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CHANGES IN THE HYDRAULIC PROPERTIES OF A SOIL
CAUSED BY CONSTRUCTION OF A WASTE TRENCH AT A
RADIOACTIVE WASTE DISPOSAL SITE

A Thesis

Presented to

The Faculty of the Department of Geology

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Stephanie Shakofsky

December, 1993

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ABSTRACT

CHANGES IN THE HYDRAULIC PROPERTIES OF A SOIL CAUSED BY CONSTRUCTION OF A WASTE TRENCH AT A RADIOACTIVE WASTE DISPOSAL SITE

by Stephanie Shakofsky

The changes in soil properties induced by the construction of a simulated waste burial trench were measured at a radioactive waste disposal site in the semi-arid southeast region of Idaho. Samples of an aridisol soil were collected, using a hydraulically-driven sampler to minimize sample disruption, from both a simulated waste trench and an undisturbed area nearby.

Results show an undisturbed profile with distinct horizons, whereas in the waste trench these layers are absent. Porosity was increased in the disturbed cores, and, correspondingly, saturated hydraulic conductivities were higher. Unsaturated hydraulic conductivities for the undisturbed cores were typically greater than the disturbed cores at higher water contents (greater than 0.32). At lower water contents a majority of the disturbed cores have greater hydraulic conductivities. In general the vertical movement of water is retarded in a layered medium, suggesting that the construction of the landfill has destroyed impediments to downward flow.

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INTRODUCTION

The major concern with waste isolation in shallow trenches or landfills is the infiltration of water and the eventual transport of contaminants to the groundwater. Hazardous waste sites in arid or semi-arid regions are currently regarded as less risky because they receive minimal precipitation and are usually underlain by thick unsaturated zones. However, the potential for contaminant transport is always at issue and can only be addressed by a quantitative, hydrological site characterization.

A critical element of such a characterization is analysis of the unsaturated flow. Knowledge of soil hydraulic properties is an essential requirement for prediction of flow through the unsaturated zone. A complete study involving unsaturated flow requires knowledge of the hydraulic conductivity (K) and the relation between water content (θ) and matric potential (ψ), and should include an understanding of the soil profile and any artificial disturbances to the profile.

The K , θ , and ψ relations are often not directly measured but are estimated by a computational procedure. Common strategies include inferring soil hydraulic parameters from empirical or theoretical relationships based on particle-size or pore-size distributions, or using measured values from presumably comparable situations. Such techniques can involve errors of an order of magnitude or more. Additionally, these

methods are inadequate for the assessment of complicating factors such as soil layering, spatial variability, the presence of aggregates and macropores, and unstable flow phenomena that can critically influence the fluxes of water. For these reasons it is important to have field and laboratory techniques that directly measure the hydraulic properties with a high degree of accuracy.

This study was undertaken at a radioactive and chemical waste landfill to characterize the soil properties that govern flow in both an undisturbed soil profile and an adjacent simulated waste trench.

Idaho National Engineering Laboratory (INEL)

The Idaho National Engineering Laboratory (INEL), established in 1949 by the Department of Energy (DOE), is primarily dedicated to the advancement of commercial nuclear energy. The INEL is situated on the eastern Snake River Plain in southeastern Idaho and comprises approximately 2300 km² (Fig. 1).

The Radioactive Waste Management Complex (RWMC), located in the southwest corner of the INEL, was established in 1952 as a controlled area for the management of radioactive waste. The site is relatively level and is situated in a shallow depression surrounded by low hills (Fig. 2). Due to the topographic situation of the RWMC, the area is vulnerable to flooding,

Figure 1. Location map showing boundary of INEL and generalized direction of groundwater flow (Pittman, et al., 1988).

Figure 2. Site map of the INEL showing the Radioactive Waste Management Complex (RWMC) and the USGS test trench area. The Subsurface Disposal Area (SDA) comprises the western 60% of the RWMC. (Pittman, 1989).

having been flooded three times in the recent past (1962, 1969, and 1982) as a result of rapid spring snow melt.

Chemical and low level and transuranic radioactive wastes, mostly stored in 55 gallon drums, were buried in trenches and pits in the surficial sediments, approximately 3 to 6 meters below the surface, at the Subsurface Disposal Area within the RWMC. From 1952 to 1986, approximately 180,000 m³ of chemical and radioactive wastes, with a total activity of approximately 9.5 million Curies of radioactivity, were buried at the Subsurface Disposal Area. Groundwater monitoring wells in and downgradient of the RWMC show that contamination by organic compounds has occurred (Laney and Minkin, 1988). Radionuclide migration has occurred at the site, and radionuclides have been detected to a depth of approximately 34 meters below the surface (Humphrey et al., 1982). A comprehensive study to determine the potential for future migration of radionuclides into the underlying Snake River Plain aquifer, approximately 180 meters below the surface, has been undertaken by the DOE, in cooperation with the United States Geological Survey (USGS).

