APPENDIX F - STATISTICAL ANALYSES OF HYDRAULIC CONDUCTIVITY DATA

Statistical Comparison of K_{SDRI} and K_{TSB}

Store-and-Release Covers

F-Test Two-Sample for Variances

	K_{SDRI}	K_{TSB}		
Mean	-14.5509	-13.0977		
Variance	1.448922	10.18088		
Observations	6	48		
df	5	47		
F	0.142318			
P(F<=f) one-tail	0.018632		P<0.05	Equal Variance
F Critical one-tail	0.224751			

t-Test: Two-Sample Assuming Equal Variances

	K_{SDRI}	K_{TSB}		
Mean	-14.5509	-13.0977		
Variance	1.448922	10.18088		
Observations	6	48		
Pooled Variance	9.341273			
Hypothesized Mean Difference	0			
df	52			
t Stat	-1.09798			
P(T<=t) one-tail	0.138635		P>0.05	Data are similar
t Critical one-tail	1.674689			
P(T<=t) two-tail	0.27727			
t Critical two-tail	2.006647			

Statistical Comparison of K_{SDRI} and K_{TSB}

Conventional Covers with Clay Barriers

F-Test Two-Sample for Variances

	K_{SDRI}	K_{TSB}		
		-		
Mean	-15.2366	14.0796		
Variance	6.931005	9.05163		
Observations	3	18		
df	2	17		
F	0.765719			
P(F<=f) one-tail	0.519616		P>0.05	Not Equal Variance
F Critical one-tail	0.051448			

t-Test: Two-Sample Assuming Unequal Variances

	K_{SDRI}	K_{TSB}		
		-		
Mean	-15.2366	14.0796		
Variance	6.931005	9.05163		
Observations	3	18		
Hypothesized Mean Difference	0			
df	3			
t Stat	-0.6898			
P(T<=t) one-tail	0.269946		P>0.05	Data Are Similar
t Critical one-tail	2.353363			
P(T<=t) two-tail	0.539893			
t Critical two-tail	3.182446			

Statistical Comparison of K_{SDRI} and K_{TSB}

Conventional Covers with Composite Barriers

F-Test Two-Sample for Variances

	K_{SDRI}	K_{TSB}		
	-			
Mean	17.28961744	-15.0984		
Variance	0.112905114	1.543798		
Observations	3	17		
df	2	16		
F	0.07313465			
P(F<=f) one-tail	0.070215445		P>0.05	Not Equal Variance
F Critical one-tail	0.051458084			

t-Test: Two-Sample Assuming Unequal Variances

	K_{SDRI}	K_{TSB}		
	-			
Mean	17.28961744	-15.0984		
Variance	0.112905114	1.543798		
Observations	3	17		
Hypothesized Mean Difference	0			
df	13			
t Stat	-6.11396806			
P(T<=t) one-tail	1.84806E-05		P<0.05	Data Are Not Similar
t Critical one-tail	1.770933383			
P(T<=t) two-tail	3.69612E-05			
t Critical two-tail	2.160368652			

Table F-1. Statistical comparison of different size laboratory hydraulic conductivity test specimens using a two-sample t-Test assuming unequal variances.

Site	$K_{150\text{-mm}}$ to $K_{75\text{-mm}}$		$K_{L\text{-}LS}$ to $K_{L\text{-}SS}$	
	P(T<=t) one-tail	Statistically Similar	P(T<=t) one-tail	Statistically Similar
Store-and-Release Covers				
Altamont	-	-	0.004	No
Apple Valley	-	-	-	-
Boardman	0.111	Yes	0.001	No
Cedar Rapids			-	-
Helena	0.111	Yes	0.292	Yes
Monticello	0.059	Yes	0.203	Yes
Omaha 1	-	-	0.237	Yes
Omaha 2	0.247	Yes	0.010	Yes
Polson	-	-	0.405	Yes
Underwood	-	-	0.192	Yes
Sacramento 1	0.463	Yes	0.003	No
Sacramento 2	-	-	0.124	Yes
Conventional Covers with Clay Barriers				
Albany	-	-	-	-
Apple Valley	0.137	Yes	0.097	Yes
Cedar Rapids	-	-	0.107	Yes
Underwood 5'	-	-	0.185	Yes
Underwood 3'	-	-	-	-
Conventional Covers with Composite Barriers				
Altamont	0.225	Yes	0.056	Yes
Cedar Rapids	-	-	0.495	Yes
Omaha	-	-	-	-
Polson	-	-	0.038	No

Statistical Comparison of K_{si}/K_{sa} in Humid and Sub-Humid Climates to K_{si}/K_{sa} in Arid or Semi-Arid Climates

All Cover Types

F-Test Two-Sample for Variances

	Humid and Sub-Humid	*Arid and Semi-Arid*		
Mean	4.490021	4.531037		
Variance	2.160222	4.760167		
Observations	9	12		
df	8	11		
F	0.453812			
P(F<=f) one-tail	0.135818		P>0.05	Unequal variance
F Critical one-tail	0.301846			

t-Test: Two-Sample Assuming Unequal Variances

	Humid and Sub-Humid	*Arid and Semi-Arid*		
Mean	4.490021	4.531037		
Variance	2.160222	4.760167		
Observations	9	12		
Hypothesized Mean Difference	0			
df	19			
t Stat	-0.0514			
P(T<=t) one-tail	0.479771		P>0.05	Data are similar
t Critical one-tail	1.729133			
P(T<=t) two-tail	0.959542			
t Critical two-tail	2.093024			

Statistical Comparison of K_{si}/K_{sa} in Humid and Sub-Humid Climates to K_{si}/K_{sa} in Arid or Semi-Arid Climates

Conventional Covers Only

F-Test Two-Sample for Variances

	Humid and Sub-Humid	Arid and Semi-Arid		
Mean	4.574031	6.467112		
Variance	3.552464	4.28226		
Observations	5	4		
df	4	3		
F	0.829577			
P(F<=f) one-tail	0.415081		P > 0.05	Unequal variance
F Critical one-tail	0.151713			

t-Test: Two-Sample Assuming Unequal Variances

	Humid and Sub-Humid	Arid and Semi-Arid		
Mean	4.574031	6.467112		
Variance	3.552464	4.28226		
Observations	5	4		
Hypothesized Mean Difference	0			
df	6			
t Stat	-1.4185			
P(T<=t) one-tail	0.102917		P > 0.05	Data are similar
t Critical one-tail	1.94318			
P(T<=t) two-tail	0.205835			
t Critical two-tail	2.446912			

APPENDIX G - METHODS USED IN CHEMICAL ANALYSIS FOR GEOSYNTHETIC CLAY LINERS (GCLS)

G-1. ICP METHOD

A Varian MPX ICP-OES equipped with an axial torch was used to analyze for concentrations of principle cations (Ca, K, Mg and Na). An attached Varian SPS 3 Autosampler was used to expedite analysis. Before sample analysis, the ICP was calibrated with dilution series of certified aqueous standards from High Purity standards (Charleston, North Carolina). Calibration dilution series were prepared with nitric acid or ammonia acetate matrix depending on the matrix of samples to be tested; with a nitric acid matric used for subgrade batch elution and soluble cation samples, and an ammonia acetate matrix used for bound cation samples.

Quality control (QC) was performed following the guidelines detailed in US EPA procedure SW-846. Every 5 samples, continuing calibration verifications (CCV) and continuing calibration blanks (CCM) were analyzed. In addition, sample spikes and duplicates were analyzed every 10 samples. US EPA procedure SW-846 provides QC criteria for CCV, CCM, spiked and duplicate samples: CCVs must be within 10% of expected concentration, CCBs must be below concentration detection limits, spiked samples must have a recovery within 75-125% of the original sample and duplicate samples must demonstrate a concentration within 20% of the original sample. All US EPA Method SW-846 QC criteria were met for all calibrated wavelengths.

Calibration curve, quality control, and method detection limit (MDL) concentrations for subgrade soil batch elution and GCL bound and soluble cation tests are provided in Table G.1.

Table G. 1. Calibration curves, quality control and method detection limits for subgrade soil batch elution, soluble cation and bound cation tests.

		Cation Concentration (ppm)			
		Ca	K	Mg	Na
Method detection limit	Bound cations	2.2	0.3	0.7	3.6
	Soluble cations	0.17	0.01	0.04	0.16
	Subgrade batch	0.11	0.20	0.05	0.02
Calibration curve	Bound cations	0.5, 1, 5, 10, 50, 100, 500	0.05, 0.1, 0.5, 1, 5, 10, 50	0.05, 0.1, 0.5, 1, 5, 10, 50	1, 5, 10, 50, 100, 500, 1000
	Soluble cations Subgrade batch	1, 5, 10, 50, 100, 200	1, 5,10, 50, 100, 200	1, 5,10, 50, 100, 200	10, 50, 100, 300, 500, 1000
CCV	Bound cations	10	10	1	50
	Soluble cations Subgrade batch	50	50	50	100
Matrix spike	Bound cations	5	5	5	5
	Soluble cations Subgrade batch	50	50	50	250

G-2. SALICYLATE METHOD AND SPECTROPHOTOMETRY

The proposed standard test method for determining bentonite CEC used in this study and contained in Appendix H requires the determination of ammonium concentration in an extract solution. The Hack DR/4000 saliciylate method using high-range nitrogen NH_4^+ Test 'N Tube vials (Hach Company Method 10031) and a Spectronic 20 Genesys spectrophotometer were used to analyze the ammonium extract. The extract solution from CEC testing was diluted 1:10 for analyses. Additionally, method blanks, method spikes and CCVs were analyzed per the guidelines recommended in US EPA procedure SW-846. A calibration curve, CCV, and spike were prepared using certified air-dried ammonium sulfate $(NH_4)_2SO_4$ from Fisher Scientific (Hanover Park, Illinois) Ammonium concentrations used for the calibration curve and CCV are presented in Table G.2.

Table G.2. Calibration curve and CCV Ammonium concentrations used for CEC determination.

	Ammonium concentration (ppm)
Calibration curve	10, 20, 40, 60, 80
CCV	40

APPENDIX H - TEST METHOD FOR MEASURING SOLUBLE CATIONS, BOUND CATIONS, AND CATION EXCHANGE CAPACITY

1 SCOPE

1.1 This test method describes the procedures for measuring the soluble and bound cations as well as the cation exchange capacity (CEC) of fine-grained inorganic soils. Clay minerals in fine-grained soils carry a negative surface charge that is balanced by bound cations near the mineral surface. These bound cations can be exchanged by other cations in the pore water, which are referred to as soluble cations. The cation exchange capacity is a measure of the negative surface charge on the mineral surface. The CEC generally is satisfied by calcium (Ca), sodium (Na), magnesium (Mg), and potassium (K), although other cations may be present depending on the environment in which the soil exists. This test method was developed from concepts described previously in Lavkulich (1981) and Rhoades (1982).

1.2 In this method, the soluble salts from the mineral surface are washed off with de-ionized water and then the concentration of soluble salts within the extract is measured. The bound cations of the clay are measured by using a solution containing an index ion that forces the existing cations in the bound layer into solution. The total concentrations of bound and soluble cations in this solution are measured. The CEC is measured by displacing the index ion with another salt solution and measuring the amount of the displaced index ion.

1.3 This method requires chemical analyses on aqueous samples. USEPA methods are specified for these chemical analyses. All chemical analyses shall conform to the quality control (QC) requirements in USEPA Method SW 846, Chapter One, Quality Control Guidelines.

1.4 This standard does not purport to address the safety problems associated with its use. The user of this standard is responsible for establishing appropriate safety and health practices and determining the applicability of regulatory limitations prior to use.

1.5 All observed and calculated values shall conform to the guide for significant digits and rounding established in Practice D 6026. The procedures in Practice D 6026 that are used to specify how data are collected, recorded, and calculated are regarded as the industry standard. In addition, they are representative of the significant digits that should generally be retained. The procedures do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the objectives of the user. Increasing or reducing the significant digits of reported data to be commensurate with these considerations is common practice. Consideration of the significant digits to be used in analysis methods for engineering design is beyond the scope of this standard.

2 REFERENCED DOCUMENTS

2.1 *ASTM Standards:*

D 1193 Specification for Reagent Water

E 145 Specification for Gravity-Convection and Forced Ventilation Ovens

D 2216 Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

2.2 *USEPA Methods:*

Method 6010B, Inductively coupled plasma spectroscopy

Method 7000A, Atomic absorption methods

Method SW 846, Chapter One, Quality Control Guidelines

3 TERMINOLOGY

3.1 *Definitions:*

3.1.1 *Acid wash* - the process of initially rinsing equipment with tap water, followed by a rinse with 10% HNO_3 solution, and then finally rinsing 3 times with DI water.

3.1.2 *Inorganic soils* – any soil with a loss of ignition (LOI) less than 1%.

3.1.3 *Fine-grained soils* – any soil with more than 50% passing the No. 200 US standard sieve.

3.1.4 *Bound cations (BC)* – cations that are adsorbed (bound) to mineral surfaces that may be exchanged.

3.1.5 *Soluble cations (SC)* – cations in the soil that are not bound to the mineral surface.

3.1.6 *Cation exchange capacity (CEC)* – the total negative charge on mineral surface to be satisfied by bound cations.

3.1.7 *Exchange Complex* – the collection of bound cations satisfying the CEC

3.2 For definitions of other terms used in this standard, see ASTM D 653.

4 SIGNIFICANCE AND USE

4.1 Fine-grained soils are used in waste containment systems as barriers to flow and contaminant transport. Liquids contained by these barriers can contain ions that may interact with the mineral surfaces in fine-grained soils.

4.2 The liquid passing through the pores of fine-grained soil can interact with the mineral surface, and affect the physical and chemical characteristics of the soil. This method can be used as part of an evaluation of these interactions.

NOTE 1 – The quality of the result produced by this standard depends on the competence of the personnel performing the test and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D 3740 are generally considered capable of competent and objective testing, sampling, inspection, etc. Users of this standard are cautioned that compliance with Practice D 3740 does not in itself ensure reliable results. Reliable results depend on many factors. Practice D 3740 provides a means of evaluating some of these factors.

5 APPARATUS

5.1 *Drying oven*, capable of maintaining a uniform temperature of 105 ± 5°C that meets the requirements of Specification E145.

5.2 *No. 10 U.S. standard sieve.*

5.3 *Desiccator,* containing silica gel.

5.4 *Laboratory balance,* 20 g capacity, ± 0.001 g accuracy and precision.

5.5 *Weighing paper,* or small weighing dish.

5.6 *End over end shaker,* capable of 30 rpm.

5.7 *Capped containers,* should tightly fit in the end over end shaker holding compartment with capacities larger than 40 mL.

5.8 *500 mL filtering flask,* connectable to low-pressure vacuum line, acid washed (Figure H.1).

5.9 *Flexible tubing,* appropriate size to connect filtering flask to the low-pressure vacuum line (Figure H.1).

5.10 *Buchner funnel,* 55 mm or 90 mm diameter, acid washed (Figure H.1).

5.11 *Wash bottle*, for dispensing solutions, new or acid washed.

5.12 *Graduated cylinder,* for measuring solution portions, acid washed.

5.13 *2.5 μm ashless filter paper* that covers the surface of Buchner funnel.

5.14 *250 mL volumetric flasks,* class A flask for precision and accuracy.

6 REAGENTS

6.1 *Reagent Water:* Use only ASTM Type I water as defined in D 1193.

6.2 *Ammonium Acetate, 1M:* dissolve 77.08 g of 99.9% pure NH_4OAc in Type II DI water (ASTM D 1193) and fill to volume in a 1000 mL volumetric flask. Adjust the pH of the solution to 7 with ammonium hydroxide or acetic acid. Approximately 1 L of NH_4OAc is needed per 6 samples.

6.3 *Isopropanol*

6.4 *Potassium Chloride, 1M:* dissolve 74.6 g of 99% pure KCl in Type II DI water and fill to volume in a 1000 mL volumetric flask. Approximately 1 L of KCl is needed per 6 samples.

6.5 *Ammonium sulfate:* dry 238 mg of ACS Certified $(NH_4)_2SO_4$ for 4 hr at 40°C. Make a 200 mg/L stock solution by dissolving the dried compound in 100 mL Type II DI water and fill to volume in a 250 mL volumetric flask. Prepare calibration standards by diluting the stock solution into concentrations of 10, 20, 40, 50, and 80 mg/L.

6.6 *Ca, Mg, K, and Na:* Use ICP-grade or AA-grade element standards in an HNO_3 matrix to prepare Ca, Mg, K, and Na calibration standards in a NH_4OAc matrix.

7 HAZARDS

7.1 This standard does not address all of the safety concerns associated with its use. The user of this standard is responsible for implementing proper safety precautions and should be aware of any possible health concerns and risks related with the materials and chemicals used while following this standard.

8 DETERMINATION OF REQUIRED AIR-DRIED MASS OF SOIL FOR ANALYSIS

8.1 Air dry 30 g of soil (12 g of solid is required for testing) according to the procedures described in ASTM D 2216.

8.2 Oven-dry 2 g of the air-dry soil to determine the water content following ASTM D 2216.

8.3 Determine total mass of air-dry soil needed to have 2 g of solid particles for determination of soluble cations.

8.4 Determine total mass of air-dry soil needed to have 10 g of solid particles for determination of bound cations.

8.5 Use the oven-dry weight (2 or 10 g) of the soil for all calculations.

Note 2 - Oven-dried soils should not be used for determining CEC, soluble cations, or bound cations because gypsum ($CaSO_4 \cdot 2H_2O$) is transformed to plaster of paris ($CaSO_4 \cdot 1/2H_2O$) at high temperatures, and plaster of paris is more soluble in water than gypsum.

9 DETERMINATION OF SOLUBLE CATIONS

9.1 Use only air-dry soil that passes the No. 10 US Standard Sieve.

9.2 Add mass of air-dry soil corresponding to 2 g of oven-dry solid particles and 100 mL of Type II DI water to a covered container that fits tightly.

9.3 Place the containers in an end-over-end shaker and shake for 1 hr at 30 rpm.

9.4 Vacuum filter the mixture in each container using 2.5 μm ashless filter paper.

9.5 Transfer the extract to a 100 mL acid washed volumetric flask preserve with 1% HNO_3 and fill to volume.

9.6 Analyze each extract for cation concentration using EPA Method 6010B (inductively coupled plasma spectrometry) or Method 7000A (atomic absorption). Ensure that these analyses meet the quality control criteria in USEPA Method SW 846 (Chapter One, Quality Control Guidelines).

10 DETERMINATION OF BOUND CATIONS

10.1 Use only air-dry soil that passes the No. 10 US Standard Sieve.

10.2 Prepare a blank sample for analysis by placing 100 mL of DI water in a covered container.

10.3 Prepare a quality control sample for analysis by creating a duplicate or a spike and place in a covered container. Add determined mass of air-dried soil corresponding to 10.0 g of solid particles and 40 mL of 1 M NH_4OAc into 100 mL covered container (use a container which tightly fits into the end over end shaker).

10.4 Shake the covered containers for 5 minutes in an end over end shaker at 30 rpm. Agitate the container to rinse the particles from the side of the container and let the mixture stand for 24 h.

10.5 After 24 hours shake the container with the mixture for 15 minutes at 30 rpm in the end over end shaker.

10.6 Rinse the 500 mL filtering flask and Buchner funnel with NH_4OAc.

10.7 Place the Buchner funnel over the 500 mL filtering flask and line the Buchner funnel with 2.5 µm ashless filter paper (Fig. H.1).

10.8 Transfer the contents of the shaken container to the Buchner funnel.

10.9 Rinse the container and cap into the Buchner funnel using a squirt bottle containing 1 M NH_4OAc.

10.10 Apply low suction to the filtering flask (< 10 kPa).

10.11 Wash the soil in the Buchner funnel with four 30 mL portions of 1 M NH_4OAc. Add each 30 mL portion slowly and allow the entire 30 mL portion to drain before adding the next 30 mL portion. Do not allow the soil to crack between additions of NH_4OAc.

10.12 Turn the suction off to the filtering flask after the last washing. Leave the NH_4OAc washed soil in the Buchner funnel; this soil is to be used for determining the cation exchange capacity (CEC).

10.13 Rinse the 250 mL volumetric flask with 1 M NH_4OAc.

10.14 Transfer the filtered aqueous solution into the 250 mL volumetric flask. Preserve the solution to pH of 2 with ICP-grade nitric acid and fill the volumetric flask to volume with NH_4OAc.

10.15 Analyze the cations in the aqueous solution using USEPA Method 6010B (inductively coupled plasma spectrometry) or USEPA Method 7000A (atomic absorption). Ensure that these analyses meet the quality control criteria in USEPA Method SW 846 (Chapter One, Quality Control Guidelines).

