optimum. Conductivity tests with water (0.01 N $CaSO_4$) were conducted on replicate samples. The effects of pressure on conductivity were tested with both acetone and xylene on laboratory compacted soils that had been saturated first with 0.01 N $CaSO_4$ and on unsaturated soils at the moisture content used for compaction. Pressures of 5, 15, and 30 psi equivalent to hydraulic heads of 31, 91, and 181, respectively, were tested. Samples tested with water were permeated until approximately one pore volume of water had penetrated the core. The liquid chamber was then opened, waste was substituted for the water, and pressure was reapplied. Samples of effluent were collected, quantified, and subsampled. Collection

TABLE 11. CHEMICAL PROPERITES OF THREE BLENDED CLAY SOILS

Clay	CEC meq/100g Soil(NaOAC)	CEC meq/100g Clay(NaOAc)	ESP	SAR	NH_4OAC Extractable Ca	Mg	Na	K
					------ meq l^{-1} ------			
Kaolinite	9.4	38.0	3.0	1.3	26.0	2.1	0.5	0.3
Mica	7.3	33.0	5.0	3.0	20.5	2.8	0.9	0.2
Bentonite	18.9	94.0	84.0	84.7	29.7	3.2	20.5	0.2

TABLE 12. ENGINEERING PROPERTIES OF THE THREE BLENDED CLAY SOILS

Clay	Liquid Limit	Plastic Limit	Plastic Index	Activity
Kaolinite	20.5	14.3	6.2	0.25
Mica	21.6	14.1	7.5	0.34
Bentonite	202.0	49.5	153.0	7.55

continued until the conductivity data indicated no further increase or until the flow exceeded the reliable range of the measurements.

The last four conductivity values for each test, as reported in Appendix C, were analyzed by ANOVA to determine if there were significant differences due to pressure. Analyses were done within each soil type, saturation condition, and chemical treatment.

RESULTS AND DISCUSSION

Elevated hydraulic gradients did significantly reduce the conductivity of the kaolinite and mica soils to water by 0.38 and 0.22 orders of magnitude, respectively, between gradients of 10 and 181. No significant change for bentonite was found. No significant interactions between clay type and hydraulic gradient were found, thereby leading to the conclusion that all three tested soils were similarly affected by gradients.

A summary of the conductivity of laboratory permeameters is given in Table 13. The presaturated kaolinite soil exposed to xylene showed

TABLE 13. AVERAGE FINAL PERMEABILITY OF SOILS TO ACETONE AND XYLENE AT DIFFERENT HYDRAULIC GRADIENTS

		Acetone	Xylene
Kaolinite (presaturated)	31	4.2×10^{-5}a*	6.7×10^{-7}a
	91	3.3×10^{-7}b	9.2×10^{-7}a
	181	6.4×10^{-7}b	2.9×10^{-8}a
(non-presaturated)	31	1.6×10^{-6}b	4.3×10^{-7}b
	91	3.2×10^{-8}c	5.7×10^{-6}b
	181	3.7×10^{-6}a	9.9×10^{-5}a
Mica (presaturated)	31	2.9×10^{-7}a	1.8×10^{-6}b
	91	2.8×10^{-7}a	1.6×10^{-6}b
	181	1.4×10^{-3}b	1.8×10^{-5}a
(non-presaturated)	31	8.6×10^{-7}a	8.7×10^{-6}b
	91	4.5×10^{-7}b	9.8×10^{-5}a
	181	4.2×10^{-8}c	2.1×10^{-5}b
Bentonite (presaturated)	91	5.6×10^{-7}a	7.0×10^{-8}a
	181	5.1×10^{-8}b	3.1×10^{-9}a
	272	4.1×10^{-8}b	2.3×10^{-7}a
(non-presaturated)	31		7.2×10^{-5}b
	91	4.9×10^{-8}a	6.4×10^{-5}b
	181	9.9×10^{-8}a	1.6×10^{-4}a
	272	1.8×10^{-7}a	

* Values in a given column for a given soil and saturation condition followed by the same letter do not differ significantly at P = 0.05.

no significant differences in conductivity at the three tested gradients. When exposed to acetone, the soil showed higher conductivity at a gradient of 31, as compared to gradients of 91 and 181. Nonsaturated kaolinite permeated with acetone showed no trend, even though there were some significant differences. The highest gradient had the highest conductivity; however, the lowest conductivity occurred at the intermediate gradient. When permeated with xylene, the nonsaturated kaolinite soil had the highest conductivity at the highest gradient while the lowest and intermediate gradients showed similar but lower conductivities. When viewing all the kaolinite data, there is no clear pattern of any gradient consistently causing higher or lower conductivity measurements.

The presaturated mica showed a decreased conductivity at the highest gradient for xylene. When nonsaturated, the mica showed decreased conductivity to acetone as the gradient increased. For nonsaturated mica permeated with xylene, the highest conductivity occurred at the intermediate gradient. When considering all mica data as a group, there are no clear trends in conductivity as a function of gradient.

Presaturated bentonite permeated with acetone showed a decreased conductivity at gradients 181 and 272. When permeated with xylene, however, there were no differences in conductivity. When nonsaturated, the bentonite showed similar conductivities to acetone at all gradients. The corresponding conductivities to xylene showed an increase at a gradient of 181. Again when viewed as a group, there are no consistent trends with two treatments having no significant differences, one with a decrease, and one with an increase as the gradient increases.

The xylene content of leachate from selected permeameters is given in Appendix D. The initial leachate from presaturated soils contained low concentration of xylene. After 0.2 to 0.7 pore volumes had passed, the leachate was 95 to 100% xylene. Leachate from nonsaturated soils was 95 to 100% xylene from the very first appearance, even though the soils contained 11 to 16% moisture. These measurements support the hypothesis that the xylene displaces water only from the large macropores and does not move through the soil as a wetting front.

Permeameters Disassembled Prior to Completion

A total of eight permeameters were disassembled prior to breakthrough. A summary of pertinent data and observations is given in Table 14. Each permeameter will be discussed in the order presented in the table.

The permeameter containing nonsaturated kaolinite soil exposed to acetone at a gradient of 31 was under pressure for over one year, and 1.1 pore volumes of effluent were collected. The data are plotted in Figure 19 as Replication 2. The initial conductivity was similar to that of Replication 1; however, no sharp increase in conductivity was observed. Upon disassembly, the outflow was found to be obstructed by a white deposit. A small leak between the fluid and soil chambers of the permeameters was noted. The leak probably allowed the acetone to slowly evaporate over the long period of pressurization.

A third replication of this treatment was run for 15 months, and no effluent was collected. Upon disassembly, the fluid chamber was full of acetone; however, the porous plate and outflow were clogged with a yellow colored gelatinous material.

The bentonite core (Replication 1) was still in the presaturated stage at a gradient of 181 and never gave any leachate in a seven month period. Upon disassembly, free water was noted to still be present in the fluid chamber, and the soil had swelled 6.1 cm. In addition, the

TABLE 14. DATA AND OBSERVATIONS OF PERMEAMETERS DISASSEMBLED BEFORE BREAKTHROUGH

Soil	Fluid	Rep.	Gradient	Date Started	Date Ended	Was Fluid Present on Top of Core	Was Outflow Clear or Clogged	Swelling	Number of P.V. Collected
Kaolinite	Acetone nonsaturated	2	31	3/29/83	7/11/84	no (leak between perm parts)	clogged with white deposit.		1.1
Kaolinite	Acetone nonsaturated	3	31	4/29/83	7/11/84	yes (full chamber)	clogged with yellow gel.		0
Bentonite	Acetone presaturated still in H_2O stage.	1	181	12/19/83	7/11/84	yes (half full with water)	clogged with white deposit.	core swelled 6.1 cm	0
Bentonite	Acetone nonsaturated.	1	91	6/28/83	9/19/84	no	appeared clear	swelled 1.3 cm	1.6
Bentonite	Acetone nonsaturated.	1	181	6/28/83	7/26/84	no (dry & cracked)	clogged	swelled 1.9 cm	1.9
Bentonite	Acetone nonsaturated.	2	181	6/28/83	9/19/84	dry & crumbly	clear		0
Bentonite	Acetone presaturated	1	91	3/4/82	7/26/84	no but soil was wet.	clear	swelled 3.4 cm	1.9
Bentonite	Xylene presaturated	2	91	1/4/82	9/19/84	no but soil was wet	partially clogged with dark colored deposit	swelled 5 cm	0.3

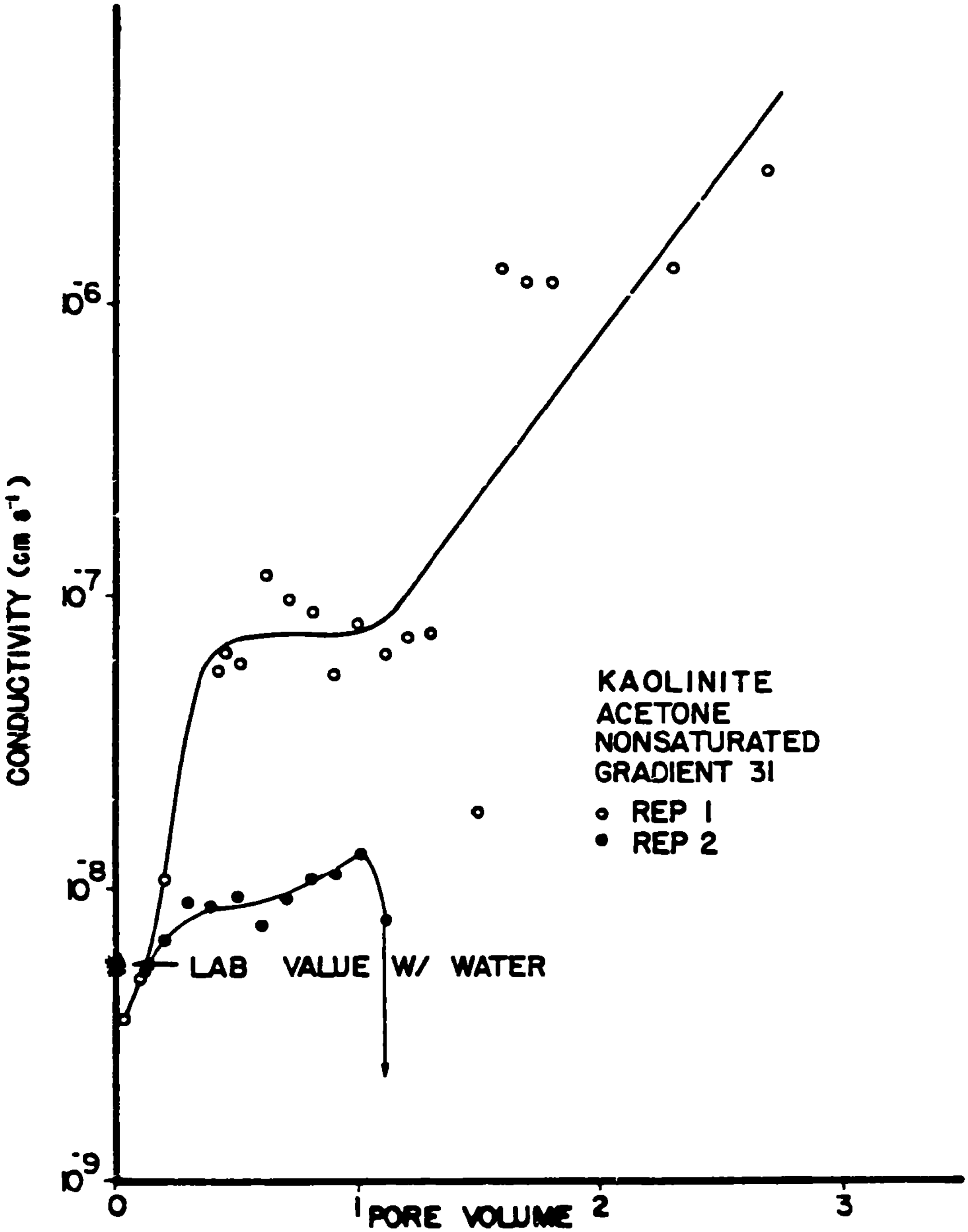

Figure 19. Conductivity of nonsaturated soil containing kaolinitic clay to acetone as a function of pore volume at a hydraulic gradient of 31.

outflow was again obstructed with a white deposit.

The permeameter containing nonsaturated bentonite soil exposed to acetone at a gradient of 91 yielded 1.6 pore volumes of leachate over the 15 month experimental period. These data are plotted as Replication 1 in Figure 20. The initial conductivity was 6.6×10^{-10}, which was below that of Replication 2. The final conductivity was, however, similar to that of Replication 2 at 1×10^{-7} cm sec^{-1}. This represents an increase in conductivity of about 2.5 orders of magnitude. Swelling of this core was much less than that of the presaturated core.

The permeameter containing nonsaturated bentonite soil exposed to acetone for 13 months at a gradient of 181 resulted in 1.9 pore volumes of leachate (Figure 21). The initial change in conductivity was a decrease followed by a very large increase to a final conductivity of 1.8×10^{-7} cm sec^{-1}. This is about 2.5 orders of magnitude greater than the original conductivity of the soil and 3.5 orders of magnitude greater than the lowest conductivity of 6.1×10^{-11} cm sec^{-1} measured for this sample. Since the outflow was obstructed at the end of the experimental period, the conductivity may have continued to rise had the deposit not formed. Again, the swelling was much less than that measured for bentonite exposed to water.

Replication 2 of nonsaturated bentonite soil exposed to acetone for 15 months resulted in no leachate. The outflow appeared to be unobstructed, and no swelling of the soil was observed. The soil surface was dry, indicating all the acetone had either evaporated or leaked from the fluid chamber.

The permeameter containing presaturated bentonite soil exposed to acetone for 28 months at a gradient of 91 resulted in 1.9 pore volumes of leachate (Figure 22). The curve is similar to that for Replication 2. The initial conductivity of about 1×10^{-8} cm sec^{-1} dropped to 5×10^{-10} cm sec^{-1} before acetone was applied. After addition of acetone, the conductivity rose to about 4×10^{-8} cm sec^{-1} and then dropped slightly. Both replications exhibited a drop in conductivity near the end, presumably due to a shortage in free liquid head. The soil swelled 3.4 cm, probably during the initial presaturation stage.

The permeameter containing presaturated bentonite soil exposed to xylene at a gradient of 91 for 32 months did result in 0.3 pore volumes of leachate (Figure 23). The outflow was still functional, although some dark deposit was present. The soil surface was wet and had swelled 5 cm, presumably during the presaturation stage. The low conductivity of this replication was probably caused by the lack of sufficient permeant liquid due to the swelling of the soil material which reduced the volume of the fluid chamber.

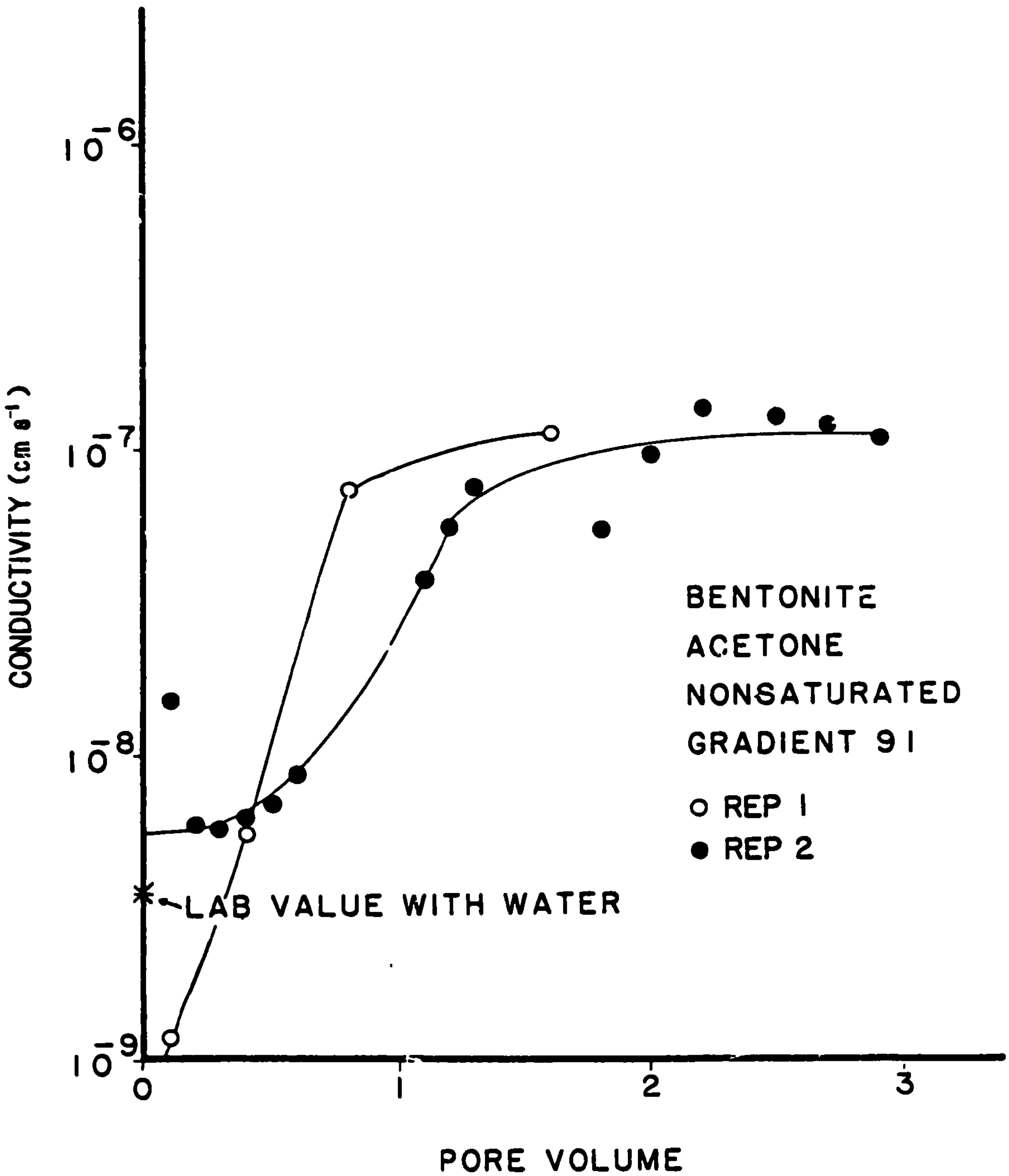

Figure 20. Conductivity of nonsaturated soil containing bentonitic clay to acetone as a function of pore volume at a hydraulic gradient of 91.

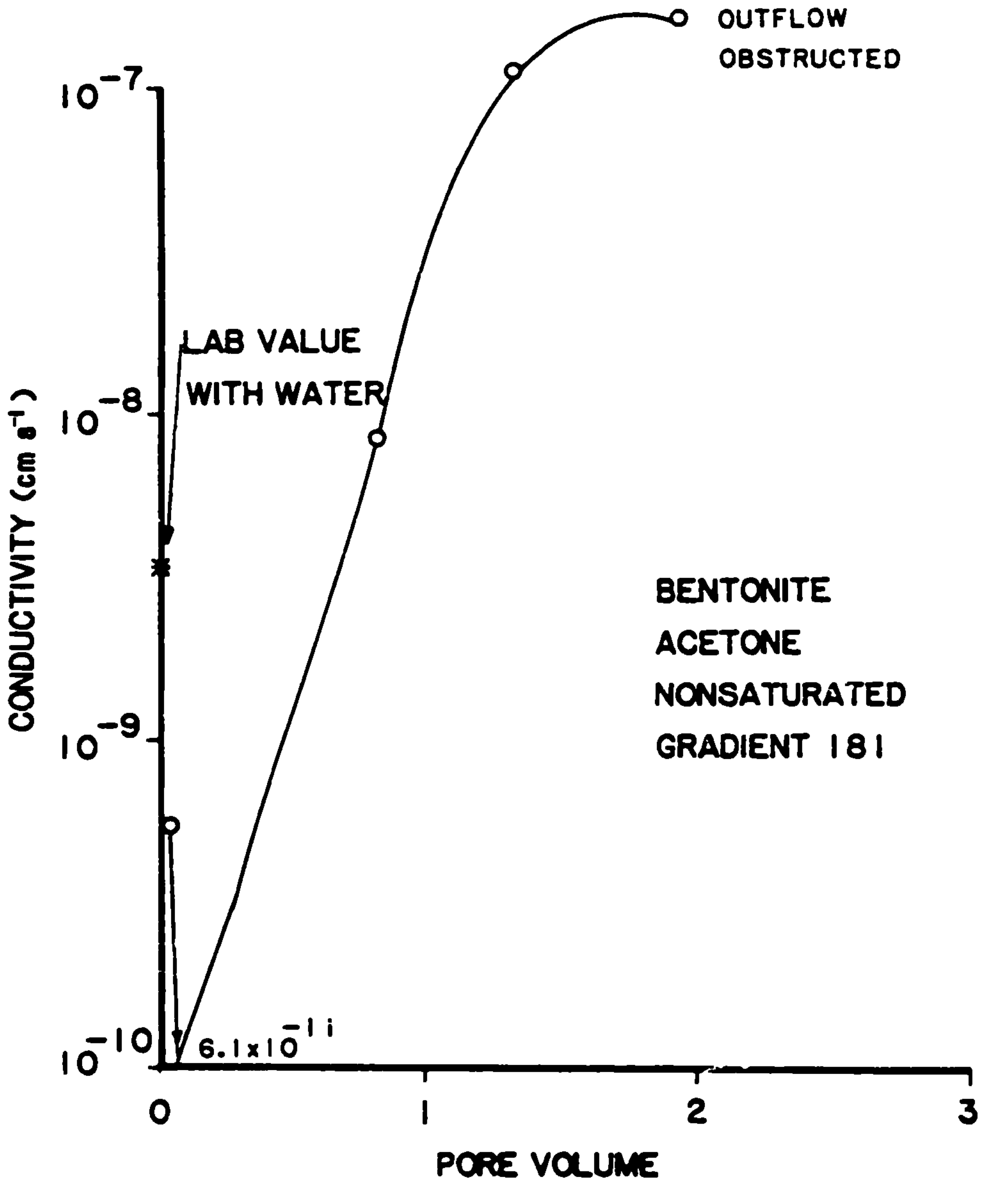

Figure 21. Conductivity of nonsaturated soil containing bentonitic clay to acetone as a function of pore volume at a hydraulic gradient of 181.

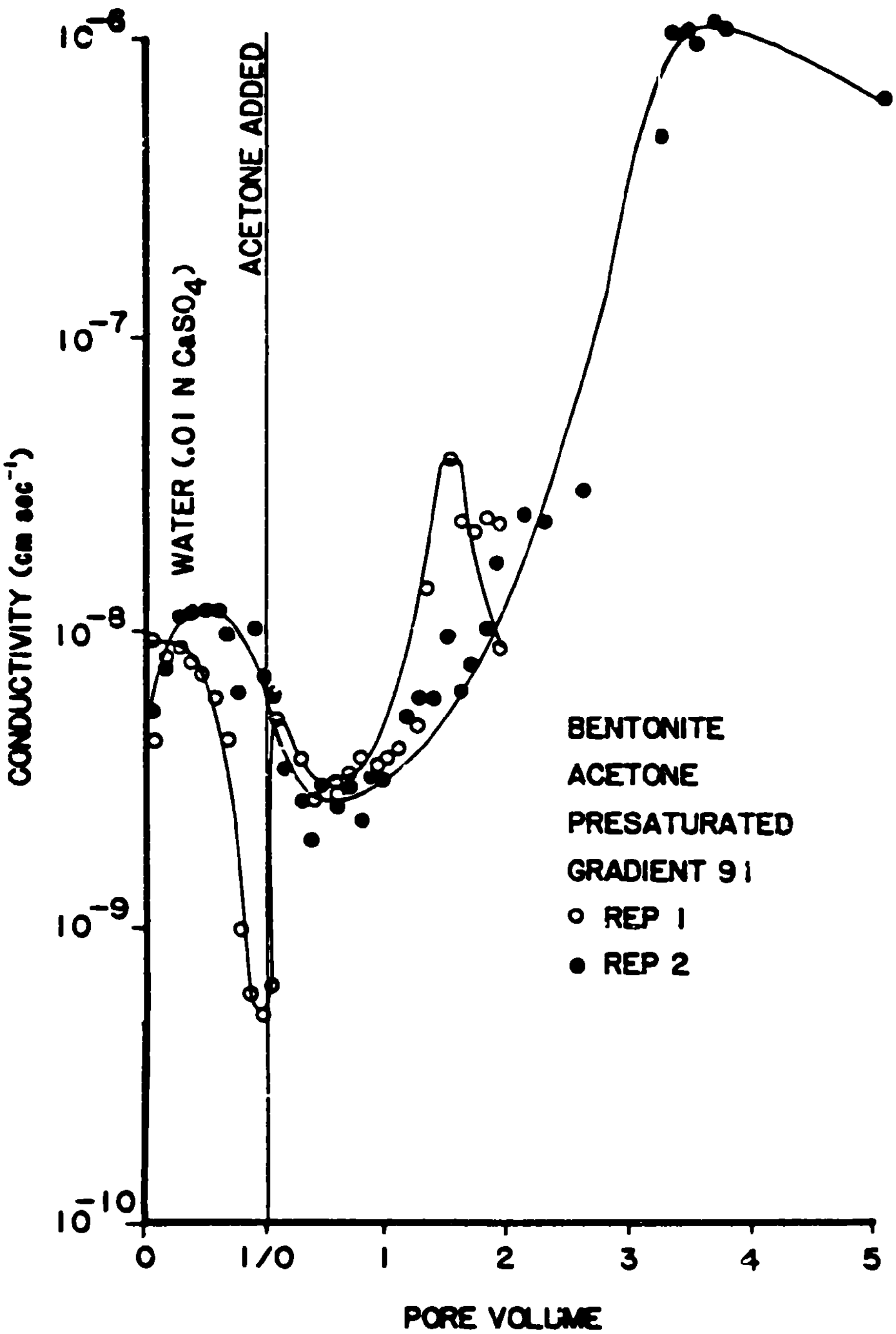

Figure 22. Conductivity of presaturated soil containing betonitic clay to acetone as a function of pore volume at a hydraulic gradient of 91.