Because hydrologic experimentation in the waste pits is potentially dangerous, the USGS in 1986 constructed a simulated waste trench just north of the SDA boundary (Davis and Pittman, 1990). In constructing the simulated waste trench (Fig. 3), an attempt was made to employ the

Figure 3. Cross section of simulated waste trench within USGS test trench area showing excavated area and location of neutron probes (Pittman, unpublished data).

methods of waste burial historically practiced at the Subsurface Disposal Area. This practice involved excavation of the trench to the top basalt layer (ranging between 3 to 6 meters below the ground surface), emplacement of the barrels, and backfilling the trench with the excavated soil. Neither compaction of soil nor capping of the trench were regular practices at the SDA.

Because the ease with which radionuclides migrate depends greatly upon the amount of water reaching and passing through buried waste, the objective of the overall effort at the USGS Test Trench is to model the Subsurface Disposal Area and to investigate water movement through the unsaturated surficial sediments. The study is designed to obtain a reliable estimate of the quantity of water that infiltrates, comes in contact with the waste, and eventually recharges the aquifer in this area.

Water Movement in the Unsaturated Zone

Water movement in the unsaturated zone is driven mostly by gravitational and capillary forces. The matric potential (ψ) in an unsaturated soil is a measure of the water pressure in the soil, which is negative. The gradient of this potential constitutes a driving force, as a result of which water flows from where total potential is higher to where it is lower. The matric potential depends on the soil moisture content (θ)

increasing as the soil moisture content increases. Generally, at soil moisture contents close to saturation, gravitational force dominates; however, as the soil dries, the matric potential gradient becomes much greater than the gravitational force. The nonlinear relationship between θ and ψ is called a soil moisture retention curve.

The amount of water retained at relatively high values of matric potential, between 0 and -1 atmosphere, depends primarily upon the pore-size distribution (Hillel, 1980). Effective pore size is commonly related to ψ by the capillary equation:

$$-\psi = 2\gamma/r$$

where: γ = surface tension between liquid and air

r = pore radius

Therefore, as ψ decreases, the largest pores empty out first followed by progressively smaller pores.

When ψ has decreased to the point where only the narrowest pores retain water, most of the water is held in hydration envelopes as adsorbed water, and the size and shape of pores have little influence. Therefore, the soil moisture retention curves may be nearly identical for many soils in the low matric potential range (i.e., less than -1 atmosphere), where the predominant mechanism of water retention is adsorptive rather than capillary, and the retention capacity becomes more of a textural than a

structural characteristic.

The hydraulic conductivity of an unsaturated soil depends on soil moisture content. In a saturated soil all the pores are water filled and conducting and hydraulic conductivity is maximal. But, as the soil desaturates, the larger pores empty and become air filled, and flow is restricted to the interconnections between smaller and smaller water filled pores. Thus, as the soil desaturates, tortuosity increases and hydraulic conductivity decreases.

Existing radioactive waste disposal sites have provided an opportunity for characterizing the hydrologic and geologic factors that affect water and radionuclide movement through the unsaturated zone. Schultz (1984) examined unsaturated water movement through trench covers at a site in Maxey Flats, Kentucky. Mills and Healey (1991) characterized water and tritium movement through the portion of the unsaturated zone beneath the waste trenches at a low level radioactive site near Sheffield, Illinois. Johnson et al. (1983) also examined water movement through experimental trench covers at the Sheffield site. Gruber (1983) looked at water movement in and between burial trenches at a radioactive waste disposal site in Aiken, South Carolina. Rates and directions of water movement through the unsaturated zone at a low-level radioactive waste site near Beatty, Nevada, were determined in a 1990 study by Fischer. These studies

investigated only the hydraulic properties of undisturbed soils or hydraulically engineered trench caps. Few studies have been conducted to investigate how soil disruption by the construction of waste burial trenches affects the rate of water movement through the trenches.

Historically, studies concerned with the mechanical disruption of *in situ* soils have focused mainly on agricultural applications, predominantly the effects of tillage or compaction by vehicle traffic, and have rarely included the region below the root zone (Klute, 1982; Ehlers, 1977; Allmaras et al., 1977; Jayawardane and Prathapar, 1992).

Study Objectives

This study compares the hydraulic characteristics of both the undisturbed soil profile and the disturbed burial trench, focusing on the changes that occur when a soil is disturbed by the construction of a waste trench. Specifically, this study examines the texture, bulk density, porosity, and aggregation of an undisturbed and a disturbed soil and the effects of these properties on soil moisture retention and hydraulic conductivities.

Employing laboratory techniques on both a disturbed simulated waste trench soil and undisturbed soil adjacent to the simulated waste trench, an attempt was made to determine the effects of disturbance on soil hydraulic properties.

This study determined the physical and hydraulic properties of minimally disrupted soil core samples, including at least two each of disturbed and undisturbed from 18, 30, 80, 145, and 235 cm average depths. To minimize disruption of the soil sample in the laboratory, the hydraulic experiments were carried out with the sample remaining in its original soil ring (i.e., no recoring, repacking, or subsampling of the samples occurred).