11 DETERMINATION OF THE CATION EXCHANGE CAPACITY

11.1 Rinse an acid washed 500 mL filtering flask with isopropanol.

11.2 Place the Buchner funnel with the 1 M NH_4OAc washed sample onto the 500 mL filtering flask (Fig. H.1).

11.3 Apply low suction (< 10 kPa) to the filtering flask. Do not allow the soil to crack when suction is applied.

11.4 Wash the soil with three 40 mL portions of isopropanol. Allow each 40 mL portion to drain before adding the next portion. Washing with isopropanol removes residual NH_4OAc.

11.5 Turn off the suction to the filtering flask when free liquid is no longer visible.

11.6 Separate the Buchner funnel from the filtering flask. Discard the isopropanol collected in the 500 mL filtering flask and rinse the flask with Type II DI water three times.

11.7 Return the Buchner funnel containing the isopropanol washed soil to the rinsed filtering flask (Fig. H.1).

11.8 Apply suction to the filtering flask and wash the soil with four 50 mL portions of 1 M KCl solution. Allow each portion of the 1 M KCl solution to drain before adding the next portion. Do not allow the soil to crack between additions of KCl solution.

11.9 Rinse a 250 mL volumetric flask with 1 M KCl.

11.10 Transfer the extract into the 250 mL volumetric flask. Rinse the filtering flask with Type II DI water and transfer the contents into the volumetric flask.

11.11 Fill the volumetric flask to volume with water.

11.12 Analyze the KCl extract for nitrogen concentration using a spectrophotometer. Ensure that these analyses meet the quality control criteria in USEPA Method SW 846 (Chapter One, Quality Control Guidelines).

12 CALCULATIONS

12.1 Calculate the concentration of soluble cations as follows:

$$S = C \times \frac{0.100L}{M_o(g)} \times 1000\frac{g}{kg}$$

where:

S = concentration of soluble cations ($cmol^+/kg$) in the soil

C = concentration of cations ($cmol^+/L$) in the DI water extract from 9.7

M_o = oven-dry mass of soil

12.2 Calculate the concentration of bound cations as follows:

$$M^+ = C \times \frac{0.25L}{M_o(g)} \times 1000\frac{g}{kg} - S$$

where:

M^+ = concentration of adsorbed cation ($cmol^+/kg$) in soil

C = concentration of cation ($cmol^+/L$) in the NH_4OAc extract from 10.15

12.3 Calculate the cation exchange capacity as follows:

$$CEC = N \times \frac{1cmol^+}{140mg} \times \frac{0.25L}{M_o(g)} \times 1000\frac{g}{kg}$$

where:

CEC = concentration of cation exchange capacity ($cmol^+$ / kg)

N = concentration of nitrogen (mg/L) from 11.12

13 REPORT

13.1 Report the following information:

13.1.1 Source and description of the soil.

13.1.2 Source and description of all chemicals used to make mixtures and solutions.

13.1.3 Dilution factor of aqueous samples prior to chemical analysis.

13.1.4 Concentration of bound cations, concentration of soluble cations, and CEC in units of $cmol^{+}/kg$.

13.1.5 Any modifications to this standard test method.

14 PRECISION AND BIAS

14.1 *Precision*—Test data on precision are not presented due to the nature of the soil or rock, or both materials tested by this standard. It is either not feasible or too costly at this time to have ten or more laboratories participate in a round-robin testing program. In addition, it is either not feasible or too costly to produce multiple specimens that have uniform physical properties. Any variation observed in the data is just as likely to be due to specimen variation as to operator or laboratory testing variation.

14.1.1 Subcommittee D18.04 is seeking any pertinent data from users of these test methods that might be used to make a limited statement on precision.

14.1.2 *Bias*—There is no accepted reference value for these test methods, therefore, bias cannot be determined.

15 FIGURES

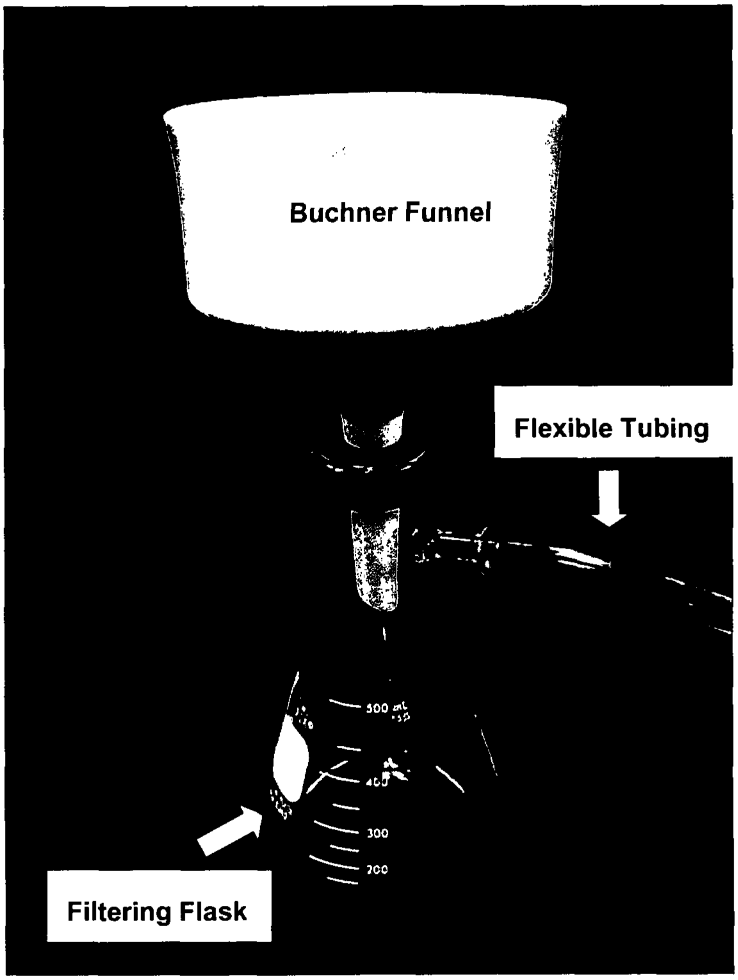

Fig. H. 1. Experimental setup for vacuum filtration.

16 REFERENCES

Lavkulich, L. (1981). Exchangeable Cations and Total Exchange Capacity by the Ammonium Acetate Method at pH 7.0. in *Soil Sampling and Methods of Analysis* (Martin R. Carter, editor). Canadian Society of Soil Science, Ottawa, Ontario, Canada, 173-175.

Rhoades, J. (1982). Soluble Salts. in *Methods of Soil Analysis*, Part 2. Chemical and Microbiological Properties, 2nd Edition (A. Page, R. Miller, D. Keeney, editors). Soil Science Society of America, Madison, Wisconsin, USA, 167-180.

APPENDIX I - SCHEMATIC AND PHOTOGRAPH OF HYDRAULIC CONDUCTIVITY TEST SETUP FOR GCLS

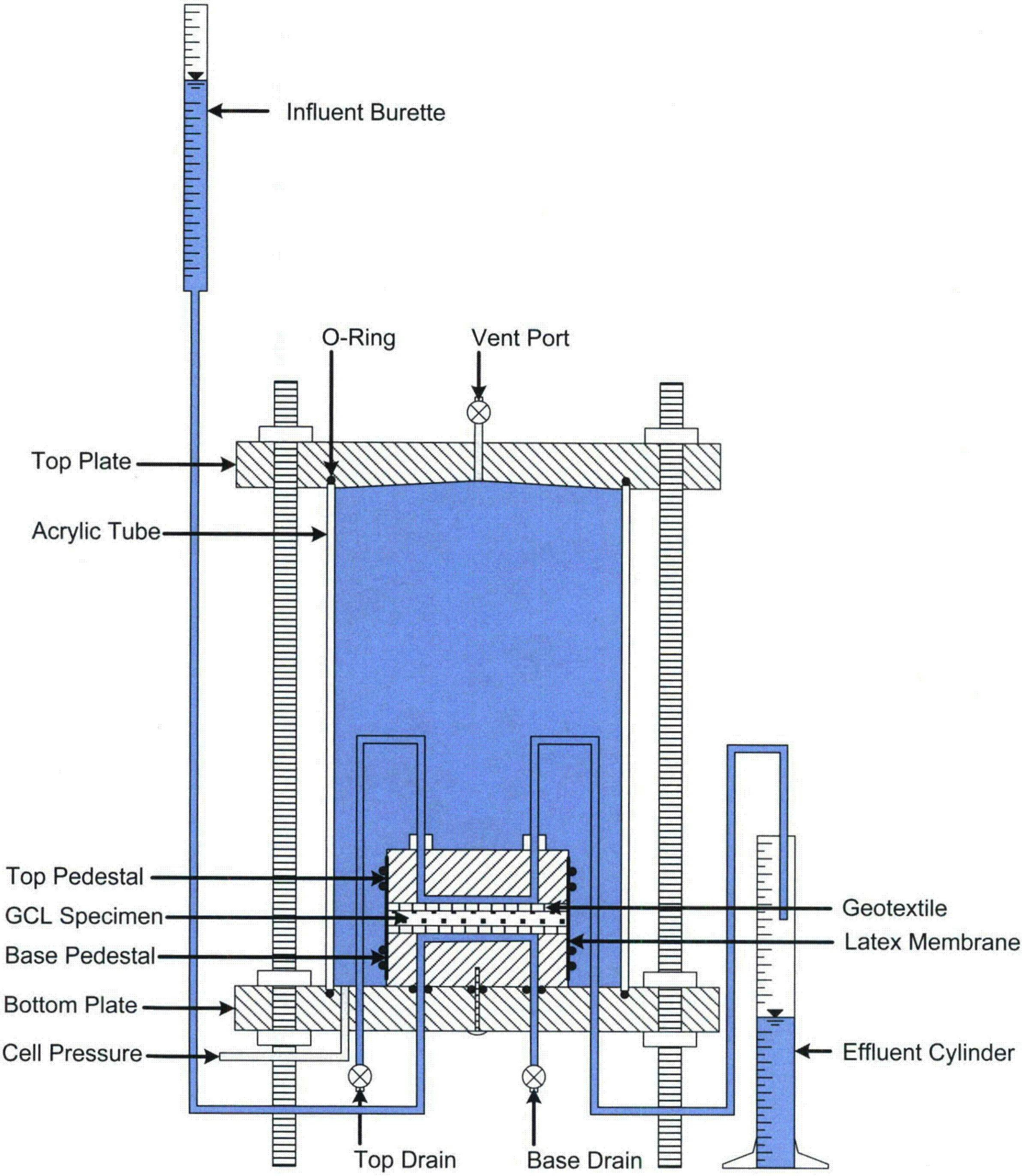

Fig. I. 1. Schematic of hydraulic conductivity test setup used in the laboratory.

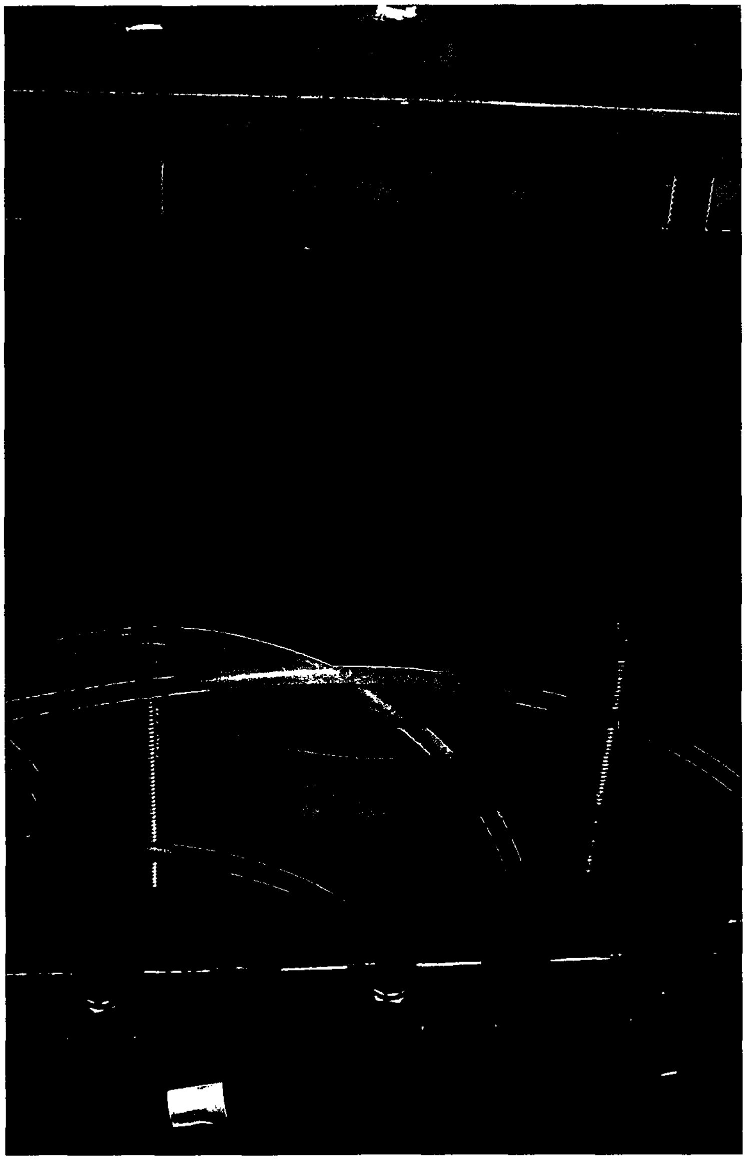

Fig. I. 2. Photograph of hydraulic conductivity test setup in the laboratory.

APPENDIX J - EXHUMED SUBGRADE POREWATER CHEMISTRIES

Table J. 1. Site A exhumed subgrade soil water contents and chemical indicator parameters.

Site ID	Subgrade w (%)	Ionic strength (M)	RMD ($M^{0.5}$)
A-1	9.8	0.035	1.16
A-2	9.8	0.037	1.67
A-3	9.8	0.035	2.59
A-4	9.8	0.047	1.38
A-5	9.8	0.024	1.53
A-6	9.8	0.028	1.06
A-7	9.8	0.034	5.08
A-8	9.8	0.026	1.21
A*	9.8	0.033	1.96

*Geometric Mean

Table J. 2. Site B exhumed subgrade soil water contents and chemical indicator parameters.

Site ID	Subgrade w (%)	Ionic strength (M)	RMD ($M^{0.5}$)
B-1	2.8	0.141	5.86
B-2	2.5	0.141	5.86
B-3	2.1	0.137	5.06
B-4	2.2	0.137	5.06
B-5	2.2	0.137	5.06
B-6	2.4	0.156	6.42
B-7	2.4	0.152	5.12
B-8	2.4	0.152	5.12
B-9	2.3	0.152	5.12
B-10	2.2	0.143	3.93
B-11	2.1	0.143	3.93
B*	2.3	0.145	5.14

*Geometric Mean

Table J. 3. Site E exhumed subgrade soil water contents and chemical indicator parameters.

Site ID	Subgrade w (%)	Ionic strength (M)	RMD ($M^{0.5}$)
E-1	15.1	0.015	0.54
E-2	15.1	0.013	0.96
E-3	15.1	0.005	0.37
E-4	14.5	0.017	0.38
E-5	11.4	0.030	0.28
E-6	14.0	0.027	0.27
E-7	14.0	0.051	0.19
E-8	14.0	0.034	0.26
E-9	14.0	0.029	0.24
E-10	16.2	0.004	0.52
E-11	16.2	0.005	0.58
E-12	16.2	0.011	0.99
E Lower k*	15.5	0.010	0.62
E Higher k*	13.5	0.034	0.25

*Geometric Mean

Table J. 4. Site F exhumed subgrade soil water contents and chemical indicator parameters.

Site ID	Subgrade w (%)	Ionic strength (M)	RMD ($M^{0.5}$)
F-1	15.9	0.018	0.58
F-2	15.9	0.014	0.33
F-3	15.9	0.017	0.21
F-4	8.5	0.063	1.81
F-5	8.5	0.058	1.62
F-6	8.5	0.056	1.52
F TP1 *	15.9	0.016	0.37
F TP2 *	8.5	0.059	1.65

*Geometric Mean

APPENDIX K - EXHUMED GCL WATER CONTENT, BOUND CATIONS, AND SOLUBLE CATIONS

Table K. 1. Site A exhumed GCL water content, swell index and soluble cations.

			Soluble cations (cmol+/kg)				Soluble cations	
Site ID	Exhumed w (%)	Swell index (mL/2 g)	Ca	K	Mg	Na	CMR	TCM
A-1	43.4	20.5	0.14	0.06	0.13	4.43	0.94	4.77
A-2	44.8	18.0	0.09	0.05	0.09	5.23	0.97	5.45
A-3	53.3	22.0	0.02	0.04	0.08	6.18	0.98	6.31
A-4	45.7	19.8	0.25	0.09	0.10	6.20	0.95	6.64
A-5	53.0	13.0	0.00	0.05	0.13	4.01	0.97	4.20
A-6	60.9	20.5	0.20	0.05	0.07	5.00	0.95	5.32
A-7	56.9	20.0	0.00	0.07	0.03	6.61	1.00	6.71
A-8	58.7	16.5	0.10	0.08	0.11	4.59	0.96	4.89
A*	52.1	18.8	0.10	0.06	0.09	5.28	0.96	5.54

*Arithmetic mean

Table K. 2. Site A exhumed GCL bound cations.

	Bound cations (cmol+/kg)				Bound cations		Bound cation (molar ratio)			
Site ID	Ca	K	Mg	Na	CMR	TCM	Ca	K	Mg	Na
A-1	29.5	0.71	11.3	19.7	0.33	15.3	0.48	0.01	0.18	0.32
A-2	34.9	0.81	12.0	23.5	0.34	17.8	0.49	0.01	0.17	0.33
A-3	25.9	0.83	10.1	24.0	0.41	15.2	0.43	0.01	0.17	0.39
A-4	31.8	0.60	11.1	23.7	0.36	16.8	0.47	0.01	0.16	0.35
A-5	38.9	0.68	11.7	17.3	0.26	17.1	0.57	0.01	0.17	0.25
A-6	28.7	0.65	10.6	17.3	0.31	14.3	0.50	0.01	0.19	0.30
A-7	29.0	0.68	10.7	16.5	0.30	14.2	0.51	0.01	0.19	0.29
A-8	32.8	0.60	11.0	22.5	0.35	16.7	0.49	0.01	0.16	0.34
A*	31.4	0.69	11.1	20.6	0.33	15.9	0.49	0.01	0.17	0.32

*Arithmetic mean

Table K. 3. Site B exhumed GCL water content, swell index and soluble cations.

Site ID	Exhumed w (%)	Swell index (mL/2 g)	Soluble cations (cmol+/kg)				Soluble cations	
			Ca	K	Mg	Na	CMR	TCM
B-1	21.5	12.0	0.03	0.07	0.10	10.1	0.99	10.3
B-2	21.4	14.0	0.02	0.06	0.12	9.09	0.98	9.30
B-3	21.4	19.0	0.05	0.06	0.10	9.72	0.98	9.94
B-4	21.1	20.0	0.05	0.38	0.12	10.2	0.98	10.8
B-5	20.9	16.5	0.04	0.11	0.04	8.27	0.99	8.47
B-6	17.3	16.0	0.03	0.06	0.13	8.68	0.98	8.90
B-7	19.6	14.0	0.02	0.06	0.08	9.53	0.99	9.69
B-8	18.3	17.0	0.12	0.12	0.08	8.33	0.98	8.65
B-9	18.6	13.0	0.01	0.57	0.12	8.85	0.99	9.55
B-10	19.6	15.0	0.01	0.00	0.00	8.74	1.00	8.76
B-11	21.2	18.0	0.03	0.05	0.08	8.34	0.99	8.50
B*	20.1	15.9	0.04	0.14	0.09	9.08	0.99	9.35

*Arithmetic mean

Table K. 4. Site B exhumed GCL bound cations.