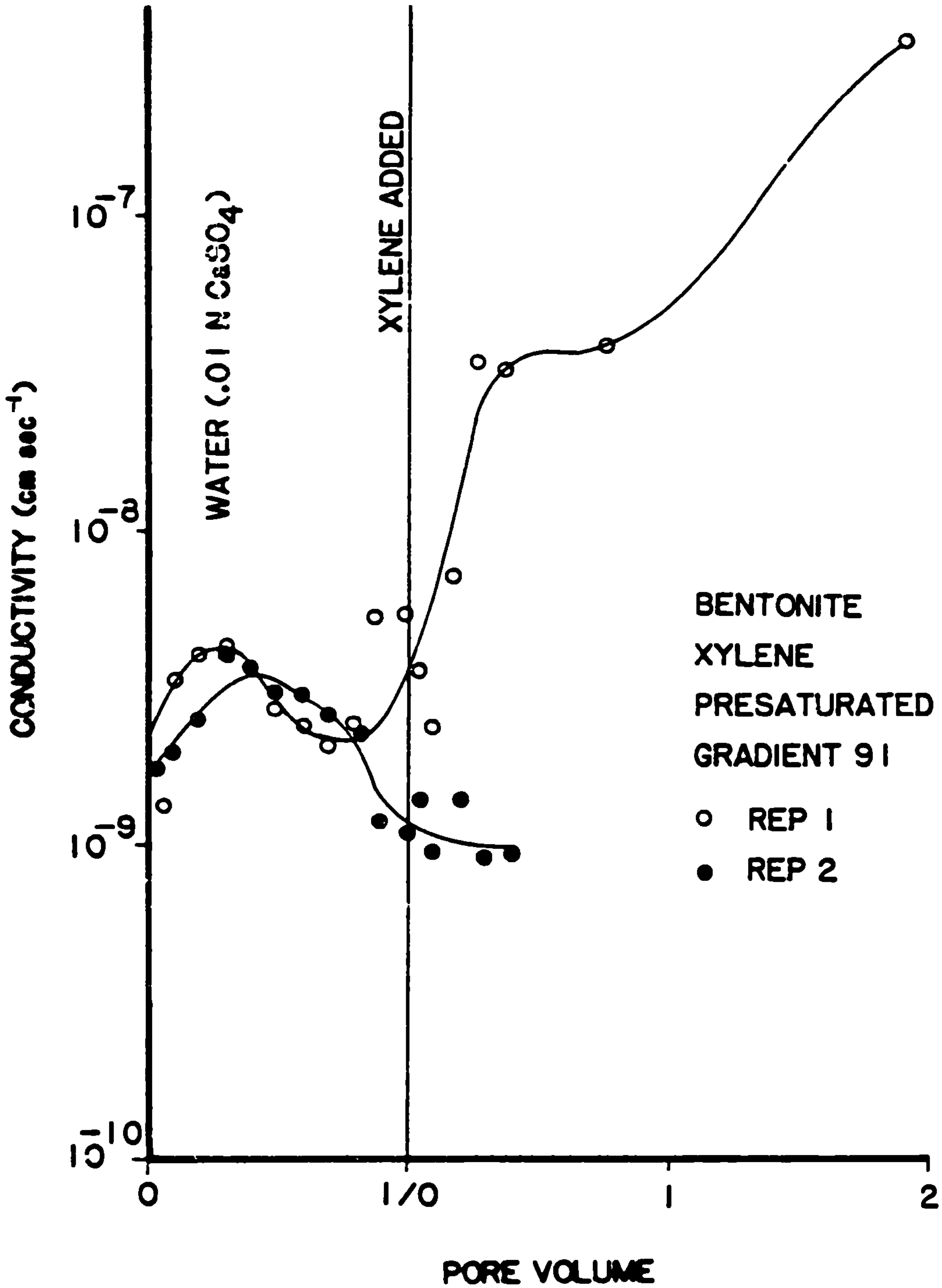

Figure 23. Conductivitv of presaturated soil containing benonitic clay to xylene as a function of pore volume at a hydraulic gradient of 91.

SECTION 8

FIELD TESTS

INTRODUCTION

Laboratory testing has indicated that concentrated organic liquids will have an adverse affect on compacted clay soils and result in conductivities one to four orders of magnitude higher than those measured using water as the permeant. The extrapolation of these data to field situations has been questioned due to the sophisticated technology and equipment available for field installation, the low hydraulic gradients in the field, and the presence of overburden pressure. Other workers question the use of fixed wall permeameters in the laboratory saying that shrinkage in such a permeameter will cause side wall flow, whereas in a field situation sidewall flow is not possible. It is possible, however, that shrinkage in the field may result in the formation of cracks or the enlargement of existing pores, thus greatly increasing the conductivity.

This field study was, therefore, designed to compare the measured conductivity of compacted clay soil to concentrated organics in the laboratory and in the field.

MATERIALS AND METHODS

Field Cells

Twenty-eight field test cells, 1.5 m x 1.5 x 1.8 m tall, were constructed of 15.24 cm concrete reinforced with 1.27 cm steel. A schematic diagram of the cells is shown in Figure 24. Design of the concrete cells was done by Dr. Myron Anderson, P.E., licensed to practice in the State of Texas. The units were designed and built using the drawings shown in Figure 25. The cells were built on a compacted, lime stabilized subbase similar to that used for road base in South Central Texas. Thus, the soils under the cells had adequate bearing capacity to support the structures without shifting or sinking. Lateral soil and water pressure from outside the cells was minimal since the cells were only 0.9144 m below average ground level, and a minimal amount of soil was mounded around them. They exceeded all engineering requirements to be used as retaining walls for a 1.8 m height. A list of construction materials and specifications are given in Table 15.

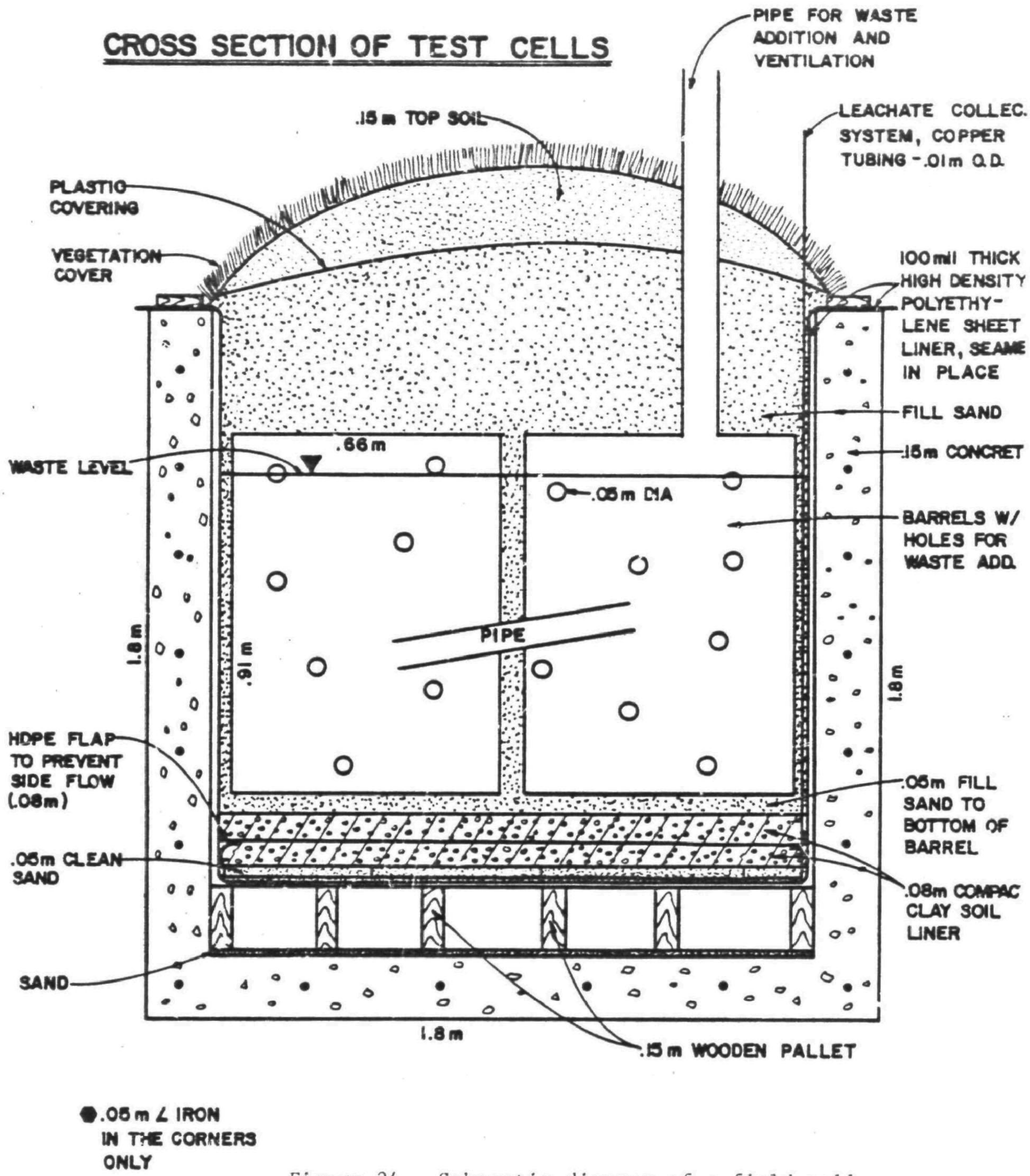

Figure 24. Schematic diagram of a field cell.

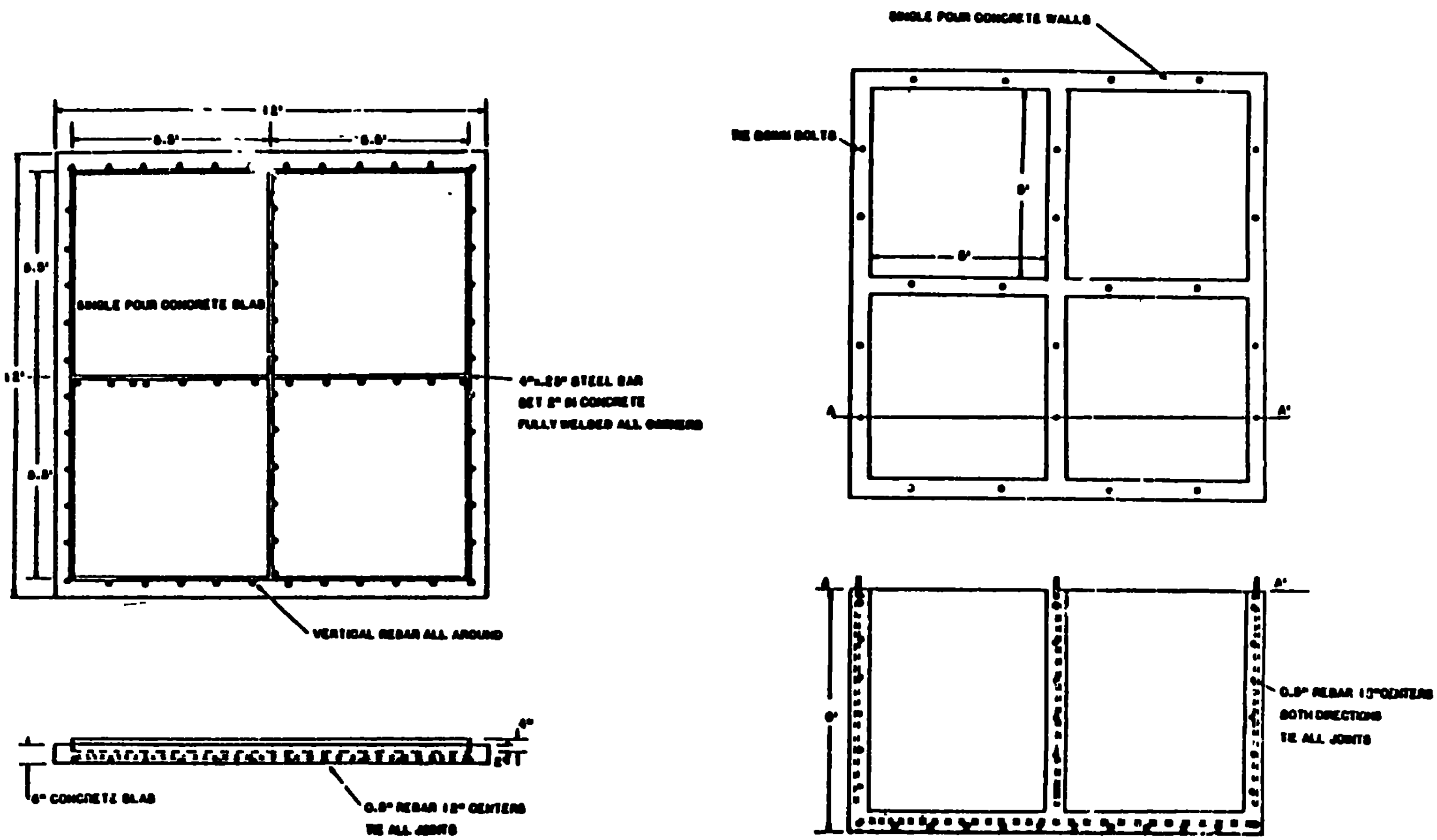

Figure 25. Construction diagrams for concrete test cells.

TABLE 15. CONSTRUCTION MATERIALS AND SPECIFICATIONS FOR FIELD CELLS

Concrete	5 sacks from Bernath Co.
Steel	1.3 cm rebar, 30.5 cm on center in all walls and base.
Water Barrier	0.6 cm x 10.2 cm strap steel in all wall/ base joints to prevent leakage.

A wooden platform, 1.5 m x 1.5 m x 0.15 m, with lifting devices on each corner was placed in each cell to facilitate final removal of the clay liners. The inner lining of 100 mil HDPE, high density polyethylene, was designed and installed by the Schlegel Company, and the specifications are shown in Figure 26. The 0.25 cm thick HDPE liners were extended to the top of the cell walls. A collection system consisting of a manifold of four 0.95 cm i.d. perforated copper tubes was laid on the HDPE liner and covered with 5 cm of washed masonry sand.

The optimum water content for field compaction, using clay blended with sand, was determined in the laboratory. Water, sand and clay were blended to meet the laboratory determined specifications. The blended clay soils were added to the cells in two 7.5 cm thick lifts and compacted to 95% Proctor with a gasoline engine-powered vibratory compactor. Density and moisture measurements were determined after placement of each lift (Troxler 3411 Density Meter). A 10 cm layer of fill and four perforated barrels were placed above the liners. Each cell was then backfilled to a dome shape to encourage rainfall runoff and covered with polyethylene.

The wastes to be placed in these field cells were dyed with Automate Red B and Fluorescent Yellow at 154 and 50 mg l^{-1}, respectively. About 1,400 liter of each waste was introduced into each cell through a standpipe on one of the four perforated barrels. Leachate was collected twice weekly by applying a vacuum to the collection manifold into 20 liter glass containers, from which it was measured and subsampled. Two ground rods and a network of wiring grounded the vacuum tank, storage drums, and all field cells. This grounding prevented sparks and possible ignition of waste due to static electrical charge.

After the permeability was measured at 2×10^{-7} cm sec^{-1} or greater by calculation from the volume of cell drainage collected over time, each cell was disassembled. The fill soil and perforated barrels were carefully removed with a backhoe. The pallets, HDPE liners, and clay liners were lifted from the concrete cell by a crane. The HDPE sides were cut and removed to expose the compacted clay liners which

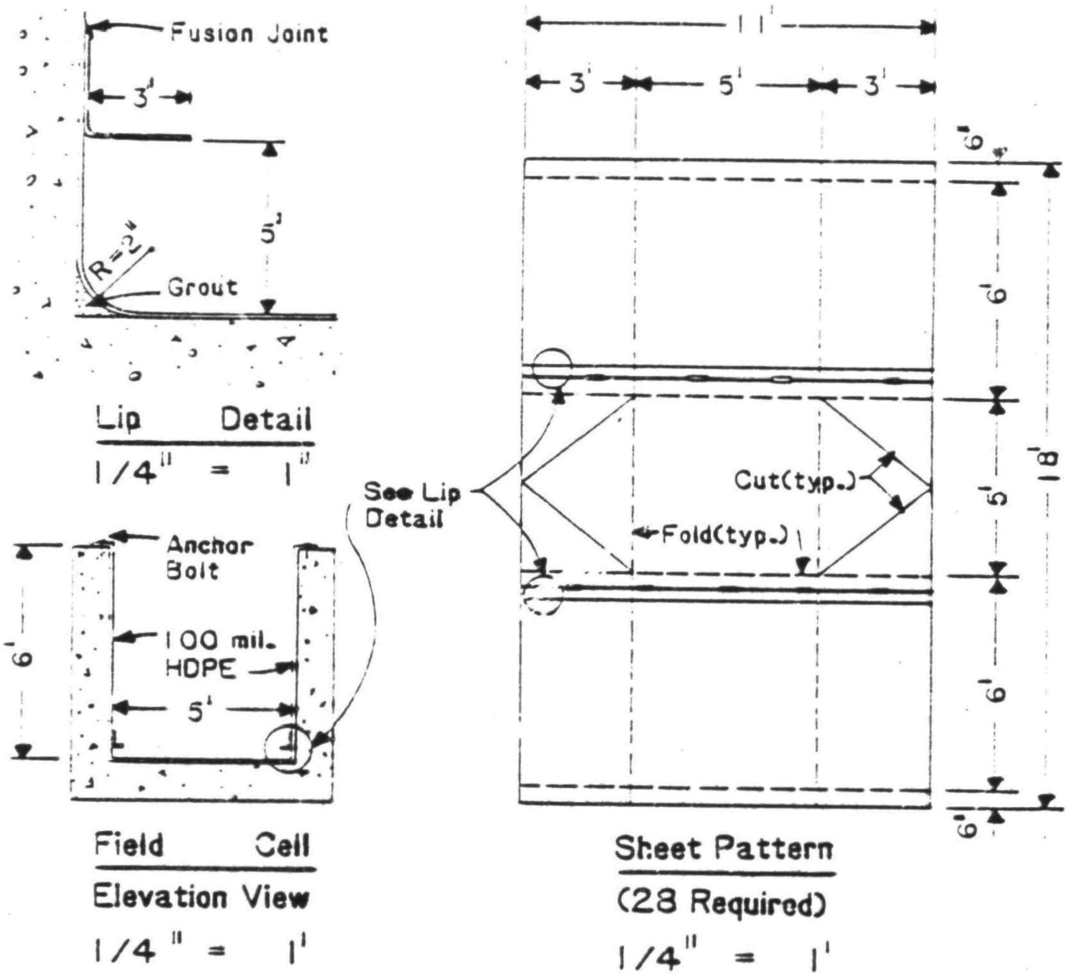

Figure 26. Design specifications for 100 mil HDPE linings.

were divided according to a randomized grid system and sampled for analysis. Typically, four vertical profiles were sampled in 2.5 cm depth increments for chemical analysis, and 10 sample profiles were taken for morphological study. Additional samples were taken from readily observable cleavage planes, which were often colored by dye, and from cut surfaces representing the inside of single natural soil aggregates or peds.

Chemical Analysis

Xylene in liquid samples--

Since xylene and water are immiscible and this study was concerned with large concentrations of xylene, liquid samples were allowed to settle into separated phases for 24 hr. The volume of each phase was then measured using a graduated cylinder, and the percent xylene was calculated assuming the xylene content of the water phase to be zero.

Xylene in soil samples--

Soil samples were placed in one pint mason jars with foil lined lids and stored at 4°C. The contents of a jar were emptied onto a teflon sheet, quickly mixed to achieve homogeneity, and a 25 g subsample was taken. The subsample was put in a Waring blender jar with 50 ml of 20% CH_3OH:80% CH_2CL_2 and blended at high speed for 10 min. The mixture was vacuum filtered through Whatman #41 filter paper, and the extract brought to 50 ml by addition of CH_2CL_2. This solution was mixed and analyzed by high performance liquid chromatography (HPLC). The HPLC was equipped with a 4 μm "ultrasphere ODS" inverse phase column, a 254 nm u.v. detector and a 20 μl loop injector. The flow rate was set at 1 ml min^{-1} using 80:20 methanol:water as the elutant. Sample peaks were compared to standards to quantify the concentrations.

Acetone in liquid samples--

Liquid samples were placed in one pint mason jars with foil-lined lids and stored at 4°C. Using a syringe, 100 μl of the sample was injected into a 125 ml flask through a septum stopper. Addition of 2,4 dinitrophenylhydrazine was made through the septum until the resultant precipitate formation ceased. The solution containing the precipitate was vacuum filtered, dried overnight at 60°C, and weighed. The precipitate weight was then compared to a standard curve for quantification.

Acetone in soil samples--

Soil samples were placed in one pint mason jars with foil lined lids and stored at 4°C. The contents were homogenized, and a 5 g subsample was accurately weighed and placed in a 125 ml flask equipped with a septum stopper. Addition of 2,4 dinitrophenylhydrazine was made through the septum until the resultant precipitate formation ceased. The contents of the flask were vacuum filtered, dried overnight at $60^{o}C$, and weighed. The soil weight was subtracted, and the precipitate weight was compared to standard curves for quantification. Individual standard curves were made for acetone concentrations in each soil type.

RESULTS AND DISCUSSIONS

Field Cells

A summary of test cell disassembly dates and observations is given in Table 16. Of the 12 cells containing xylene waste, free xylene was found outside 10 of the HDPE liners indicating leakage. Of the 16 cells containing acetone waste, only eight were dry. Since the acetone leachate was basically colorless, the liquid in the eight cells containing liquid below the HDPE could be water and/or acetone. Due to the long period of time between waste application and cell disassembly and the many possibilities for degradation, acetone centrations were not measured in these liquids.

The time between waste application and the beginning of leachate collection was two to three days for kaolinitic and micaceous soils exposed to xylene and 21 to 28 days when exposed to acetone (Table 17). The bentonitic soils had a much longer time delay of 70 days for xylene and 704 days for acetone. Permeation of acetone through the 15 and 30 cm micaceous soil required 20 days. No additional time was gained by doubling the soil thickness to 30 cm. Thus, the compacted micaceous and kaolinitic soils appear to only contain concentrated organics for 30 days or less while the bentonitic soil may contain them for up to 700 days.

Xylene

Exposure of the field cells containing compacted kaolinitic soil to xylene resulted in a two to three order of magnitude increase in conductivity (Figure 27). Detailed data are given in Appendix E. Replication 1 of the kaolinite soils showed the greatest conductivity increase. By the passage of two pore volumes of leachate, the conductivity had risen to about 5×10^{-6} cm sec^{-1}, which is three orders of magnitude over the laboratory value with water. After two pore volumes, the conductivity dropped to 1×10^{-7} cm sec^{-1}, presumably due to the entrance of water. The conductivity of Rep. 2 rose to 5×10^{-7}, a two order of magnitude increase, by 0.8 pore volumes, decreased to 3×10^{-8} cm sec^{-1} by 1.5 pore volumes, and then increased to 2×10^{-7} cm sec^{-1}. Analysis of the leachate showed that 100% xylene was collected for the first 1.8 pore volumes, after which it became mixed with 5 to 15% water (Appendix F). The conductivity of Rep. 3 followed a very similar trend as Rep. 2. It

TABLE 16. DATE WASTE WAS ADDED TO AND REMOVED FROM THE WASTE CELLS, AVERAGE THICKNESS OF CLAY LINERS AND DEPTH OF WASTE WHICH LEAKED FROM THE HDPE LINER

Waste	Soil	Rep	Cell #	Average Liner Thickness (cm)	Date Waste Added	Date Waste Removed	Depth of Waste in Concrete Cell (cm)	Did Waste Penetrate Clay soil
Xylene	Kaolinite	1	2	19.8	10/1&11/3/81	11/17/81	9.0	Yes
		2	4	16.0	11/3/81	7/15/82	4.5	Yes
		3	10	16.8	11/5/81	6/16/82	8.0	Yes
		4	12	19.4	11/5/81	12/15/81	2.5	Yes
	Mica	1	5	19.2	11/4/81	11/17/81	13.0	Yes
		2	6	19.1	11/4/81	12/15/81	0.0	Yes
		3	8	19.5	11/4/81	4/6/82	13.0	Yes
		4	11	20.2	11/5/81	4/27/82	14.0	Yes
	Bentonite	1	1	19.3	11/3/81	7/9/82	9.0	Yes
		2	3	16.6	11/4/81	3/30/83	13.5	Yes
		3	7	22.6	11/4/81	7/21/83	0.0	No
		4	9	22.4	11/4/81	7/15/82	19.0	Yes
Acetone	Kaolinite	1	18	17.4	10/13/81	8/26/82	13.0	Yes
		2	20	24.13	10/12/81	4/25/84	0.0	Yes
		3	25	21.3	10/7/81	4/4/85	14.4(water)	Yes
		4	28	17.3	10/67/81	4/3/85	0	Yes
	Mica	1	21	17.0	10/16/81	3/31/83	6.7	Yes
		2	23	16.3	10/20/81	7/21/83	0.0	Yes
		3	26	17.8	10/6/81	6/30/83	0.2	Yes
		4	27	17.7	10/7/81	10/27/82	13.0	Yes
	Bentonite	1	17	9.2	10/15/81	4/8/85	13.3(water)	Yes
		2	19	19.2	10/12/81	4/4/85	14.0(water)	Yes
		3	22	19.5	10/12/81	4/4/85	12.7(water)	Maybe
		4	24	20.75	10/17/81	7/21/83	0.0	No
	Mica 12"	1	13	35.08	10/21/81	4/25/84		Yes
		2	14	34.3	10/21/81	4/8/85	8.3(water)	Yes
		3	15	34.4	10/13/81	4/8/85	13.3(water)	Yes

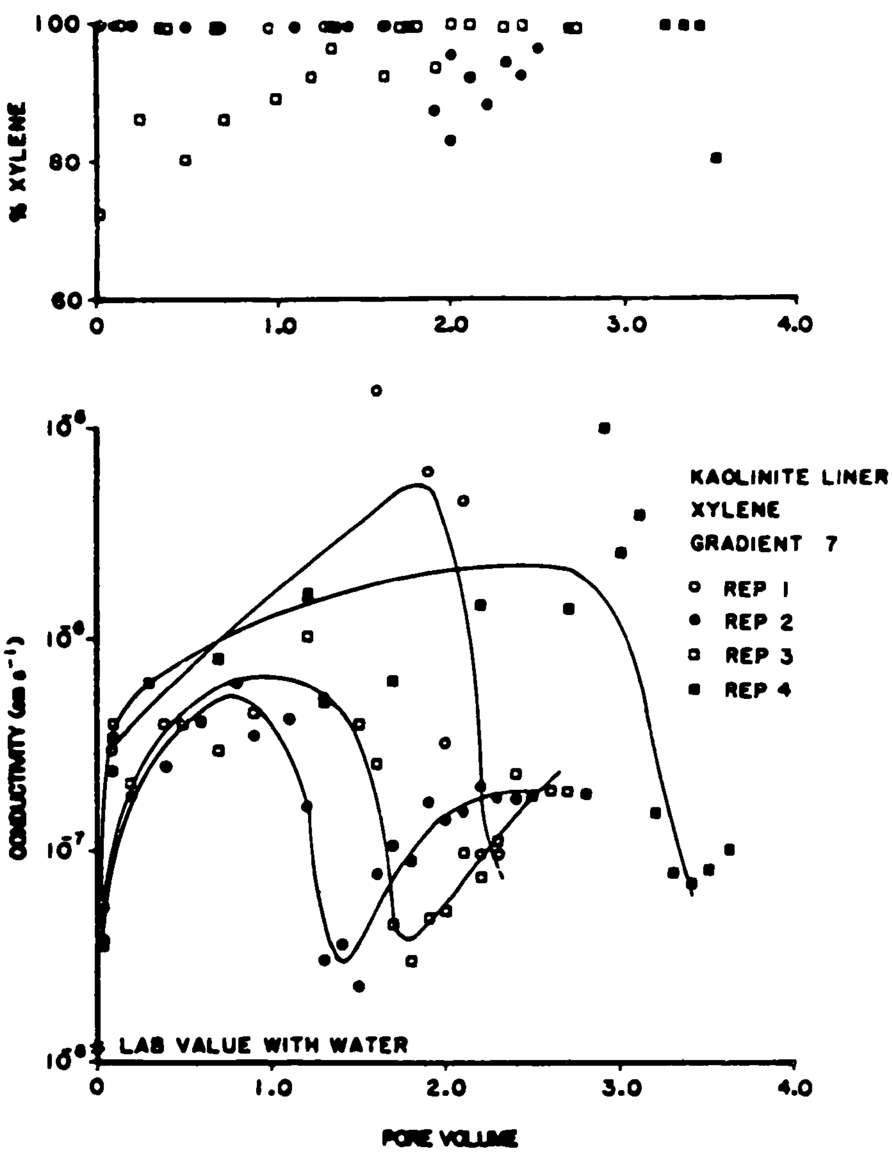

Figure 27. Conductivity and breakthrough curves for compacted kaolinitic soil liners in the field cells containing xylene.