STUDY AREA

Geologic Setting

The Eastern Snake River Plain is a structural basin approximately 325 km long and 100 km wide, and is underlain by a sequence of basalt flows intercalated with thin sedimentary units (Fig.4). These flow units, in turn, are underlain by older rhyolitic material.

The RWMC is located in a shallow depression floored by basaltic lava flows and by wind and water deposited sediments. It is surrounded by hummocky basalt flows of low relief which control the thickness of the overlying surficial sediment. The surficial sediment consists of approximately 3 to 6 meters of sand, silt, clay, and lesser amounts of gravel. The sediments are dominantly flood plain and wind blown deposits. The fluvial deposits resulted from periodic Late Pleistocene and Holocene incursions of the Big Lost River into the area. Sediments from ephemeral lacustrine environments are also present (Rightmire and Lewis, 1987).

Stratigraphic relations in the unsaturated zone and uppermost part of the aquifer are the result of 10 major cycles of volcanism and sediment deposition during the past 600,000 years. Brief volcanic eruptions from at least 10 different source vents resulted in periodic inundation of the area by basaltic lava flows and cinders. Individual flows range in thickness from 7 to 51 meters. Long intervals of volcanic inactivity were marked by the

Figure 4. Cross section of subsurface geology at the Radioactive Waste Management Complex (RWMC) (Anderson and Lewis, 1989).

accumulation of sediment in stream channels, floodplains, playas, and dunes. The sedimentary sequences vary in thickness from 0 to 12 meters, averaging about 1.5 meters. The very thick sedimentary sequence between C and D, mostly silt and clay, is probably the remnant of a shallow lake.

The youngest flow sequence in the RWMC consists of one to two flows that erupted from Quaking Aspen Butte, approximately 19 kilometers southwest of the RWMC, and flowed down the valley of the Big Lost River. The age is $95,000 \pm 50,000$ years based on K-Ar ratios (Anderson and Lewis, 1989).

Hydrogeologic Setting

Basaltic rock and intercalated sediment of the eastern Snake River Plain form the Snake River Plain Aquifer, one of the world's largest aquifers. The aquifer is estimated to have a potential storage capacity of roughly 1 billion acre-feet of water. The aquifer is utilized extensively in industrial, agricultural, and domestic applications. At the RWMC, the depth to water is approximately 180 meters. Groundwater flow is generally to the south-southwest, and hydraulic conductivities range from 1.5 to 6 m/day (Robertson et al., 1974).

Climate

The INEL is bounded on the north, south and east by mountains and high plateaus. For the most part this area is sagebrush-covered and semi-arid. Based on National Oceanic and Atmospheric Administration (NOAA) records from 1950 to 1988 (Clawson et al., 1989), the area receives an average annual precipitation of 221 mm, with about 30 percent falling as snow. The annual precipitation at the RWMC for 1986 and 1987 was 240 mm and 175 mm, respectively. The average daily air temperatures for 1987 at the USGS test trench ranged from 26.7 °C on August 6, to -14.6 °C on December 25 (Davis and Pittman, 1990).

METHODS

Field Methods

During two site visits in June 1991 and August 1992, thirty-five soil core samples for use in hydraulic property studies were collected from twelve hand-augured bore holes at two locations within the USGS Test Trench area: (1) the undisturbed north-central portion, and (2) the simulated waste pit area (Figure 5). Four samples from 18 cm depth, collected by traditional hammering technique during an October 1990 site visit, were also used in this study.

Sample Collection

During sample collection, some soil properties are irreversibly changed to a greater or lesser extent. Several mechanisms that result in disturbance during soil sampling have been identified (Gilbert, 1992):

1. Compression, extension, shear, and vibration due to the intrusion of the sampling tube;
2. Tension and shear as the tube is extracted;
3. Shock and structural disturbance during transportation and storage; and
4. Compression, extension, shear, and vibration during extrusion and trimming operations.

Hydraulic conductivity measurements are particularly vulnerable to

Figure 5. Site map of USGS test trench area with sampling locations (compiled from Pittman, unpublished data).

sample disruption caused by sampling. Because the method of hydraulically pushing a sampler causes less disruption than other conventional methods such as hammering, samples for this study were collected with a thin-walled, hydraulically driven sampler. The sample cores are 5.1 cm in height and 5.0 cm in diameter. Sampling holes were hand-augured and sample cores were collected at intervals between 0.29 m and 3.25 m depth. Samples were then trimmed, weighed, capped, and wrapped in aluminum foil to prevent moisture loss. The soil trimmings were retained for use in particle size analysis.

Soil Aggregate Determination

It is well known that many structural features change during the various seasons of the year. Aggregation can deteriorate rapidly as the aggregates are subjected to seasonal precipitation, which causes slaking, swelling, shrinkage, and erosion. Because aggregate distribution is a dynamic property, this study evaluates and discusses only those differences observed between undisturbed and disturbed soils at the time of sampling.