Site ID	Bound cations (cmol+/kg)				Bound cations		Bound cation (molar ratio)			
	Ca	K	Mg	Na	CMR	TCM	Ca	K	Mg	Na
B-1	19.9	1.26	9.84	17.9	0.39	12.2	0.41	0.03	0.20	0.37
B-2	20.3	1.30	0.00	17.6	0.48	9.78	0.52	0.03	0.00	0.45
B-3	17.2	1.81	9.34	30.3	0.55	14.7	0.29	0.03	0.16	0.52
B-4	14.3	1.48	8.17	34.8	0.62	14.7	0.24	0.03	0.14	0.59
B-5	19.5	1.55	10.8	27.0	0.49	14.7	0.33	0.03	0.18	0.46
B-6	16.5	1.29	9.03	22.7	0.48	12.4	0.33	0.03	0.18	0.46
B-7	16.8	1.25	9.28	20.9	0.46	12.1	0.35	0.03	0.19	0.43
B-8	20.4	1.56	11.1	25.2	0.46	14.6	0.35	0.03	0.19	0.43
B-9	17.7	0.78	9.82	20.0	0.43	12.1	0.37	0.02	0.20	0.41
B-10	13.7	1.31	7.52	26.5	0.57	12.2	0.28	0.03	0.15	0.54
B-11	16.9	1.59	9.38	30.7	0.55	14.6	0.29	0.03	0.16	0.52
B*	17.5	1.38	8.58	24.9	0.50	13.1	0.33	0.03	0.16	0.47

*Arithmetic mean

Table K. 5. Site E exhumed GCL water content, swell index and soluble cations.

			Soluble cations (cmol+/kg)				Soluble cations	
	Exhumed	Swell index						
Site ID	w (%)	(mL/2 g)	Ca	K	Mg	Na	CMR	TCM
E-1	70.0	8.0	0.14	0.16	0.18	2.56	0.89	3.05
E-2	64.0	8.0	0.01	0.15	0.11	2.33	0.96	2.59
E-3	58.0	10.0	0.00	0.03	0.09	0.78	0.90	0.91
E-4	60.0	10.0	0.22	0.17	0.25	1.95	0.82	2.59
E-5	58.0	8.0	0.70	0.15	0.44	2.35	0.69	3.65
E-6	56.0	10.0	0.73	0.07	0.17	2.21	0.72	3.17
E-7	56.0	10.0	1.63	0.18	0.78	2.30	0.51	4.89
E-8	63.0	11.0	0.97	0.40	0.55	2.19	0.63	4.11
E-9	60.0	9.0	0.76	0.16	0.49	2.08	0.64	3.49
E-10	68.0	11.0	0.00	0.05	0.05	0.87	0.95	0.97
E-11	67.0	10.0	0.00	0.04	0.04	0.92	0.96	1.01
E-12	61.0	8.0	0.00	0.09	0.09	2.09	0.96	2.26
E lower k*	64.0	9.3	0.05	0.10	0.12	1.64	0.92	1.91
E higher k*	58.6	9.6	0.96	0.19	0.49	2.23	0.64	3.86

*Arithmetic mean

Table K. 6. Site E exhumed GCL bound cations.

	Bound cations (cmol+/kg)				Bound cations		Bound cation (molar ratio)			
Site ID	Ca	K	Mg	Na	CMR	TCM	Ca	K	Mg	Na
E-1	45.6	0.82	13.8	4.06	0.08	16.1	0.71	0.01	0.21	0.06
E-2	44.6	0.86	14.3	4.01	0.08	15.9	0.70	0.01	0.22	0.06
E-3	46.3	0.58	17.0	3.49	0.06	16.9	0.69	0.01	0.25	0.05
E-4	44.3	0.97	13.5	3.11	0.07	15.5	0.72	0.02	0.22	0.05
E-5	48.7	0.41	17.3	3.21	0.05	17.4	0.70	0.01	0.25	0.05
E-6	38.7	0.92	15.4	3.35	0.07	14.6	0.66	0.02	0.26	0.06
E-7	46.4	0.61	16.8	2.13	0.04	16.5	0.70	0.01	0.26	0.03
E-8	50.4	0.34	17.5	2.77	0.04	17.7	0.71	0.00	0.25	0.04
E-9	46.0	0.77	16.6	2.95	0.06	16.6	0.69	0.01	0.25	0.04
E-10	44.0	0.66	17.5	3.18	0.06	16.3	0.67	0.01	0.27	0.05
E-11	45.1	0.63	16.2	3.44	0.06	16.3	0.69	0.01	0.25	0.05
E-12	43.8	0.94	13.0	3.28	0.07	15.3	0.72	0.02	0.21	0.05
E lower k*	44.8	0.78	15.0	3.51	0.07	16.0	0.70	0.01	0.23	0.05
E higher k*	46.0	0.61	16.7	2.88	0.05	16.6	0.69	0.01	0.25	0.04

*Arithmetic mean

Table K. 7. Site F exhumed GCL water content, swell index and soluble cations.

Site ID	Exhumed w (%)	Swell index (mL/2 g)	Soluble cations (cmol+/kg) Ca	K	Mg	Na	Soluble cations CMR	TCM
F-1	60.7	8.0	0.20	0.08	0.11	2.72	0.70	3.10
F-2	60.7	10.0	0.21	0.05	0.21	1.77	0.71	2.23
F-3	64.9	10.0	0.38	0.06	0.37	1.52	0.68	2.32
F-4	42.8	13.0	0.21	0.03	0.18	8.24	0.95	8.67
F-5	46.3	12.0	0.23	0.03	0.20	8.05	0.95	8.51
F-6	45.3	13.0	0.22	0.03	0.22	7.51	0.94	7.98
F TP1 *	62.1	9.3	0.26	0.06	0.23	2.00	0.70	2.55
F TP2 *	44.8	12.7	0.22	0.03	0.20	7.93	0.95	8.39

*Arithmetic mean

Table K. 8. Site F exhumed GCL bound cations.

Site ID	Bound cations (cmol+/kg) Ca	K	Mg	Na	Bound cations CMR	TCM	Bound cation (molar ratio) Ca	K	Mg	Na
F-1	34.6	0.91	0.00	0.99	0.05	9.13	0.95	0.03	0.00	0.03
F-2	31.8	0.84	0.00	0.40	0.04	8.26	0.96	0.03	0.00	0.01
F-3	35.0	0.81	0.00	0.44	0.03	9.07	0.97	0.02	0.00	0.01
F-4	32.2	1.30	0.00	5.49	0.17	9.74	0.83	0.03	0.00	0.14
F-5	32.0	1.36	0.00	5.35	0.17	9.69	0.83	0.04	0.00	0.14
F-6	33.7	1.24	0.00	5.00	0.16	9.98	0.84	0.03	0.00	0.13
F TP1 *	33.8	0.86	0.00	0.61	0.04	8.82	0.96	0.02	0.00	0.02
F TP2 *	32.6	1.30	0.00	5.28	0.17	9.80	0.83	0.03	0.00	0.13

*Arithmetic mean

APPENDIX L - HYDRAULIC CONDUCTIVITY RECORDS FOR EXHUMED GCLS

L-1 HYDRAULIC CONDUCTIVITY PROFILES FOR GCLS EXHUMED FROM SITE A.

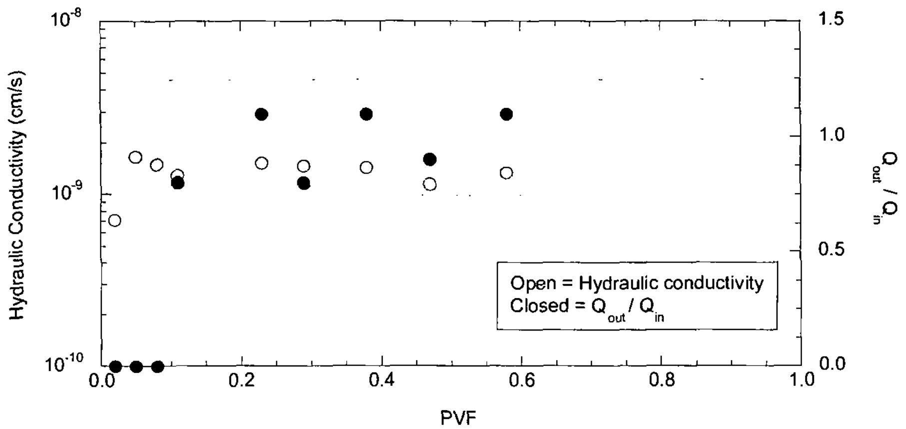

Fig. L. 1. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL A-1 permeated with SW.

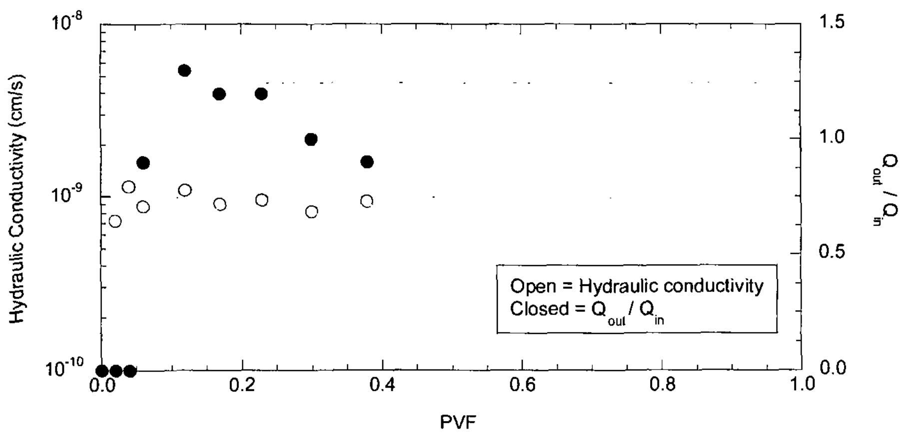

Fig. L. 2. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL A-2 permeated with SW.

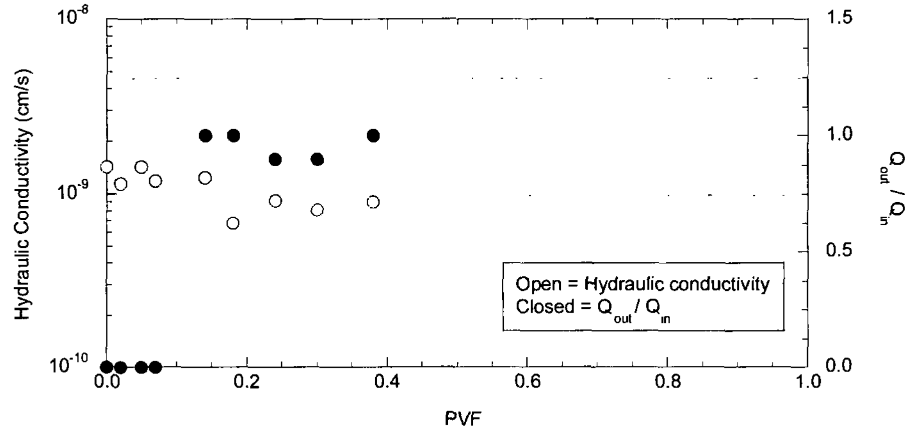

Fig. L. 3. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL A-3 permeated with SW.

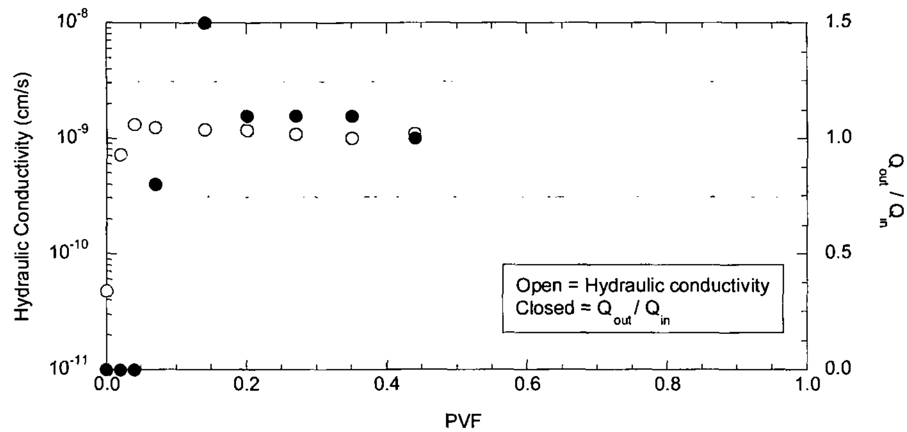

Fig. L. 4. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL A-4 permeated with SW.

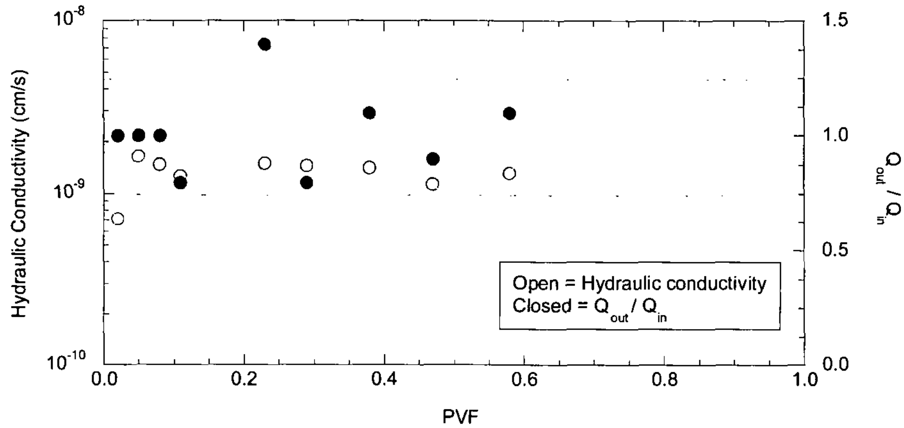

Fig. L. 5. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL A-5 permeated with SW.

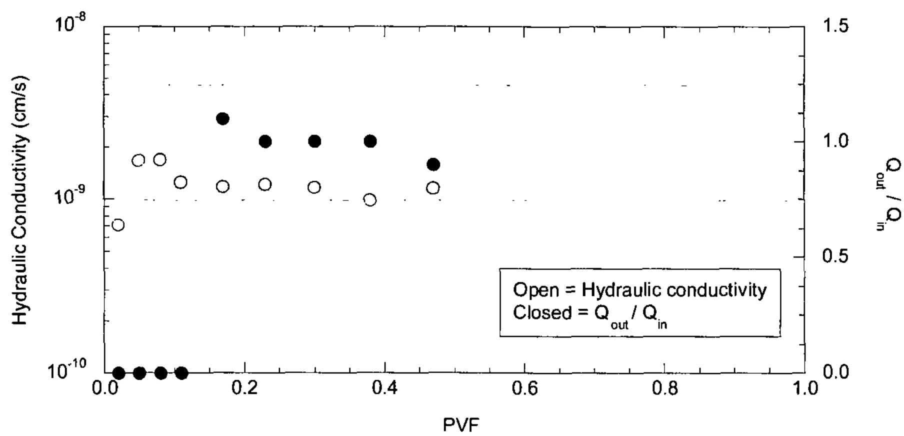

Fig. L. 6. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL A-6 permeated with SW.

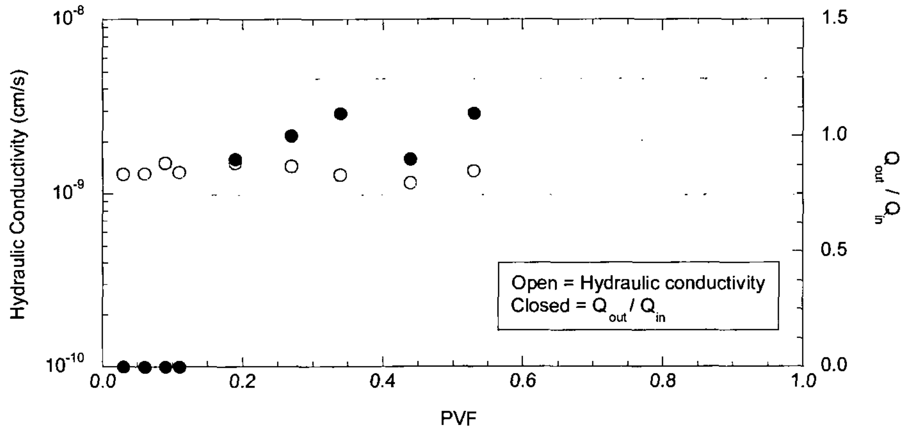

Fig. L. 7. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL A-7 permeated with SW.

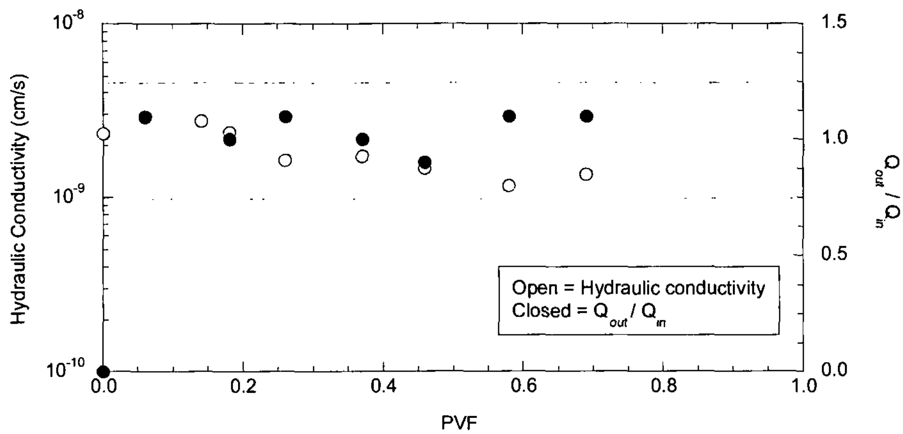

Fig. L. 8. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL A-8 permeated with SW.

L-2 HYDRAULIC CONDUCTIVITY PROFILES OF GCLS EXHUMED FROM SITE B.

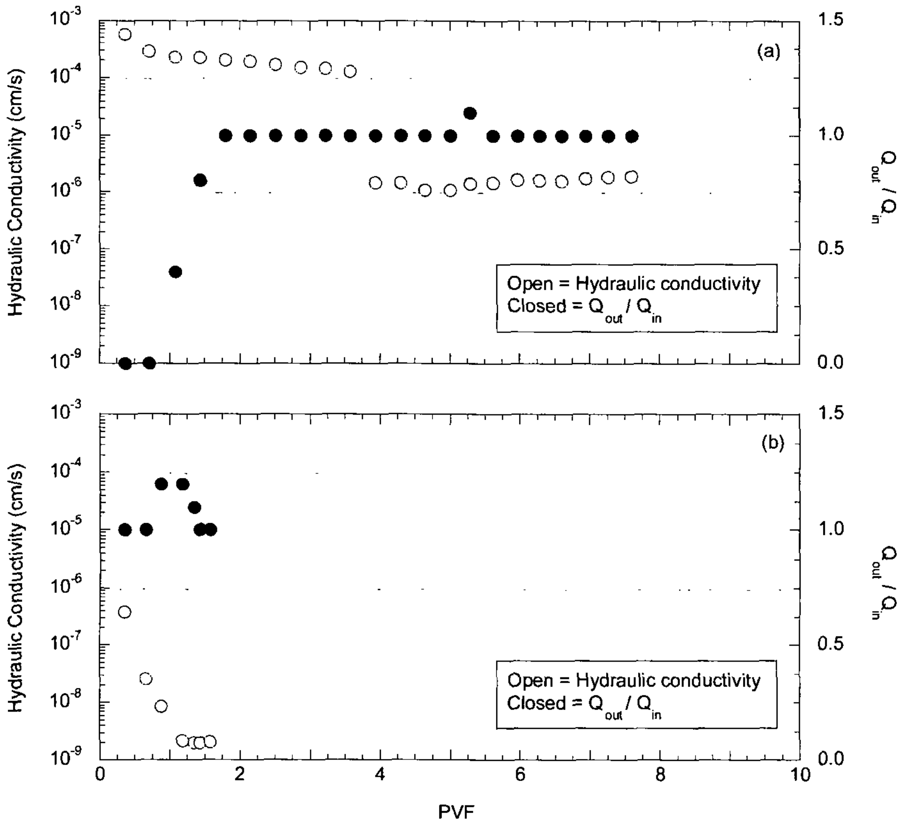

Fig. L. 9. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL B-1 permeated with standard water (a), and average water (b).