TABLE 17. AVERAGE NUMBER OF DAYS BETWEEN THE DATE OF WASTE APPLICATION AND TIME LEACHATE APPEARED

Soil	Waste	Time(days)
Kaolinite	Xylene	2.5
Mica	Xylene	3.0
Bentonite	Xyele	70.6*
Kaolinite	Acetone	28.2
Mica (15 cm)	Acetone	21.0
(30 cm)	Acetone	19.0
Bentonite	Acetone	704.0**

* Average of 3 of 4 cells. One did not produce leachate within 624 days.

** Average of 2 of 4 cells. Two did not produce leachate within 642 and 1,269 days between the date of waste application and the date of disassembly.

peaked at just over 6 x 10^{-7} cm sec^{-1} by 1 pore volume, decreased to about 4 x 10^{-8} cm sec^{-1} by 1.8 pore volumes, and again increased to 2 x 10^{-7} cm sec^{-1}. Initially the leachate from Rep. 3 contained 27% water. The water content decreased with increasing pore volumes until pure xylene was leaching out at about 1.6 pore volumes. The conductivity of Rep. 4 quickly rose to 6 x 10^{-7} within the first 0.3 pore volumes after which it continued a slow but steady rise reaching 2.2 x 10^{-6} cm sec^{-1} by the passage of 2.7 pore volumes of leachate. The conductivity then sharply dropped to 1 x 10^{-7} cm sec^{-1} at 3.5 pore volumes. Leachate analysis showed 100% xylene until 3.5 pore volumes, when it became mixed with about 20% water. In general, the kaolinitic soil liners exhibited a two to three order of magnitude rise in conductivity and were very sensitive to the presence of water. When rain water leaked into the head fluid, the xylene floated, water permeated the soil, and the conductivity decreased. After most of the water leached through the soil, an increase in conductivity was again observed, indicating that the conductivity change mechanism is at least in part reversible.

A rise in conductivity of all field cells containing micaceous soils exposed to xylene was also observed (Figure 28). Replication 1 had the largest conductivity increase of three orders of magnitude by the passage of two pore volumes after which it decreased over two orders of magnitude. Here again, leachate analysis indicated the presence of water in the system which caused the decrease. Replication 2 had a two

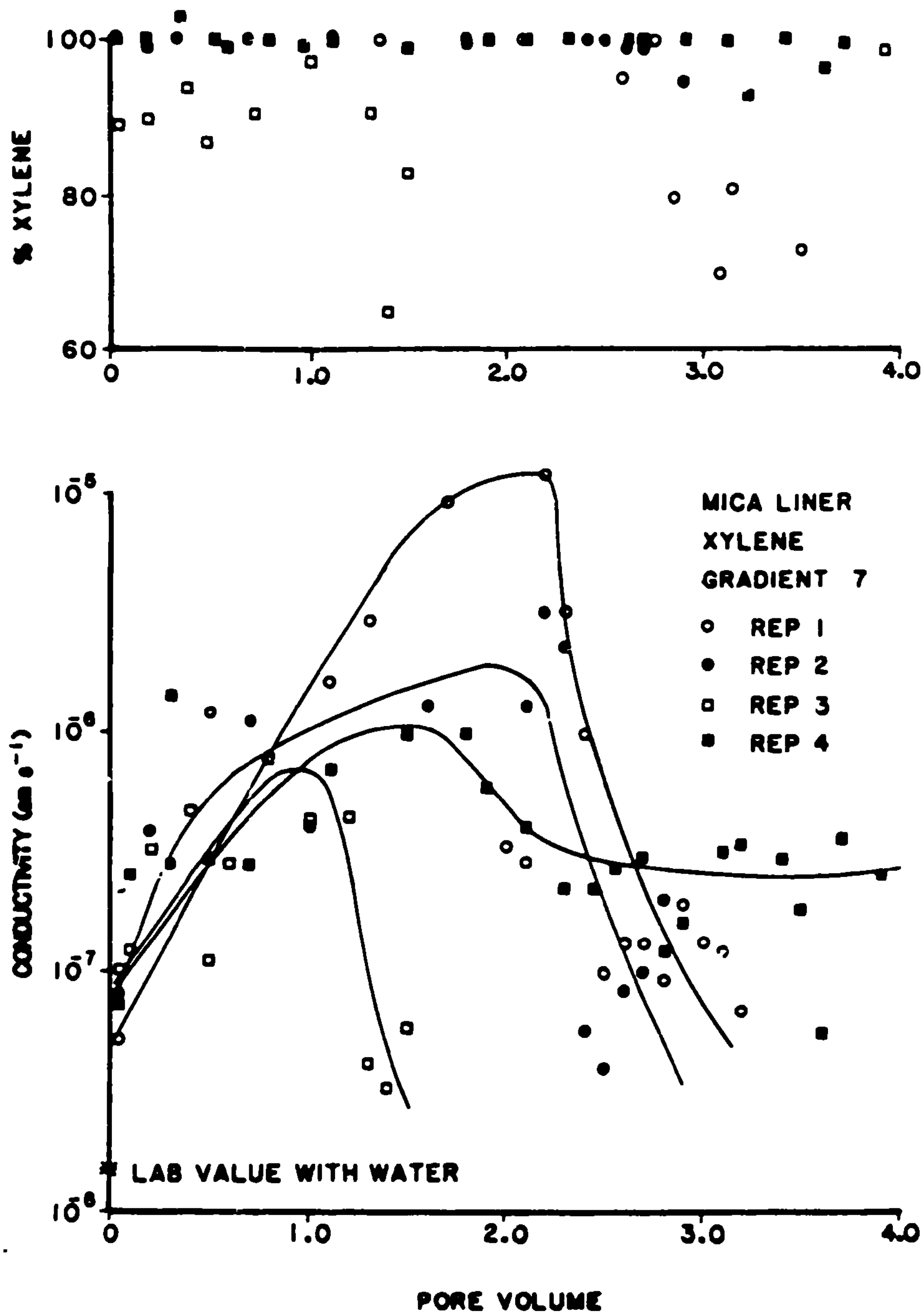

Figure 28. Conductivity and breakthrough curves for compacted micaceous soil liners in the field cells containing xylene.

order of magnitude increase in the first two pore volumes of leachate and again exhibited a decrease due to water. Replication 3 had a 1.5 order of magnitude increase in conductivity during the first pore volume of leachate. The conductivity then decreased almost to the laboratory value with water by the passage of another 0.5 pore volume of leachate. The leachate at this time was 65 to 85% xylene and 15 to 35% water. The conductivity of Rep. 4 increased two orders of magnitude above the laboratory value with water by the passage of 1.5 pore volumes, after which it decreased to 2.5×10^{-7} cm sec^{-1} and remained fairly steady. Leachate from the first three pore volumes was 100% xylene and became mixed with small amounts (less than 5%) of water thereafter. In general, the micaceous soils behaved similarly to the kaolinitic soils and showed two to three orders of magnitude increases when exposed to concentrated xylene. This soil was also reversibly affected by the presence of water and some conductivity values decreased almost to the laboratory value with water.

Conductivity of Rep. 1 of the bentonitic soil increased two orders of magnitude in 0.6 pore volumes, after which it was disassembled (Figure 29). Replication 2 increased 1.5 orders of magnitude within the first 0.25 pore volumes and remained fairly steady until 1.7 pore volumes were passed. The conductivity of Rep. 4 increased two orders of magnitude in the first 0.5 pore volumes. The conductivity then decreased one order of magnitude, presumably due to water, and rose again to 1.7×10^{-7} cm sec^{-1} by the passage of 1.25 pore volumes.

<u>Acetone</u>

Replications 1 and 2 of the kaolinite field cells gave conductivity plots very similar to those reported by Anderson <u>et</u> <u>al</u>. (1985) for presaturated laboratory permeameters permeated with acetone. The initial response to acetone was a decrease in conductivity in the 0.75 pore volumes and followed by an increase in conductivity (Figure 30). In Rep. 1, which was sampled through four pore volumes, the highest conductivity occurred after the passage of 2.7 pore volumes. Replication 3 of this soil showed the initial conductivity decrease during the first 0.25 pore volume, after which it rose until 0.6 pore volumes. After 0.6 pore volumes, the conductivity decreased. Replication 4 also decreased in conductivity during the first 0.4 pore volumes and then increased until 0.8 pore volumes, after which the conductivity decreased again. Conductivity decreases at the end of the experimental periods were due to water which diluted the acetone as indicated by the decreases in acetone concentration of the leachate. Replication 1 of the micaceous soil exhibited the typical drop in conductivity in the first 0.75 pore volumes and was followed by an increase in conductivity which peaked at about 2.7 pore volumes (Figure 31). Replication 3 followed a very similar pattern in conductivity with the minimum value reached at 0.8 pore volumes and the maximum at 1.8 pore volumes. The fourth replication of this soil dropped in

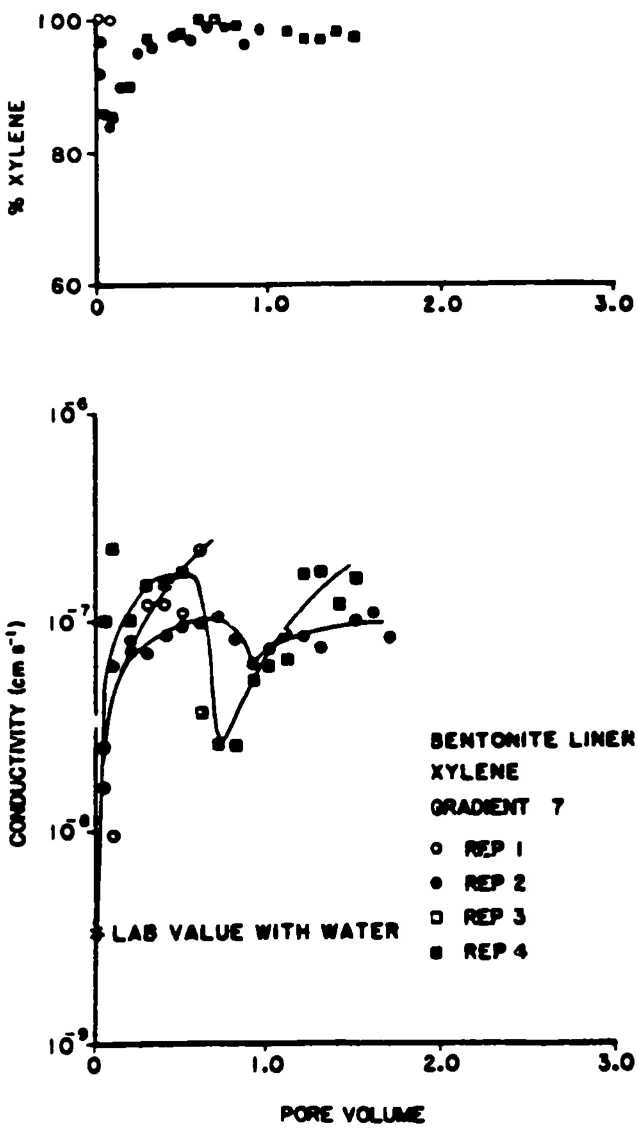

Figure 29. Conductivity and breakthrough curves for compacted bentonitic soil liners in the field cells containing xylene.

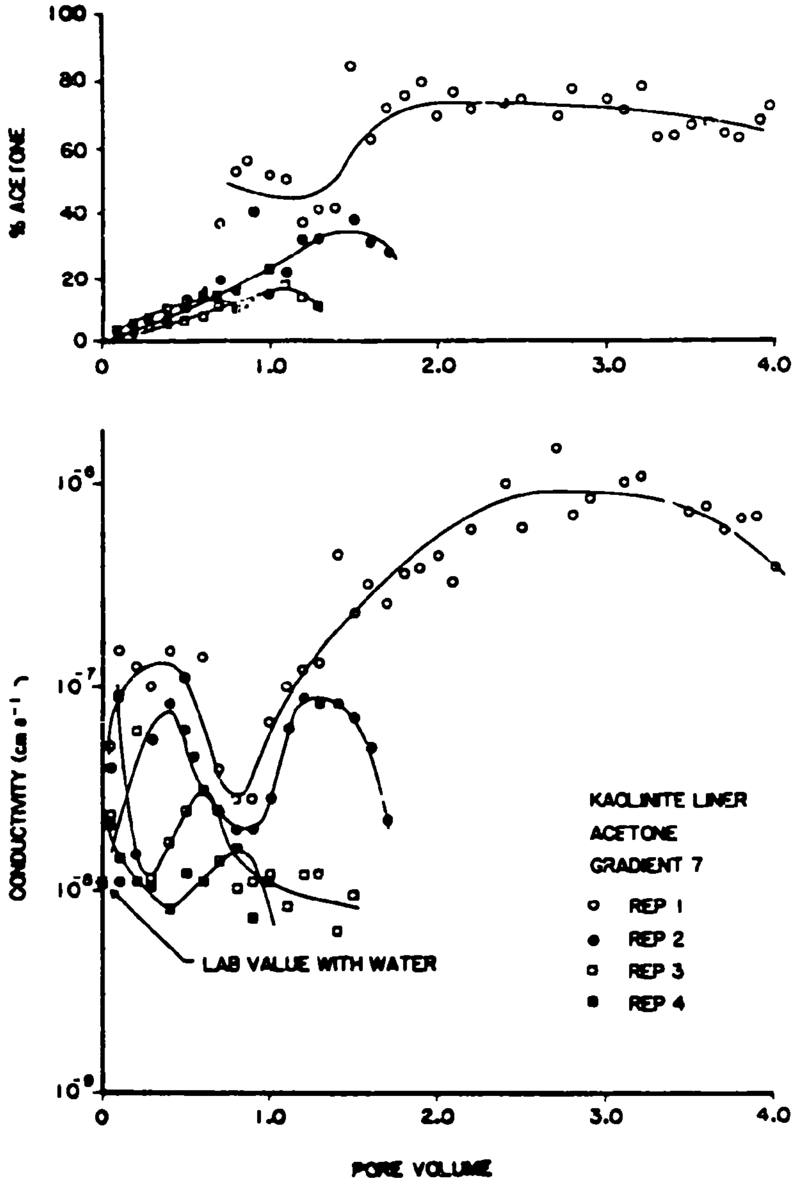

Figure 30. Conductivity and breakthrough curves for compacted kao'initic soil liners in the field cells containing acetone.

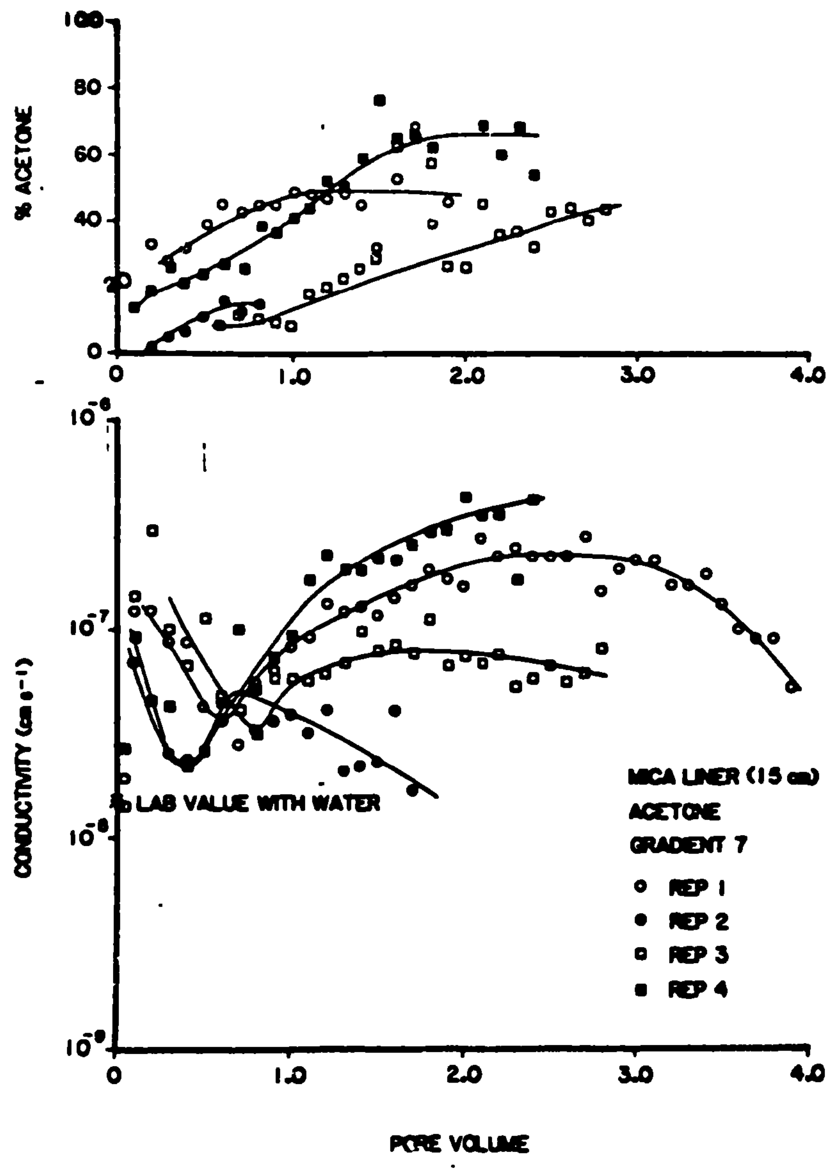

Figure 31. Conductivity and breakthrough curves for compacted micaceous soil liners in the field cells containing acetone.

conductivity for the first 0.4 pore volumes and then progressively increased. The second replication also decreased for the first 0.4 pore volumes, increased until 0.7 pore volumes, and finally decreased for the remainder of the study. This decrease was due to dilution of the acetone by rainfall as evidenced by low acetone concentration in the leachate. In general, the final conductivities of the micaceous soils were about one order of magnitude larger than those measured with water in the laboratory.

Conductivities for the 30 cm thick micaceous soils (Figure 32) were very similar to those of the 15 cm thick micaceous soils and generally were in the range of 5 x 10^{-8} to 1 x 10^{-7}. The time required for initial leachate collection was 20 to 30 days for all micaceous soils regardless of the soil thickness. Therefore, the extra 15 cm thickness of soil appears to have had little to no apparent effect in containing the acetone.

Of the four cells containing bentonitic soil, only two cells produced leachate during the course of this experiment. Almost two years were required until leachate collection began from these soils. Flow through Rep. 1 began at about 6 x 10^{-8} cm sec^{-1}, decreased to 6 x 10^{-9}, and then began to increase again as was typical for acetone in other soils (Figure 33). Replication 2 rose to about 8 x 10^{-8} and then dropped to 6 x 10^{-9}. The final decrease in conductivity was due to the entrance of water which diluted the acetone and caused the soil to swell. Acetone concentrations in the leachate from these two bentonitic soils never exceeded 20 percent.

Chemical Concentrations

Typical xylene concentrations found in profile samples of each clay soil liner are presented in Table 18. The variability of concentrations occurring with depth in any one profile and across the clay soil liner at any given depth indicates that the movement of the liquid was through preferential pathways and did not move in a clearly defined wetting front through the entire soil mass. Some samples which had a volume of approximately 25 cm^3 at a particular location were nearly free of xylene, while others had contents as high as 20,000 mg kg^{-1}. Thus, large segments of the clay soil liner had little penetration by the solvent, while other adjacent segments were nearly saturated. Detailed data are presented in Appendix G.

Similar evidence that xylene moved through the soil in cracks or around blocky sub-angular structural components of the liner is presented in Table 19, in which the xylene content of dyed and undyed surfaces of clay soil liner fragments are compared. The xylene content of the dyed surfaces exposed by breaking the liner along spontaneous cleavage planes in a given cell were typically at least 10 times greater than found in samples scraped from cut surfaces on which dye was not apparent. The lower xylene content of the undyed surfaces adds credence

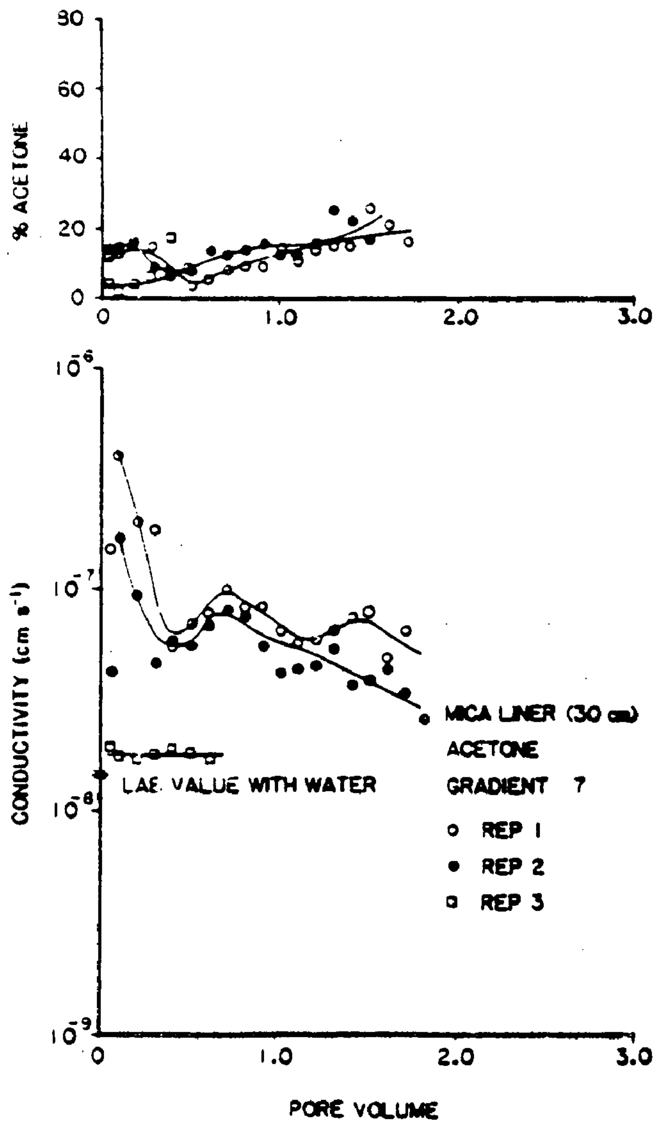

Figure 32. Conductivity and breakthrough curves for compacted micaceous soil liners in the field cells containing acetone.

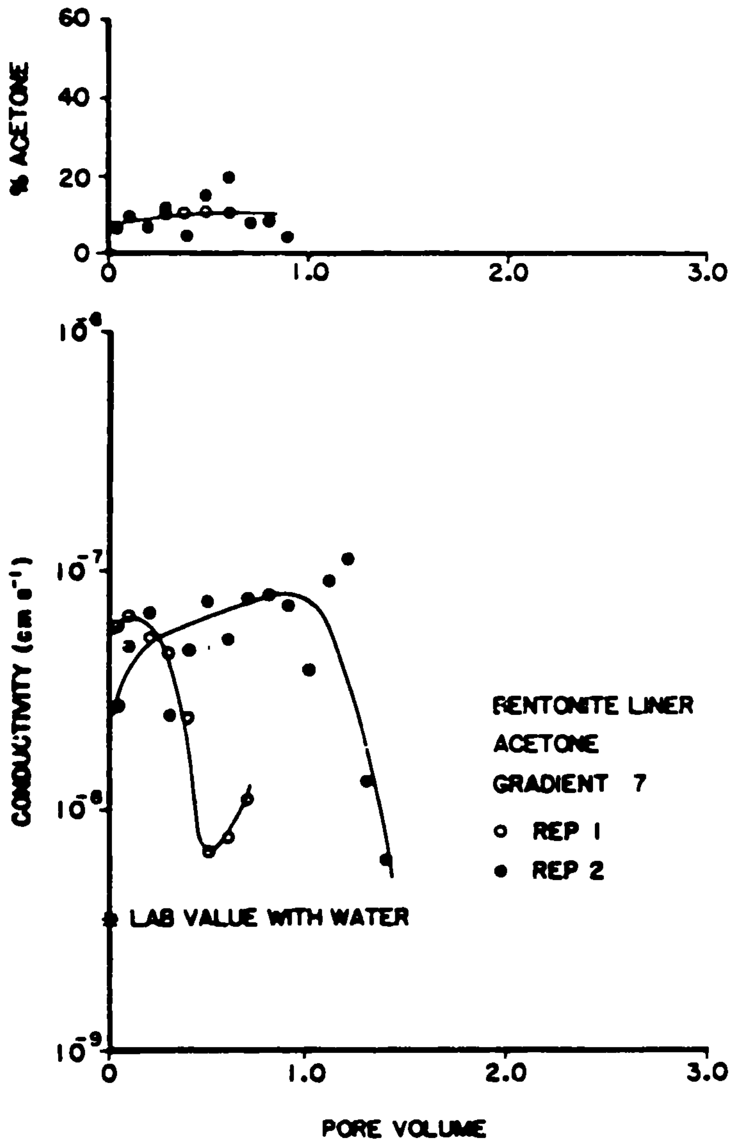

Figure 33. Conductivity and breakthrough curves for compacted bentonitic soil liners in the field cells containing acetone.

TABLE 18. CONCENTRATION OF XYLENE IN MG KG^{-1} IN SOIL SAMPLES FROM A TYPICAL CELL OF THE THREE DIFFERENT CLAY SOIL LINERS

Depth (cm)	Kaolinite Location No.				Mica Location No.			Bentonite Location No.*			
	1	2	3	4	1	2	3	1	2	3	4
0-2.5	235	18	44	170	237	112	51	533	16	4	71
2.5-5.0	1,214	45	238	303	251	1,027	105	5,689	8	38	4
5.0-7.5	5,060	333	806	122	584	1,158	611	15,969	31	685	1
7.5-10.0	352	419	564	36	714	4,035	2,031	23,099	139	1,520	822
10.0-12.5	13	12	71	160	1,289	4,310	77	29,168	2,585	1,085	17,785
12.5-15.0	9,391	2	0	1,669	204	1,903	232	4,144	4,750	7,272	1,336
15.0-17.5	3,757	722	2,015	ND	452	55	1,887	12,706	2,409	7,500	2,542
17.5-20.0	3,401	860	ND	ND	2,005	ND	3,952	20,900	ND	11,352	6,950
20.0-22.5	ND	ND	ND	ND	ND	ND	4,609	ND	ND	ND	ND

* Randomly selected from 42 possible sample areas as determined by grid system.
* Not determined.