During sample collection in August 1992, a dry sieve analysis method (Burke et al., 1986) was performed. The method is based on the simple principle of sieving the soil to separate aggregates of different sizes. Samples used for analysis were collected from a hand-augured bore hole

with a "riverside" auger. Approximately one kilogram of soil was collected then rotated in a series of nested sieves (4, 2, and 1 mm) for three minutes. Each aggregate fraction was then weighed in the field.

Carbonate Content Determination

A qualitative index of calcium carbonate content was obtained in the field by observing the reaction of the soil with five percent hydrochloric acid solution.

Laboratory Methods

Physical Properties

Particle Size Analysis. Particle size analysis (PSA) on all the samples was performed using a Coulter LS100 Optical Particle Size Analyzer. This machine directs a beam of light through an aqueous suspension of the particles and measures the diffracted light. An array of detectors measures how much light is scattered through various angles. The computer then calculates a particle size distribution from the scattered light observed by the detectors.

Samples were sieved through a 1-mm sieve and then split using a spinning riffler. Approximately 0.3 gram of sample was utilized for each measurement. In order to adequately disperse the soil, pretreatment of the

sample included 15 minutes of sonication in an ultrasonic bath.

Additionally, since optical methods are not currently in wide use for soil application, four samples (two disturbed and two undisturbed) were also measured by the traditional pipette and sieving method (Gee and Bauder, 1986) for comparison with the optical method. The samples were measured once with Sodium Hexametaphosphate (HMP) pretreatment only, to deflocculate the clays, and then again after the following pretreatments: 1) hydrogen peroxide washing to remove organics and carbonate, 2) centrifuging with distilled water to remove soluble salts, and 3) addition of HMP to deflocculate the clays.

Bulk Density. Soil cores were oven dried at 110°C and weighed daily until the change in mass was less than or equal to 0.02 g (approximately 4-5 days). Bulk density was calculated from the measurement of the oven-dry mass (M_o), of soil and the known soil ring volume (V_r):

$$\text{Bulk density} = M_o/V_r$$

Porosity. Porosity was calculated from the bulk density measurement using a value of 2.65 g/cm³ for particle density:

$$\text{Porosity} = 1 - (\text{bulk density}/\text{particle density})$$

Hydraulic Properties

Soil Moisture Retention Curves. The fundamental relationship of moisture content (θ) and matric potential (ψ) was determined by means of a modified tension plate assembly: a submersible pressure outflow cell (SPOC) (Constanz and Herkelrath, 1984).

Each sample was sealed in the SPOC apparatus and suspended in a bath of 0.005 mol/L of CaSeO and CaSO_4 (to minimize biological growth and simulate a natural electrolyte balance), hanging from an electronic balance that measured sample weight. Pressure increments were applied to an initially saturated soil. At each pressure increment water was driven out of the sample until each sample met an equilibration criterion: change of sample weight less than or equal to 0.02 gram in a 14 hour period. The applied air pressure was equated to a matric potential, taking into account a correction for the submerged depth of the sample. The sample weights at equilibrium points were converted to moisture contents after samples were dried to a constant weight in an oven at 110°C and reweighed. The difference in weight measurements is equal to the water content on a dry mass basis.

Measurements were taken in the 0 to 1 atmosphere range where moisture retention is strongly influenced by the soil structure and where differences had been expected for a disturbed versus undisturbed soil.

Saturated Hydraulic Conductivity. Saturated hydraulic conductivity (K_{sat}) was measured by a falling head method (Klute and Dirksen, 1986). K_{sat} measurements were performed immediately after the soil ring was removed from the SPOC apparatus. The K_{sat} apparatus consisted of an open, cylindrical reservoir sealed with an O-ring to the top of the soil core sample. A stainless steel filter on the bottom of the soil ring allowed for the outflow of solution while minimizing soil loss. When the cores were initially placed into the K_{sat} apparatus, their saturation was about 75%. Because complete saturation is necessary for the K_{sat} measurement, wetting of the sample was accomplished with de-aired 0.005 mol/L of $CaSeO$ and $CaSO_4$ solution, allowing the sample to saturate from the bottom upwards for at least 24 hours. Then the reservoir above the sample was carefully filled with de-aired, selenate solution. As water flowed through the sample under the influence of gravity, the drop in water level was repeatedly measured using a depth gauge to an accuracy of ± 0.02 mm. K_{sat} measurements in the laboratory are known to vary with time due to the changes in trapped air and growth of soil microorganisms (Christiansen, 1944; Allison, 1947). It was found that a minimum of six runs (a run being equivalent to one full reservoir, approximately 220 cm³ of solution, running through the soil core) was necessary to achieve a constant K_{sat} .