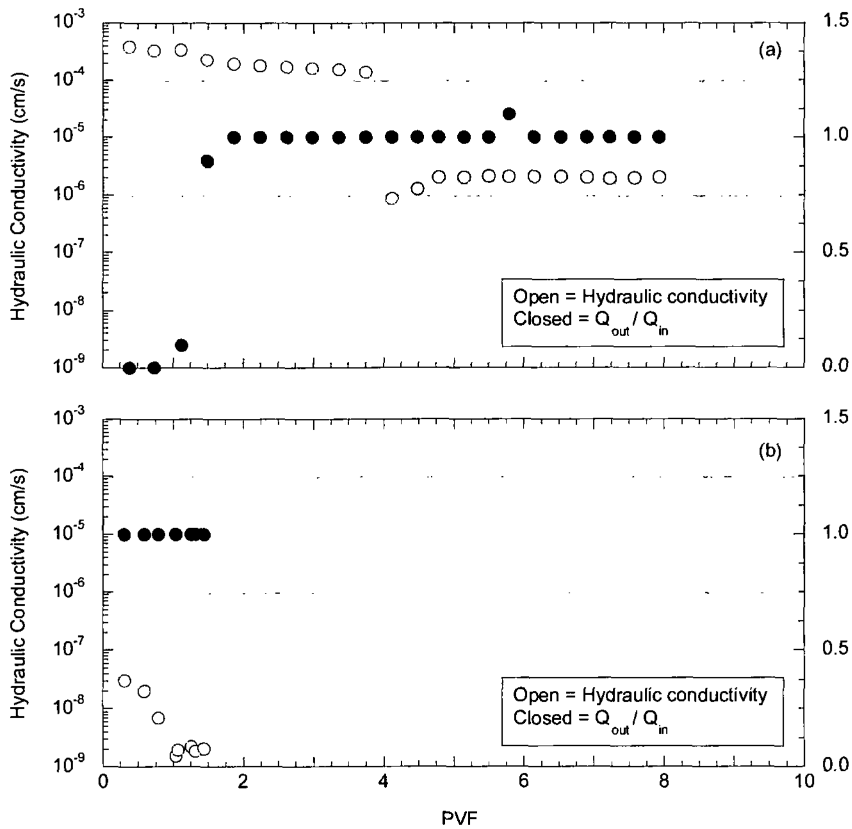

Fig. L. 10. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL B-2 permeated with standard water (a), and average water (b).

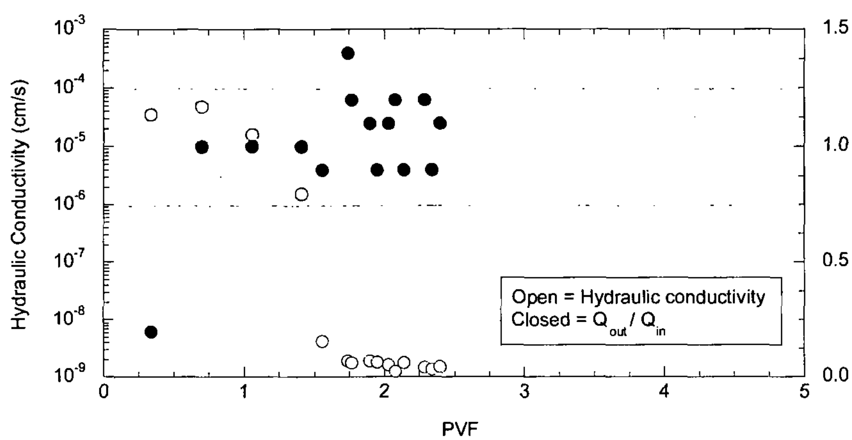

Fig. L. 11. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL B-3 permeated with standard water.

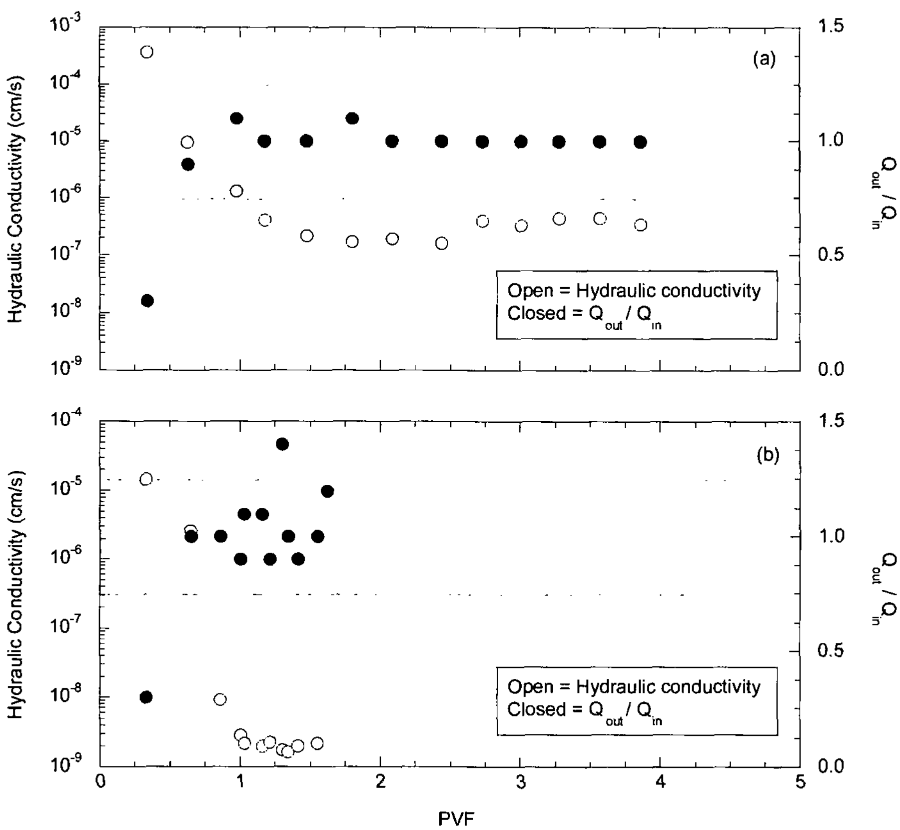

Fig. L. 12. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL B4 permeated with standard water (a), and average water (b).

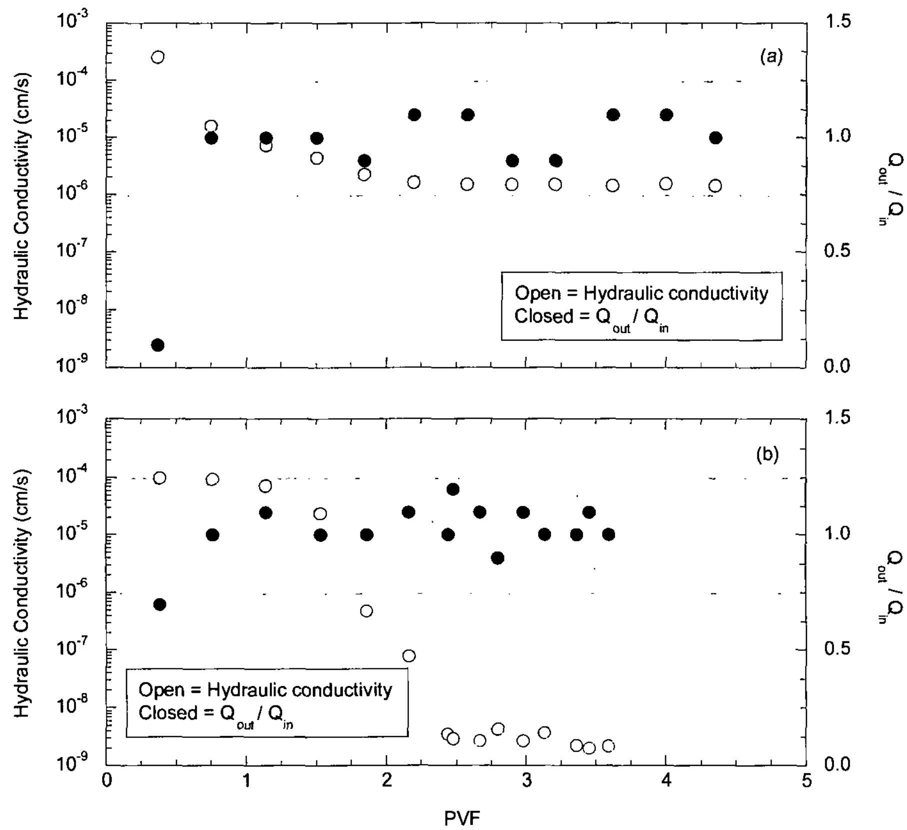

Fig. L. 13. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL B-5 permeated with standard water (a), and average water (b).

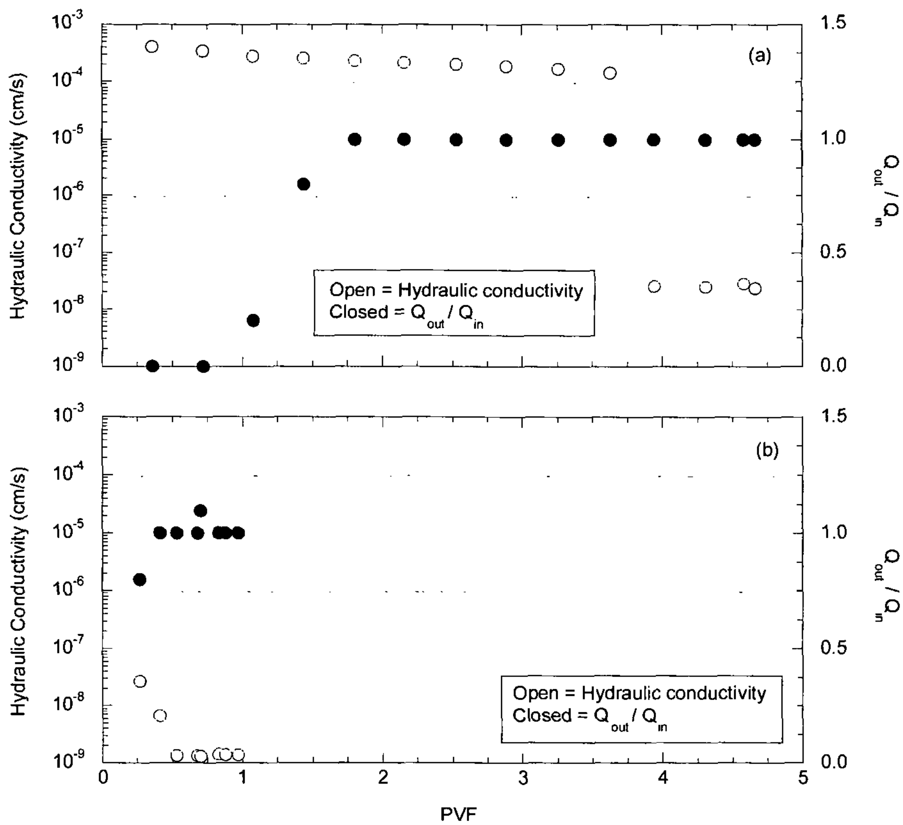

Fig. L. 14. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL B-6 permeated with standard water (a), and average water (b).

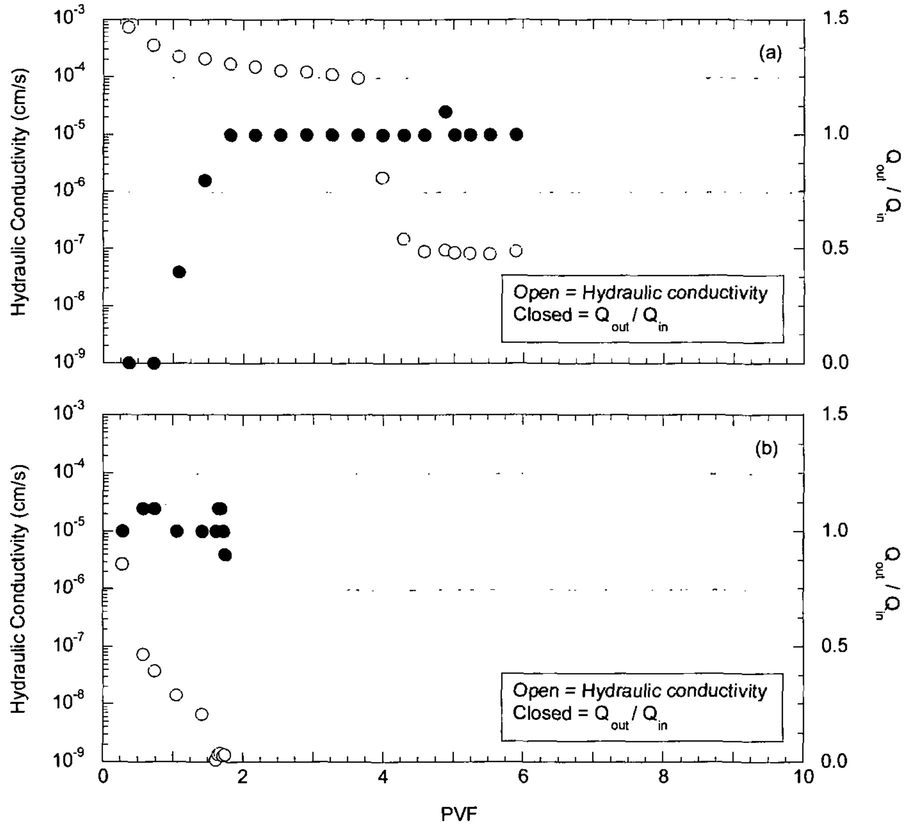

Fig. L. 15. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL B-7 permeated with standard water (a), and average water (b).

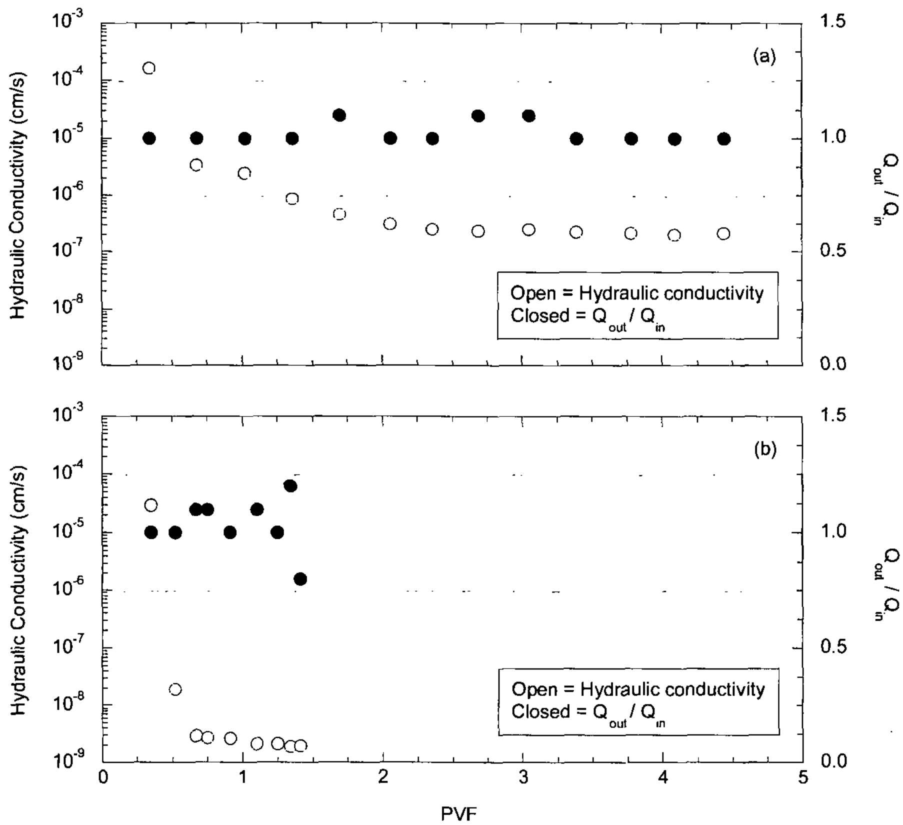

Fig. L. 16. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL B-8 permeated with standard water (a), and de-ionized water (b).

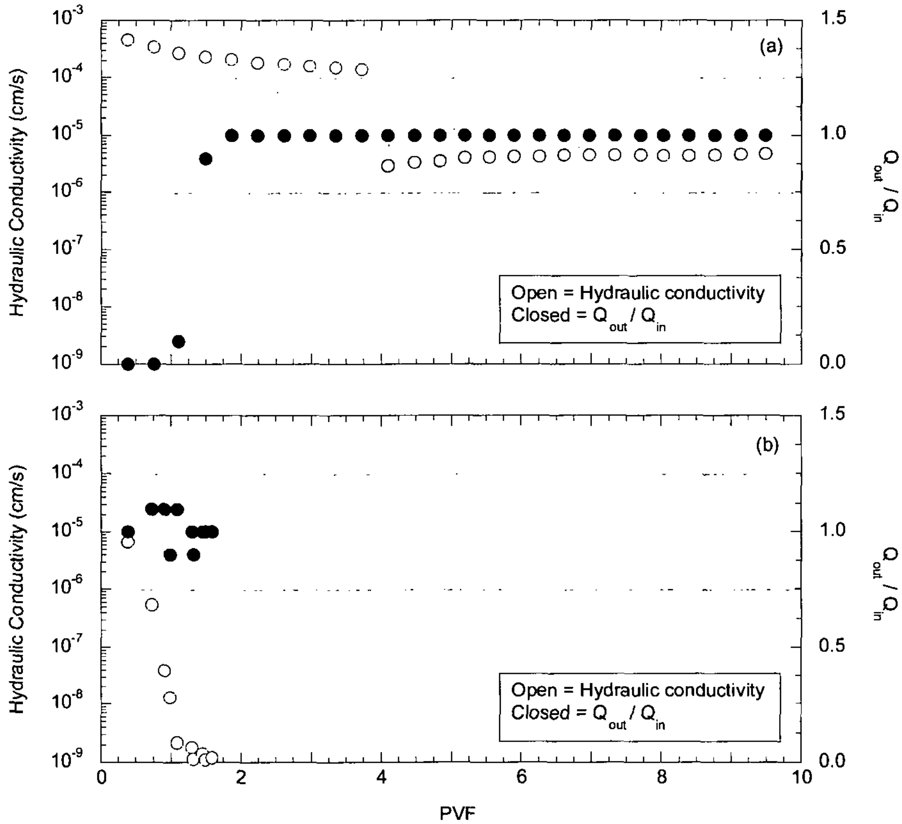

Fig. L. 17. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL B-9 permeated with standard water (a), and average water (b).

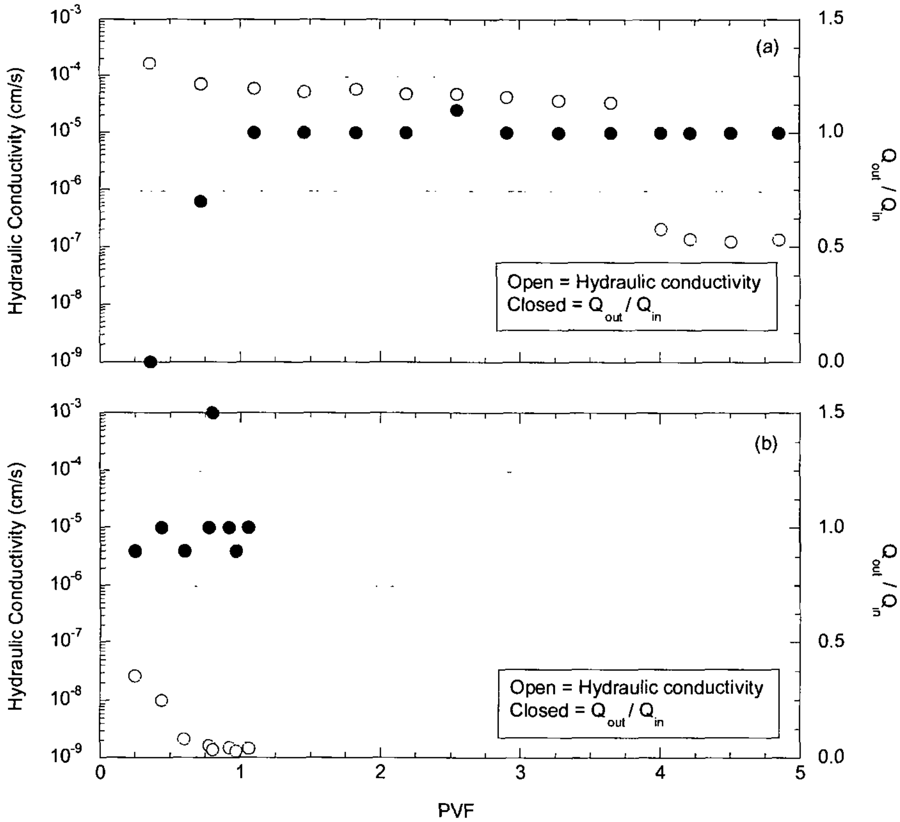

Fig. L. 18. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL B-10 permeated with standard water (a), and average water (b).