TABLE 19. XYLENE CONTENT IN MG KG^{-1} OF DYED AND UNDYED SURFACES (1 MM THICK SOIL FRAGMENT SURFACE) OF CLAY SOIL LINERS

Lysimeter No.	Dyed Surface	Undyed
11	19,404	1,147
	9,149	0
	12,456	ND †
8	2,814	155
	2,691	704
3	13,112	392
	16,834	511

† not determined.

to the conclusion that xylene moved through preferential pathways, perhaps along cracks and ped faces, and not uniformly through the compacted clay soil mass.

Xylene analysis of soil samples from Cell 7 showed no xylene present in any sample (Appendix G). No leachate had been collected from this cell, and the data indicate that in this one of four bentonite clays exposed to xylene, the soil effectively prevented xylene movement. It appears, however, that this will be the exception rather than the normal case.

Acetone concentrations in soil samples were very variable and ranged from 0 to 31.8% (Appendix E). This again indicates that the acetone did not move uniformly through the soil mass but rather moved through channels or cracks. Typical acetone concentrations in soil from one cell of each mineralogy is given in Table 20 and show the large variability in acetone concentrations. Both ped faces and cut surfaces showed similar acetone concentrations (Table 21). This may be due to the fact that acetone is soluble in water and was, therefore, able to penetrate into the peds rather than being excluded, as in the case of a hydropholic chemical.

Density

Measurements of the moisture content and dry density of each lift in each cell were made as they were constructed. The average percent moisture, dry density, and percent proctor for the upper lift of each cell are reported as initial values in Tables 22 to 25. The design densities were 2,000, 1,950, and 1,700 kg m^{-3} for the kaolinite, mica, and bentonite soils, respectively. For the mica and bentonite soils in

TABLE 20. CONCENTRATION OF ACETONE IN PERCENT IN SOIL SAMPLES FROM A TYPICAL CELL OF THE THREE DIFFERENT CLAY SOIL LINERS

Depth (cm)	Kaolinite Location No. †				Mica Location No. †				Bentonite Location No. †			
	1	2	3	4	1	2	3	4	1	2	3	4
0-2.5	6.8	5.8	1.9	5.9	2.3	4.0	2.2	3.7	8.7	26.3	8.5	10.1
2.5-5.0	6.2	5.9	5.0	5.7	3.0	2.5	2.7	3.1	6.5	9.5	8.9	8.7
5.0-7.5	6.1	5.4	5.5	5.9	3.1	2.3	3.2	2.6	7.7	31.8	5.8	7.7
7.5-10.0	6.9	5.6	5.6	5.8	3.5	2.2	2.8	2.9	5.4	6.7	6.1	6.4
10.0-12.5	6.7	5.0	5.7	5.3	3.5	2.7	2.8	2.7	5.8	ND††	6.7	6.9
12.5-15.0	5.8	5.6	6.4	5.7	3.4	2.6	3.5	3.1	4.6	5.8	5.7	6.0
15.0-17.5	6.1	6.2	7.2	5.7	3.3	2.6	3.5	2.1	8.1	1.6	6.0	6.0
17.5-20.0	ND	ND	7.8	6.1	ND	ND	ND	ND	ND	ND	ND	ND

† Randomly selected from 42 possible sample areas as determined by grid system.
†† Not determined.

TABLE 21. ACETONE CONTENT IN PERCENT OF DYED AND UNDYED SURFACES (1 MM THICK SOIL FRAGMENT SURFACE) OF CLAY SOIL LINERS

Lysimeter No.	Ped Face	Cut Surface
13	4.8	5.6
	6.0	5.3
14	1.4	2.7
	1.5	2.4
15	1.6	1.8
	2.4	1.2
17	5.6	6.8
19	5.1	6.9
	5.0	5.6
20	5.9	6.4
	8.1	6.8
22	4.7	5.2
	5.2	
25	1.5	1.1
	1.3	0.9
	0.3	13.9
	1.5	
28	0.6	1.0
	1.3	0.6

all but one cell, compactions of 90 to 100% Proctor were achieved. The kaolinite soil was much more difficult to pack and only Proctor values of 82.0 to 91.4 were achieved. Compaction was stopped at this point because further compaction was found to result in a lessening of the density. This may have been due to the moisture contents being generally a little over the design of 15.5 or an overestimation of the design density of 2,000 kg m^{3-1}.

A separate calibration experiment with the density gauge showed that the presence of acetone and xylene does not affect density readings; however, moisture content readings are increased by the presence of either acetone or xylene.

When each cell was disassembled, moisture-density readings were taken immediately after the clay soil surface was exposed. Average moisture content readings in all soils are higher than original, probably due to the presence of the acetone or xylene. Dry density and Proctor values generally decreased after exposure to acetone and xylene. Decreases were least in kaolinite soil, intermediate in mica soil, and greatest in the bentonite soil. Much of this reduction may be due to swelling of the upper layer of soil, which become thoroughly permeated with organic fluid.

TABLE 22. AVERAGE MOISTURE DENSITY AND COMPACTION OF THE KAOLINITIC CLAY LINERS

Lysimeter No.	Initial Values: Moisture (%)	Initial Values: Dry Density (kg m^{-3})	Initial Values: Proctor (%)	Final Values: Moisture (%)	Final Values: Dry Density (kg m^{-3})	Final Values: Proctor (%)
2	17.5	1,769	90.7	-†	-†	-†
4	17.2	1,738	89.1	18.7	1,641	82.0
10	18.6	1,663	85.3	17.3	1,727	86.4
12	16.0	1,784	91.4	19.1	1,672	83.6
18	14.8	1,756	87.8	17.6	1,699	85.0
20	17.4	1,656	84.0	18.1	1,741	87.0
25	18.8	1,641	82.0	20.2	1,669	83.4
28	14.8	1,756	87.8	18.3	1,743	87.2
Design Value	15.5	2,000	100.0			

† Not measured.

TABLE 23. AVERAGE MOISTURE DENSITY AND COMPACTION OF THE MICA CLAY LINERS.

Lysimeter No.	Initial Values			Final Values		
	Moisture (%)	Dry Density ($kg\ m^{-3}$)	Proctor (%)	Moisture (%)	Dry Density ($kg\ m^{-3}$)	Proctor (%)
5	12.8	1,886	96.7	14.8	1,716	88.0
6	15.2	1,797	91.7			
8	11.7	1,886	96.7	16.5	1,768	86.6
11	14.4	1,844	94.6	14.7	1,887	96.8
21	14.8	1,849	94.8	13.9	1,788	91.6
23	13.1	1,868	95.8	13.4	1,843	92.1
26	12.8	1,884	96.6	13.6	1,933	94.9
27	13.9	1,818	93.2	14.2	1,797	92.1
Design Value	13.5	1,950	100.0			

TABLE 24. AVERAGE MOISTURE DENSITY AND COMPACTION OF THE 30 CM THICK MICA CLAY LINERS

Lysimeter No.	Initial Values: Moisture (%)	Initial Values: Dry Density (kg m^{-3})	Initial Values: Proctor (%)	Final Values: Moisture (%)	Final Values: Dry Density (kg m^{-3})	Final Values: Proctor (%)
13	12.8	1,966	100.8	17.1	1,716	88.0
14	13.8	1,847	94.7	16.8	1,733	88.9
15	15.1	1,829	93.8	14.7	1,878	96.3
Design Value	13.5	1,950	100.0			

TABLE 25. AVERAGE MOISTURE DENSITY AND COMPACTION OF THE BENTONITIC CLAY LINERS

Lysimeter No.	Initial Values Moisture (%)	Initial Values Dry Density (kg m^{-3})	Initial Values Proctor (%)	Final Values Moisture (%)	Final Values Dry Density (kg m^{-3})	Final Values Proctor (%)
1	17.6	1,627	95.6	27.3	1,426	82.8
3	15.6	1,690	99.4	27.8	1,480	85.8
7	13.6	1,693	92.6	35.1	1,254	73.8
9	16.2	1,622	95.4	27.8	1,502	87.0
17	22.5	1,496	88.0	50.3	1,103	64.9
19	20.1	1,586	93.3	49.8	1,135	66.8
22	18.6	1,645	91.8	45.0	1,176	69.2
24	16.6	1,578	92.9	41.1	1,195	70.2
Design Value	16.5	1,700	100.0			

Comparison of Laboratory and Field Data

The conductivity of all three soils to water, pure acetone, pure xylene, waste acetone used in the field cells, and waste xylene used in the field cells was measured in the laboratory using fixed wall permeameters and a gradient of 181 (Appendix H). These values plus those measured in the field cells are presented in Table 26. Laboratory conductivities to pure acetone were 300, 3, and 43 times the water controls for the kaolinite, mica, and bentonite soils, respectively. Conductivities for waste acetone in the laboratory were much smaller, presumably due to the water content of the waste acetone used for the field work. Conductivities measured in the field cells containing waste acetone were almost one order of magnitude greater than the corresponding conductivities to water. The actual increases were 7.0, 6.7, and 9.7 times the water values for kaolinite, mica, and bentonite soils, respectively.

All three soils exhibited large (three to five orders of magnitude) conductivity increases when permeated with pure xylene in the laboratory permeameters. Conductivity increases for waste xylene in laboratory permeameters were between two and three orders of magnitude. In the field cells, the conductivities also increased about two orders of magnitude.

As noted previously, the xylene waste contained some paint pigments, which proved to be very useful in tracing movement through the soil. These pigments were found on the surface of cracks and natural soil peds in both the laboratory permeameters and field cells. Structural development was observed in the field for both acetone and xylene permeated kaolinite soil and to a lesser extent for the mica and bentonite soils.

Therefore, with water immiscible chemicals such as xylene, laboratory testing with fixed wall permeameters appears to reasonably predict field data. When dealing with water miscible chemicals, the conductivity appears to be highly dependent upon the exact conentration of the solution. Care does need to be taken to assure that the solution being tested is representative of the solution or leachate that will be in contact with the soil.

Quality control during construction of the field project was very high and, therefore. the field data reported herein may more closely resemble the laboratory data than in a large scale field installation. Daniel (1985) reported that field conductivities to water often are two orders of magnitude greater than laboratory design values. It is postulated that this difference is due to larger soil units (clods), poorer moisture control, and poorer quality control during field construction. Therefore, in large field installations the conductivity increases resulting from organic fluids may be much larger than those reported here.

TABLE 26. CONDUCTIVITIES OF THREE SOILS TO WATER, PURE CHEMICAL, AND WASTES IN BOTH LABORATORY AND FIELD CELLS

	Average Laboratory Conductivity to Water	Laboratory Conductivity to Pure Acetone at a Gradient of 181	Laboratory Conductivity to Waste Acetone at a Gradient of 181	Field Cell Conductivity to Waste Acetone at a Gradient of 7	Laboratory Conductivity to Pure Xylene at a Gradient of 181	Laboratory Conductivity to Waste Xylene at a Gradient of 181	Laboratory Conductivity to Waste Xylene at a Gradient of 7
Kaolinite	1.1×10^{-8}	3.7×10^{-6}	4.6×10^{-9}	7.7×10^{-8}	1.0×10^{-4}	6.1×10^{-6}	1.1×10^{-6}
Mica	1.5×10^{-8}	4.5×10^{-8}	2.4×10^{-8}	1.0×10^{-7}	2.2×10^{-5}	6.4×10^{-6}	2.1×10^{-6}
Bentonite	3.5×10^{-9}	1.5×10^{-7}	-	3.4×10^{-8}	1.5×10^{-4}	8.5×10^{-7}	1.3×10^{-7}

Suggestions for Improvement

While, in the opinion of the authors, this project was successful in terms that the objectives of the research were achieved, there always exist possibilities for improvement. While the authors see no need to repeat the research, the following is a list of such improvements:

1. The drain system in the field cells could be improved by using a larger diameter pipe or tube and by installing an air vent to the sand collection layer so that there would not be a possibility of pulling a vacuum on the bottom of the clay liner when sampling leachate.

2. The HDPE liners should have been water tested for leaks prior to use.

3. The concrete cells should have been water tested for leaks prior to use.

4. The field treatments should have been expanded to include three replications of water controls.

5. The bentonite soil mixture could be refined to yield a water permeability closer to 1 x 10-7.

6. A larger cover should have been used so that as the fill soil inside the cells subsided, leaks would not occur. This was primarily a difficulty with the acetone cells.

Gundle Samples

Eight samples of plastic were obtained from the Gundle Corporation. Each was 45 x 167 cm. Four of the samples were welded while the remaining four were unwelded. Details of where each sample was placed and what clay liner soil and chemicals were used are given in Table 27.

The samples were placed in a U shape about 5 cm above the clay liner and between the leaking barrels of waste. Sandy loam soil was then backfilled around each sample, the cell was capped, and the test fluid was introduced. After the fluid had penetrated the clay liner and the cell was to be dismantled, the cap was removed and the back fill was removed. When the plastic samples became accessible, it was carefully lifted out, examined, rinsed with tap water, and sent to Dr. Henry Haxo for further testing.

TABLE 27. PLACEMENT OF GUNDLE SAMPLES IN FIELD TEST CELLS

Samples	Soil	Cell No.	Chemical
30 mil HDPE			
1 sheet welded	Kaolinite	28	Acetone
1 sheet unwelded	Kaolinite	25	Acetone
40 mil HDPE alloy			
1 sheet welded	Mica	14	Acetone
1 sheet unwelded	Mica	15	Acetone
60 mil HDPE			
1 sheet welded	Kaolinite	18	Acetone
1 sheet unwelded	Mica	13	Acetone
60 mil HDPE alloy			
1 sheet welded	Kaolinite	2	Xylene
1 sheet unwelded	Kaolinite	4	Xylene

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APPENDIX A

CONDUCTIVITY OF COMPACTED SOILS TO SELECTED CONCENTRATIONS OF ACETONE, ETHANOL AND NaCl

Table A-1. Average Conductivity of Compacted Soil Containing Bentonitic Clay to 80:20 Solution of Acetone:Water (v/v) at a Gradient of 181.

Replication 1		Replication 2		Replication 3	
Pore Vol.	Ave K	Pore Vol.	Ave K	Pore Vol.	Ave K
.1	2.75E-6	.1	8.35E-6	<.1	1.34E-6
.2	3.43E-6	.2	1.53E-5	.1	9.87E-6
.3	2.78E-6	.3	1.85E-5	.2	9.29E-6
.4	2.46E-6	.4	1.92E-5	.3	7.97E-6
.5	2.14E-6	.5	1.97E-5	.4	7.27E-6
1.1	9.80E-7	.6	1.81E-5	.5	6.67E-6
1.2	7.57E-7	.7	1.86E-5	.6	5.30E-6
1.3	4.76E-7	.8	1.69E-5	.7	5.85E-6
		.9	1.77E-5	.8	3.41E-6
		1	1.85E-5	.9	6.58E-6
		1.1	1.87E-5	1	4.45E-6
		1.2	1.90E-5	1.1	4.30E-6
		1.3	1.83E-5		
		1.4	1.81E-5		
		1.5	1.78E-5		

Table A-2. Average Conductivity of Compacted Soil Containing Bentonitic Clay to 60:40 Solution of Acetone:Water (v/v) at a Gradient of 181.

Replication 1		Replication 2		Replication 3	
Pore Vol.	Ave K	Pore Vol.	Ave K	Pore Vol.	Ave K
<.1	1.66E-6	.1	3.56E-8	<.1	1.10E-6
.1	1.06E-5	.2	4.14E-8	.1	8.63E-6
.2	1.18E-5	.3	3.15E-8	.2	8.51E-6
.3	1.17E-5	.4	1.03E-8	.3	8.18E-6
.4	1.16E-5	.5	3.27E-8	.4	7.78E-6
.5	1.08E-5	.6	3.06E-8	.5	7.32E-6
.6	1.10E-5	.7	2.70E-8	.6	7.10E-6
.7	1.12E-5	.9	9.68E-9	.7	6.71E-6
.8	1.11E-5			.8	6.67E-6
.9	1.08E-5			.9	6.50E-6
1	9.52E-6			1	5.94E-6
1.1	1.00E-5			1.1	5.63E-6
1.2	9.64E-6			1.2	5.61E-6
1.3	9.68E-6			1.3	5.24E-6
1.5	1.09E-5			1.4	4.97E-6
				1.5	4.89E-6
				1.6	4.68E-6

Table A-3. Average Conductivity of Compacted Soil Containing Bentonitic Clay to 75:25 Solution of Ethanol:Water (v/v) at a Gradient of 191.

Replication 1		Replication 2		Replication 3	
Pore Vol.	Ave K	Pore Vol.	Ave K	Pore Vol.	Ave K
.1	3.85E-6	<.1	1.11E-6	.1	3.49E-6
.2	7.63E-6	.1	1.50E-5	.2	4.75E-6
.3	1.17E-5	.2	1.37E-5	.3	6.08E-6
.4	1.14E-5	.3	1.29E-5	.4	5.79E-6
.5	1.26E-5	.4	1.22E-5	.5	5.58E-6
.6	1.24E-5	.5	1.19E-5	.6	5.45E-6
.7	1.25E-5	.6	1.13E-5	.7	5.35E-6
.8	1.29E-5	.7	1.12E-5	.8	5.22E-6
.9	1.31E-5	.8	1.12E-5	.9	4.83E-6
1	1.20E-5	.9	1.13E-5	1	4.78E-6
1.1	1.33E-5	1	1.12E-5	1.1	4.49E-5
1.2	1.35E-5	1.1	1.13E-5	1.2	4.44E-6
1.3	1.40E-5	1.2	1.09E-5	1.3	4.39E-6
1.4	1.40E-5			1.4	4.04E-6
1.5	1.39E-5			1.9	3.66E-6

Table A-4. Average Conductivity of Compacted Soil Containing Bentonitic Clay to a 50:50 Solution of Ethanol:Water (v/v) at a Gradient of 181.

Replication 1		Replication 2		Replication 3	
Pore Vol.	Ave K	Pore Vol.	Ave K	Pore Vol.	Ave K
<.1	3.64E-6	<.1	9.49E-7	<.1	8.03E-7
.1	9.01E-6	.1	3.27E-6	.1	1.46E-6
.2	8.19E-6	.2	3.61E-6	.2	1.28E-6
.3	8.26E-6	.3	3.46E-6	.3	1.23E-6
.4	6.86E-6	.4	2.95E-6	.4	1.28E-6
.5	6.02E-6	.5	3.29E-6	.5	1.12E-6
.6	5.13E-6	.6	2.63E-6	.6	7.46E-7
.7	4.82E-6	.7	2.93E-6	.7	9.19E-7
.8	4.33E-6	.8	2.89E-6	.8	5.33E-7
.9	4.21E-6	.9	2.72E-6	.9	9.35E-7
1	4.38E-6	1	2.59E-6	1	1.16E-6
1.1	4.33E-6	1.2	2.48E-6	1.1	1.20E-6
1.2	4.27E-6	1.3	2.31E-6		
1.3	4.02E-6	1.4	2.16E-6		
1.4	3.69E-6	1.5	2.19E-6		
1.6	3.27E-6				

Table A-5. Average Laboratory Conductivity of Compacted Soil Containing Bentonitic Clay to 0.01 N $CaSO_4$ at a Gradient of 181.

Replication 1		Replication 2		Replication 3	
Pore Vol.	Ave K	Pore Vol.	Ave K	Pore Vol.	Ave K
.1	8.76E-7	.1	1.57E-6	.1	8.26E-6
.2	5.62E-7	.2	1.50E-6	.2	1.38E-5
.3	4.35E-7	.3	1.48E-6	.3	3.43E-6
.4	3.62E-7	.4	1.25E-6	.4	3.23E-6
.5	3.57E-7	.5	1.12E-6	.5	2.87E-6
1	2.10E-7	.6	9.22E-7	.6	2.67E-6
1.1	1.39E-7	.7	8.83E-7	.7	2.62E-6
1.2	1.23E-7			.8	2.65E-6
1.4	8.36E-8			1	2.28E-6
1.5	4.93E-8			1.2	2.53E-6
1.7	9.03E-8			1.3	2.66E-6
				1.4	2.49E-6
				1.5	2.51E-6

Table A-6. Average Conductivity of Compacted Soil Containing Bentonitic Clay to 0.5 N NaCl at a Gradient of 181.

Replication 1		Replication 2		Replication 3	
Pore Vol.	Ave K	Pore Vol.	Ave K	Pore Vol.	Ave K
.1	5.50E-6	.1	9.08E-7	<.1	6.03E-7
.2	8.86E-6	.2	3.80E-6	.1	1.10E-6
.3	8.61E-6	.3	3.07E-6	.3	8.99E-7
.4	8.30E-6	.4	2.81E-6	.6	9.06E-7
.5	8.32E-6	.5	1.69E-6	.7	1.43E-6
.6	8.26E-6	.6	2.09E-6	.8	9.08E-7
.7	7.89E-6	.7	2.04E-6	2	5.07E-7
.8	7.97E-6	.8	2.02E-6		
.9	7.86E-6	1.2	1.72E-6		
1	7.86E-6	1.5	1.67E-6		
1.1	7.92E-6	1.6	1.54E-6		
1.2	7.74E-6	1.7	1.54E-6		
1.3	7.74E-6				
1.4	7.59E-6				

Table A-7. Average Conductivity of Compacted Soil Containing Bentonitic Clay to 1.0 N NaCl at a Gradient of 181.

Replication 1		Replication 2		Replication 3	
Pore Vol.	Ave K	Pore Vol.	Ave K	Pore Vol.	Ave K
.1	5.34E-6	.1	3.06E-5	.1	3.15E-6
.2	7.46E-6	.2	2.75E-5	.2	2.86E-6
.3	7.00E-6	.4	2.41E-5	.3	2.88E-6
.4	6.54E-6	.5	2.31E-5	.5	2.68E-6
.5	5.93E-6	.7	2.32E-5	.7	2.60E-6
.6	9.56E-6	.8	2.29E-5	2.1	2.76E-6
.8	6.88E-6	.9	2.38E-5	2.2	1.50E-6
1.2	3.64E-6	1	2.38E-5		
1.7	4.10E-6	1.1	2.58E-5		
		1.3	2.64E-5		
		1.4	2.73E-5		
		1.6	2.75E-5		
		1.7	2.83E-5		
		1.9	2.87E-5		
		2	2.93E-5		

APPENDIX B

AVERAGE CONDUCTIVITY OF COMMERCIAL CLAY MIXTURES TO ACETONE AND PETROLEUM PRODUCTS

Table B-1. Average Conductivity of Compacted Soil Containing CCl to Acetone at a Gradient of 91.

Replication 1			Replication 2			Replication 3		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
	<.1	1.41E-5		<.1	3.85E-4		<.1	3.31E-5
	.1	8.30E-7		.1	8.41E-5		.1	3.67E-5
	.2	1.47E-5		.2	9.37E-5		.2	4.02E-5
	3	2.24E-5		.3	1.03E-4		.3	3.87E-5
	.4	1.71E-5		.4	1.03E-4		.4	3.72E-5
	.5	6.15E-5		.5	1.00E-4		.5	3.58E-5
	.6	2.87E-5		.6	1.03E-4		.6	3.43E-5
	.7	2.78E-5		.7	9.87E-5		.7	3.39E-5
	.8	2.59E-5		.8	2.11E-4		.8	3.19E-5
	.9	2.66E-5		.9	1.04E-4		.9	3.23E-5
	1	2.59E-5		1	1.09E-4		1	3.13E-5
	1.1	2.62E-5					1.1	3.10E-5
	1.2	2.51E-5						
	1.3	2.28E-5						

Table B-2. Average Conductivity of Compacted Soil Containing CC2 to Acetone at a Gradient of 91.

Replication 1			Replication 2			Replication 3		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
	<.1	2.35E-6		.7	3.31E-7		<.1	1.75E-7
	.1	3.54E-6		.8	1.70E-7		1	6.39E-7
	.2	3.43E-6		.9	3.82E-7		2.1	4.09E-7
	.3	3.25E-6		1.2	3.15E-7		2.5	2.25E-7
	.4	3.28E-6		1.5	2.51E-7		3.3	3.01E-7
	.5	2.99E-6		1.8	1.69E-7		3.8	4.77E-7
	.6	2.61E-6		2.2	8.04E-8		3.9	3.09E-7
	.7	2.21E-6		2.3	6.14E-8		4.1	2.85E-8
	.8	2.05E-6		2.5	9.73E-8		4.2	1.57E-6
	.9	2.15E-6		2.6	5.95E-7		5.4	7.57E-7
	1	2.12E-6		3.1	3.71E-7		5.5	1.26E-6
				3.3	1.50E-7		6.5	1.08E-6
				3.6	2.25E-7		6.8	8.45E-7
				4.4	1.86E-7		6.9	7.91E-7
				4.6	1.53E-7		8.9	1.43E-6

Table B-3. Average Conductivity of Compacted Soil Containing CC3 to Acetone at a Gradient of 91.

Replication 1			Replication 2			Replication 3		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
Acetone	<.1	7.25E-9	Acetone	<.1	3.14E-9			
	.1	4.68E-9		.1	7.06E-9			
	.2	6.23E-9		.2	7.81E-9			
	.3	8.56E-9		.3	5.98E-9			
	.4	8.81E-9		.5	1.46E-8			
	.5	1.02 -8		.7	2.06E-8			
	.6	1.54E-8		.8	1.09E-8			
	1.4	9.30E-8		1.1	4.56E-8			
	1.5	8.17E-7		1.2	4.93E-8			
	1.8	1.08E-6		1.4	5.48E-8			
	2.1	1.35E-6		2.3	6.29E-8			
				2.4	5.51E-8			
				2.6	8.00E-8			

Table B-4. Average Conductivity of Compacted Soil Containing CCl to Xylene at a Gradient of 91.

Replication 1			Replication 2			Replication 3		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
	<.1	1.79E-4		<.1	1.79E-4		<.1	3.80E-6
	.1	2.28E-4		.1	2.05E-4		.1	3.59E-6
	.2	2.31E-4		.2	2.39E-4		.2	3.82E-6
	.3	1.79E-4		.3	2.05E-4		.3	7.48E-6
	.4	1.99E-4		.4	2.56E-4		.4	1.09E-5
	.5	2.48E-4		.5	2.16E-4		.5	1.23E-5
	.6	2.13E-4		.6	2.73E-4		.6	9.58E-6
	.7	2.45E-4		.7	2.65E-4		.8	1.02E-5
	.8	2.48E-4		.8	2.48E-4		.9	1.23E-5
	.9	2.73E-4		.9	2.50E-4		1	9.63E-6
	1	2.45E-4		1	2.56E-4		1.1	1.14E-5
	1.1	2.65E-4		1.1	2.90E-4			
	1.2	2.82E-4		1.2	3.07E-4			
	1.3	2.73E-4						

Table B-5. Average Conductivity of Compacted Soil Containing CC2 to Xylene at a Gradient of 91.

Replication 1			Replication 2			Replication 3		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
	0.40	.001095		<.1	1.14E-5		0.50	7.12E-4
	1.00	.001588		.1	9.01E-6		1.00	6.98E-4
	1.90	.002190		.2	7.99E-6		1.50	7.26E-4
	3.00	.002601		.3	8.10E-6		2.00	6.84E-4
	3.20	5.48E-4		.4	7.15E-6		2.50	7.26E-4
	3.80	.001314		.5	6.73E-6		3.00	7.26E-4
	4.50	.001780		.6	6.16E-6			
	5.5	.002409		.7	5.86E-6			
	6.2	5.93E-4		.8	6.01E-6			
	6.9	5.93E-4		.9	5.93E-6			
	7.7	6.02E-4		1	5.93E-6			

Table B-6. Average Conductivity of Compacted Soil Containing CC3 to Xylene at a Gradient of 91.