Unsaturated Hydraulic Conductivity, Transient Method. The $K(\theta)$ values were generated using the one-step outflow method, a transient flow method originally described by Gardner (1956). The one-step outflow method directly produces values of diffusivity, $D(\theta)$. Unsaturated hydraulic conductivity, $K(\theta)$, is then calculated using $\theta(\psi)$ values from the SPOC data and the equation:

$$K(\theta) = D(\theta) (d\theta/d\psi)$$

The one-step outflow experiments were carried out at the end of the moisture retention experiment while the samples were still in the SPOC apparatus. When the last equilibrium point was established for the moisture retention curve, the sample was then allowed to resaturate. Then a positive air pressure of 1000 cm water was applied to the saturated sample and the change in sample weight was recorded as a function of time. $D(\theta)$ was calculated by the method of Passioura (1976).

Unsaturated Hydraulic Conductivity, Steady State Method. For accurate measurements of $K(\theta)$, steady state methods are preferable to transient methods because many critical elements of a transient method must be inferred by approximation or assumption. Steady state methods are more direct, and are considered more accurate. As a check on the one step outflow method, and because of the extra time necessary for steady state, only two samples were measured for $K(\psi)$ in a steady state

experiment after the transient method had been performed. The method used was the Steady State Centrifuge Method (SSCM) (Nimmo et al., 1987). The centrifuge establishes steady flow in a way that permits measurement of the flux density (q). Application of Darcy's law for the method yields:

$$q = -K(\theta) [d\psi/dr - \rho\omega^2 r] \quad \text{where:}$$

$d\psi/dr$ = matric potential gradient

ρ = density of water

ω = centrifuge angular speed

r = distance from the center of rotation

At high centrifuge speeds the centrifugal driving force dominates, and the equation reduces to:

$$K(\theta) \approx q/\rho\omega^2 r.$$

The apparatus included a constant-head reservoir with an overflow hole that maintained a constant level of water above the ceramic plate on top of the soil core. After steady state was reached, that is, change in sample weight was less than 0.02 grams between runs, q was measured directly by weighing the various reservoirs. The sample weight was later transformed to a moisture content based on oven-dry weight.

RESULTS

Field Results

Soil Profile

A continuous core (CLC-3 on Figure 5) was drilled within the surficial sediments of an undisturbed area of the USGS Test Trench in October 1990. Drilling was completed to a depth of 5.8 meters before encountering basalt. Table 1 is a description of the continuous core as described in August 1992.

Table 1. Soil Profile Description

HORIZON	COLOR (Munsell Color Chart)	DEPTH (CM)	STRUCTURE	TEXTURE	Hydrochloric Acid Reaction
A	dark, yellowish, brown 10YR4/2	0-17	granular	sandy silt	none to moderate
B _{k1}	pale, yellowish, brown 10YR7/2	17-140	angular blocky (3-33mm), coarse to fine	sandy silt	moderate to strong
2B ₂	pale, yellowish, brown 10YR7/2	140-164	angular blocky (3-33mm), course to fine	clayey silt 10% sand	moderate
2C	moderate, yellowish, brown 10YR5/4	164-295	subangular blocky (30mm), medium to coarse	sandy silt	moderate to slight
3C ₂	moderate, yellowish, brown 10YR6/2	295-453	massive (buried soil?)	clayey silt	none to slight

Aggregate Distribution

The results of the dry sieving of the soil for determination of aggregate distribution are listed in Table 2. Normally, this method is

proposed for air dry soil, however, the moisture content of the soil at the time of sampling was considered low enough (ranging from 14 to 30 percent) that the sieve analysis could be carried out in the field.

Table 2. Aggregate Distribution

HOLE I.D.	DEPTH	>4.0 mm	4.0-2.0 mm	2.0-1.0 mm	<1.0 mm
UNDISTURBED	(cm)	percent by weight			
Anchor A	17-23	12.2	18.7	13.3	55.8
Anchor A	33-38	30.7	13.4	12.0	44.0
Anchor A	41-48	34.5	12.3	12.2	41.1
Hole 25	78-85	22.5	14.5	14.4	51.4
Hole 25	120-126	23.6	15.7	13.9	46.7
Hole 25	131-138	31.9	20.9	13.4	33.8
Hole 25	155-162	50.7	16.5	12.1	20.8
Hole 25	186-192	52.2	14.0	11.6	22.2
Hole 25	209-217	23.7	15.8	18.3	42.3
Hole 25	255-261	9.5	18.5	18.6	53.4
Hole 25	328-332	14.7	20.9	21.3	43.2
DISTURBED					
Anchor D	20-30	17.9	10.8	11.4	59.9
Anchor D	37-45	17.4	13.4	14.0	55.2
Anchor D	50-59	18.4	12.0	13.7	56.0
Hole 28	55-62	16.4	14.3	14.3	55.0
Hole 28	79-87	17.0	13.7	15.0	54.4
Hole 27	123-134	20.4	16.8	14.7	48.1
Hole 28	158-163	26.4	16.5	15.7	41.4
Hole 28	187-197	31.7	15.3	15.6	37.4
Hole 29	211-219	32.6	17.4	15.1	34.8
Hole 27	348-357	45.2	17.9	13.7	23.2

Laboratory Results

A comprehensive listing of measured soil properties and sample holes and numbers is presented in Table 4. The field θ values reported for samples that were not artificially wetted during sampling are computed from sample weight at time of collection and oven dry weight.