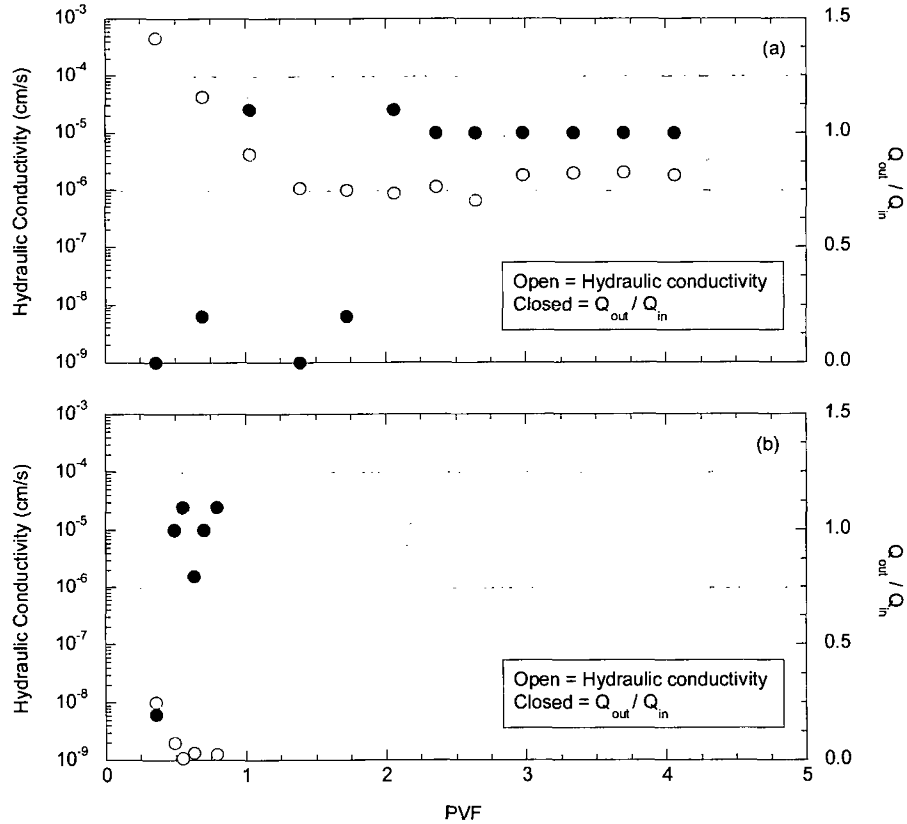

Fig. L. 19. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL B-11 permeated with standard water (a), and average water (b).

L-3 HYDRAULIC CONDUCTIVITY PROFILES OF GCLS EXHUMED FROM SITE E.

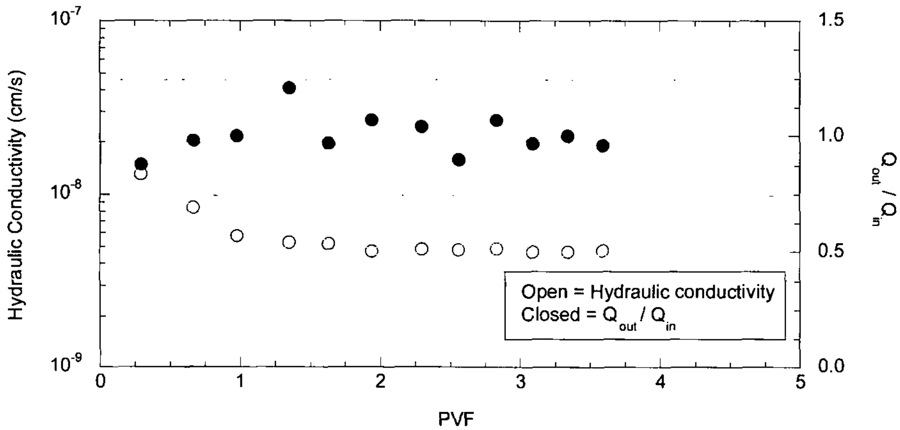

Fig. L. 20. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL E-1 permeated with standard water.

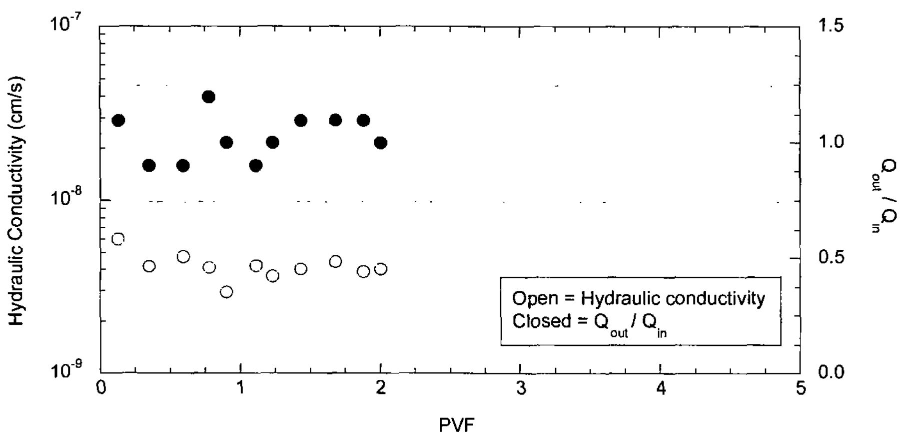

Fig. L. 21. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL E-2 permeated with standard water.

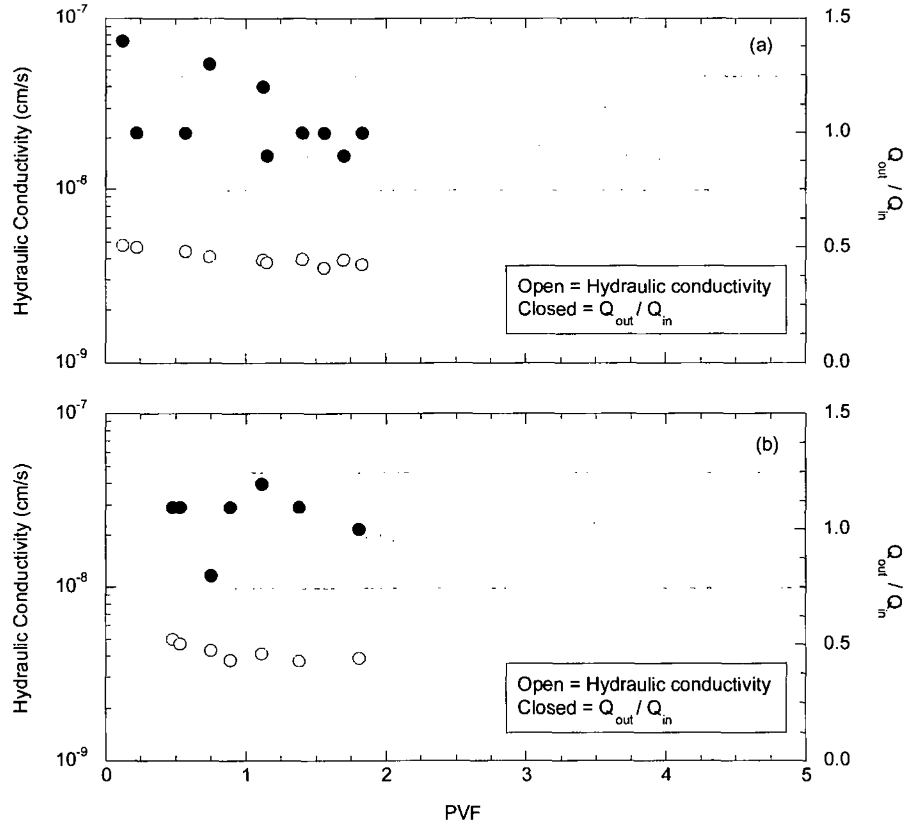

Fig. L. 22. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL E-3 with stress maintained (a) and no stress maintained (b) permeated with standard water.

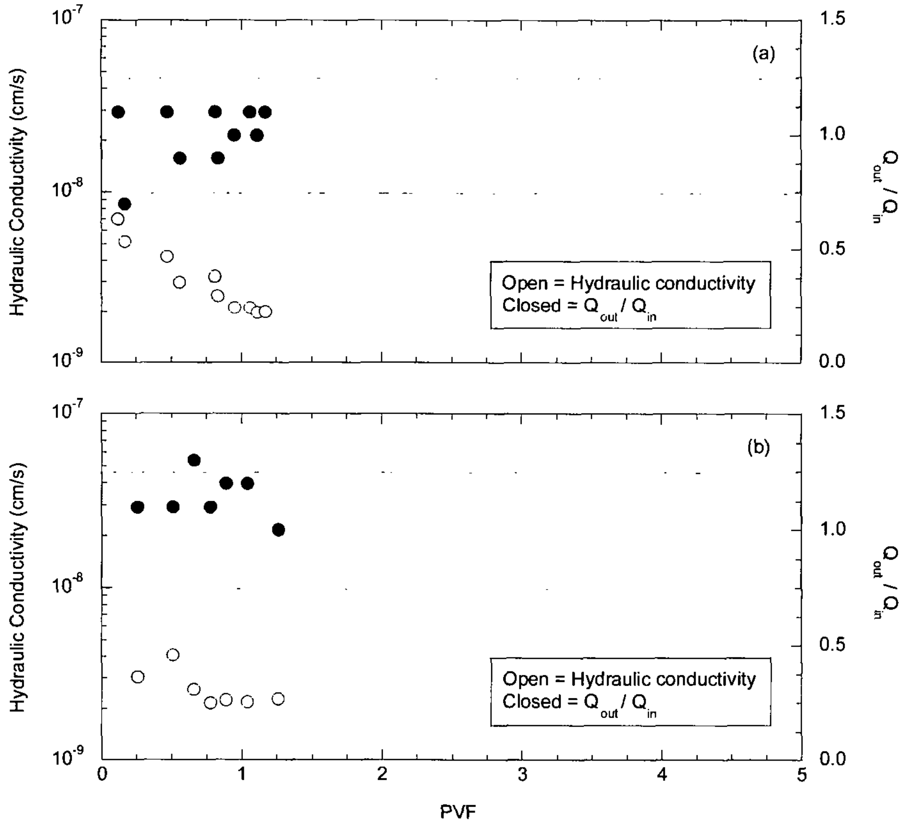

Fig. L. 23. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL E-4 with stress maintained (a) and no stress maintained (b) permeated with standard water.

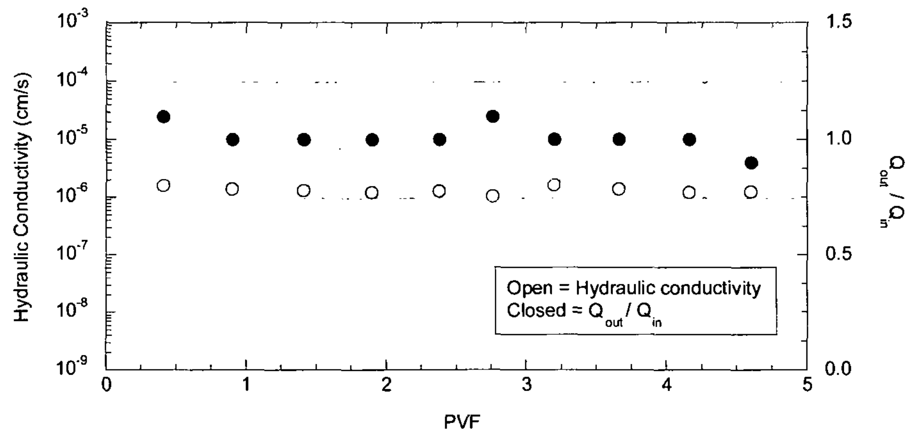

Fig. L. 24. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL E-5 permeated with standard water.

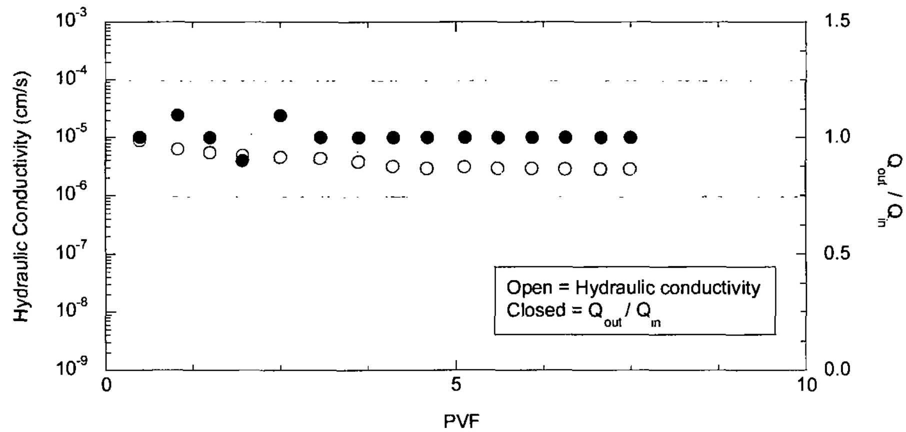

Fig. L. 25. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL E-6 with stress maintained (a) and no stress maintained (b) permeated with standard water.

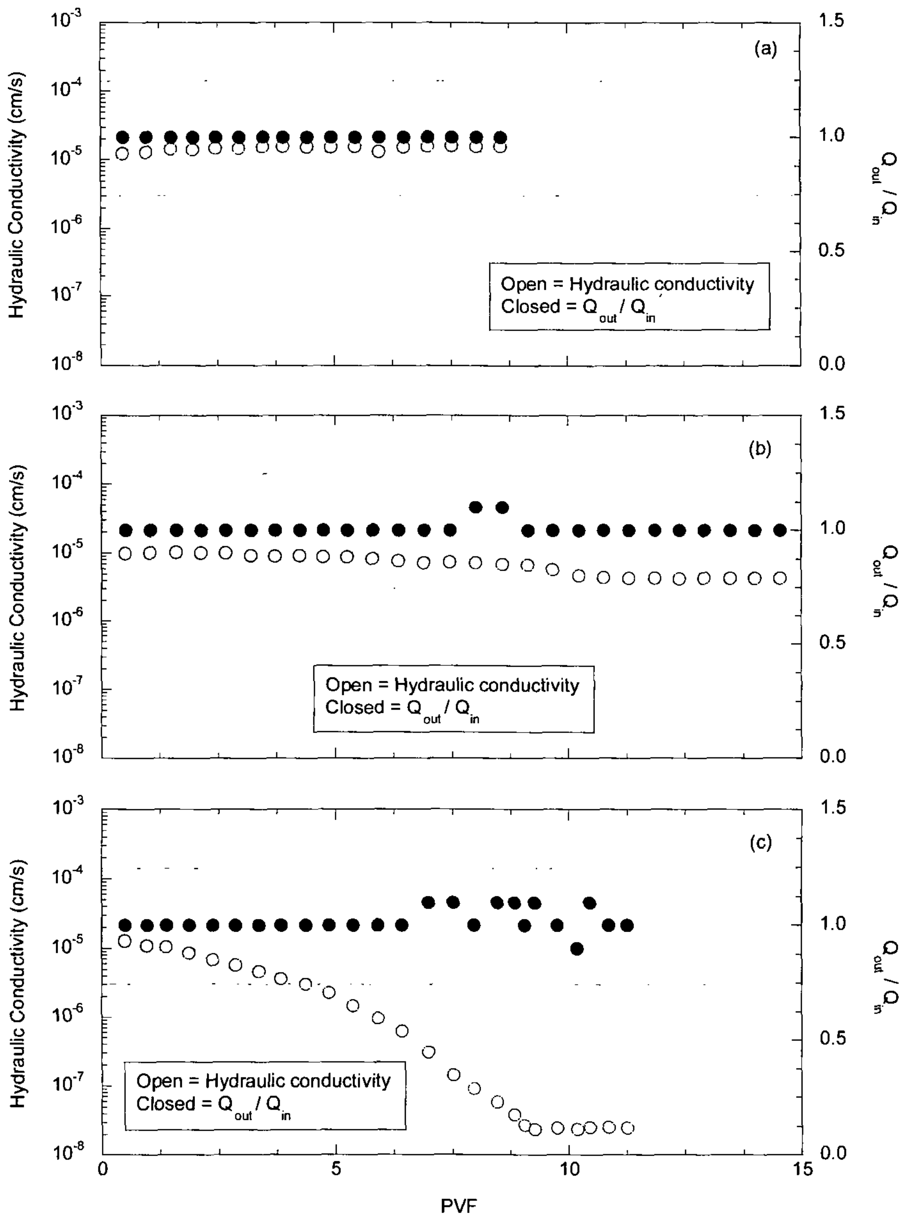

Fig. L. 26. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL E-7 permeated with standard water (a), average water (b), and de-ionized water (c).

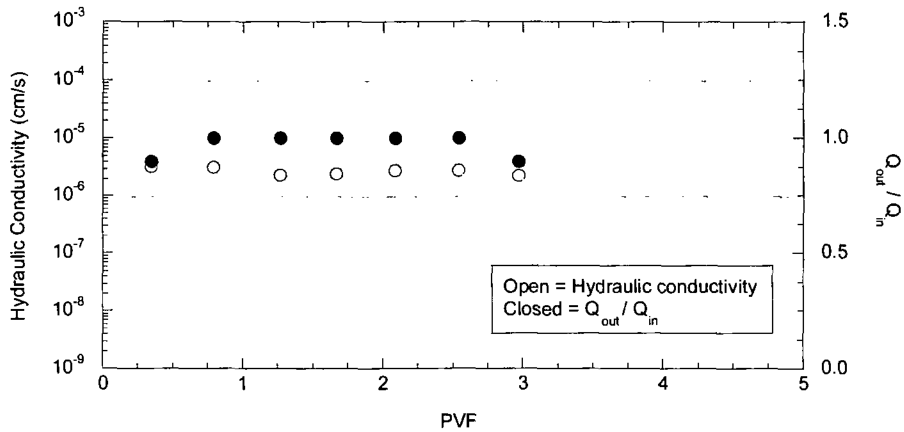

Fig. L. 27. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL E-8 permeated with standard water.

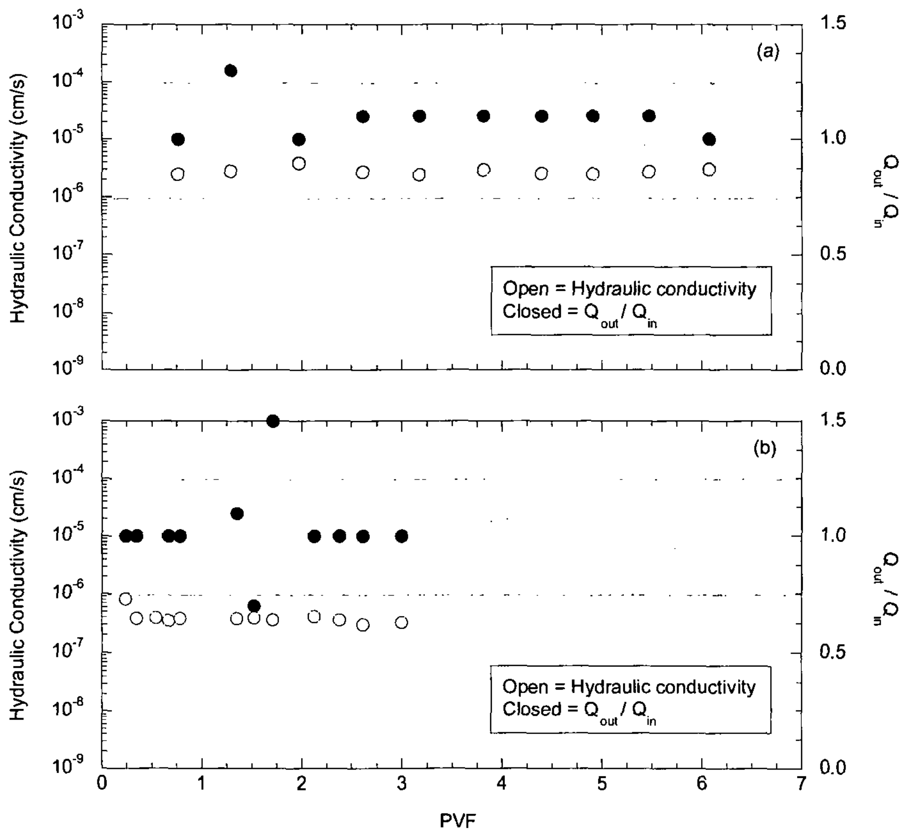

Fig. L. 28. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL E-9 with stress maintained (a) and no stress maintained (b) permeated with standard water.