Replication 1			Replication 2			Replication 3		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
Xylene	<.1	3.60E-5	Xylene	.1	1.14E-4			
	.2	6.84E-5		.2	1.38E-4			
	.3	6.39E-5		.3	1.34E-4			
	.4	6.16E-5		.4	1.37E-4			
	.5	7.30E-5		.5	1.38E-4			
	.6	5.93E-5		.6	1.14E-4			
	.7	7.71E-5		.7	1.30E-4			
	.8	7.28E-5		.8	1.38E-4			
	.9	6.17E-5		.9	1.34E-4			
			0.01 N $CaSO_4$					
				<.1	2.13E-9			
				.1	1.33E-8			
				.2	1.45E-8			
				.3	8.55E-9			

Table B-7. Average Conductivity of Compacted Soil Containing CCl to Gasoline at a Gradient of 91.

Replication 1			Replication 2			Replication 3		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
	<.1	2.66E-4		<.1	6.94E-5		<.1	1.37E-4
	.1	3.39E-4		.1	1.29E-4		.1	1.55E-4
	.2	3.11E-4		.2	1.21E-4		.2	1.42E-4
	.3	2.96E-4		.3	1.27E-4		.3	1.08E-4
	.4	3.16E-4		.4	1.28E-4		.4	9.58E-5
	.5	3.16E-4		.5	1.26E-4		.5	9.49E-5
	.6	3.05E-4		.6	1.27E-4		.6	9.35E-5
	.7	3.14E-4		.7	1.22E-4		.7	9.07E-5
	.8	3.10E-4					.8	9.49E-5
	.9	2.83E-4					.9	9.13E-5
	1	4.54E-4						

Table B-8. Average Conductivity of Compacted Soil Containing CC2 to Gasoline at a Gradient of 91.

Replication 1			Replication 2			Replication 3		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
	<.1	1.25E-4		<.1	4.38E-6		<.1	4.68E-4
	.1	1.48E-4		.1	4.93E-6		.1	4.31E-4
	.3	1.48E-4		.2	5.25E-6		.2	1.53E-4
	.4	1.48E-4		.3	5.11E-6		.3	1.47E-4
	.5	1.57E-4		.4	5.29E-6		.4	1.48E-4
	.6	1.34E-4		.5	5.38E-6		.5	1.51E-4
	.7	1.57E-4		.6	5.34E-6		.6	1.50E-4
	.8	1.34E-4		.7	5.38E-6		.7	1.47E-4
	.9	1.34E-4		.8	5.34E-6		.8	1.49E-4
	1	9.13E-5		.9	5.43E-6		.9	1.52E-4
	1.1	9.13E-5		1	5.48E-6		1	1.51E-4
				1.1	5.29E-6		1.1	1.44E-4
				1.2	5.36E-6		1.2	1.40E-4
				1.3	5.43E-6		1.3	1.49E-4
				1.4	5.43E-6		1.4	1.44E-4
				1.5	5.66E-6		1.5	1.39E-4
				1.6	4.97E-6		1.6	1.42E-4

Table B-9. Average Conductivity of Compacted Soil Containing CC3 to Gasoline at a Gradient of 91.

Replication 1			Replication 2			Replication 3		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
	<.1	2.17E-6		<.1	1.49E-6		<.1	1.21E-4
	.1	3.65E-5		.1	2.19E-6		.2	7.04E-5
	.2	3.38E-5		.2	2.04E-6		.3	1.43E-4
	.3	3.53E-5		.3	2.00E-6		.4	1.21E-4
	.4	2.93E-5		.6	1.62E-6		.5	1.36E-4
	.5	2.91E-5		.7	1.39E-6		.6	1.39E-4
	.6	2.57E-5		.8	1.81E-6		.7	1.21E-4
	.7	2.20E-5		.9	1.10E-6		.8	1.43E-4
	.8	2.51E-5		1.9	1.14E-6		.9	1.27E-4
	.9	2.46E-5					1	1.36E-4
							1.1	1.24E-4
							1.2	1.36E-4
							1.3	1.33E-4

Table B-10. Average Conductivity of Compacted Soil Containing CCl to Kerosine at a Gradient of 91.

Replication 1			Replication 2			Replication 3		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
	<.1	1.25E-4		<.1	1.62E-4		<.1	1.20E-4
	.1	1.41E-4		.1	1.63E-4		.1	1.15E-4
	.2	1.52E-4		.2	1.67E-4		.2	1.18E-4
	.3	1.56E-4		.3	1.68E-4		.3	1.16E-4
	.4	1.55E-4		.4	1.61E-4		.4	1.16E-4
	.5	1.60E-4		.5	1.67E-4		.5	1.15E-4
	.6	1.68E-4		.6	1.69E-4		.6	1.15E-4
	.7	1.69E-4		.7	1.66E-4		.7	1.11E-4
	.8	1.68E-4		.8	1.77E-4		.8	1.16E-4
	.9	1.77E-4		.9	1.71E-4		.9	1.16E-4
	1	1.80E-4		1	1.71E-4		1	1.15E-4
				1.1	1.67E-4			

Table B-11. Average Conductivity of Compacted Soil Containing CC2 to Kerosine at a Gradient of 91.

Replication 1			Replication 2			Replication 3		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
	<.1	9.95E-5		<.1	3.80E-5		<.1	2.35E-5
	.1	1.23E-4		.1	9.61E-5		.1	2.95E-5
	.2	1.27E-4		.2	9.98E-5		.2	3.45E-5
	.3	1.21E-4		.3	1.00E-4		.3	3.47E-5
	.4	1.31E-4		.4	1.11E-4		.4	3.54E-5
	.5	1.30E-4		.5	1.05E-4		.5	3.63E-5
	.6	1.32E-4		.6	9.92E-5		.6	3.83E-5
	.7	1.31E-4		.7	1.02E-4		.7	3.71E-5
	.8	1.30E-4		.8	1.01E-4		.8	3.83E-5
	.9	1.29E-4		.9	1.03E-4		.9	3.92E-5
	1	1.31E-4		1	1.05E-4		1	3.88E-5
				1.1	1.05E-4		1.1	3.92E-5
				1.2	1.03E-4		1.2	3.89E-5
				1.3	1.03E-4			
				1.4	1.04E-4			
				1.5	1.02E-4			

Table B-12. Average Conductivity of Compacted Soil Containing CC3 to Kerosine at a Gradient of 91.

Replication 1			Replication 2			Replication 3		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
				<.1	1.14E-5		<.1	3.91E-7
	.1	4.56E-5		.1	5.02E-5		.1	4.91E-7
	.2	5.93E-5		.2	5.86E-5		.2	5.13E-7
	.3	7.76E-5		.3	7.76E-5		.3	5.36E-7
	.4	9.58E-5		.4	6.62E-5		.4	3.70E-7
	.6	5.48E-5		.5	7.30E-5		.7	4.42E-7
	.7	1.51E-4		.6	7.30E-5		.8	2.47E-7
	.8	5.93E-5		.7	7.07E-5		.9	3.76E-7
	.9	7.53E-5		.8	9.13E-5		1	4.11E-6
	1	9.13E-5		.9	5.93E-5		1.2	8.47E-6
	1.1	7.76E-5		1	7.53E-5		1.4	3.56E-6
	1.2	7.76E-5		1.1	7.76E-5		1.5	5.70E-6
	1.3	7.99E-5		1.2	6.84E-5		1.6	1.83E-5
	1.4	9.13E-5		1.3	7.07E-5		1.7	1.71E-5
	1.5	7.76E-5		1.4	7.76E-5		1.8	1.92E-5
	1.6	9.58E-5		1.5	6.84E-5		1.9	1.69E-5
	1.7	8.44E-5		1.6	8.21E-5		2	1.02E-5
	1.8	6.84E-5		1.7	7.30E-5		2.1	1.54E-5
	1.9	8.21E-5		1.8	8.67E-5		2.2	1.48E-5
	2	7.76E-5		1.9	7.30E-5		2.3	1.56E-5
	2.1	1.00E-4		2	7.30E-5		2.4	1.37E-5
	2.2	1.14E-4		2.1	1.14E-4		2.5	1.39E-5
	2.3	5.70E-5		2.2	9.13E-5		2.6	1.37E-5
							2.7	1.38E-5
							2.8	1.33E-5
							2.9	1.41E-5
							3	1.23E-5
							3.1	1.28E-5
							3.2	1.30E-5

Table B-13. Average Conductivity of Compacted Soil Containing CCl to Diesel Fuel at a Gradient of 91.

Replication 1			Replication 2			Replication 3		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
	<.1	8.52E-5		<.1	3.26E-5		<.1	2.28E-5
	.1	8.94E-5		.1	3.26E-5		.1	3.17E-5
	.2	9.08E-5		.2	3.18E-5		.2	3.08E-5
	.3	9.00E-5		.3	3.26E-5		.3	3.16E-5
	.4	9.55E-5		.4	3.79E-5		.4	2.86E-5
	.5	9.72E-5		.5	4.03E-5		.5	3.07E-5
	.6	9.67E-5		.6	4.18E-5		.6	3.11E-5
	.7	9.98E-5		.7	4.23E-5		.7	3.18E-5
	.8	9.73E-5		.8	4.36E-5		.8	2.99E-5
	.9	1.00E-4		.9	4.38E-5		.9	3.03E-5
				1	4.46E-5		1	3.03E-5
				1.1	4.50E-5			
				1.2	4.59E-5			
				1.3	4.56E-5			

Table B-14. Average Conductivity of Compacted Soil Containing CC2 to Diesel Fuel at a Gradient of 91.

Replication 1			Replication 2			Replication 3		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
	<.1	1.78E-5		<.1	1.08E-5		<.1	3.09E-5
	.1	2.28E-5		.1	1.36E-5		.1	4.75E-5
	.2	2.28E-5		.2	1.64E-5		.2	4.72E-5
	.3	2.36E-5		.3	1.62E-5		.3	4.75E-5
	.4	2.37E-5		.4	1.69E-5		.4	4.90E-5
	.5	2.43E-5		.5	1.78E-5		.5	4.56E-5
	.6	2.37E-5		.6	1.79E-5		.6	4.84E-5
	.7	2.43E-5		.7	1.78E-5		.7	4.78E-5
	.8	2.42E-5		.8	1.78E-5		.8	4.84E-5
	.9	2.49E-5		.9	1.78E-5		.9	4.72E-5
	1	2.43E-5		1	1.72E-5		1	4.90E-5
	1.1	2.51E-5						

Table B-15. Average Conductivity of Compacted Soil Containing CC3 to Diesel Fuel at a Gradient of 91.

Replication 1			Replication 2			Replication 3		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
	1	2.67E-7		.7	4.09E-7		<.1	1.24E-7
	1.2	4.78E-7		.8	4.68E-7		.4	5.67E-7
	1.3	4.17E-7		.9	3.71E-7		.6	6.23E-7
	1.7	2.70E-7		1	3.06E-7		1.3	5.97E-7
	1.8	2.13E-7		1.4	2.25E-7		2.3	5.90E-6
	2	1.59E-7		1.6	1.74E-7		2.5	5.73E-7
	2.3	1.32E-7		1.9	1.32E-7		2.7	5.47E-7
							3.6	5.21E-7
							3.9	4.86E-7

Table B-16. Average Conductivity of Compacted Soil Containing CCl to Motor Oil at a Gradient of 91.

Replication 1			Replication 2			Replication 3		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
	<.1	3.23E-6		<.1	3.04E-6		<.1	3.96E-6
	.1	4.75E-6		.1	4.35E-6		.1	5.54E-6
	.2	5.07E-6		.2	5.07E-6		.2	5.13E-6
	.3	5.89E-6		.3	4.94E-6		.3	5.70E-6
	.4	4.73E-6		.4	4.99E-6		.4	5.70E-6
	.5	4.94E-6		.5	5.13E-6		.5	5.70E-6
	.6	5.42E-6		.6	5.32E-6		.6	6.34E-6
	.7	5.70E-6		.7	5.32E-6		.7	6.65E-6
	.8	5.96E-6		.8	5.32E-6		.8	5.70E-6
	.9	5.96E-6		.9	5.32E-6		.9	6.59E-6
	1	5.13E-6		1	5.70E-6		1	5.96E-6
	1.1	5.70E-6		1.1	5.32E-6		1.1	6.65E-6
	1.2	5.96E-6		1.2	5.32E-6		1.2	6.97E-6
	1.3	5.70E-6		1.3	6.11E-6		1.3	6.34E-6
	1.4	7.06E-6		1.4	5.70E-6		1.4	6.65E-6
	1.5	6.08E-6		1.5	5.70E-6		1.5	6.97E-6
	1.6	6.11E-6		1.6	4.68E-6		1.6	7.61E-6
	1.7	5.70E-6		1.7	6.34E-6		1.7	6.51E-6
	1.8	6.61E-6		1.8	5.32E-6		1.8	7.02E-6
	1.9	6.34E-6					1.9	6.65E-6
	2	6.65E-6					2	1.14E-5
	2.1	5.70E-6					2.1	7.31E-6
							2.2	7.61E-6
							2.3	7.61E-6
							2.4	9.13E-6

Table B-17. Average Conductivity of Compacted Soil Containing CC2 to Motor Oil at a Gradient of 91.

Replication 1			Replication 2			Replication 3		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
	<.1	1.08E-6		<.1	3.02E-7		<.1	4.18E-7
	.1	1.76E-6		.1	6.69E-7		.1	8.61E-7
	.2	1.96E-6		.2	7.07E-7		.2	1.68E-6
	.3	2.02E-6		.3	8.16E-7		.3	1.96E-6
	.4	2.30E-6		.4	8.65E-7		.4	1.19E-6
	.5	2.72E-6		.5	1.11E-6		.5	1.30E-6
	.6	2.85E-6		.6	1.20E-6		.6	1.38E-6
	.7	2.87E-6		.7	1.17E-6		.7	1.37E-6
	.8	2.54E-6		.8	1.23E-6		.8	1.41E-6
	.9	3.06E-6		.9	9.51E-7		.9	1.98E-6
	1	2.99E-6		1	1.56E-6		1	1.77E-6
	1.1	3.12E-6		1.1	1.64E-6		1.1	1.73E-6
	1.2	3.26E-6		1.2	9.30E-7		1.2	1.74E-6
	1.3	3.26E-6		1.3	1.56E-6		1.3	1.80E-6
	1.4	3.62E-6		1.4	1.56E-6		1.4	1.98E-6
	1.5	3.80E-6		1.5	1.86E-6		1.5	1.58E-6
	1.6	3.53E-6		1.6	2.17E-6		1.6	2.23E-6
	1.7	3.80E-6		1.7	1.71E-6		1.7	2.21E-6
	1.8	2.83E-6		1.8	1.63E-6		1.8	1.92E-6
	1.9	4.06E-6		1.9	1.73E-6		1.9	2.14E-6
	2	3.44E-6		2	1.43E-6		2	2.14E-6
	2.1	5.32E-6					2.1	2.24E-6
							2.2	2.54E-6
							2.3	2.45E-6

Table B-18. Average Conductivity of Compacted Soil Containing CC3 to Motor Oil at a Gradient of 91.

Replication 1			Replication 2			Replication 3		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
	.4	3.54E-7		.5	2.08E-7		<.1	1.38E-8
	.5	4.73E-7		2	5.37E-7		.5	8.95E-8
	.7	5.36E-7		2.3	8 07E-7		.6	6.48E-8
	1	6.27E-7		2.5	1.14E-6		.8	1.49E-7
	2	1.28E-6		2.7	1.16E-6		1	1.38E-7
	2.1	7.65E-7		3.2	1.71E-6		1.5	2.15E-7
	2.2	1.01E-6						
	2.4	9.65E-7						
	2.5	1.21E-6						
	3	1.02E-6						
	5.6	1.56E-6						

APPENDIX C

AVERAGE CONDUCTIVITY DATA FROM LABORATORY PERMEAMETERS

Table C-1. Average Conductivity of Compacted Soil Containing Bentonitic Clay to 0.01 N $CaSO_4$ at a Gradient of 181.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
0.01 N $CaSO_4$	<.1	2.56E-9			
	.1	4.53E-9			
	.2	4.27E-9			
	.3	7.31E-9			
	.4	4.43E-9			
	.5	3.65E-9			
	.6	4.06E-9			
	.8	3.47E-9			
	.9	2.43E-9			
	1	2.49E-9			

Table C-2. Average Conductivity of Compacted Soil Containing Micaceous Clay to 0.01 N $CaSO_4$ at a Gradient of 31.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
0.01 N $CaSO_4$	<.1	1.30E-8			
	.1	1.62E-8			
	.2	1.60E-8			
	.3	1.55E-8			
	.4	1.51E-8			
	.5	1.35E-8			
	.6	1.24E-8			
	.7	1.07E-8			
	.8	1.48E-8			
	.9	1.37E-8			
	1	1.63E-8			
	1.1	2.84E-8			

Table C-3. Average Conductivity of Compacted Soil Containing Bentonitic Clay to 0.01 N $CaSO_4$ Followed by Acetone at a Gradient of 91.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
0.01 N $CaSO_4$	<.1	4.77E-9	0.01 N $CaSO_4$	<.1	1.03E-8
	.1	5.41E-9		.1	4.33E-9
	.2	7.46E-9		.2	8.29E-9
	.3	1.28E-8		.3	8.71E-9
	.4	1.27E-8		.4	8.13E-9
	.5	1.30E-8		.5	7.33E-9
	.6	1.34E-8		.6	5.99E-9
	.7	1.01E-8		.7	4.38E-9
	.8	6.32E-9		.8	1.02E-9
	.9	1.01E-8		9	5.9E-10
	1	7.17E-9		1	5.2E-10
Acetone			Acetone		
	<.1	7.02E-9		<.1	6.6E-10
	.1	6.16E-9		.1	5.16E-9
	.2	3.41E-9		.2	3.72E-9
	.3	2.69E-9		.3	3.79E-9
	.4	1.95E-9		.4	2.69E-9
	.5	3.01E-9		.5	2.97E-9
	.6	2.65E-9		.6	2.58E-9
	.7	2.97E-9		.7	3.28E-9
	.8	2.28E-9		.8	3.80E-9
	.9	3.10E-9		.9	3.44E-9
	1	3.06E-9		1	3.63E-9
	1.1	4.00E-9		1.1	4.30E-9
	1.2	5.48E-9		1.2	5.04E-9
	1.3	6.08E-9		1.3	1.36E-8
	1.4	6.08E-9		1.5	4.00E-8
	1.5	9.78E-9		1.6	2.40E-8
	1.6	6.40E-9		1.7	2.17E-8
	1.7	7.87E-9		1.8	2.44E-8
	1.8	1.06E-8		1.9	9.09E-9
	1.9	1.74E-8			
	2.1	2.59E-8			
	2.3	2.45E-8			
	2.6	3.12E-8			
	3.2	4.94E-7			
	3.3	1.10E-6			
	3.4	1.08E-6			
	3.5	1.03E-6			
	3.6	1.15E-6			
	3.7	1.13E-6			
	5	6.86E-7			

Table C-4. Average Conductivity of Compacted Soil Containing Bentonitic Clay to 0.01 N $CaSO_4$ Followed by Acetone at a Gradient of 181.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
0.01 N $CaSO_4$	<.1	4.83E-9			
	.1	2.10E-9			
	.2	2.01E-9			
	.3	4.38E-9			
	.4	3.89E-9			
	.5	5.26E-9			
	.6	4.73E-9			
	.7	3.07E-9			
	.8	3.66E-9			
	.9	5.16E-9			
	1	3.15E-9			
	1.1	4.87E-9			
	1.2	4.46E-9			
	1.3	4.02E-9			
	1.4	1.44901			
	1.5	1.88E-9			
	1.6	1.74E-9			
	1.7	1.91E-9			
Acetone	<.1	2.39E-9			
	.1	1.92E-9			
	.2	2.51E-9			
	.3	2.38E-9			
	.4	2.46E-9			
	.5	2.17E-9			
	.6	2.41E-9			
	.7	5.23E-9			
	.8	5.15E-9			
	.9	5.44E-9			
	1	8.17E-9			
	1.2	9.82E-9			
	1.3	1.25E-8			
	1.6	1.64E-8			
	1.7	1.88E-8			
	1.8	2.06E-8			

Table C-4 continued.

Fluid	Replication 1 Pore Vol.	Ave K
	1.9	1.92E-8
	2.1	1.96E-8
	2.2	2.07E-8
	2.3	1.85E-8
	2.4	2.27E-8
	3	2.47E-8
	3.2	4.33E-8
	3.4	4.77E-8
	4	5.34E-8
	4.2	5.32E-8
	4.4	5.43E-8
	5.4	4.26E-8

Table C-5. Average Conductivity of Compacted Soil Containing Bentonitic Clay to 0.01 N $CaSO_4$ Followed by Acetone at a Gradient of 272.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
0.01 N $CaSO_4$	<.1	2.55E-9	0.01 N $CaSO_4$	<.1	1.82E-9
	.1	2.42E-9		.1	1.11E-8
	.2	1.94E-9		.2	1.03E-8
	.3	1.66E-9		.3	1.02E-8
	.4	1.33E-9		.4	1.09E-8
	.5	1.30E-9		.5	7.63E-9
	.6	1.06E-9		.6	6.44E-9
	.7	9.8E-10		.7	3.66E-9
	.8	1.51E-9		.8	3.24E-9
	.9	2.04E-9		.9	2.77E-9
	1	3.21E-9		1	2.54E-9
	1.1	3.82E-9	Acetone		
Acetone				<.1	3.29E-9
	<.1	2.42E-9		.1	1.64E-9
	.1	2.53E-9		.2	7.5E-10
	.2	2.02E-9		.3	3.1E-10
	.3	1.46E-9		.4	2.8E-10
	.4	1.3[illegible]-9		.5	6.2E-10
	.5	1.65E-9		.6	8.9E-10
	.6	1.54E-9		.7	1.85E-9
	.7	2.06E-9		.8	3.08E-9
	.8	3.12E-9		1.6	1.33E-8
	.9	4.25E-9		2	3.43E-8
	1	3.61E-9			
	1.2	3.74E-9			
	1.4	8.72E-9			
	1.5	1.14E-8			
	1.7	8.98E-9			
	1.8	6.95E-9			
	1.9	1.17E-8			
	2	1.18E-8			
	2.1	1.04E-8			
	2.2	1.47E-9			
	2.4	3.09E-8			
	2.8	7.91E-8			
	3.7	1.60E-7			

Table C-6. Average Conductivity of Compacted Soil Containing Kaolinitic Clay to 0.01 N $CaSO_4$ Followed by Acetone at a Gradient of 31.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
0.01 N $CaSO_4$	<.1	7.10E-9	0.01 N $CaSO_4$	<.1	8.14E-9
	.1	1.03E-8		.1	9.53E-9
	.2	1.01E-8		.2	7.79E-9
	.3	6.71E-9		.3	9.05E-9
	.4	1.01E-8		.4	1.02E-8
	.5	9.65E-9		.5	1.13E-8
	.6	1.05E-8		.6	1.17E-8
	.7	1.26E-8		.7	1.27E-8
	.8	1.53E-8		.8	1.24E-8
	.9	1.43E-8		.9	1.22E-8
	.1	1.71E-8	Acetone		
Acetone				<.1	1.21E-8
	<.1	1.90E-8		.1	1.12E-8
	.1	1.05E-8		.2	9.31E-9
	.2	7.34E-9		.3	6.51E-9
	.3	5.78E-9		.4	1.09E-8
	.4	8.63E-9		.5	2.27E-8
	.5	6.97E-9		.6	9.22E-9
	.6	7.07E-9		.7	1.81E-8
	.7	9.42E-9		.8	4.99E-8
	.8	1.20E-8		.9	5.67E-8
	.9	1.07E-8		1	6.14E-8
	1	1.32E-8		1.1	6.01E-8
	1.1	1.34E-8		1.3	7.52E-8
	1.2	1.56E-8		1.4	1.04E-7
	1.3	2.09E-8		1.5	1.05E-7
	1.4	1.90E-8		1.6	8.37E-9
	1.5	5.23E-8		1.8	9.34E-8
	1.6	5.62E-8		1.9	1.37E-7
	1.7	4.19E-8		2.1	1.33E-7
	1.8	1.03E-7		2.2	1.38E-7
	1.9	5.15E-8		2.3	1.14E-7
	2	4.72E-8		2.5	1.72E-7

Table C-6 continued.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
	2.1	9.99E-9		2.8	2.19E-6
	2.2	3.84E-8		3	2.88E-6
	2.3	5.49E-8		3.6	2.06E-6
	2.4	7.94E-8	0.01 N $CaSO_4$		
	3.5	3.02E-7		.2	1.05E-6
	3.6	1.10E-4		.3	1.57E-7
	3.7	1.07E-4		.4	3.91E-8
	3.8	1.05E-4		.5	2.08E-8
	3.9	9.37E-5		.6	1.42E-8
	4	9.13E-5		.7	2.27E-8
	4.1	9.20E-5			
	4.2	8.70E-5			
	4.3	8.36E-5			
	4.4	8.30E-5			
	4.5	8.36E-5			
	4.6	8.03E-5			

Table C-7. Average Conductivity of Compacted Soil Containing Kaolinitic Clay to 0.01 N $CaSO_4$ Followed by Acetone at a Gradient of 91.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
0.01 N $CaSO_4$			0.01 N $CaSO_4$	<.1	9.31E-9
	.1	1.33E-8		.1	1.61E-8
	.2	1.66E-8		.2	2.05E-8
	.3	1.54E-8		.3	6.32E-8
	.4	1.54E-8		.6	4.79E-8
	.5	1.59E-8		.9	1.24E-7
	.6	1.06E-8		1.5	1.05E-7
	.7	9.20E-9		1.6	1.67E-8
	.8	9.60E-9		1.7	3.62E-9
	.9	8.41E-9		1.8	5.60E-9
Acetone				1.9	6.36E-9
	<.1	6.97E-9		2	6.11E-9
	.1	7.44E-9	Acetone		
	.2	6.78E-9		<.1	6.27E-9
	.3	3.78E-9		.1	5.60E-9
	.4	3.55E-9		.2	3.58E-9
	.5	2.90E-9		.3	2.81E-9
	.6	3.57E-9		.4	1.99E-9
	.7	5.80E-9		.5	1.13E-8
	.8	1.02E-8		.6	4.23E-8
	2.3	6.12E [illegible]		.7	8.4E-8
	2.5	1.03E-6		.9	1.06E-7
				1.3	1.88E-7
				1.4	1.95E-7
				1.8	2.73E-7

Table C-8. Average Conductivity of Compacted Soil Containing Kaolinitic Clay to 0.01 N $CaSO_4$ Followed by Acetone at a Gradient of 181.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
0.01 N $CaSO_4$	<.1	7.82E-9	0.01 N $CaSO_4$	<.1	6.76E-9
	.1	9.94E-9		.1	5.14E-9
	.6	3.65E-8		.2	4.65E-9
	.9	5.86E-8		.3	4.48E-9
	1	8.82E-9		.4	4.38E-9
	1.1	4.22E-9		.5	4.13E-9
	1.2	4.35E-9		.6	3.83E-9
	1.3	4.39E-9	Acetone		
	1.4	4.88E-9		<.1	3.70E-9
	1.5	4.74E-9		.1	5.35E-9
Acetone				.2	4.78E-9
	<.1	3.28E-9		.3	3.86E-9
	.1	5.70E-9		.4	2.51E-9
	.2	4.13E-9		.5	2.88E-9
	.3	3.12E-9		.6	2.80E-9
	[illegible]	3.65E-9		.7	1.37E-7
	.5	3.12E-9		.8	1.57E-7
	.6	3.28E-9		1.2	1.29E-7
	.7	1.67E-8		1.3	9.21E-8
	1.1	5.22E-8		1.4	2.06E-7
	1.7	1.25E-7		1.8	1.29E-7
	1.8	8.72E-8		2	6.93E-8
	2.2	1.11E-6		2.4	5.09E-7
	2.5	1.12E-6		2.8	3.52E-7
	2.8	1.13E-6		3.8	3.01E-7
				4.1	3.56E-7
				5	6.34E-7

Table C-9. Average Conductivity of Compacted Soil Containing Micaceous Clay to 0.01 N $CaSO_4$ Followed by Acetone at a Gradient of 31.