Table 4. Summary of Soil Properties

Hole No.	Sample No.	Depth (cm)	Bulk Density (g/cm ³)	Clay %	Field θ	Porosity	K _{sat} (cm/s)
UNDISTURBED							
9	2	18	1.400	13.7	.1052	.4716	---
3	13	18	1.392	---	.1752	.4746	---
17	9	27	1.427	18.2	.1478	.4615	1.6x10 ⁻³
14	1	33	1.478	17.7	---	.4424	4.4x10 ⁻⁴
14	8	75	1.372	19.1	.1412	.4821	5.5x10 ⁻³
16	3	80	1.434	20.2	---	.4589	3.3x10 ⁻³
16	4	129	1.458	24.1	.1827	.4497	2.6x10 ⁻³
26	B21	140	1.455	22.6	---	.4510	2.1x10 ⁻³
25	B17	148	1.460	24.1	---	.4490	1.7x10 ⁻³
16	5	175	1.407	25.1	.2725	.4691	5.6x10 ⁻⁴
26	B24	223	1.387	20.1	---	.4766	4.4x10 ⁻⁴
16	6	225	1.246	23.9	.2620	.5299	2.1x10 ⁻³
25	B20	226	1.228	14.2	---	.5367	2.3x10 ⁻³
DISTURBED							
12	1s	18	1.312	15.5	.2010	.5015	---
6	7	18	1.247	14.8	.1247	.5294	---
21	17	29	1.520	19.2	.2264	.4299	5.5x10 ⁻⁴
22	18	29	1.360	20.8	---	.4869	2.3x10 ⁻³
22	21	79	1.258	20.3	---	.5254	5.5x10 ⁻³
21	20	79	1.313	20.6	---	.5044	9.2x10 ⁻³
19	14	135	1.191	21.3	.1664	.5505	---
29	C12	147	1.387	20.4	---	.5640	4.4x10 ⁻³
27	C8	148	1.325	19.8	---	.5001	1.2x10 ⁻²
27	C10	223	1.208	19.5	---	.5441	6.0x10 ⁻³
29	C17	237	1.175	19.3	---	.5567	1.3x10 ⁻²

Particle Size Analysis

Comparison between the sieve and pipette and the optical method showed very small differences as seen in Table 5.

Table 5. Particle Size Distribution by Method

Sample	Depth (cm)	Sieve & Pipette (No Pretreatment)			Sieve & Pipette (Pretreated)			Optical Method (Sonication only)		
		Sand %	Silt %	Clay %	Sand %	Silt %	Clay %	Sand %	Silt %	Clay %
Undisturbed	75	34.1	51.3	14.6	34.3	48.8	16.9	29.7	51.3	19.1
Undisturbed	27	26.2	56.3	17.4	19.6	60.1	20.4	25.4	56.4	18.2
Disturbed	29	34.2	51.3	14.6	29.8	51.6	18.6	28.4	52.5	19.2
Disturbed	79	21.2	60.3	18.5	19.2	60.9	19.8	21.3	58.4	20.3

Sieve and pipette analysis performed by Laney and Minkin (1988) at the INEL showed similar results for undisturbed samples from approximately the same location and depth in the Test Trench area.

Figure 6 shows the particle size distribution with depth for the disturbed waste trench and the adjacent undisturbed area.

Soil Moisture Retention Curves

The moisture retention curves are plotted by depth in Figure 7. The most extreme differences between disturbed and undisturbed appear at the 235 centimeter depth. The undisturbed cores at this depth show high porosities and gradual slopes in their moisture retention curves. However,

Figure 6. Particle size distribution with depth.

Figure 7. Moisture retention drying curves for two samples from each of 5 depths in the simulated waste trench (disturbed) and from the same depths in the adjacent undisturbed area.

it appears that the disturbance, resulting in a small increase in porosity but a large increase in the number of larger pores, produced a substantially steeper curve.

Saturated Hydraulic Conductivity

The results of the K_{sat} experiments are shown in Figure 8. The change in conductivity decreases and the values stabilize after approximately 6 runs or 27 pore volumes of solution (a volume of about 220 cm^3 solution per run flowing through a sample with an average soil volume of 100 cm^3 and an average porosity of 0.50) are passed through the soil. The increase of K_{sat} with time and the eventual constant value obtained are presumably due to the removal of entrapped air and a decrease in microbial activity.