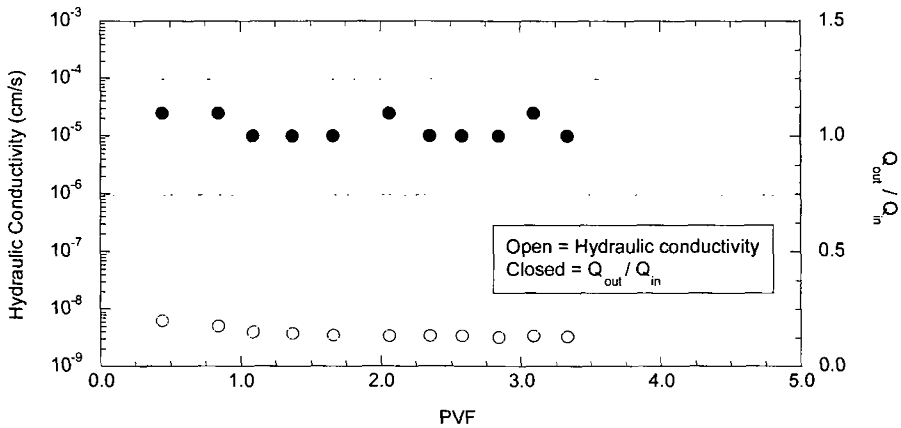

Fig. L. 29. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL E-10 permeated with standard water.

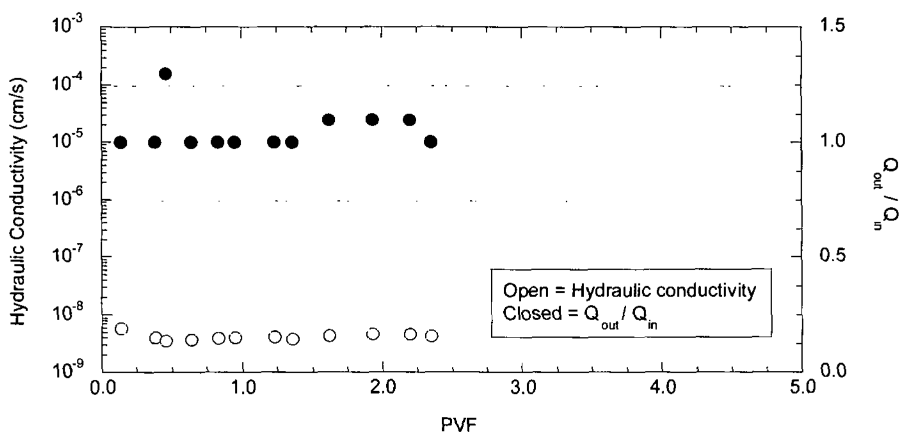

Fig. L. 30. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL E-11 permeated with standard water.

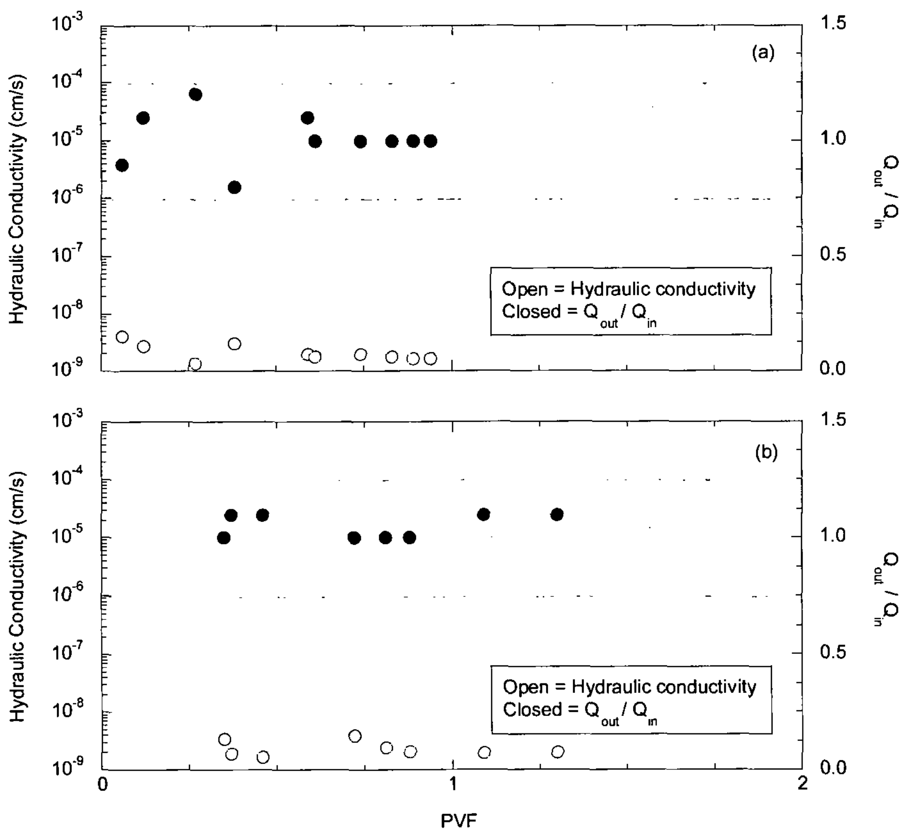

Fig. L. 31. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL E-12 with stress maintained (a) and no stress maintained (b) permeated with standard water.

L-4 HYDRAULIC CONDUCTIVITY PROFILES OF GCLS EXHUMED FROM SITE F.

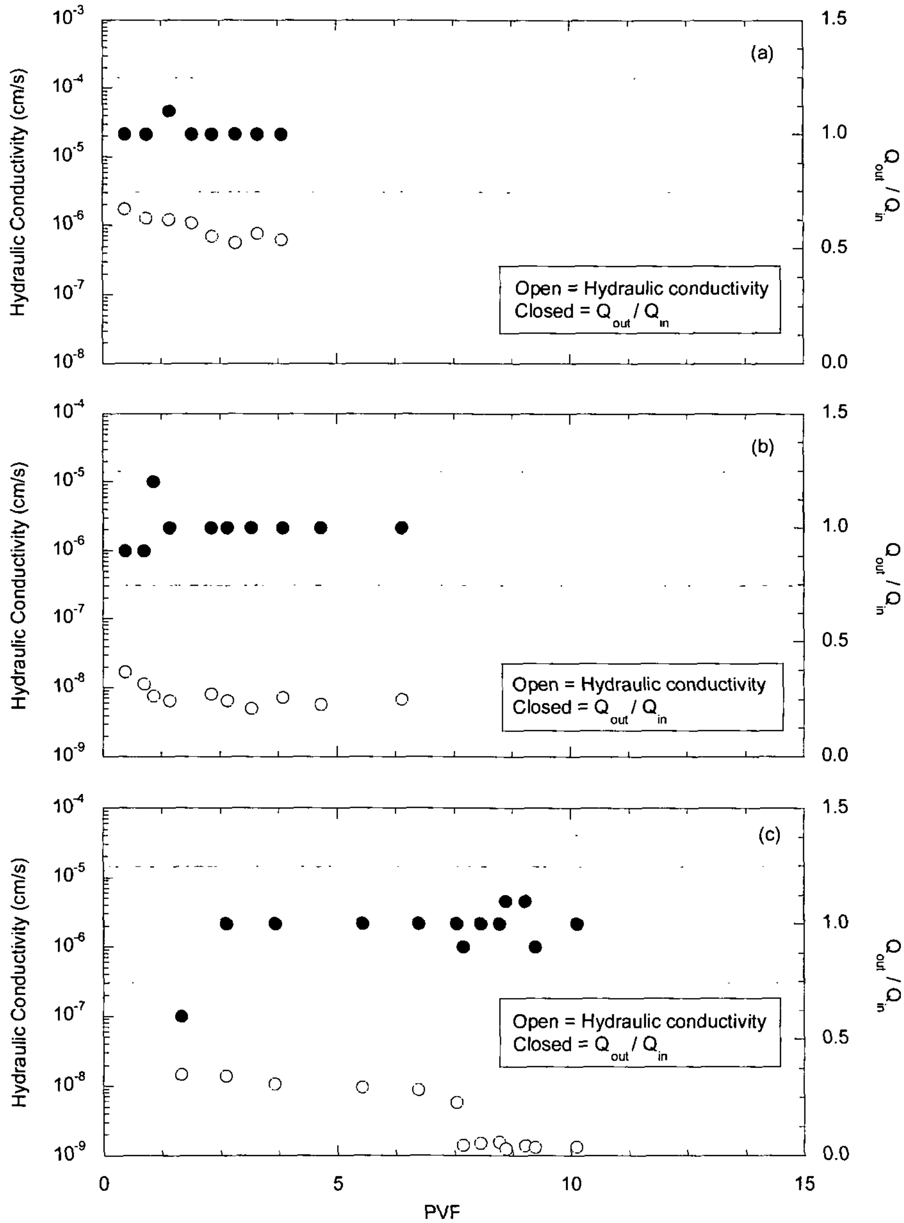

Fig. L. 32. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL F-1 permeated with standard water (a), average water (b), and de-ionized water (c).

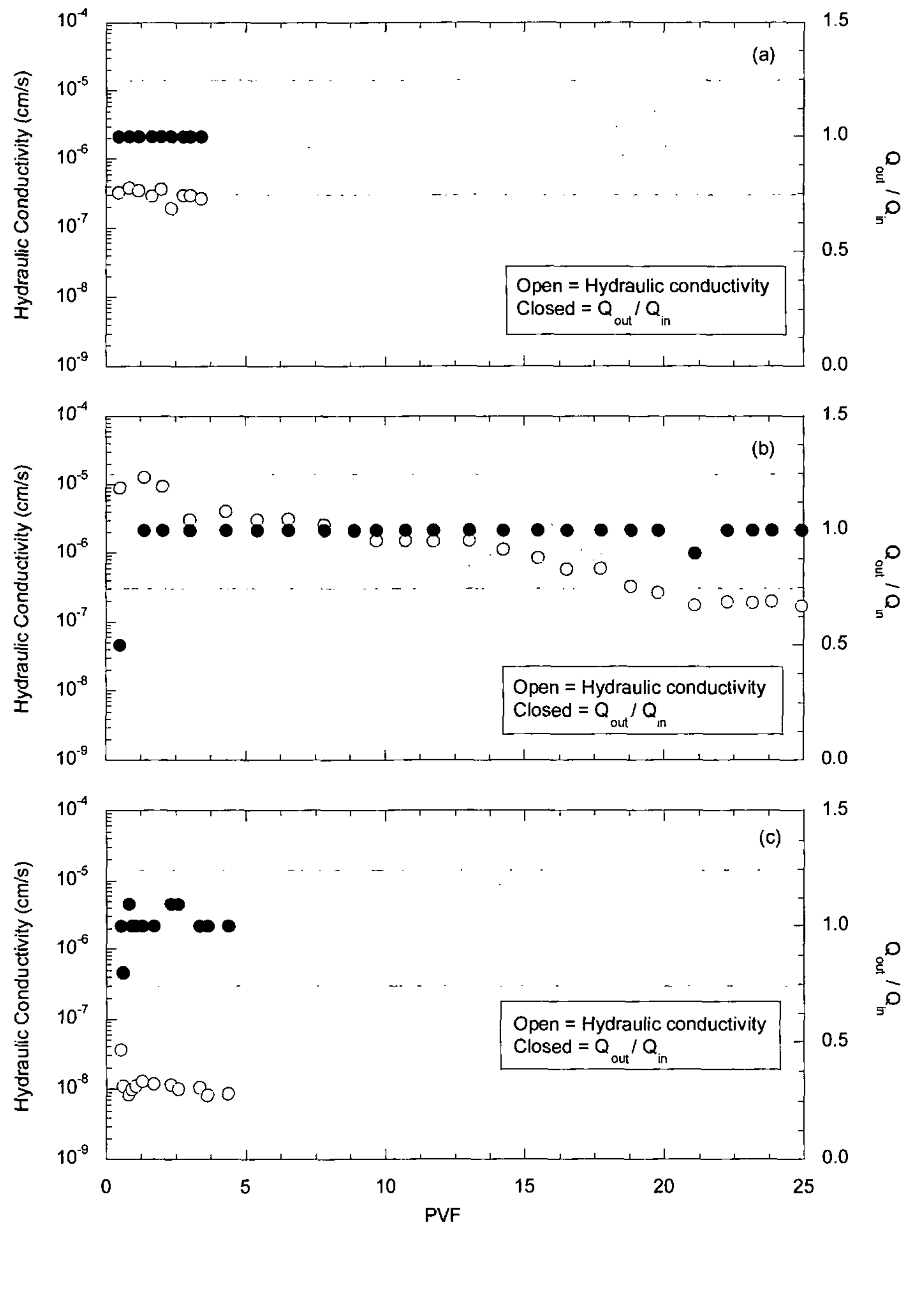

Fig. L. 33. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL F-2 permeated with standard water (a), average water (b), and de-ionized water (c).

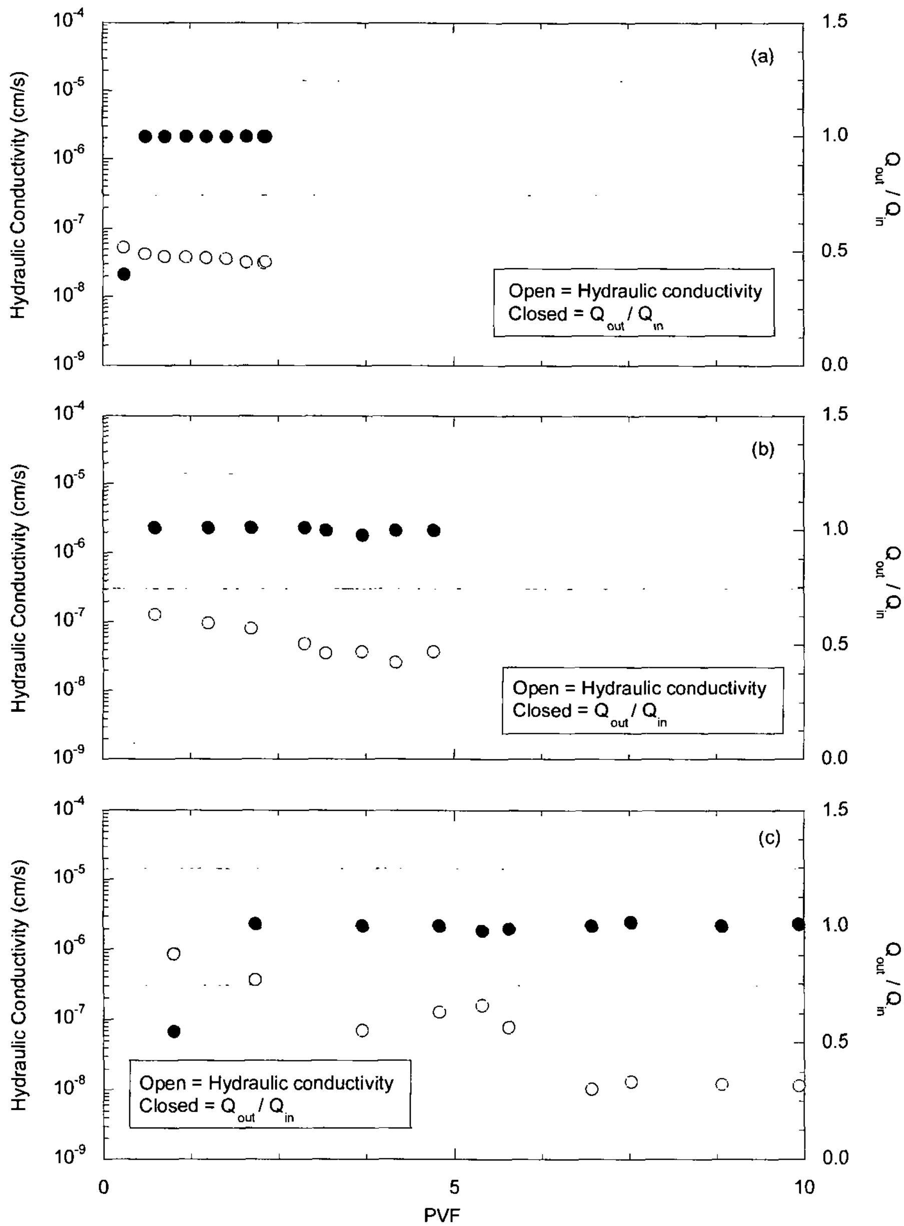

Fig. L. 34. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL F-3 permeated with standard water (a), average water (b), and de-ionized water (c).

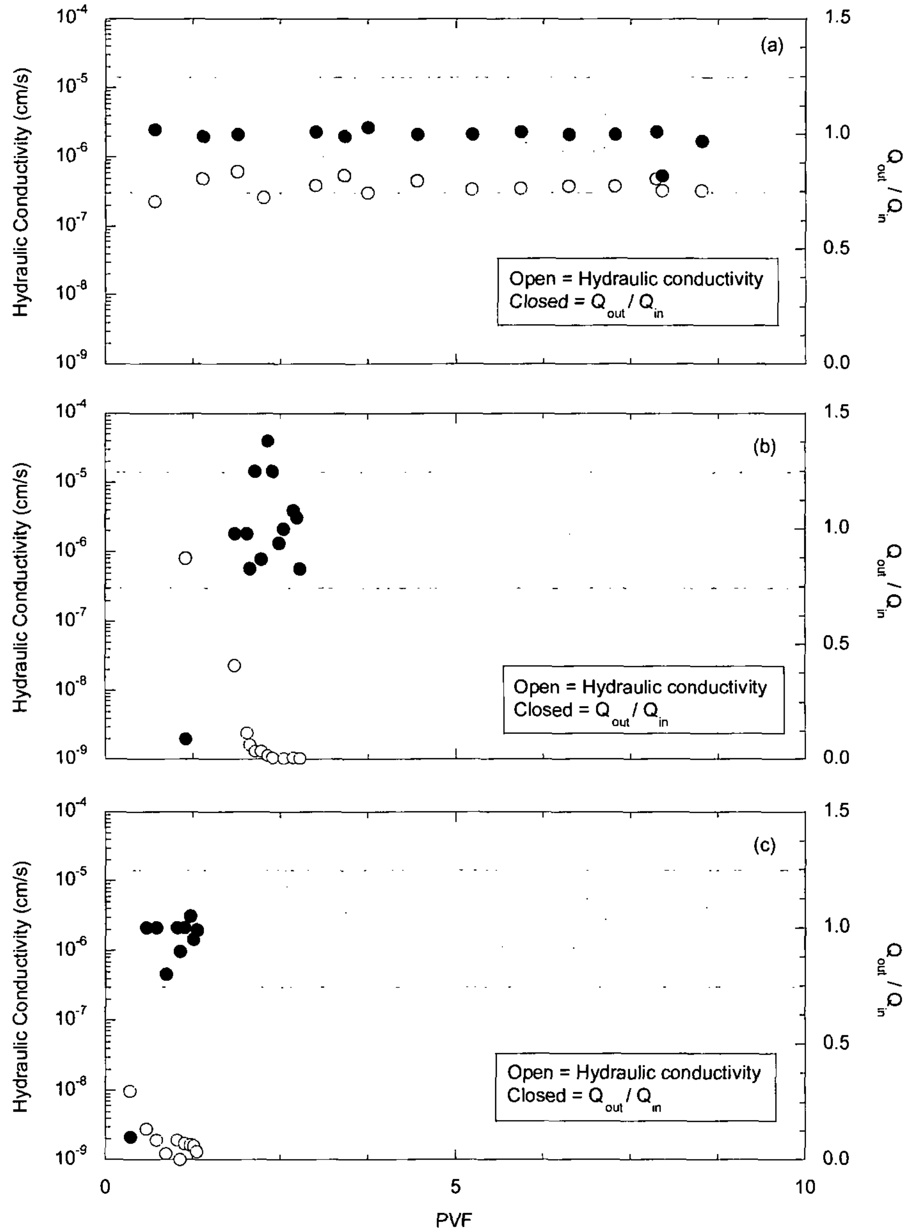

Fig. L. 35. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL F-4 permeated with standard water (a), average water (b), and de-ionized water (c).