Replication 1

Fluid	Pore Vol.	Ave K
0.01 N $CaSO_4$	<.1	1.30E-8
	.1	1.78E-8
	.2	1.96E-8
	.3	1.79E-8
	.4	1.78E-8
	.5	1.73E-8
	.6	1.79E-8
	.7	1.31E-8
	.8	1.67E-8
	.9	1.77E-8
	1	1.51E-8
	1.1	2.28E-8
	1.2	2.88E-8
Acetone		
	<.1	1.26E-8
	.1	1.50E-8
	.2	2.12E-8
	.3	1.07E-8
	.4	4.96E-9
	.5	1.32E-8
	.6	1.13E-8
	.7	9.46E-9
	.8	7.18E-9
	.9	6.29E-9
	1	8.10E-9
	1.1	9.93E-9
	1.2	1.11E-8
	1.3	1.24E-8
	1.4	2.01E-8
	1.5	7.25E-8
	2.2	9.24E-7
	2.3	1.06E-6

Replication 2

Fluid	Pore Vol.	Ave K
0.01 N $CaSO_4$	<.1	4.92E-7
	.1	7.04E-9
	.2	6.51E-9
	.3	6.91E-9
	.4	8.69E-9
	.5	8.13E-9
	.6	9.03E-9
	.7	9.51E-9
	.8	1.05E-8
	.9	1.04E-8
Acetone		
	<.1	9.69E-9
	.1	6.76E-9
	.2	4.47E-9
	.3	2.14E-9
	.4	7.12E-9
	.5	1.04E-8
	.6	1.23E-8
	.7	9.87E-9
	.8	2.53E-9
	.9	1.17E-8
	1	9.07E-9
	1.1	2.91E-8
	1.2	2.47E-8
	1.4	2.21E-8
	1.7	2.68E-8
	1.8	1.87E-8
	1.9	2.31E-8
	2	1.63E-8
	2.2	2.06E-8
	2.3	8.91E-9
	2.4	6.75E-8
	2.5	2.99E-8
	2.6	2.74E-8
	2.7	2.86E-8

Table C-9 continued.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
				2.8	2.46E-8
				3.7	1.87E-9
				3.9	2.66E-9
				4.1	2.62E-8
				4.2	2.30E-8
				4.3	2.32E-8
				4.4	2.22E-8
				4.5	1.72E-8
				4.6	1.75E-8
				4.7	3.84E-8
				4.8	3.74E-8
				5	4.21E-8
				5.1	3.67E-8
				5.3	3.92E-8
				5.6	5.20E-8
				5.7	5.63E-8
				5.8	7.06E-8
				5.9	7.14E-8
				6	7.63E-8
				6.1	6.21E-8
				6.2	8.76E-9

Table C-10. Average Conductivity of Compacted Soil Containing Micaceous Clay to 0.01 N $CaSO_4$ Followed by Acetone at a Gradient of 91.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
0.01 N $CaSO_4$	<.1	1.09E-8	0.01 N $CaSO_4$		
	.1	1.04E-8		.1	1.29E-8
	.2	1.03E-8		.2	1.25E-8
	.3	1.20E-8	Acetone		
	.4	1.27E-8		<.1	1.05E-8
	.5	1.26E-8		.1	1.22E-8
	.6	1.21E-8		.2	9.93E-9
	.7	1.06E-8		.3	1.10E-8
	.8	1.22E-8		.4	7.25E-9
	.9	1.07E-8		.5	6.59E-9
Acetone				.6	6.90E-9
	.01	8.96E-9		.7	5.79E-9
	.1	1.03E-8		.8	6.79E-9
	.2	8.77E-9		.9	7.91E-9
	.3	1.06E-8		1	1.73E-8
	.4	6.68E-9		1.1	3.89E-8
	.5	5.86E-9		1.2	4.72E-8
	.6	4.89E-9		1.3	6.20E-8
	.7	5.03E-9		2.7	1.98E-7
	.8	4.67E-9			
	.9	7.32E-9			
	1	1.13E-8			
	1.3	1.70E-7			
	1.4	2.99E-7			
	1.5	3.68E-7			
	1.9	4.24E-7			
	2	3.96E-7			
	2.2	4.82E-7			
	2.6	6.23E-7			

Table C-11. Average Conductivity of Compacted Soil Containing Micaceous Clay to 0.01 N $CaSO_4$ Followed by Acetone at a Gradient of 181.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
0.01 N $CaSO_4$	<.1	3.72E-9	0.01 N $CaSO_4$	<.1	7.92E-9
	.1	7.32E-9		.1	8.22E-9
	.2	8.70E-9		.3	8.34E-9
	.3	7.59E-9		.4	9.61E-9
	.4	8.62E-9		.5	9.94E-9
	.5	8.75E-9		.6	9.96E-9
	.6	9.30E-9		.7	1.06E-8
	.7	1.04E-8		.8	1.08E-8
	.8	1.08E-8		.9	1.12E-8
	1	1.06E-8		1	2.11E-8
Acetone			Acetone		
	<.1	9.08E-9		<.1	9.87E-9
	.1	8.84E-9		.1	9.03E-9
	.3	7.08E-9		.3	8.2E-9
	.4	7.32E-9		.4	7.57E-9
	.5	6.22E-9		.5	6.33E-9
	.6	5.28E-9		.6	5.19E-9
	.7	4.82E-9		.7	4.82E-9
	.8	3.70E-9		.8	5.19E-9
	.9	5.75E-9		.9	4.89E-9
	1	4.28E-9		1	5.49E-9
	1.1	5.20E-9		1.1	6.15E-9
	1.2	5.69E-9		1.2	6.65E-9
	1.3	5.99E-9		1.3	8.01E-9
	1.4	7.47E-9		1.4	8.41E-9
	1.5	7.47E-9		1.5	9.13E-9
	1.6	9.19E-9		1.6	1.23E-8
	1.7	1.02E-8		1.8	1.22E-8
	1.8	7.19E-9		1.9	1.41E-8
	1.9	1.11E-8		2	1.48E-8
	2	1.25E-8		2.1	1.49E-8
	2.1	1.23E-8		2.3	1.14E-8
	2.3	1.06E-8		2.4	1.49E-8
	2.4	1.24E-8		2.5	1.74E-8
	2.5	1.38E-8		2.6	1.74E-8
	2.7	1.33E-8			

Table C-12. Average Conductivity of Compacted Soil Containing Bentonitic Clay to Acetone at a Gradient of 91.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
	<.1	6.7E-10			
	.1	1.20E-9			
	.4	5.51E-9			
	.8	7.43E-8			
	1.6	1.13E-7			

Table C-13. Average Conductivity of Compacted Soil Containing Bentonitic Clay to Acetone at a Gradient of 181.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
	<.1	5.5E-10			
	.1	6.1E-11			
	.8	8.74E-9			
	1.3	1.16E-7			
	1.9	1.74E-7			

Table C-14. Average Conductivity of Compacted Soil Containing Bentonitic Clay to Acetone at a Gradient of 272.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
Acetone	<.1	5.77E-9	Acetone	<.1	2.72E-8
	.1	9.84E-9		.2	4.09E-8
	.2	1.87E-8		.3	5.20E-8
	.9	9.14E-8		.7	5.58E-8
	1.3	1.41E-7		1.1	5.97E-8
	1.4	1.67E-7		1.2	5.38E-8
	2.4	1.93E-7		1.3	7.44E-8
				1.8	1.69E-7
				1.9	2.05E-7
				2	2.28E-7
				2.2	2.63E-7

Table C-15. Average Conductivity of Compacted Soil Containing Kaolinitic Clay to Acetone at a Gradient of 31.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
Acetone	<.1	4.30E-9			
	.1	1.11E-8			
	.3	9.57E-8			
	.4	4.59E-8			
	.5	1.18E-7			
	.6	9.78E-8			
	.8	8.76E-8			
	.9	5.42E-8			
	1	7.99E-8			
	1.1	6.38E-8			
	1.2	7.08E-8			
	1.3	7.36E-8			
	1.4	4.51E-8			
	1.5	2.13E-9			
	1.6	1.40E-6			
	1.7	1.18E-6			
	1.8	1.13E-6			
	2.3	1.26E-6			
	2.6	2.7E-6			

Table C-16. Average Conductivity of Compacted Soil Containing Kaolinitic Clay to Acetone at a Gradient of 91.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
Acetone	<.1	4.51E-9	Acetone	<.1	1.35E-7
	.1	1.22E-9		.4	1.10E-7
	.2	1.84E-9		.6	1.10E-7
	.3	2.65E-9		.7	7.31E-8
	.4	3.96E-9		.8	5.84E-8
	.5	5.37E-9		.9	5.13E-8
	.6	6.72E-9		1	3.15E-9
	.7	8.48E-9			
	.8	1.01E-8			
	.9	1.07E-8			
	1	1.34E-8			
	1.1	7.77E-9			
	1.2	1.54E-8			
	1.3	1.97E-8			
	1.4	2.04E-8			
	1.6	2.55E-8			
	1.7	5.43E-9			

Table C-17. Average Conductivity of Compacted Soil Containing Kaolinitic Clay to Acetone at a Gradient of 181.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
Acetone	<.1	5.92E-7	Acetone	<.1	4.98E-6
	.2	8.09E-7		.1	5.83E-6
	.3	6.56E-7		.2	5.60E-6
	.4	6.49E-7		.3	5.74E-6
	.5	6.08E-7		.4	5.39E-6
	.6	4.89E-7		.5	5.28E-6
	1.9	3.24E-7		.6	5.32E-6
	2	1.94E-6		..7	5.16E-6
	2.1	2.20E-6		.8	5.07E-6
	2.2	2.25E-6		.9	5.05E-6
	2.3	2.17E-6		1	5.11E-6
	2.4	2.20E-6		1.1	5.09E-6
	2.5	2.18E-6		1.2	5.05E-6
	2.6	1.96E-6		2.5	4.59E-6
	2.7	2.94E-6			
	2.9	2.43E-6			

Table C-18. Average Conductivity of Compacted Soil Containing Micaceous Clay to Acetone at a Gradient of 31.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
Acetone	<.1	7.82E-9	Acetone	<.1	4.34E-9
	1	6.66E-9		.1	4.52E-9
	.2	1.01E-8		.2	7.31E-9
	.3	1.53E-8		.3	8.30E-9
	.4	2.92E-8		.4	1.13E-8
	.5	3.68E-8		.5	3.13E-8
	.6	3.66E-8		.6	5.85E-8
	.7	1.08E-8		.7	3.71E-8
	.8	1.54E-8		1.1	1.36E-7
	.9	2.35E-8		1.2	7.43E-9
	1	4.42E-8		1.4	3.31E-7
	1.1	2.58E-7		1.6	3.19E-7
	1.2	3.48E-7		1.7	8.20E-7
	1.3	7.89E-7		1.8	8.03E-7
	1.4	8.60E-7	0.01 N $CaSO_4$		
	1.9	1.27E-6		.1	2.14E-7
	2.3	1.69E-6		.2	6.60E-8
				.3	2.51E-8
				.4	1.76E-8
				.5	2.02E-8
				.6	1.47E-8
				.7	1.68E-8

Table C-19. Average Conductivity of Compacted Soil Containing Micaceous Clay to Acetone at a Gradient of 91.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
Acetone	<.1	7.25E-9	Acetone	<.1	3.14E-9
	.1	4.68E-9		.1	7.06E-9
	.2	6.23E-9		.2	7.81E-9
	.3	8.56E-9		.3	5.98E-9
	.4	8.81E-9		.5	1.48E-8
	.5	1.02E-8		.7	2.06E-8
	.6	1.54E-8		.8	1.09E-8
	1.4	9.30E-8		1.1	4.56E-8
	1.5	8.17E-7		1.2	4.93E-8
	1.8	1.08E-6		1.4	5.48E-8
	2.1	1.35E-6		2.3	6.29E-8
				2.4	5.51E-8
				2.6	8.00E-8

Table C-20. Average Conductivity of Compacted Soil Containing Micaceous Clay to Acetone at a Gradient of 181.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
Acetone	.1	4.59E-8	Acetone	.1	7.06E-9
	.2	3.70E-8		.2	1.47E-8
	.3	3.78E-8		.3	1.58E-8
	.5	4.30E-8		.6	1.58E-8
	.6	4.49E-8		.7	1.60E-8
	.8	5.04E-8		.9	2.02E-8
	1.8	6.24E-8		1.4	1.58E-8
				1.5	2.70E-8
				1.9	7.09E-8

Table C-21. Average Conductivity of Compacted Soil Containing Bentonitic Clay to 0.01 N $CaSO_4$ Followed by Xylene at a Gradient of 91.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
0.01N $CaSO_4$	<.1	1.21E-9	0.01N $CaSO_4$	<.1	1.75E-9
	.1	3.46E-9		.1	2.07E-9
	.2	3.98E-9		.2	2.52E-9
	.3	3.63E-9		.3	[illegible].24E-9
	.4	2.[illegible]3E-9		.4	3.[illegible]E-9
	.5	2.88E-9		.5	3.00E-9
	.6	2.05E-9		.6	2.98E-9
	.7	1.89E-9		.7	2.57E-9
	.8	1.04E-9		.8	2.30E-9
	.9	5.71E-9		.9	1.21E-9
	1	5.24E-9		1	1.11E-9
Xylene	<.1	3.53E-9		1.1	1.37E-9
	.1	2.34E-9	Xylene	<.1	1.35E-9
	.2	7.69E-9		.1	9.6E-10
	.3	3.71E-8		.2	1.39E-9
	.4	3.64E-8		.3	9.2E-10
	.5	2.81E-8		.4	9.5E-10
	.7	3.85E-8			
	.8	4.75E-8			
	2	4.41E-7			

Table C-22. Average Conductivity of Compacted Soil Containing Bentonitic Clay to 0.01 N $CaSO_4$ Followed by Xylene at a Gradient of 181.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
0.01 N $CaSO_4$	<.1	2.51E-9	0.01 N $CaSO_4$	<.1	3.09E-9
	.1	3.83E-9		.1	4.48E-9
	.2	5.82E-9		.2	3.45E-9
	.3	4.83E-9		.3	3.71E-9
	.4	5.10E-9		.4	3.98E-9
	.5	4.99E-9		.5	3.77E-9
	.6	5.53E-9		.6	3.81E-9
	.7	5.00E-9		.7	3.[illegible]E-9
	.8	6.65E-9		.8	3.21E-9
	.9	5.24E-9		.9	4.05E-9
	1	3.82E-9	Xylene		
Xylene				<.1	4.10E-9
	<.1	5.72E-9		.1	6.40E-9
	.1	3.95E-9		.2	5.78E-9
	.2	2.26E-9		.3	4.26E-9
	.3	3.85E-9		.4	[illegible].45E-9
	.4	6.00E-9		.5	[illegible].62E-9
	.5	5.27E-9		.6	1.92E-9
	.6	6.79E-9		.7	2.25E-9
	.7	6.25E-9		.8	2.42E-9
	.8	5.82E-9		.9	2.26E-9
	.9	5.99E-9		1	1.61E-9
	1	6.44E-9		1.1	1.35E-9
	1.1	6.68E-9		1.2	2.16E-9
	1.2	2.81E-8		1.3	1.47E-9
	1.3	1.33E-8		1.4	1.22E-9
	1.4	5.93E-9		1.5	1.66E-9
	1.5	3.73E-8		1.6	1.80E-9
	1.6	3.25E-9			
	1.8	2.70E-8			
	1.9	2.40E-8			
	2	1.23E-8			
	2.1	7.85E-9			
	2.2	1.31E-8			
	2.4	1.78E-8			

Table C-22 continued.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
	2.5	1.29E-8			
	2.7	4.93E-8			
	2.8	9.37E-9			
	2.9	7.56E-9			
	3	1.19E-8			
	3.1	7.10E-9			
	3.2	7.91E-9			
	3.3	8.17E-9			
	3.4	8.67E-9			
	3.5	3.24E-9			
	3.6	7.36E-9			
	3.7	7.02E-9			
	3.8	4.76E-9			
	3.9	2.34E-9			
	4	9.97E-9			
	4.1	3.27E-9			
	4.2	3.20E-9			
	4.3	2.28E-9			

Table C-21. Average Conductivity of Compacted Soil Containing Bentonitic Clay to 0.01 N $CaSO_4$ Followed by Xylene at a Gradient of 272.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
0.01 N $CaSO_4$	<.1	7.59E-9			
	.1	1.E-8			
	.2	1.09E-8			
	.3	9.68E-9			
	.4	1.09E-8			
	.6	1.07E-8			
	.7	1.10E-8			
	.9	9.82E-9			
	1	9.68E-9			
Xylene					
	.1	2.E-7			
	.3	1.26E-8			
	.4	1.4E-8			
	.5	1.28E-8			
	.6	1.22E-8			
	.7	1.22E-8			
	.8	1.31E-8			
	.9	1.29E-8			
	1	1.23E-8			
	1.4	7.94E-8			
	1.5	7.77E-8			
	2	1.28E-7			
	2.6	6.46E-7			
0.01 N $CaSO_4$					
	<.1	3.32E-9			
	.1	3.02E-9			
	.2	7.32E-9			
	.3	8.24E-9			
	.4	8.35E-9			
	.5	8.62E-9			
	.6	8.17E-9			
	.7	8.56E-9			
	.8	7.39E-9			
	.9	9.36E-9			
	1.1	6.25E-9			
	1.2	4.7E-10			

Table C-24. Average Conductivity of Compacted Soil Containing Kaolinitic Clay to 0.01 N $CaSO_4$ Followed by Xylene at a Gradient of 31.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
0.01 N $CaSO_4$	<.1	3.76E-9	0.01 N $CaSO_4$	<.1	2.72E-8
	.1	7.15E-9		.2	5.91E-8
	.2	7.84E-9		.3	1.40E-8
	.3	8.17E-9		.4	1.37E-8
	.4	1.08E-8		.5	1.32E-8
	.5	8.89E-9		.6	1.15E-8
	.6	8.94E-9		.7	8.43E-9
	.7	9.28E-9		.8	9.31E-9
	.8	9.33E-9		.9	9.13E-9
	.9	9.35E-9	Xylene		
	1	1.25E-8		<.1	9.49E-9
	1.1	8.53E-9		.1	8.08E-9
Xylene				.2	2.31E-7
	<.1	9.46E-9		1.3	3.66E-6
	.1	1.05E-8			
	.2	1.04E-8			
	.3	1.13E-8			
	.4	1.24E-8			
	.5	1.09E-8			
	.6	1.35E-8			
	.7	9.28E-9			
	.8	1.18E-8			
	.9	8.20E-9			
	1	9.78E-9			
	1.1	1.06E-8			
	1.2	8.66E-9			
	1.3	4.92E-9			
	1.7	2.01E-7			
	2	3.85E-7			
	2.3	4.43E-7			
	2.6	4.48E-7			

Table C-25. Average Conductivity of Compacted Soil Containing Kaolinitic Clay to 0.01 N $CaSO_4$ Followed by Xylene at a Gradient of 91.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
0.01 N $CaSO_4$	<.1	1.26E-8	0.01 N $CaSO_4$		
	.1	1.32E-8		.1	7.92E-8
	.2	1.28E-8		.2	1.95E-8
	.3	1.37E-8		.3	1.70E-8
	.4	1.16E-8		.5	2.38E-8
	.5	1.16E-8		.6	1.49E-8
	.6	1.21E-8		.7	9.67E-9
	.7	1.30E-8		.8	6.21E-9
	.8	1.22E-8		.9	6.04E-9
	.9	1.09E-8		1	5.95E-9
Xylene			Xylene		
	<.1	8.60E-9		<.1	4.92E-9
	.1	6.10E-9		.1	1.14E-8
	1.7	7.01E-7		.8	4.81E-7
	4.7	2.21E-6		.9	8.37E-7
				1.7	1.08E-6
				4.7	2.03E-6

Table C-26. Average Conductivity of Compacted Soil Containing Kaolinitic Clay to 0.01 N $CaSO_4$ Followed by Xylene at a Gradient of 181.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
0.01 N CaSO4	<.1	5.57E-9	0.01 N CaSO4	.2	1.67E-8
	.1	4.91E-9		.3	9.12E-9
	.3	4.47E-9		.4	7.96E-9
	.4	4.81E-9		.6	7.19E-9
	.5	3.84E-9		.7	1.77E-8
	.6	4.54E-9		.8	6.05E-9
	.7	4.35E-9		.9	5.12E-9
	.8	4.26E-9		1	5.61E-9
	.9	3.59E-9		1.1	8.77E-9
Xylene				1.2	2.19E-8
	<.1	1.83E-9		1.7	2.26E-8
	.1	4.81E-9		2	4.63E-8
	1.5	1.04E-7		2.4	6.31E-8
				2.9	7.38E-8
				3.1	2.71E-8
				3.3	5.57E-9
				3.4	2.51E-9
			Xylene		
				<.1	1.19E-9
				.1	6.31E-9
				.9	1.63E-7

Table C-26 continued.

	Replication 3	
Fluid	Pore Vol.	Ave K
0.01 N $CaSO_4$	.1	2.37E-8
	.2	3.56E-8
	.3	2.73E-8
	.5	9.79E-9
	.6	9.89E-9
	.7	7.82E-9
	.8	7.28E-9
	.9	1.04E-8
	1	1.01E-8
	1.6	5.69E-9
Xylene		
	<.1	2.66E-9
	.1	3.37E-9
	.2	2.75E-9
	.3	3.01E-9
	.4	9.36E-9
	.5	1.38E-8
	.7	1.41E-8
	.9	1.42E-8
	1	1.62E-8
	1.2	1.43E-8
	1.3	1.35E-8
	1.7	1.38E-8
	2	2.14E-8
	2.1	1.59E-8
	2.2	1.78E-8
	2.4	1.87E-8
	2.6	2.00E-8
	2.9	1.78E-8
	3	2.07E-8
	3.1	2.09E-8
	3.3	2.11E-8
	3.6	1.98E-8
	3.8	2.00E-8
	4	2.96E-9
	4.3	1.51E-8

Table C-27. Average Conductivity of Compacted Soil Containing Micaceous Clay to 0.01 N $CaSO_4$ Followed by Xylene at a Gradient of 31.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
0.01 N $CaSO_4$	<.1	1.45E-8	0.01 N $CaSO_4$	<.1	1.35E-8
	.1	1.66E-8		.1	1.71E-8
	.2	1.32E-8		.2	1.75E-8
	.3	1.32E-8		.3	1.83E-8
	.4	1.35E-8		.4	1.98E-8
	.5	1.35E-8		.5	1.84E-8
	.6	1.60E-8		.6	1.91E-8
	.7	1.49E-8		.7	2.03E-8
	.8	1.77E-8		.8	2.25E-8
	.9	1.71E-8		.9	1.99E-8
	1	1.40E-8		1	2.36E-8
	1.1	1.34E-8		1.1	2.84E-8
Xylene			Xylene		
	<.1	1.43E-8		<.1	1.53E-8
	.1	7.70E-9		.1	2.99E-8
	1.3	1.46E-6		.2	2.04E-8
	1.4	3.69E-6		.3	2.08E-8
	1.5	3.76E-6		4	2.08E-8
	1.6	3.79E-6		.5	2.91E-8
	1.7	3.44E-6		.6	2.08E-8
	1.8	3.29E-6		.7	2.28E-8
	1.9	3.55E-6		.8	1.94E-6
	2	3.75E-6		.9	1.99E-8
	2.1	2.73E-6		1	1.79E-8
	2.2	3.63E-6		1.1	2.42E-8
	2.3	4.35E-6		1.2	1.85E-8
0.01 N $CaSO_4$				1.3	1.96E-8
	<.1	3.21E-7		1.4	1.89E-8
	.1	3.82E-8			
	.2	1.99E-8			
	.3	1.70E-8			
	.4	3.21E-8			
	.6	5.08E-8			
	.7	5.92E-8			
	.8	6.90E-8			
	.9	7.01E-8			
	1	7.22E-8			
	1.1	4.77E-8			
	1.2	3.82E-8			
	1.3	4.42E-8			
	1.6	9.58E-8			

Table C-28. Average Conductivity of Compacted Soil Containing Micaceous Clay to 0.01 N $CaSO_4$ Followed by Xylene at a Gradient of 91.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
0.01 N $CaSO_4$	<.1	1.12E-8	0.01 N $CaSO_4$	<.1	8.96E-9
	.1	1.15E-8		.1	1.03E-8
	.2	1.23E-8		.2	1.1E-8
	.4	1.48E-8		.3	1.19E-8
	.5	1.56E-8		.4	1.35E-8
	.6	1.43E-8		.5	1.37E-8
	.7	1.55E-8		.7	1.40E-8
	.8	1.46E-8		.8	1.31E-8
	.9	1.28E-8		.9	1.30E-8
	1	1.46E-8		1	1.34E-8
				1.1	1.27E-8
Xylene			Xylene		
	<.1	5.53E-9		<.1	1.21E-8
	.1	1.32E-3		.1	1.22E-8
	.2	1.32E-8		.2	1.E-8
	.3	1.05E-8		2.7	9.51E-8
	.9	1.69E-7			
	1.3	3.33E-6			
	2.1	4.01E-6			
	3.3	5.55E-6			

Table C-29. Average Conductivity of Compacted Soil Containing Micaceous Clay to 0.01 N $CaSO_4$ Followed by Xylene at a Gradient of 181.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
0.01 N $CaSO_4$	<.1	8.15E-9	0.01 N $CaSO_4$	<.1	6.05E-9
	.1	7.15E-9		.1	9.90E-9
	.2	6.40E-9		.2	6.76E-9
	.3	4.60E-9		.3	6.57E-9
	.4	5.70E-9		.4	5.46E-9
	.5	6.15E-9		.5	8.29E-9
	.6	6.49E-9		.6	8.77E-9
	.7	6.61E-9		.7	1.63E-8
	.8	7.17E-9		.8	7.36E-9
	.9	7.74E-9		.9	7.58E-9
	1	8.21E-9		1	7.65E-9
	1.1	7.88E-9	Xylene		
Xylene				<.1	5.87E-9
	<.1	5.27E-9		.1	7.06E-8
	.1	6.74E-9			
	.2	6.46E-9			
	.3	3.71E-7			
	.4	2.87E-5			
	.6	1.81E-5			
	.7	1.81E-5			
	.9	1.90E-5			
	1	1.72E-5			
	1.1	1.72E-5			