Unsaturated Hydraulic Conductivity, $K(\theta)$

The results of the two methods of $K(\theta)$, the transient one step outflow and the SSCM, as plotted in Figure 9, show general consistency between the two methods. Figure 10 compares $K(\theta)$ plots from the transient one step outflow method for disturbed and undisturbed cores with depth. The K_{sat} reported is the value of the final run of the data in Figure 8 and is also plotted in Figure 10.

Figure 8. K_{sat} variations with number of experimental runs.

Figure 9. Transient $K(\theta)$ and steady state $K(\theta)$.

Figure 10. $K(\theta)$ curves with K_{sat} plotted by depth in the disturbed simulated waste trench and from the same depths in the adjacent undisturbed area.

DISCUSSION

Figure 11 shows a distribution with depth of relative carbonate content, clay content, moisture content from neutron probe data collected at time of sampling, porosity, aggregates, and K_{sat} for both the undisturbed profile and the disturbed, simulated waste trench. Distinct horizon development is seen in the undisturbed profile. The most noteworthy feature in the simulated waste trench profile is the homogeneity of the soil profile. The absence of the natural layers is evident from the relatively smooth profiles of the aggregate distribution, clay content, and relative carbonate content in the disturbed simulated waste trench.

The calcic horizon described from the continuous core at the depth interval of 17-164 cm was confirmed in the field by the HCl test (Table 3). The increase in clay content at the 140-220 cm undisturbed depth interval, as determined by laboratory methods from samples collected in the undisturbed area, was not observed in the continuous core. It is not surprising, though, that the finger assessment method used for determining soil texture from the continuous core would not allow for the discernment of the 10 to 20% increase in clay content. After microbial gum, the most important constituent in the formation of aggregates is clay content, hence, the increase in clay is possibly the main factor responsible for the increase

Figure 11. Distribution with depth of carbonate, clay, moisture, porosity, aggregates, and K_{sat} in a silt loam aridisol. Profiles, composited from multiple sampling holes, are shown for both the undisturbed profile and the disturbed simulated waste trench.

in aggregation (Table 2) at the same depths.

The moisture contents plotted in Figure 11 were data taken at the time of sampling from neutron probe number 18 in the undisturbed area and neutron probe number 15 (Fig. 5 for location) in the simulated waste trench (Pittman, unpublished data). The increase in moisture content between the 140-220 cm depth is most likely the result of the increase in clay content.

What is most discernible about the disturbed soil profile is the destruction of the original horizoned profile. The clay content, carbonate profile, and aggregate distribution are more uniform through the disturbed profile than the undisturbed. As a result, the moisture content profile is uniform with depth. Construction of the simulated waste trench has essentially created an unlayered, homogenized soil of unconsolidated sediments with an increase in porosity of about 5 percent due to "fluffing" or "loosening" of the soil.

The heterogeneity of the undisturbed soil and the homogeneity of the disturbed soil are also apparent in the retention curves as shown in Figure 12. At the driest point on the undisturbed curves, where $\psi = -1000$ centimeters of water, the moisture contents range from 0.21 to 0.34 for the undisturbed soils. Lateral heterogeneity is also apparent since samples from the same depths are from different sampling holes ranging from about

Figure 12. Moisture retention drying curves for samples from 5 depths in the simulated waste trench and from the same depths in the adjacent undisturbed area.

1 to 30 meters apart. For the undisturbed cores at $\psi = -1000$ the moisture contents differ by as much as 0.06 at the 30 centimeter depth and by as little as 0.025 at the 145 centimeter depth. The moisture retention curves for the disturbed samples are strikingly similar in shape and the moisture contents at the driest point, $\psi = -1000$, vary between 0.22 and 0.28, a much smaller range than for the undisturbed samples. Additionally, the lateral heterogeneity, apparent in the undisturbed cores, is diminished in the disturbed cores, which differ in moisture content at $\psi = -1000$ by a maximum of 0.028 at the 30 centimeter depth and by a minimum of 0.003 at the 235 centimeter depth.

As listed in Table 4 the saturated hydraulic conductivities in the undisturbed profile range from 4.4×10^{-4} to 5.5×10^{-3} cm/s, and the saturated hydraulic conductivities in the disturbed profile range from 5.48×10^{-4} to 1.27×10^{-2} cm/s. Overall, K_{sat} in the disturbed cores is higher. A relationship between porosity and K_{sat} is predicted by the Kozeny-Carman equation, $K_{sat}(\phi) = [\phi^3/ca(1 - \phi)^2]$, where ϕ = porosity, a = specific surface exposed to the fluid, c = constant representing a particle shape factor. As porosity increases K_{sat} increases. Figure 13 plots porosity and $\log K_{sat}$ for undisturbed and disturbed samples at all depths sampled. The regression plot for the undisturbed samples displays an insignificant correlation, with a correlation coefficient $R^2 = 0.04$.

Figure 13. K_{sat} as a function of porosity with linear fit.