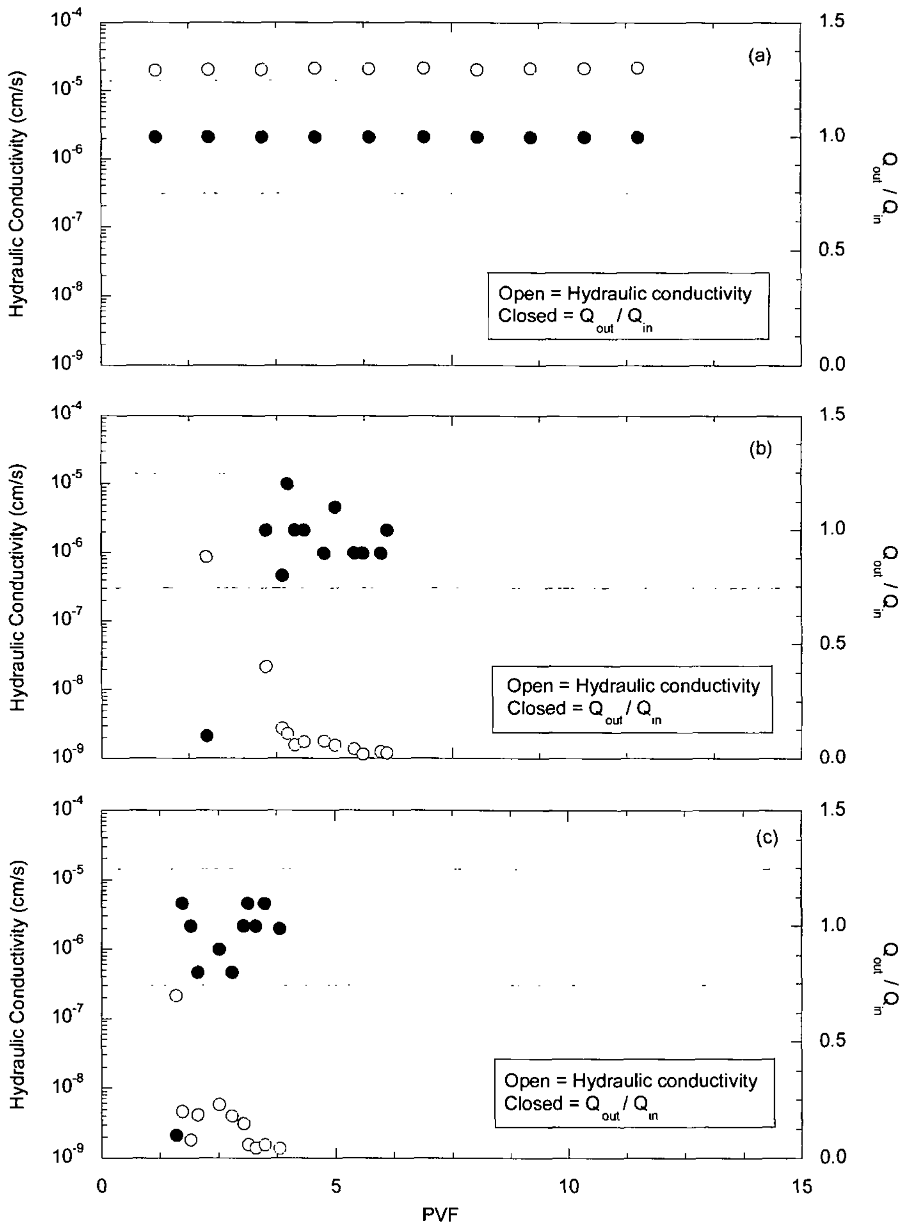

Fig. L. 36. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL F-5 permeated with standard water (a), average water (b), and de-ionized water (c).

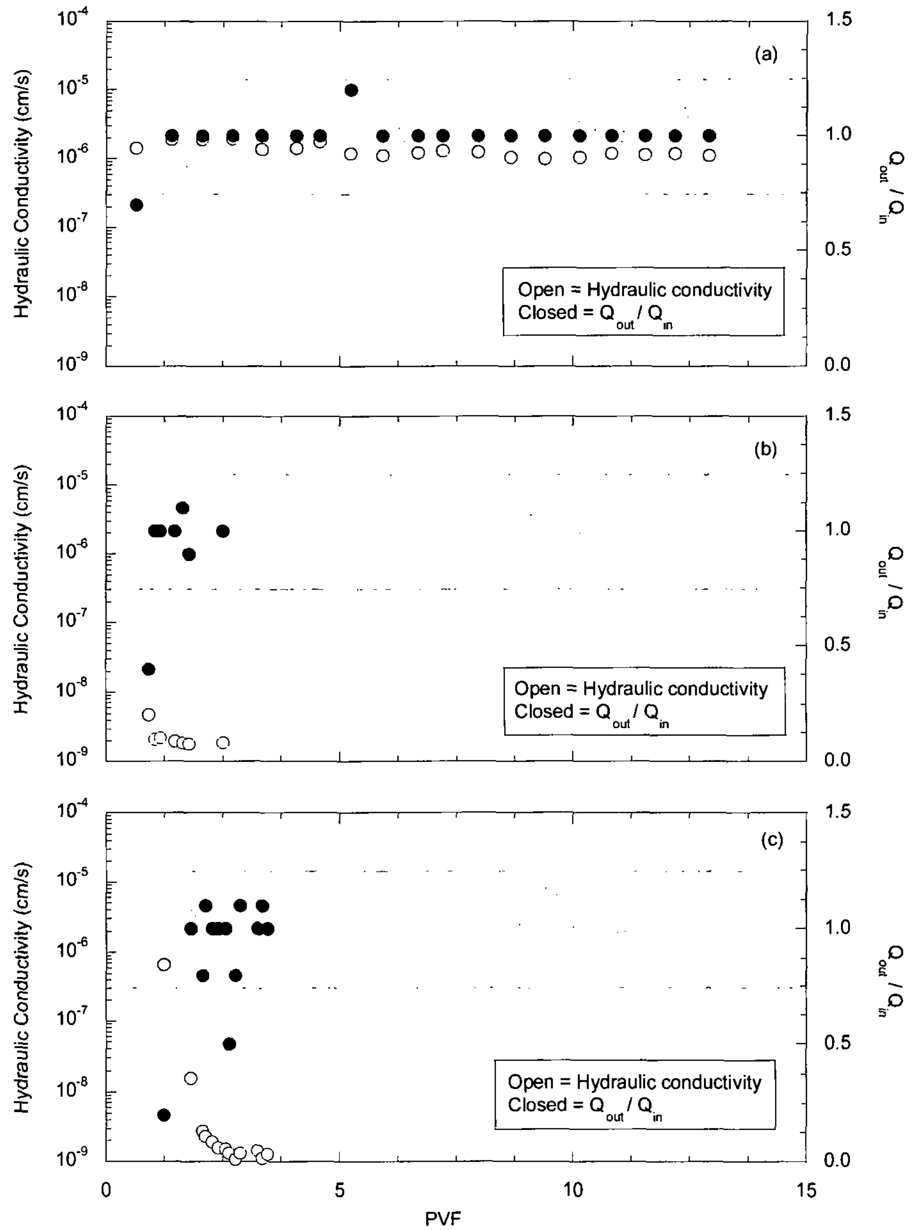

Fig. L. 37. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for GCL F-6 permeated with standard water (a), average water (b), and de-ionized water (c).

APPENDIX M - FIELD EXHUMATION PHOTOGRAPHY AND OBSERVATIONS

M-1 SITE B FIELD OBSERVATIONS

Fig. M. 1. Removing cover soils by hand at Site B.

Fig. M. 2. Rooting observed at GDL-GM interface but not at GDL overlaps.

Fig. M. 3. Minimal moisture observed at GDL-GM interface upon exposure.

Fig. M. 4. Installed whole in lysimeters GM exposed during exhumation.

Fig. M. 5. Cutting sample perimeters during GCL exhumation.

Fig. M. 6. Sliding rigid PVC plate under GCL sample during exhumation.

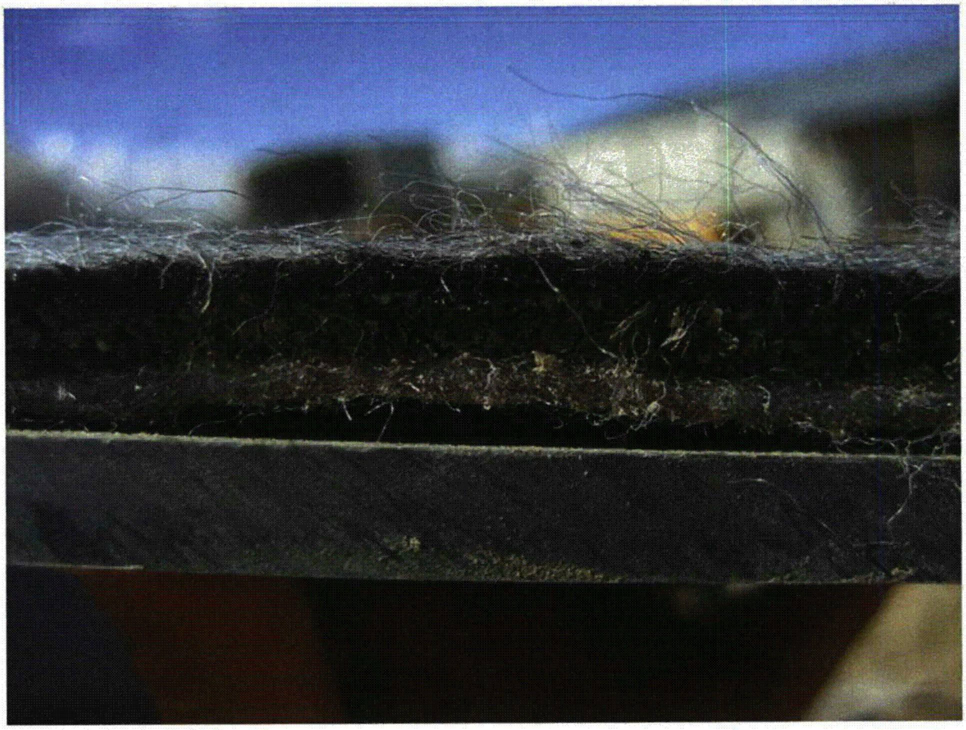

Fig. M. 7. GCL cross section on rigid PVC sampling plate immediately after exhumation.

M-2 SITE E FIELD OBSERVATIONS

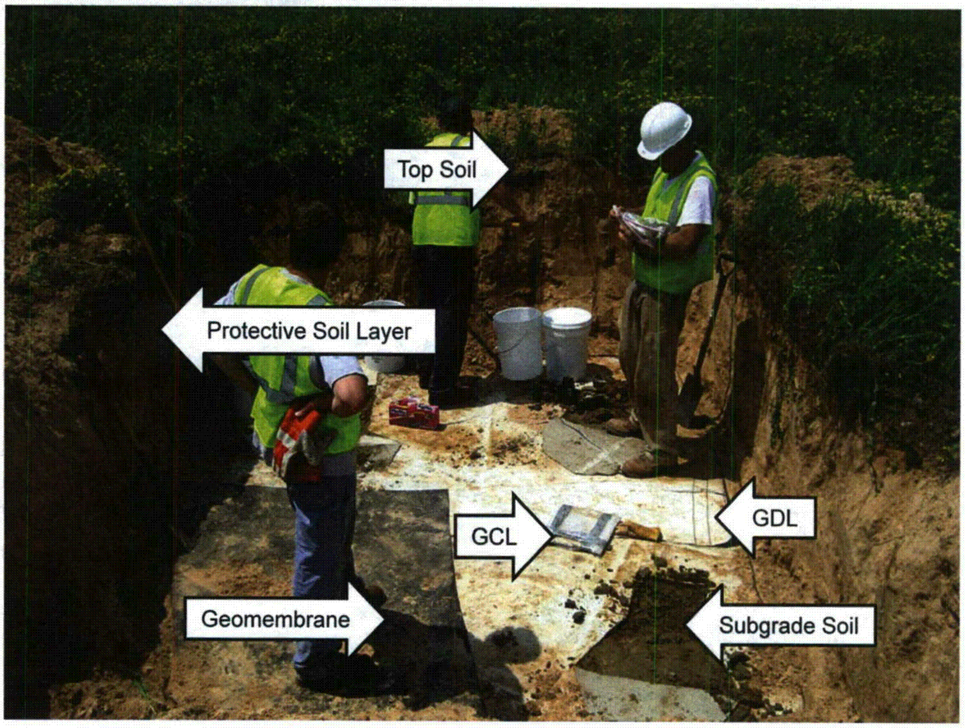

Fig. M. 8. Labeled schematic of GCL sampling test pit.

Fig. M. 9. Manual removal of soil layer overlying geocomposite barrier layer.

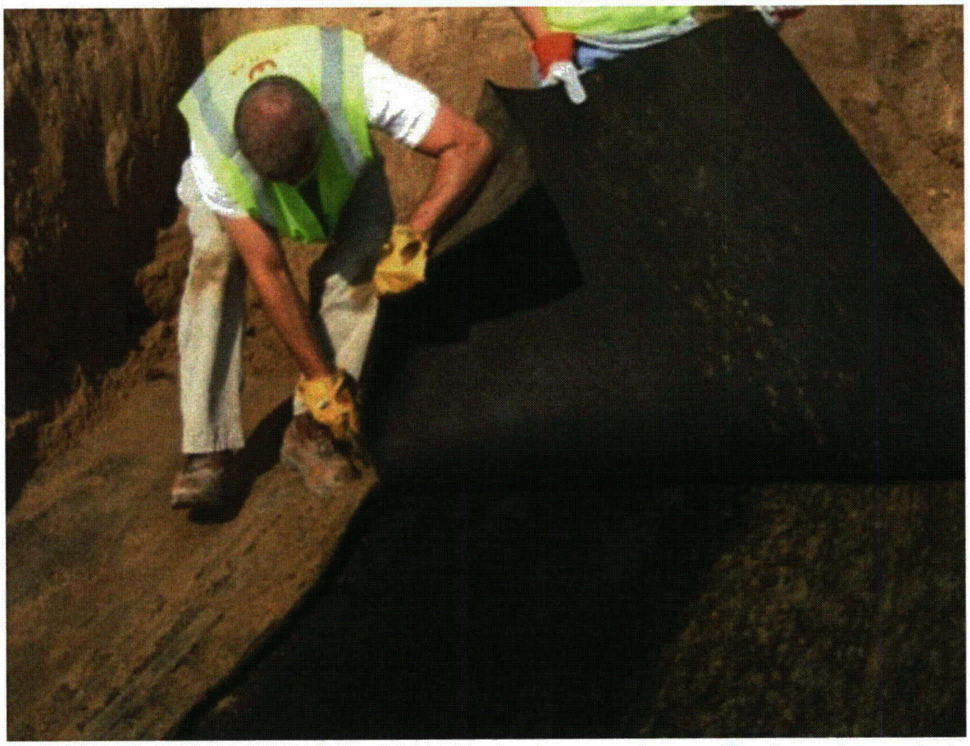

Fig. M. 10. Removal of GDL exposing GM.

Fig. M. 11. Moisture visible across GM immediately after GDL removal.

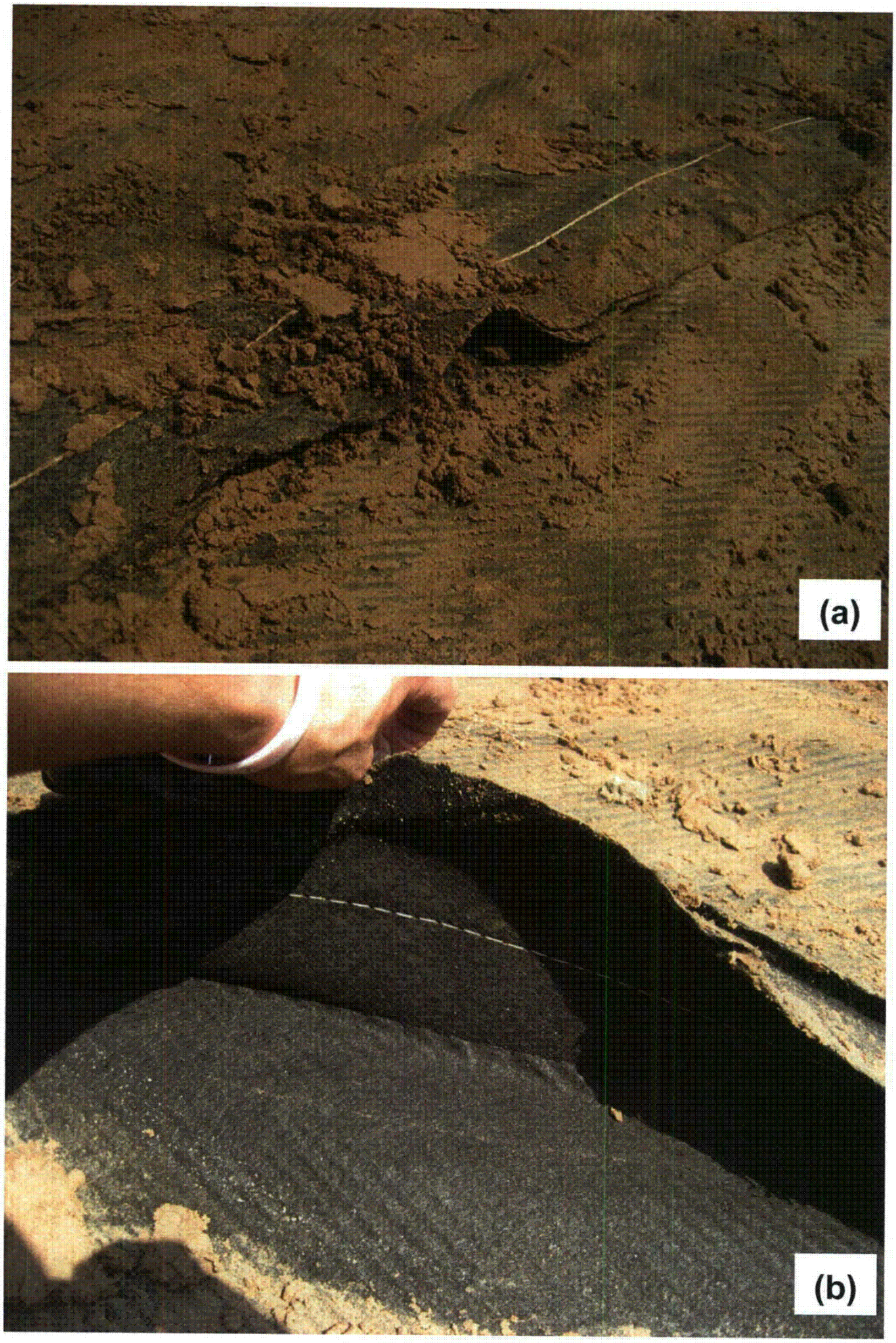

Fig. M. 12. Seam joining geotextiles in adjacent GDL panels in: (a) seam after removing cover soil (fish mouth in middle is due to disturbance during excavation) and (b) close up showing stitching of geotextiles and clean geotextiles in the overlap.