Table C-30. Average Conductivity of Compacted Soil Containing Bentonitic Clay to Xylene at a Gradient of 31.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
Xylene	<.1	2.45E-5	Xylene	<.1	2.27E-5
	.1	5.58E-5		.1	3.23E-5
	.2	7.72E-5		.2	3.38E-5
	.4	7.49E-5		.3	3.84E-5
	.5	6.42E-5		.4	4.14E-5
	.6	9.12E-5		.5	4.29E-5
	.7	9.41E-5		.6	4.61E-5
	.8	9.44E-5		.7	4.84E-5
	.9	9.86E-5		.8	4.96E-5
				.9	5.08E-5
				1	5.21E-5
			0.01 N $CaSO_4$		
				.1	1.05E-8

Table C-31. Average Conductivity of Compacted Soil Containing Bentonitic Clay to Xylene at a Gradient of 91.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
Xylene	<.1	5.02E-5	Xylene	<.1	2.84E-5
	.1	7.57E-5		.1	4.63E-5
	.2	7.48E-5		.2	4.82E-5
	.3	7.46E-5		.3	4.82E-5
	.4	7.62E-5		.4	4.94E-5
	.5	7.62E-5		.5	4.97E-5
	.6	7.53E-5		.6	5.06E-5
	.7	7.67E-5		.7	5.03E-5
	.8	7.62E-5		.8	5.05E-5
	.9	7.69E-5		.9	5.02E-5
	1	7.67E-5		1	5.11E-5
	1.1	7.67E-5	0.01 N $CaSO_4$		
	1.2	7.67E-5		<.1	2.84E-9

Table C-32. Average Conductivity of Compacted Soil Containing Bentonitic Clay to Xylene at a Gradient of 181.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
Xylene	<.1	1.37E-5	Xylene	.1	1.10E-4
	.2	5.87E-5		.2	1.33E-4
	.3	9.38E-5		.3	1.38E-4
	.4	7.83E-5		.4	2.20E-4
	.5	7.83E-5		.5	2.25E-4
	.7	7.90E-5		.7	2.30E-4
	.8	7.84E-5		.8	2.[illegible]E-4
	.9	7.30E-5		1	2.[illegible]9E-4
	1	8.93E-5		1.1	2.30E-4
	1.1	7.56E-5		1.3	2.43E-4
	1.2	8.55E-5		1.5	2.48E-4
	1.3	7.86E-5	0.01 N $CaSO_4$		
	1.4	8.31E-5		<.1	1.26E-7

Table C-33. Average C uctivity of Compacted Soil Containing Kaolinitic Clay to Xylene at a Gradient of 31.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
Xylene	<.1	0	Xylene	<.1	8.77E-7
	1	1.31E-6		.1	[illegible].70E-6
	2	4.42E-7		.4	8.17E-8
	2.1	1.62E-6		.5	5.01E-9
	2.2	1.25E-6		.9	2.27E-7
	2.3	1.19E-6		1.5	7.13E-7
	2.7	4.89E-7			
	3.4	22			
	3.5	1.08E-6			
	3.6	3.40E-7			

Table C-34. Average Conductivity of Compacted Soil Containing Kaolinitic Clay to Xylene at a Gradient of 91.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
Xylene	<.1	1.28E-6	Xylene	<.1	3.52E-7
	.1	7.41E-7		.1	9.74E-8
	.2	3.98E-7		.2	8.86E-8
	.3	2.22E-7		.3	1.76E-8
	.7	2.86E-7		.4	6.06E-8
	.9	5.77E-8		.5	5.12E-8
	1.2	2.14E-7		.6	3.16E-8
	1.6	1.54E-7		.7	3.70E-8
	2	1.76E-7		.8	3.19E-8
	2.2	1.28E-7		.9	2.98E-8
	2.5	1.74E-7		1	3.17E-8
	2.7	9.65E-8		1.2	3.07E-8
	2.8	1.01E-8		1.3	5.35E-8
				1.4	5.02E-8
			0.01 N $CaSO_4$		
				<.1	9.00E-8
				.1	4.24E-8
				.4	1.19E-7
				.5	5.02E-8
				.6	4.64E-8
				.7	4.25E-8
				.8	3.85E-8
				1.1	3.70E-8
				1.2	3.50E-8
				1.3	3.48E-8
				1.4	3.20E-8
				1.5	1.42E-8
				1.6	2.76E-8
				1.9	3.05E-8
				2.1	3.08E-8
				2.4	3.14E-8
				2.5	3.06E-8
				2.6	3.01E-8
				2.8	5.91E-9

Table C-35. Average Conductivity of Compacted Soil Containing Kaolinitic Clay to Xylene at a Gradient of 181.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
Xylene	<.1	0	Xylene	<.1	1.72E-5
	.2	8.61E-5		.1	4.59E-5
	.6	1.15E-4		.3	6.89E-5
	1	1.26E-4		.4	6.89E-5
				.5	6.89E-5
				.6	8.03E-5
				.7	8.03E-5
				.8	8.03E-5
				1	9.18E-5
				1.1	9.18E-5
				1.3	9.18E-5
				1.4	1.03E-4
				1.6	9.18E-5

Table C-38. Average Conductivity of Compacted Soil Containing Micaceous Clay to Xylene at a Gradient of 31.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
Xylene	<.1	2.82E-8	Xylene	<.1	4.65E-7
	.1	4.44E-8		.1	6.87E-7
	.2	7.07E-8		.2	6.[illegible]E-7
	.3	9.20E-8		.5	4.21E-7
	1.7	1.52E-6		.8	3.28E-7
	1.8	4.03E-8		1.1	3.E-7

Table C-36 continued.

	Replication 3	
Fluid	Pore Vol.	Ave K
Xylene	<.1	3.96E-8
	.3	4.11E-7
	.9	6.99E-7
	1.3	3.43E-7
	2.8	6.69E-5
	3.1	2.72E-7
	3.2	2.66E-7
	3.6	2.02E-7
0.01 N $CaSO_4$		
	<.1	4.83E-9
	.1	8.04E-9
	.2	7.64E-9
	.3	7.21E-9
	.4	1.57E-8
	.5	2.07E-8
	.6	1.23E-8
	.7	1.69E-8
	.8	1.57E-8
	.9	1.21E-8

Table C-37. Average Conductivity of Compacted Soil Containing Micaceous Clay to Xylene at a Gradient of 91.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
Xylene	<.1	3.60E-5	Xylene	.1	1.14E-4
	.2	6.84E-5		.2	1.38E-4
	.3	6.39E-5		.3	1.34E-4
	.4	6.16E-5		.4	1.37E-4
	.5	7.30E-5		.5	1.38E-4
	.6	5.93E-5		.6	1.14E-4
	.7	7.71E-5		.7	1.30E-4
	.8	7.28E-5		.8	1.38E-4
	.9	6.17E-5		.9	1.34E-4
			0.01 N $CaSO_4$	<.1	2.13E-9
				.1	1.33E-8
				.2	1.45E-8
				.3	8.55E-9

Table C-38. Average Conductivity of Compacted Soil Containing Micaceous Clay to Xylene at a Gradient of 181.

Replication 1			Replication 2		
Fluid	Pore Vol.	Ave K	Fluid	Pore Vol.	Ave K
Xylene	<.1	4.3E-6	Xylene	<.1	1.86E-5
	.1	1.26E-5		.1	3.12E-5
	.2	1.61E-8		.2	2.92E-5
	.3	1.57E-5		.3	2.97E-5
	.4	1.67E-5		.4	2.92E-5
	.5	1.52E-5		.5	2.87E-5
	.6	1.52E-5		.6	2.92E-5
	.7	1.53E-5		.7	2.75E-5
	.8	1.64E-5		.8	2.64E-5
	.9	1.70E-5		.9	2.69E-5
	1	1.59E-5		1	2.66E-5
0.01 N $CaSO_4$	<.1	9.74E-9		1.1	2.62E-5
	.1	5.35E-9		1.2	2.57E-5
	.2	5.75E-9		1.3	2.54E-5
	.3	6.73E-9			
	.4	6.84E-9			
	.5	6.69E-9			
	.6	6.56E-9			
	.7	9.03E-9			

APPENDIX D

XYLENE CONTENT OF LEACHATE FROM LABORATORY PERMEAMETERS

Table D-1. Xylene Content of Leachate from Compacted Soil Containing Bentonitic Clay Permeated with 0.01 N $CaSO_4$ Followed by Xylene at a Gradient of 181.

Pore Volume	Rep 1	Rep 2
	------- % xylene ------	
<0.1	0	0
0.1	0	0
0.2	33	0
0.3	96	0
0.4	91	0
0.5	95	7
0.6	94	63
0.7	100	91
0.8	100	96
0.9	100	91
1.0	100	88
1.1	100	84
1.2	100	100
1.3	100	100
1.4	100	
1.5	100	
1.6	100	
1.7	100	
1.8	100	
1.9	100	
2.0	100	
2.1	100	
2.2	100	
2.3	100	
2.4	100	

Table D-2. Xylene Content of Leachate from Compacted Soil Containing Bentonitic Clay Permeated with Xylene at a Gradient of 31.

Pore Volume	Rep 1	Rep 2
	------- % xylene	------
0.1	100	100
0.2	100	100
0.3	100	100
0.4	100	100
0.5	100	100
0.6	100	100
0.7	100	100
0.8	100	100
0.9	100	100
1.0	100	100

Table D-3. Xylene Content of Leachate from Compacted Soil Containing Micaceous Clay Permeated with 0.01 N $CaSO_4$ Followed by Xylene at a Gradient of 31.

Pore Volume	Rep 1	Rep 2
	------- % xylene	------
<0.1	0	0
0.1		0
0.2	0	0
0.3		0
0.4		0
0.5		0
0.6		0
0.7	100	0
0.8		0
0.9		0
1.0		0
1.1		0
1.2		0
1.3		0
1.4		0
1.5	100	
1.6	100	
1.7	100	0
1.8	100	0
1.9	100	
2.0	100	
2.1	100	
2.2	100	

Table D-4. Xylene Content of Leachate from Compacted Soil Containing Micaceous Clay Permeated with Xylene at a Gradient of 31.

Pore Volume	Rep 1	Rep 2	Rep 3
	---------------- % xylene	-------------	
<0.1	100	100	100
0.1	100	100	100
0.2	100	100	100
0.3	100	100	100
0.4			100
0.5		100	100
0.6			100
0.7			100
0.8		100	100
0.9			100
1.0			100
1.2		100	
1.7	100		

APPENDIX E

AVERAGE CONDUCTIVITY DATA FROM FIELD CELLS

Table E-1. Average Conductivity of Field Cells Constructed with Soil Containing Kaolinitic Clay and Exposed to Xylene.

Cell 2		Cell 4		Cell 10		Cell 12	
Pore Vol.	Ave K	Pore Vol.	Ave K	Pore Vol.	Ave K	Pore Vol.	Ave K
.1	3.02E-7	<.1	5.395E-8	<.1	3.48E-8	<.1	3.55E-8
.6	22	.1	2.36E-7	.1	3.96E-7	.1	3.38E-7
1.2	.0000016	.2	1.8E-7	.2	2.14E-7	.3	6.43E-7
1.3	5.19E-7	.4	2.51E-7	.4	3.94E-7	.7	8.19E-7
1.6	.0000147	.6	4.15E-7	.5	3.9E-7	1.2	1.74E-6
1.9	6.25E-6	.8	6.15E-7	.7	2.95E-7	1.7	6.22E-7
2	3.2E-7	.9	3.49E-7	.9	4.56E-7	2.2	1.38E-6
2.1	4.617E-6	1.1	4.27E-7	1.2	1.02E-6	2.7	1.36E-6
2.2	9.5E-8	1.2	1.595E-7	1.3	5.11E-7	2.8	1.77E-7
2.3	9.69E-8	1.3	3.04E-8	1.5	4.01E-7	2.9	9.99E-6
		1.4	3.62E-8	1.6	2.645E-7	3	2.53E-6
		1.5	2.34E-8	1.7	4.39E-8	3.1	3.922E-6
		1.6	7.86E-8	1.8	3.01E-8	3.2	1.46E-7
		1.7	1.076E-7	1.9	4.875E-8	3.3	7.86E-8
		1.8	9.04E-8	2	5.18E-8	3.4	6.88E-8
		1.9	1.74E-7	2.1	9.57E-8	3.5	7.905E-8
		2	1.4E-7	2.2	7.355E-8	3.6	1.235E-7
		2.1	1.525E-7	2.3	1.134E-7		
		2.2	1.99E-7	2.4	2.265E-7		
		2.3	1.825E-7	2.5	1.825E-7		
		2.4	1.75E-7	2.6	1.855E-7		
		2.5	1.845E-7	2.7	1.91E-7		

Table E-2. Average Conductivity of Field Cells Constructed with Soil Containing Micaceous Clay and Exposed to Xylene.

Cell 5		Cell 6		Cell 8		Cell 11	
Pore Vol.	Ave K	Pore Vol.	Ave K	Pore Vol.	Ave K	Pore Vol.	Ave K
<.1	5.18E-8	<.1	8.096E-8	<.1	1.044E-7	<.1	7.28E-8
.5	1.19E-6	.2	3.83E-7	.1	1.27E-7	.1	2.5E-7
1.1	1.58E-6	.3	2.76E-7	.2	3.26E-7	.3	.0000014
1.3	2.99E-6	.7	1.13E-6	.4	4.65E-7	.5	3.025E-7
1.7	9.24E-6	1	4.04E-7	.5	1.09E-7	.7	2.88E-7
2	3.29E-7	1.6	1.32E-6	.6	2.86E-7	.9	0
2.1	2.82E-7	2.1	1.33E-6	.8	7.62E-7	1.1	7.06E-7
2.2	.000012	2.2	3.159E-6	1	4.31E-7	1.5	9.7E-7
2.3	3.23E-6	2.3	2.274E-6	1.2	4.415E-7	1.8	9.64E-7
2.4	9.77E-6	2.4	5.503E-8	1.3	4.103E-8	1.9	5.8E-7
2.5	1.064E-7	2.5	3.917E-8	1.4	3.225E-8	2.1	4.05E-7
2.6	1.28E-7	2.6	8.25E-8	1.5	5.755E-8	2.3	2.23E-7
2.7	1.17E-7	2.7	9.813E-8			2.4	2.19E-7
2.8	9.06E-8	2.8	2.07E-7			2.6	2.72E-7
2.9	1.918E-7	2.9	1.655E-7			2.7	3.06E-7
3	1.293E-7					2.8	1.21E-7
3.1	1.226E-7					2.9	1.645E-7
3.2	6.814E-8					3.1	3.26E-7
						3.2	3.36E-7
						3.4	2.94E-7
						3.5	1.84E-7
						3.6	5.47E-8
						3.7	3.56E-7
						3.9	2.51E-7

Table E-3. Average Conductivity of Field Cells Constructed with Soil Containing Bentonitic Clay and Exposed to Xylene.

Cell 1		Cell 3		Cell 7		Cell 9	
Pore Vol.	Ave K	Pore Vol.	Ave K	Pore Vol.	Ave K	Pore Vol.	Ave K
<.1	2.536E-8	<.1	1.692E-8	0	0	<.1	1.007E-7
.1	9.522E-9	.1	6.182E-8			.1	2.215E-7
.2	7.105E-8	.2	8.093E-8			.2	1.024E-7
.3	1.217E-7	.3	7.102E-8			.3	1.51E-7
.4	1.25E-7	.4	8.631E-8			.4	1.535E-7
.5	1.097E-7	.5	9.626E-8			.5	1.655E-7
.6	2.24E-7	.6	9.824E-8			.6	3.69E-8
		.7	1.053E-7			.7	2.645E-8
		.8	8.189E-8			.8	2.605E-8
		.9	6.186E-8			.9	5.287E-8
		1	7.641E-8			1	6.155E-8
		1.1	8.553E-8			1.1	6.492E-8
		1.2	8.627E-8			1.2	1.75E-7
		1.3	7.488E-8			1.3	1.76E-7
		1.4	1.190E-7			1.4	1.195E-7
		1.5	9.952E-8			1.5	1.587E-7
		1.6	1.098E-7				
		1.7	8.419E-8				

Table E-4. Average Conductivity of Field Cells Constructed with Soil Containing Kaolinitic Clay and Exposed to Acetone.

Cell 18		Cell 20		Cell 25		Cell 28	
Pore Vol.	Ave K	Pore Vol.	Ave K	Pore Vol.	Ave K	Pore Vol.	Ave K
<.1	5.E-8	<.1	3.963E-8	<.1	2.275E-8	<.1	2.106E-8
.1	1.535E-7	.1	1.101E-8	.1	8.899E-8	.1	1.404E-8
.2	1.25E-7	.2	1.449E-8	.2	6.088E-8	.2	1.104E-8
.3	1.026E-7	.3	5.456E-8	.3	1.072E-8	.3	1.003E-8
.4	1.52E-7	.4	8.167E-8	.4	1.669E-8	.4	8.214E-9
.5	1.094E-7	.5	6.088E-8	.5	2.380E-8	.5	1.229E-8
.6	1.44E-7	.6	4.478E-8	.6	2.985E-8	.6	1.086E-8
.7	3.96E-8	.7	2.450E-8	.7	2.407E-8	.7	1.410E-8
.8	2.85E-8	.8	1.987E-8	.8	1.019E-8	.8	1.578E-8
.9	2.74E-8	.9	2.048E-8	.9	1.066E-8	.9	7.197E-9
1	6.77E-8	1	2.802E-8	1	1.193E-8	1	1.084E-8
1.1	1.01E-7	1.1	6.189E-8	1.1	8.240E-9		
1.2	1.19E-7	1.2	8.742E-8	1.2	1.151E-8		
1.3	1.349E-7	1.3	8.077E-8	1.3	1.200E-8		
1.4	4.5E-7	1.4	8.229E-8	1.4	6.211E-9		
1.5	2.34E-7	1.5	7.003E-8	1.5	9.434E-9		
1.6	3.26E-7	1.6	4.983E-8				
1.7	2.57E-7	1.7	2.253E-8				
1.8	3.55E-7						
1.9	3.77E-7						
2	4.455E-7						
2.1	3.31E-7						
2.2	5.96E-7						
2.4	9.99E-7						
2.5	6.1E-7						
2.7	1.52E-6						
2.8	6.98E-7						
2.9	8.42E-7						

Table E-4 continued.

Cell 18		Cell 20		Cell 25		Cell 28	
Pore Vol.	Ave K	Pore Vol.	Ave K	Pore Vol.	Ave K	Pore Vol.	Ave K
3.1	9.95E-7						
3.2	1.09E-6						
3.3	3.56E-7						
3.4	1.04E-6						
3.5	7.19E-7						
3.6	7.58E-7						
3.7	5.97E-7						
3.8	6.665E-7						
3.9	6.85E-7						
4	3.81E-7						

Table E-5. Average Conductivity of Field Cells Constructed with a 30 cm Thick Layer of Soil Containing Micaceous Clay and Exposed to Acetone.

Cell 13		Cell 14		Cell 15	
Pore Vol.	Ave K	Pore Vol.	Ave K	Pore Vol.	Ave K
<.1	1.535E-7	<.1	4.325E-8	<.1	1.959E-8
.1	4.098E-7	.1	..764E-7	.1	1.771E-8
.2	2.000E-7	.2	9.423E-8	.2	1.702E-8
.3	1.869E-7	.3	4.673E-8	.3	1.823E-8
.4	5.561E-8	.4	5.925E-8	.4	1.929E-8
.5	7.017E-8	.5	5.634E-8	.5	1.832E-8
.6	7.857E-8	.6	6.948E-8	.6	1.690E-8
.7	1.060E-7	.7	8.117E-8		
.8	8.174E-8	.8	7.568E-8		
.9	8.162E-8	.9	5.460E-8		
1	6.547E-8	1	4.213E-8		
1.1	5.688E-8	1.1	4.439E-8		
1.2	5.913E-8	1.2	4.663E-8		
1.3	6.600E-8	1.3	5.410E-8		
1.4	7.487E-8	1.4	3.689E-8		
1.5	7.999E-8	1.5	3.883E-8		
1.6	4.826E-8	1.6	4.414E-8		
1.7	6.502E-8	1.7	3.378E-8		
		1.8	2.623E-8		

Table E-6. Average Conductivity of Field Cells Constructed with Soil Containing Micaceous Clay and Exposed to Acetone.

Cell 21		Cell 23		Cell 26		Cell 27	
Pore Vol.	Ave K	Pore Vol.	Ave K	Pore Vol.	Ave K	Pore Vol.	Ave K
<.1	1.855E-8	<.1	2.99E-10	<.1	1.395E-8	<.1	2.587E-8
.1	1.164E-7	.1	6.910E-8	.1	1.405E-7	.1	9.11E-8
.2	1.162E-7	.2	4.189E-8	.2	2.857E-7	.2	4.458E-8
.3	8.471E-8	.3	2.496E-8	.3	9.692E-8	.3	4.114E-8
.4	8.464E-8	.4	2.427E-8	.4	6.556E-8	.4	2.265E-8
.5	4.196E-8	.5	2.626E-8	.5	1.052E-7	.5	2.62E-8
.6	3.639E-8	.6	4.601E-8	.6	4.743E-8	.6	4.703E-8
.7	2.757E-8	.7	5.599E-8	.7	3.935E-8	.7	1.028E-7
.8	5.431E-8	.8	3.261E-8	.8	3.114E-8	.8	5.14E-8
.9	6.168E-8	.9	3.660E-8	.9	5.739E-8	.9	7.074E-8
1	8.069E-8	1	3.863E-8	1	5.692E-8	1	9.173E-8
1.1	8.994E-8	1.1	3.199E-8	1.1	5.475E-8	1.1	1.685E-7
1.2	1.282E-7	1.2	4.051E-8	1.2	5.896E-8	1.2	2.155E-7
1.3	1.172E-7	1.3	2.069E-8	1.3	6.696E-8	1.3	1.935E-7
1.4	1.250E-7	1.4	2.201E-8	1.4	9.543E-8	1.4	1.87E-7
1.5	1.153E-7	1.5	2.341E-8	1.5	7.557E-8	1.5	2.135E-7
1.6	1.410E-7	1.6	4.084E-8	1.6	8.164E-8	1.6	2.08E-7
1.7	1.572E-7	1.7	1.740E-8	1.7	7.433E-8	1.7	2.495E-7
1.8	1.922E-7			1.8	1.062E-7	1.8	2.77E-7
1.9	1.733E-7			1.9	6.588E-8	1.9	2.88E-7
2	1.575E-7			2	7.161E-8	2	4.28E-7
2.1	2.668E-7			2.1	6.720E-8	2.1	3.38E-7
2.2	2.160E-7			2.2	7.388E-8	2.2	3.49E-7
2.3	2.417E-7			2.3	5.327E-8	2.3	1.743E-7
2.4	2.233E-7			2.4	5.656E-8	2.4	3.955E-7
2.5	2.206E-7			2.5	6.673E-8		
2.6	2.206E-7			2.6	5.515E-8		
2.7	2.695E-7			2.7	6.091E-8		
2.8	1.516E-7			2.8	7.717E-8		
2.9	1.915E-7						

Table E-6 continued.

Cell 21		Cell 23		Cell 26		Cell 27	
Pore Vol.	Ave K	Pore Vol.	Ave K	Pore Vol.	Ave K	Pore Vol.	Ave K
3	2.083E-7						
3.1	2.129E-7						
3.2	1.635E-7						
3.3	1.579E-7						
3.4	1.846E-7						
3.5	1.268E-7						
3.6	9.796E-8						
3.7	8.896E-8						
3.8	8.810E-8						
3.9	5.164E-8						

Table E-7. Average Conductivity of Field Cells Constructed with Soil Containing Bentonitic Clay and Exposed to Acetone.

Cell 17		Cell 19		Cell 22		Cell 24	
Pore Vol.	Ave K	Pore Vol.	Ave K	Pore Vol.	Ave K	Pore Vol.	Ave K
<.1	5.899E-8	<.1	2.767E-8	0.00	0.00	0.00	0.00
.1	6.470E-8	.1	4.815E-8				
.2	5.212E-8	.2	6.721E-8				
.3	4.477E-8	.3	2.512E-8				
.4	2.447E-8	.4	4.696E-8				
.5	6.570E-9	.5	7.390E-8				
.6	7.632E-9	.6	5.198E-8				
.7	1.100E-8	.7	7.767E-8				
		.8	7.894E-8				
		.9	7.110E-8				
		1	3.840E-8				
		1.1	9.018E-8				
		1.2	1.109E-7				
		1.3	1.297E-8				
		1.4	6.065E-9				

Table E-8. Dates at Which Waste was Applied and When Leachate Began to Flow from Field Cells.

Cell #	Soil	Chemical	Date Waste Added	Date Leachate Flow
2	Kaolinite	Xylene	11/3/81	11/9/81
4			11/3/81	11/5/81
10			11/5/81	11/6/81
12			11/5/81	11/6/81
5	Mica	Xylene	11/4/81	11/9/81
6			11/4/81	11/5/81
8			11/4/81	11/9/81
11			11/5/81	11/6/81
1	Bentonite	Xylene	11/3/81	11/13/81
3			11/4/81	5/20/82
7			11/4/81	No leachate
9			11/4/81	11/9/81
13	Mica 30 cm	Acetone	10/21/81	11/5/81
14			10/21/81	11/10/81
15			10/13/81	11/9/81
21	Mica 15 cm	Acetone	10/16/81	11/2/81
23			10/20/81	11/3/81
26			10/6/81	11/2/81
27			10/7/81	11/2/81
18	Kaolinite	Acetone	10/13/81	11/10/81
20			10/12/81	11/10/81
25			10/7/81	11/5/81
28			10/6/81	11/2/81
17	Bentonite	Acetone	10/15/81	8/15/83
19			10/12/81	10/21/83
22			10/12/81	No leachate
24			10/17/81	No leachate

APPENDIX F

CHEMICAL CONCENTRATIONS OF LEACHATE FROM FIELD CELLS

Table F-1. Percent Xylene in Leachate From Field Cells Constructed With Soil Containing Kaolinitic Clays and Exposed to Xylene.

Cell 2		Cell 4		Cell 10		Cell 12	
P.V	% Xylene	P.V	% Xyl.	P.V	% Xyl.	P.V	% Xyl.
0.14	100	0.008	100	0.01	72	0.01	58
0.96	100	0.1	100	0.25	86	0.4	98
1.27	100	0.2	100	0.4	99	0.7	100
1.61	100	0.5	100	0.5	80	1.3	100
		0.7	100	0.7	86	1.7	100
		1.1	100	1.0	89	2.7	100
		1.3	100	1.2	92	3.2	100
		1.4	100	1.3	96	3.3	100
		1.6	100	1.6	92	3.4	100
		1.9	87	1.7	100	3.5	80
		2.0	83	1.8	100	3.6	86
		2.0	95	1.9	93		
		2.1	92	2.0	100		
		2.2	88	2.1	99		
		2.3	94	2.3	100		
		2.4	92	2.4	99		
		2.5	96	2.6	100		
				2.7	99		

Table F-2. Percent Xylene in Leachate From Field Cells Constructed With Soil Containing Micaceous Clays and Exposed to Xylene.