The disturbed samples show a stronger relationship between K_{sat} and porosity with $R^2 = 0.47$. Considering the assumptions for Kozeny-Carman of relatively uniform particle size and a structureless medium, it is understandable that the disturbed samples with uniform clay, aggregates, and carbonate profiles would more nearly conform to those assumptions. The higher K_{sat} values in the disturbed cores are most likely being controlled by the increase in porosity.

An inverse relationship between aggregates >4 mm and K_{sat} can be discerned in the undisturbed profile shown in Figure 11. As mentioned earlier the increase in large aggregates is most likely being controlled by the increase in clay at the 140-220 cm depth, and, thus, because of the higher clay content the K_{sat} is lower at this depth even with the increase in large aggregates.

It is well known that disturbing a soil by "fluffing" or "loosening" will tend to decrease its bulk density and increase its total porosity. Several studies have also shown that soil disturbance will destroy macroporosity (Ehlers, 1975; Warner and Nieber, 1991; Roseberg and McCoy, 1991). What these studies observed in the disturbed soils was the destruction of insect burrows and rootlet channels, yielding an overall decrease in macroporosity, while still showing an increase in porosity. Pore size distributions are calculated for this study from the moisture retention curve data based on

the capillary equation $r = 2\gamma/(-\psi)$, where r = pore radius and γ = surface tension of the soil solution, which is estimated at 67 mN/m based on studies by Chen and Schnitzer (1978) and Tschapek et al. (1978). The disturbed cores show an increase in pore sizes for the range of ψ measured as shown in Figure 14. Although pore sizes greater than 0.13 mm could not be measured, it is possible that the observed increase in pore sizes in the disturbed cores, shown in Figure 14, is a result of the destruction of larger pores and their replacement by smaller-sized pores. This interpretation could also help to explain the $K(\theta)$ relationships.

The $K(\theta)$ relationships in disturbed and undisturbed soils are plotted in Figure 15. The linear regression of the $\log K$ shows that the undisturbed soil is on average higher in hydraulic conductivity at water contents above 0.32. At lower water contents there is a tendency for the disturbed soil to have higher conductivity. This effect might be expected based on the lack of large pores in the disturbed soil. The loss of large pores and channels will decrease conductivity at higher moisture contents. However, the resultant increase in smaller pores will have the effect of increasing the conductivity at lower water contents. This result is consistent with the data of other studies on disturbed versus undisturbed loamy soils (Ehlers, 1977; Allmaras et al., 1977; Jayawardane and Prathapar, 1992).

A visual examination of the soil cores indicate that while the larger pores may be destroyed, with an accompanying increase in smaller pores as illustrated in Figure 14, a significant increase in intermediate size pores is created (Figure 16). This increase in medium-sized pores may account for the higher saturated hydraulic conductivities in the disturbed samples.

Figure 14. Distribution of effective pore sizes, determined from the retention curves using the capillary hypothesis.

Figure 15. $K(\theta)$ relationships from the simulated waste trench (disturbed) and the adjacent undisturbed area with regression slopes.

1 cm

Figure 16. Photograph of disturbed soil core (left) and undisturbed soil core (right) from 130 cm depth.

CONCLUSIONS

Laboratory measurements of physical and hydraulic properties, supported by the field data collected during sampling, demonstrate substantial differences between the properties of the undisturbed soil and the disturbed trench soil. The undisturbed profile shows distinct layers, or horizons, with a high clay content layer at the 140-220 cm depth interval. These layers are to a large degree homogenized in the disturbed profile which shows relatively uniform profiles of carbonate, clay, moisture, and aggregates. The disturbed samples have higher porosities and higher K_{sat} values at each depth.

Moisture retention curves obtained from the disturbed waste trench show less vertical and lateral heterogeneity of the profile relative to the corresponding undisturbed core.

Although the disturbed soil has higher K_{sat} , a sharp decrease in K was measured after a slight decrease in θ . This decrease in conductivity might be interpreted as a result of the emptying of the intermediate size pores, which were created during soil disturbance. At lower water contents the hydraulic conductivity of the disturbed soil will be greater than that of the undisturbed soil.

Considering the influence of these measured differences on the downward movement of water, a major effect probably results from the lack

of pronounced layering in the simulated waste trench. In general, the presence of layers has a retarding effect on vertical flow. At INEL, the high clay content, low K_{sat} layer between about 130 and 170 cm depth in the undisturbed profile is likely to have a significant impeding effect.

Therefore, more water may remain above this depth where evapotranspiration losses are greater in the undisturbed than the disturbed profile.

The trenches may thus have wetter soil in the 3-6 m zone in which the waste is buried. Additionally, the higher the K_{sat} of a soil, the higher its infiltrability tends to be. When conditions are drier ($\theta < 0.32$), which is the case most of the year in semiarid eastern Idaho, downward percolation will tend to be greater in the disturbed soil because $K(\theta)$ is greater for this moisture range. If these effects are substantial, then the soil property-altering effects of landfill creation are a critical element in characterizing the potential for liquid transport.

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