Cell 5		Cell 6		Cell 8		Cell 11	
P.V	% Xylene	P.V	% Xyl.	P.V	% Xyl.	P.V	% Xyl.
0.04	100	0.2	99	0.04	89	0.03	100
1.11	100	0.3	100	0.2	92	0.2	100
1.36	100	0.7	100	0.2	89	0.4	100
1.78	100	0.7	100	0.4	94	0.5	100
2.09	100	1.8	100	0.5	87	0.6	99
2.58	95	1.8	99	0.7	86	0.8	100
2.74	100	2.4	100	0.7	96	1.0	99
2.84	69	2.4	100	1.0	97	1.1	100
2.87	90	2.5	100	1.3	99	1.5	99
3.00	75	2.5	100	1.3	100	1.9	100
3.09	66	2.6	99	1.3	75	2.1	100
3.11	88	2.7	99	1.4	63	2.3	100
3.14	78	2.7	98	1.4	68	2.6	100
3.17	73	2.7	99	1.5	83	2.7	100
3.19	83	2.9	96			2.9	100
3.20	77	2.9	95			3.1	100
3.21	68					3.2	93
3.22	75					3.4	100
3.23	66					3.6	97
3.23	77					3.7	100
						3.9	99

Table F-3. Percent Xylene in Leachate From Field Cells Constructed With Soil Containing Bentonitic Clays and Exposed to Xylene.

Cell 1		Cell 3		Cell 7		Cell 9	
P.V	% Xylene	P.V	% Xyl.	P.V	% Xyl.	P.V	% Xyl.
0.03	24	0.006	0.8			0.04	67
0.03	99	0.006	6.0			0.1	82
0.05	100	0.01	92			0.1	89
0.05	74	0.03	97			0.2	92
0.06	100	0.05	85			0.2	89
		0.06	86			0.3	99
		0.08	84			0.3	94
		0.08	77			0.3	99
		0.10	85			0.5	97
		0.12	88			0.5	99
		0.15	94			0.6	100
		0.17	95			0.7	100
		0.21	97			0.8	100
		0.23	94			0.8	98
		0.27	94			1.1	99
		0.28	98			1.13	97
		0.30	94			1.14	99
		0.33	99			1.2	97
		0.33	95			1.3	97
		0.37	99			1.4	99
		0.40	99			1.4	98
		0.43	97			1.4	99
		0.44	95			1.4	96
		0.46	99			1.5	96
		0.49	99			1.5	96
		0.52	94			1.5	99
		0.57	98				
		0.59	99				
		0.63	99				
		0.64	99				
		0.67	99				
		0.70	100				
		0.73	100				
		0.76	99				
		0.78	99				
		0.78	98				
		0.78	100				
		0.82	100				
		0.82	99				
		0.82	94				
		0.86	95				
		0.93	97				
		0.93	100				

Table F-4. Percent Acetone in Leachate From Field Cells Constructed With Soil Containing Kaolinitic Clays and Exposed to Acetone.

Cell 18		Cell 20		Cell 25		Cell 28	
P.V	% Ace.	P.V	% Ace.	P.V	% Ace.	P.V	% Ace.
		.1	1.45			.1	3.92
		.2	2.93			.2	6.18
		.3	7.80	.3	4.76	.3	8.24
		.4	6.98	.4	5.67	.4	10.83
		.5	13.64	.5	6.69	.5	11.32
		.6	13.43	.6	7.89	.6	15.10
.7	36.90	.7	19.03	.7	11.15	.7	13.66
.8	53.37	.8	15.96	.8	10.77	.8	9.73
.9	45.45	.9	40.10	.9	11.66		
1	51.65	1	15.06	1	22.70		
1.1	50.20	1.1	22.05	1.1	17.08		
1.2	37.70	1.2	32.30	1.2	14.33		
1.3	41.25	1.3	31.85	1.3	11.20		
1.4	41.25	1.5	38.50				
1.5	84.00	1.6	30.68				
1.6	61.60	1.7	27.34				
1.7	71.70	1.8	25.64				
1.8	75.60						
1.9	79.20						
2	69.20						
2.1	76.20						
2.2	71.30						
2.4	72.80						
2.5	73.60						
2.7	68.70						
2.8	76.80						
3	73.70						
3.1	71.30						
3.2	78.00						
3.3	63.20						
3.4	63.10						
3.5	66.30						
3.6	67.60						
3.7	64.20						
3.8	62.90						
3.9	68.40						
4	72.20						

Table F-5. Percent Acetone in Leachate From Field Cells Constructed With Soil Containing Micaceous Clays and Exposed to Acetone.

Cell 21		Cell 23		Cell 26		Cell 27	
P.V	% Ace	P.V	% Ace.	P.V	% Ace.	P.V	% Ace.
						.1	13.71
.2	33.50	.2	2.13			.2	19.48
.3	28.43	.3	5.03			.3	26.93
.4	31.53	.4	7.38			.4	21.15
.5	39.13	.5	10.69			.5	24.35
.6	45.38	.6	16.39	.6	9.30	.6	27.47
.7	42.68	.7	12.58	.7	12.00	.7	26.08
.8	45.04	.8	15.06	.8	11.00	.8	39.53
.9	45.23			.9	9.37	.9	37.10
1	49.40			1	8.76	1	41.60
1.1	48.53			1.1	18.18	1.1	43.55
1.2	46.68			1.2	20.13	1.2	51.60
1.3	49.53			1.3	22.72	1.3	49.87
1.4	45.33			1.4	26.10	1.4	59.20
1.5	31.86			1.5	28.60	1.5	76.40
1.6	52.64			1.6	63.03	1.6	64.95
1.7	68.20			1.7	65.70	1.7	65.90
1.8	39.15			1.8	57.70	1.8	62.30
1.9	46.78			1.9	25.83	2.1	67.95
				2	26.48	2.2	59.70
				2.1	45.57	2.3	67.85
				2.2	36.83	2.4	52.75
				2.3	37.23		
				2.4	32.31		
				2.5	42.60		
				2.6	43.84		
				2.7	40.30		
				2.8	43.93		

Table F-6. Percent Acetone in Leachate From Field Cells Constructed With a 30 cm Thick Soil Layer Containing Micaceous Clay and Exposed to Acetone.

Cell 13		Cell 14		Cell 15	
P.V	% Ace	P.V	% Ace.	P.V	% Ace.
<.1	12.87	<.1	14.74	<.1	4.28
.1	12.88	.1	15.05	.1	2.16
.2	15.10	.2	15.04	.2	4.11
.3	14.79	.3	8.60	.3	6.70
.4	8.50	.4	6.58	.4	17.85
.5	4.12	.5	8.01	.5	9.33
.6	5.77	.6	14.08		
.7	8.39	.7	12.76		
.8	8.91	.8	13.98		
.9	8.91	.9	15.69		
1	14.43	1	12.99		
1.1	11.43	1.1	13.34		
1.2	13.73	1.2	15.62		
1.3	14.49	1.3	26.31		
1.4	15.30	1.4	21.55		
1.5	26.15	1.5	16.81		
1.6	21.00				
1.7	16.28				

Table F-7. Percent Acetone in Leachate From Field Cells Constructed With Soil Containing Bentonitic Clays and Exposed to Acetone.

Cell 17		Cell 19		Cell 22		Cell 24	
P V	% Ace	P.V	% Ace.	P.V	% Ace.	P.V	% Ace.
		< 1	6.60	No leachate		No leachate	
		.1	10.50				
		.2	6.90				
.3	11.03	.3	11.75				
.4	10.45	.4	5.30				
.5	11.31	.5	15.50				
.6	10.73	.6	19.60				
		.7	8.10				
		.8	9.60				
		.9	4.80				

APPENDIX G

CHEMICAL CONCENTRATIONS IN SOIL SAMPLES FROM FIELD CELLS

NOTES

Cells 2, 6, and 12 had 3, 6, and 3.5 month wait periods, respectively, between the time the head was removed and when the cell was excavated and sampled. This delay period may have allowed the free xylene to drain out of the clay into the sand collection area. Some of the retained xylene may have then vaporized from the clay liner, thereby causing the concentration data for xylene in soil samples from Cells 2, 6, and 12 to be artificially low.

Table G-1 Concentration of Xylene in mg/kg in Soil Samples of Kaolinite Liners which Received Xylene Wastes.

Depth (cm)	Cell 2				Cell 4				Cell 10				Cell 12			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0-2.5	1,111	1,997	88	10	235	18	44	170	19	2	12,862	13	3	80	ND*	ND
2.5-5.0	47	8	4	4	1,214	45	238	303	4	0	872	1	0	18	ND	ND
5.0-7.5	8	6	19	4	5,0[illegible]	133	806	122	14	0	1,223	0	1	3,768	ND	ND
7.5-10.0	6	1,010	1,344	10	352	419	564	36	759	2	37	790	2	1,578	ND	ND
10.0-12.5	877	3,664	3,988	3,500	13	12	71	160	4,667	450	3	75	0	58	ND	ND
12.5-15.0	197	3,988	3,640	4,500	9,[illegible]91	2	0	1,669	5,742	1,182	15	1,833	4	16	ND	ND
15.0-17.5	2,049	ND	ND	ND	3,7[illegible]7	722	2,0[illegible]5	ND	9,887	1,822	144	ND	22	523	ND	ND
17.5-20.0	ND	ND	ND	ND	3,401	860	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

*ND - not determined.

Table G-2. Concentration of Xylene in mg/kg in Soil Samples of Mica Liners which Received Xylene Wastes.

Depth (cm)	Cell 5				Cell 6				Cell 8				Cell 11			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0-2.5	1,643	554	504	32	22	13	0	ND*	237	112	51	0	10	68	0	160
2.5-5.0	2,622	3,735	1,262	3,040	0	0	0	ND	251	1 027	105	0	0	5	0	13
5.0-7.5	7,595	10,435	3,909	5,455	0	0	0	ND	584	1,158	611	30	258	0	0	9
7.5-10 0	9,160	5,934	3,585	15,927	0	0	0	ND	714	4,035	2,031	809	[illegible]	833	0	0
10.0-12.5	1,891	5,319	316	5,631	3	1	0	ND	1,289	4,310	[illegible]	ND	555	377	0	603
12.5-15.0	3,312	57	0	934	1	3	0	ND	204	1,903	232	ND	23	3,614	0	2,450
15.0-17.5	4,639	2,304	12	1,483	1	0	611	ND	452	55	1,887	ND	[illegible]	2,241	21	[illegible]
17.5-20.0	8,217	ND	1,036	ND	7	ND	ND	ND	2,005	ND	3,952	ND	1,250	ND	ND	ND
20.0-22.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	4,609	ND	ND	ND	ND	ND

*ND - not determined.

Table C-3. Concentration of Xylene in mg/kg in Soil Samples of Bentonite Liners which Received Xylene Waste.

Depth (cm)	Cell 1				Cell 3				Cell 7				Cell 9			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0-2.5	84	34	642	593	201	<10	80	1,487	0	0	0	0	533	16	4	71
2.5-5.0	1,809	1,994	6,248	8,206	2,794	2,788	311	5,008	0	0	0	0	5,689	8	38	4
5.0-7.5	8,465	7,867	10,033	5,550	6,542	3,172	2,174	5,664	0	0	0	0	15,[illegible]69	31	685	1
7.5-10.0	11,395	2,349	20,140	4,988	1,340	520	1,420	7,504	0	0	0	0	23,09[illegible]	139	1,520	822
10.0-12.5	19,696	22,142	49,599	17,307	3,942	ND*	1,320	6,465	0	0	0	0	29,168	2,585	1,085	17,785
12.5-15.0	9,016	1,470	39,721	24,970	7,326	9,615	134	6,617	0	0	0	0	4,144	4,750	7,272	1,336
15.0-17.5	222	7,951	21,522	1,678	ND*	11,631	ND	17,606	0	0	0	0	12,706	2,409	7,500	2,542
17.5-20.0	1,517	ND	9,092	2,887	ND	ND	ND	ND	ND	ND	ND	ND	20,900	ND	11,352	6,960
					Undyed ped 392** Undyed ped 511 Dyed ped 13,112 Dyed ped 16,834				Dyed ped 435							

*ND - not determined.

** Concentration of xylene measured on dyed and undyed soil ped surfaces sampled during disassembly.

Table G-4. Concentration of Acetone in Percent in Soil Samples of 15 cm Thick Kaolinite Liners which Received Acetone Waste.

Depth	Cell 18				Cell 20				Cell 25				Cell 28			
(cm)	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0-2.5	0	0.02	0.17	0.02	6.8	5.8	1.9	5.9	1.1	1.6	1.0	5.9	1.6	0.8	1.0	1.3
2.5-5	0	0.41	0.02	0.01	6.2	5.9	5.0	5.7	1.2	1.0	1.2	1.7	1.9	1.7	1.8	0.8
5-7.5	0.05	0.01	0.05	0.04	6.1	5.4	5.5	5.9	1.4	1.7	3.6	ND*	2.1	1.6	0.7	0.4
7.5-10	0.04	0.0	0.08	0.02	6.9	5.6	5.6	5.8	1.0	1.0	1.1	0.8	1.6	1.0	0.9	0.9
10-12.5	0.18	0.006	0.01	0.08	6.7	5.0	5.7	5.3	2.4	2.1	1.0	2.2	0.1	1.0	0.6	0.5
12.5-15	0.007	0.01	0.03	0.02	5.8	5.6	6.4	5.7	1.3	1.1	1.4	1 6	2.1	2.0	0.7	0.6
15-17.5					6.1	6.2	7.2	5.7	0.8	2.7	0.9	1.8	1.3			0.9
17.5-20							7.8	6.1								
20-22.5																

Cell 20		Cell 25		Cell 28	
Dyed Ped G-6	5.9	Ped Face	1.5	Cut Surface	1.0
Undyed Ped G-6	6.4	Ped Face	1.3	Ped Face	0.6
Dyed Ped G-2	8.1	Dyed Ped Face 1	0.3	Cut Surface	0.6
Undyed Ped G-2	6.8	Cut Surface 1	1.1	Ped Face	1.3
		Cut Surface	0.9		
		Dyed Ped Face 2	1.5		
		Cut Surface	13.9		

*Not determined

Table G-5. Concentration of Acetone in Percent in Soil Samples of Mica Liners which Received Acetone Wastes.

Depth (cm)	Cell 21				Cell 23				Cell 26				Cell 27			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0-2.5	2.5	2.8	2.4	3.2	1.1	1.4	0.6	1.5	2.3	4.0	2.2	3.7	0.3	0.3	0.1	0.0
2.5-5.0	2.4	2.8	3.0	3.6	1.5	1.5	0.7	1.5	3.0	2.5	2.7	3.1	0.4	0.1	0.1	0.2
5.0-7.5	2.2	2.4	2.7	3.2	1.7	1.0	0.6	1.3	3.1	2.3	3.2	2.6	0.3	0.4	1.1	0.5
7.5-10.0	2.6	2.2	2.3	2.5	1.8	1.1	0.5	1.8	3.5	2.2	2.8	2.9	1.2	0.2	0.0	0.4
10.0-12.5	2.5	2.2	2.7	2.8	2.2	1.1	0.8	2.0	3.5	2.7	2.8	2.7	0.9	0.3	0.1	0.1
12.5-15.0	2.8	2.1	3.2	2.8	2.1	1.6	0.9	2.0	3.4	2.6	3.5	3.1	0.6	ND	0.3	0.3
15.0-17.5	2.7	2.9	3.2	3.7	ND*	ND	ND	2.8	3.3	2.6	3.5	2.1	1.2	ND	ND	ND

*ND - not determined.

Table G-6. Concentration of acetone in percent in soil samples of 30 cm thick mica liners which received acetone waste.

Depth (cm)	Cell 13				Cell 14				Cell 15			
	1	2	3	4	1	2	3	4	1	2	3	4
0-2.5	5.9	6.5	5.9	6.7	2.5	1.4	1.6	2.2	1.2	1.5	2.1	1.7
2.5-5	5.3	6.2	5.0	5.7	ND*	1.8	1.9	1.7	0.8	2.4	0.7	1.8
5-7.5	5.4	6.0	5.7	6.5	3.2	1.5	1.1	1.8	1.5	2.1	1.8	1.4
7.5-10	5.4	5.9	5.4	6.2	2.8	1.4	1.6	1.8	1.6	2.2	1.1	2.2
10-12.5	5.5	5.1	5.7	5.6	3.3	2.0	2.4	1.9	1.6	2.1	1.9	0.5
12.5-15	5.8	5.6	5.6	[illegible].5	3.3	1.9	1.4	2.4	1.1	2.4	0.7	1.9
15-17.5	6.0	6.1	4.8	5.1	2.3	2.0	1.7	1.9	1.3	1.4	2.1	ND
17.5-20	5.3	5.9	4.7	6.0	3.0	1.7	1.7	2.2	1.6	1.3	2.5	2.5
20-22.5	5.5	5.7	4.7	6.3	4.1	1.9	2.9	2.3	1.4	1.5	2.2	1.5
22.5-25	6.0	6.0	5.6	5.9	3.2	1.7	1.5	2.6	2.3	0.8	2.3	0.5
25-27.5	5.8	5.8	5.5	5.7	3.4	1.9	1.6	0.7	0.8	1.7	2.2	1.5
27.5-30	5.8	6.1	7.0	5.8	3.3	2.0	1.6	2.5	1.5	1.4	1.8	0.6

	Cell 13		Cell 14		Cell 15	
	Ped Face	4.8	Cut Surface I	2.7	Ped Face	1.6
	Ped Face	6.0	Cut Surface II	2.4	Ped Face	2.4
	Cut Surface	5.6	Ped Face I	1.4	Cut Surface	1.8
	Cut Surface	5.3	Ped Face II	1.5	Cut Surface	1.2

*Not determined

Table G-7.Concentration of Acetone in Percent in Soil Samples of Beontonite Liners Which Received Acetone Waste. waste.

Depth (cm)	Cell 17 1	Cell 17 2	Cell 17 3	Cell 17 4	Cell 19 1	Cell 19 2	Cell 19 3	Cell 19 4	Cell 22 1	Cell 22 2	Cell 22 3	Cell 22 4	Cell 24 1	Cell 24 2	Cell 24 3	Cell 24 4
0-2 5	8.7	26.3	8.5	10.1	8.2	7.5	ND*	ND	6.1	6.0	5.2	ND	2.6	0.76	3.0	1.9
2.5-5	6.5	9.5	8.9	8.7	8.4	7.5	8.3	6.3	7.6	7.7	5.4	5.4	2.3	1.7	2.6	2.2
5-7.5	7.7	31.8	5.8	7.7	6.8	7.7	8.3	6.9	4.8	4.4	4.6	3.9	3.1	2.1	2.4	1.7
7.5-10	5.4	6.7	6.1	6.4	9.6	7.7	7.2	9.1	6.3	5.7	7.0	4.8	2.6	1.4	2.3	1.4
10-12.5	5.8	ND	6.7	6.9	7.3	7.3	7.7	7.0	4.5	4.4	4.6	3.9	2.6	0.98	2.0	1.2
12.5-15	4.6	5.8	5.7	6.0	7.8	3.1	6.6	6.8	ND	4.8	4.3	5.0	1.8	0.92	1.5	1.3
15-17.5	8.1	1.6	6.0	6.0	7.4	3.3	7.6	7.3	4.2	4.0	5.4	4.5	1.6	1.2	2.0	0.82
17.5-20							6.8	7.0								
20-22.5																

Cell 17		Cell 19		Cell 22	
Ped Face	5.6	Ped Face	5.1	Ped Face	4.7
Cut Surface	6.8	Cut Surface 1	6.9	Ped Face	5.2
		Cut Surface 2	5.6	Cut Surface	5.2
		Ped Face	5.0	Collection System 2	1.3
				Collection System 1	1.9

*Not determined.

APPENDIX H

AVERAGE CONDUCTIVITY OF COMPACTED SOILS TO WASTES USED IN FIELD CELLS

Table H-1. Average Laboratory Conductivity of Compacted Soil Containing Kaolinitic Clay to Xylene Waste Used in the Field Study at a Gradient of 181.

Replication 1		Replication 2		Replication 3	
Pore Vol.	Ave K	Pore Vol.	Ave K	Pore Vol.	Ave K
		<.1	3.31E-7	<.1	6.94E-7
.1	1.17E-6	.1	1.55E-6	.1	1.03E-5
.2	2.40E-6	.2	1.68E-6	.2	1.17E-5
.3	2.41E-6	.3	1.74E-6	.3	1.18E-5
.4	2.67E-6	.4	1.85E-6	.4	1.29E-5
.5	2.91E-6	.5	1.90E-6	.5	1.38E-5
.6	2.73E-6	.6	1.95E-6	.6	1.43E-5
.7	2.78E-6	.7	1.92E-6	.7	1.48E-5
.8	2.75E-6	.9	1.70E-6	.8	1.57E-5
.9	2.70E-6	1	1.79E-6	.9	1.55E-5
1	2.89E-6	1.1	1.96E-6	1	1.55E-5
1.1	2.78E-6			1.1	1.49E-5
1.2	2.51E-6			1.2	1.56E-5
1.3	2.40E-6			1.4	1.62E-5
1.4	1.79E-6			1.5	1.61E-5
1.5	1.44E-6			1.6	1.66E-5
				1.7	1.62E-5
				1.8	1.58E-5
				1.9	1.58E-5
				2.1	1.64E-5
				2.3	1.68E-5
				2.5	1.64E-5
				2.6	1.65E-5
				2.7	1.64E-5
				2.8	1.68E-5
				2.9	1.63E-5

Table II-2. Average Laboratory Conductivity of Compacted Soil Containing Micaceous Clay to Waste Xylene Used in the Field Study at a Gradient of 181.

Replication 1		Replication 2		Replication 3	
Pore Vol.	Ave K	Pore Vol.	Ave K	Pore Vol.	Ave K
				.1	4.14E-6
		.2	3.38E-6	.2	5.01E-6
.3	1.80E-6	.4	1.03E-5	.3	4.85E-6
.4	1.29E-5	.5	1.84E-5	.4	4.73E-6
.5	1.05E-5	.6	1.51E-5	.5	4.53E-6
.6	1.27E-5	.7	1.51E-5	.6	4.39E-6
.7	1.14E-5	.8	1.51E-5	.7	3.57E-6
.8	1.12E-5	.9	1.51E-5	.8	3.99E-6
.9	1.12E-5	1	1.53E-5	.9	3.77E-6
1	1.19E-5	1.1	1.58E-5	1	3.64E-6
1.1	1.01E-5	1.2	1.63E-5	1.1	3.48E-6
1.2	1.08E-5	1.3	1.66E-5	1.2	3.10E-6
1.3	1.12E-5	1.4	1.65E-5	1.3	3.14E-6
1.4	1.06E-5	1.5	1.62E-5	1.4	2.98E-6
1.5	1.05E-5	1.6	1.58E-5	1.5	2.90E-6
1.6	1.05E-5	1.7	1.56E-5	1.6	2.91E-6
1.7	9.87E-6	1.8	1.57E-5		
1.8	9.87E-6	1.9	1.52E-5		
1.9	1.03E-5	2	1.50E-5		
		2.1	1.49E-5		
		2.2	1.49E-5		
		2.3	1.47E-5		
		2.4	1.41E-5		

Table II-3. Average Laboratory Conductivity of Compacted Soil Containing Bentonitic Clay to Xylene at a Gradient of 181.

Replication 1		Replication 2		Replication 3	
Pore Vol.	Ave K	Pore Vol.	Ave K	Pore Vol.	Ave K
.1	2.28E-7	.1	1.41E-6	.1	2.23E-6
.2	1.60E-7	.3	1.53E-6	.2	3.28E-6
.5	7.47E-8	.4	1.31E-6	.3	2.95E-6
.7	3.87E-8	.7	1.04E-6	.4	3.06E-6
.9	2.61E-8	.8	9.88E-7	.5	2.95E-6
1	1.35E-8	.9	8.64E-7	.6	2.78E-6
1.1	1.17E-8	1.7	2.79E-7	.7	2.60E-6
1.2	8.72E-9	1.8	2.00E-7	.8	2.66E-6
		1.9	1.89E-7	1.4	1.65E-6

Table H-4. Average Laboratory Conductivity of Compacted Soil Containing Kaolinitic Clay to Acetone Used in the Field Study at a Gradient of 181.

Replication 1		Replication 2		Replication 3	
Pore Vol.	Ave K	Pore Vol.	Ave K	Pore Vol.	Ave K
		<.1	3.16E-8		
		.1	5.22E-9	.1	4.43E-7
		.2	3.16E-9	.5	9.80E-6
.3	3.57E-6	.3	2.14E-9	.6	4.53E-7
.4	3.30E-9	.4	1.7[illegible]E-9	.8	7.80E-8
.5	2.24E-9	.5	2.33E-9	.9	3.13E-9
.6	2.95E-9	.6	2.70E-9	1	2.02E-9
.7	2.31E-9	.7	3.13E-9	1.1	1.87E-9
.8	2.59E-9	.8	4.40E-9	1.2	3.88E-9
.9	2.93E-9	.9	5.20E-9	1.3	2.75E-9
1	4.47E-9	1	6.27E-9	1.4	2.38E-9
1.1	5.77E-9	1.1	5.19E-9	1.5	2.[illegible]
1.2	6.24E-9	1.3	6.58E-9	1.6	2.96[illegible]
1.4	5.66E-9	1.4	5.65E-9	1.7	3.0[illegible]E-9
1.5	4.90E-9	1.5	7.60E-9	1.8	3.84E-9
1.7	6.28E-9	1.7	6.55E-9	1.9	74E-9
		1.9	7.67E-9	2	3.88E-9
				2.1	4.14E-9
				2.2	3.95E-9
				2.3	3.96E-9
				2.5	4.59E-9

Table H-5. Average Laboratory Conductivity of Compacted Soil Containing Micaceous Clay to Acetone Used in the Field Study at a Gradient of 181.

Replication 1		Replication 2		Replication 3	
Pore Vol.	Ave K	Pore Vol.	Ave K	Pore Vol.	Ave K
<.1	8.25E-9			<.1	6.20E-9
.1	1.84E-8			.1	5.70E-9
.2	1.37E-8	.2	1.67E-8	.2	4.12E-9
.3	1.60E-8	.4	7.54E-9	.3	2.60E-9
.5	1.26E-8	.5	6.48E-9	.4	8.10E-9
.6	1.95E-8	.6	5.93E-9	.5	7.56E-9
.7	1.25E-8	.7	6.44E-9	.6	6.63E-9
1	1.75E-8	.8	5.83E-9	.9	6.98E-9
1.1	1.94E-8	.9	7.66E-9	1	8.57E-9
1.2	1.53E-8	1.1	8.77E-9		
1.3	2.06E-8	1.2	1.92E-8		
1.4	2.03E-8	1.3	1.04E-8		
1.8	2.22E-8	1.5	1.18E-8		
		1.6	1.33E-8		
		1.7	1.34E-8		
		1.9	1.35E-8		