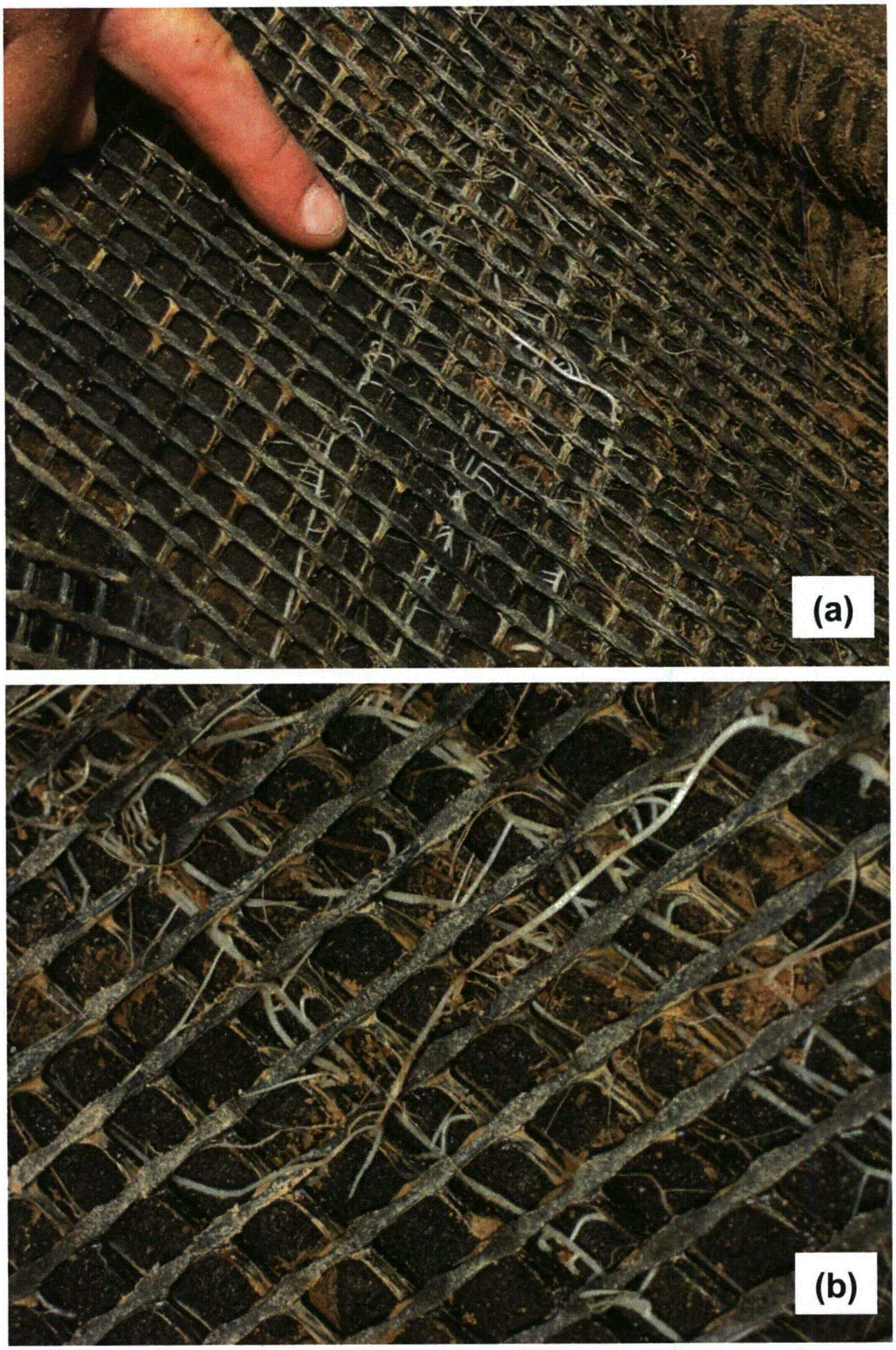

Fig. M. 13. Roots in the GDL and fines coating the ribs of the geonet in Test Pit 1: (a) overview and (b) close up.

Fig. M. 14. Examples of seams observed during exhumation: (a) dual-track wedge weld and (b) extrusion well to boot for gas well near Test Pit 4.

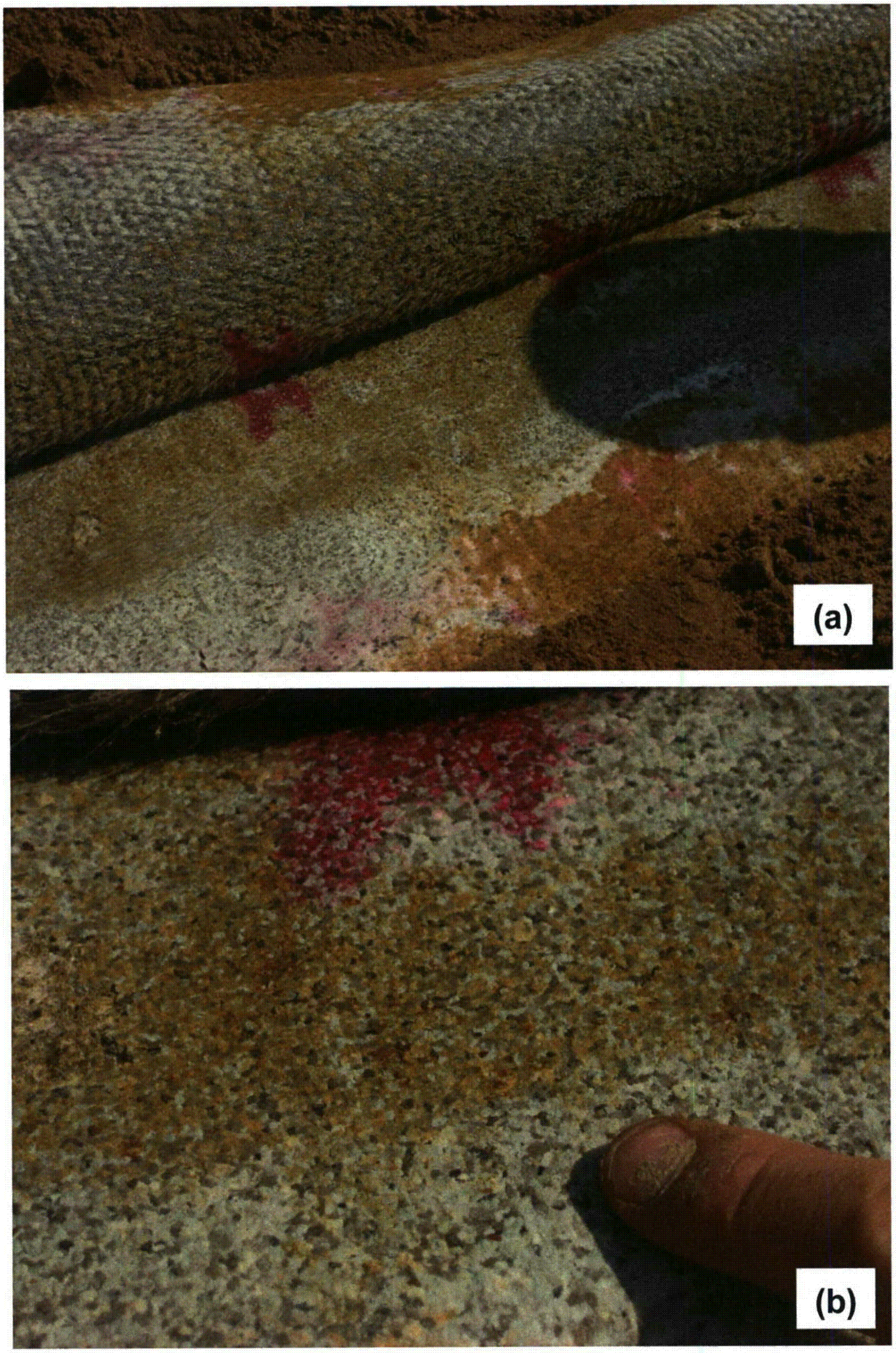

Fig. M. 15. GCL overlap: (a) match point along marks on original product and (b) close up showing hydrated bentonite granules in the overlap.

Fig. M. 16. Staining on GCL carrier nonwoven geotextiles.

Fig. M. 17. GCL sample with cut perimeter prior to sliding of sampling plate and removal.

Fig. M. 18. Black and rust colored staining underlying Site E GCL.

Fig. M. 19. Plastic bin used for GCL transport partially filled.

M-3 SITE F FIELD OBSERVATIONS

M-3.1 OBSERVATIONS DURING GCL EXHUMATION

Fig. M. 20. Test Pit 2 after removal of overlying soil layer.

Fig. M. 21. Cutting of GCL sample perimeters in Test Pit 2. Staining visible on GCL carrier geotextiles.

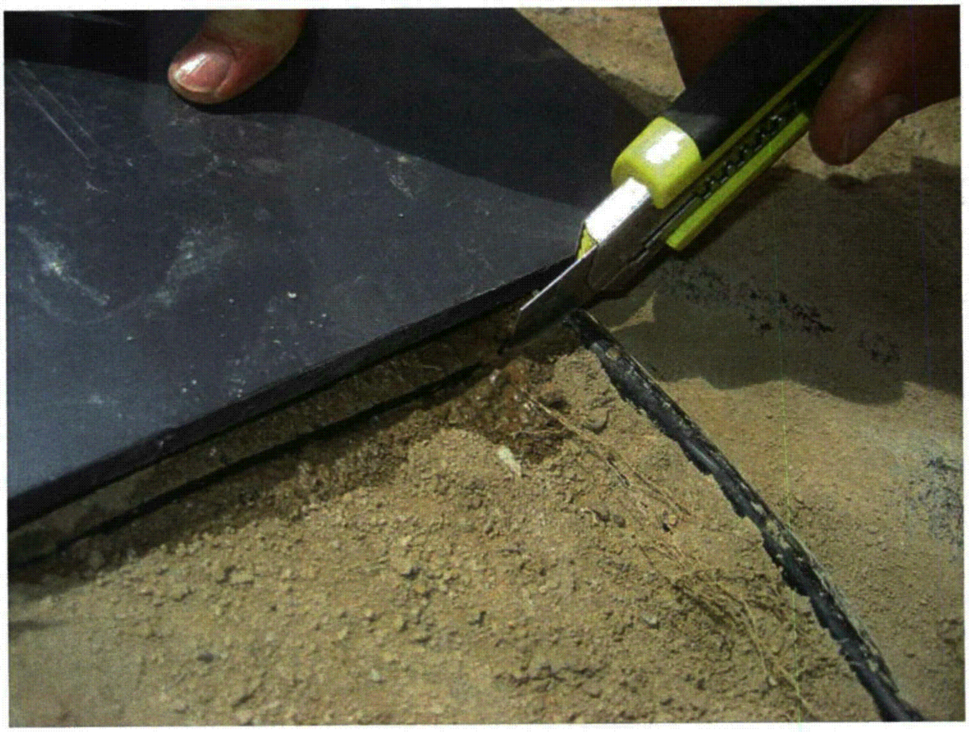

Fig. M. 22. Moisture seeping from GM while cutting through GM patch in Test Pit 1.

Fig. M. 23. Moisture visible on GCL after rupturing GM patch in Test Pit 1.

Fig. M. 24. Puncture visible in GCM patch weld in Test Pit 1.

Fig. M. 25. GM underlying GM patch. Hole in GM patch weld visible in upper right quadrant of the image.

M.3.2 GCL INSTALLATION OBSERVATIONS

Exhumation of GCL samples at Site F occurred coincident with installation of adjacent final cover at tie in points. The flowing photos represent observations made at Site F touring the instillation of the adjacent composite barrier layer.

Fig. M. 26. Condensation on GM overlying GCL underside from solar heating.

Fig. M. 27. GM overlying GCL before placement of overlying soil layer. Condensation for solar heating was observed underlying.

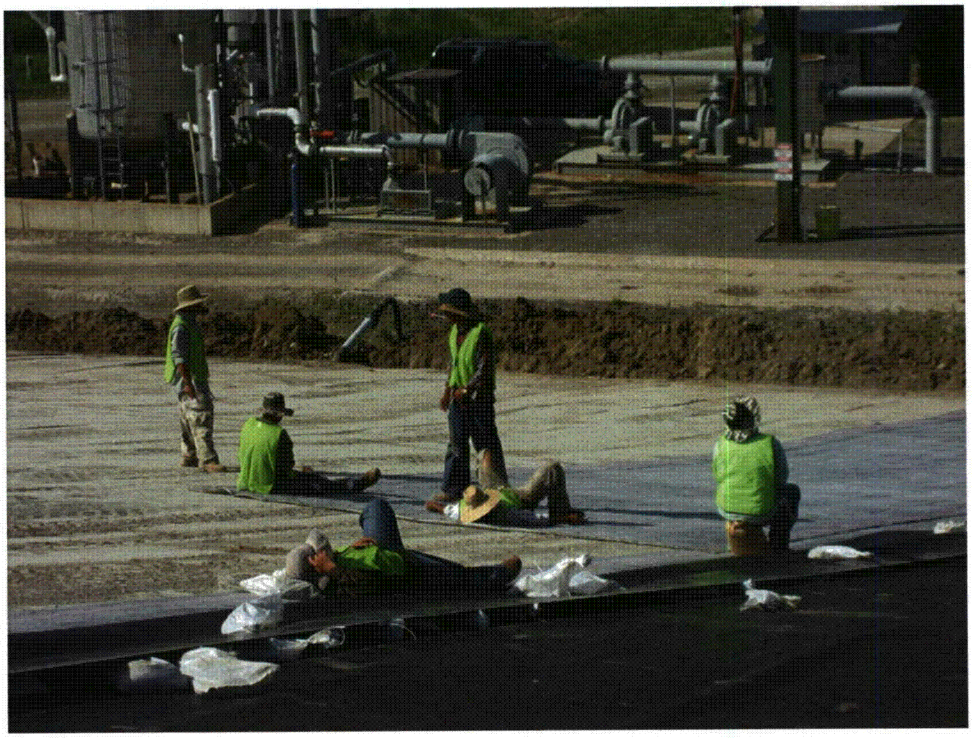

Fig. M. 28. GCL instillation team between rolls.

APPENDIX N - LABORATORY TESTING PHOTOGRAPY AND OBSERVATIONS

Fig. N. 1. Free swell testing of Site E bentonites.

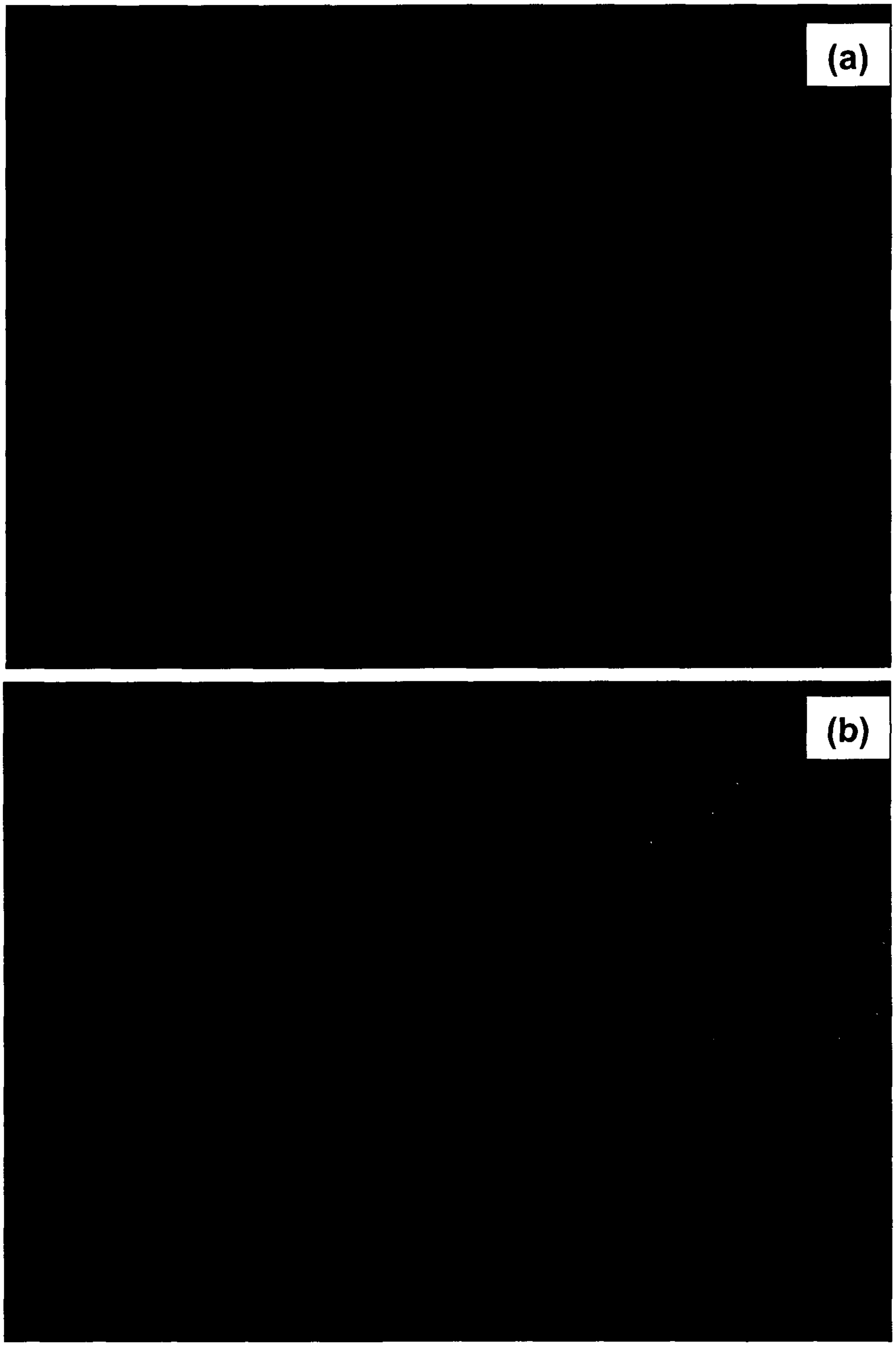

Fig. N. 2. Indentations were observed in Site A GCL in plan (a) and profile (b) view.

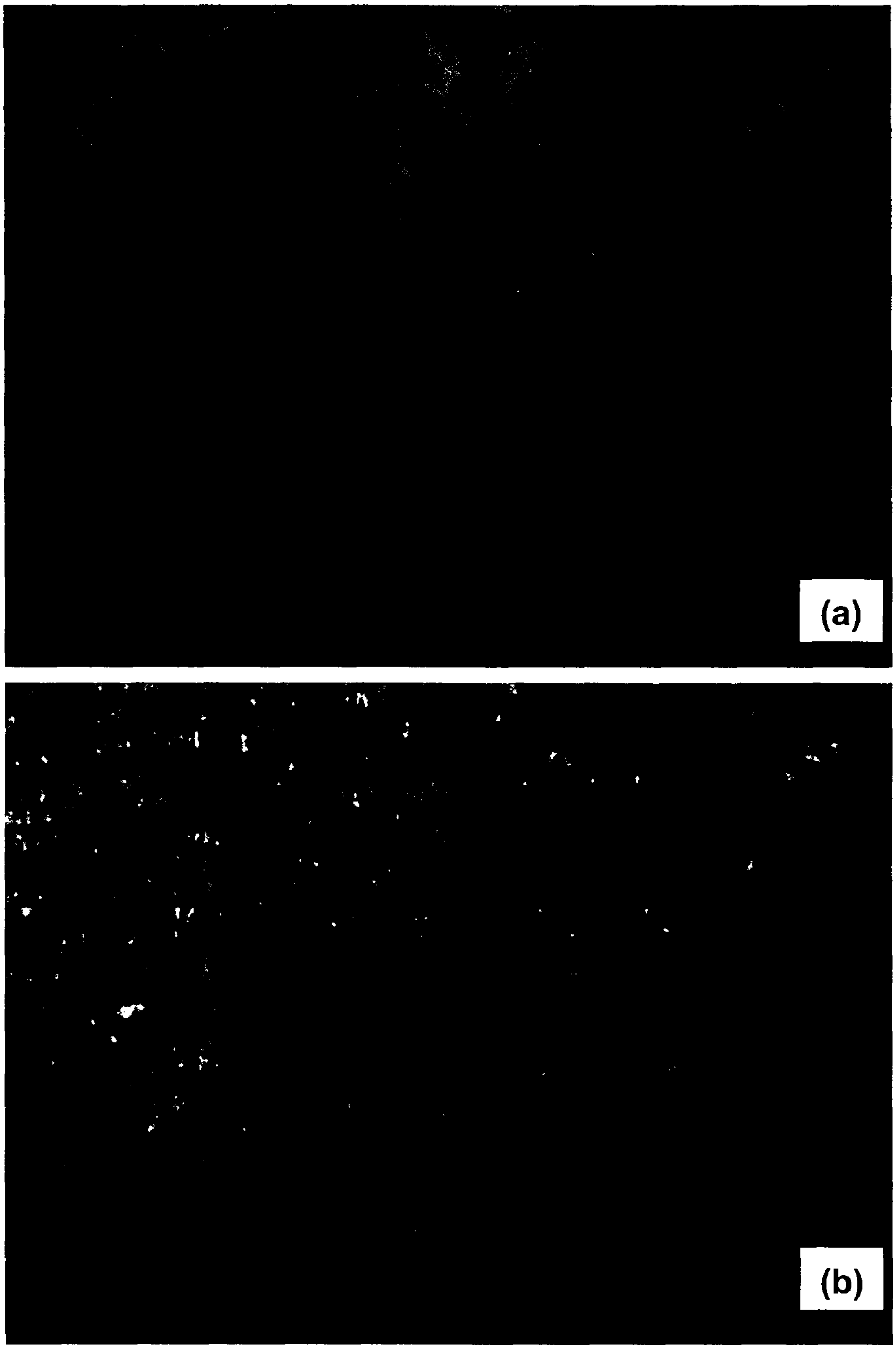

Fig. N. 3. Upper nonwoven geotextiles (a) and lower woven geotextile (b) of Site E higher hydraulic conductivity GCL prior to permeation. Dark staining visible at some needle punched fiber bundles.

Fig. N. 4. Influent nonwoven geotextiles (a) and effluent woven geotextile (b) of Site E higher hydraulic conductivity GCL after permeation and dying.

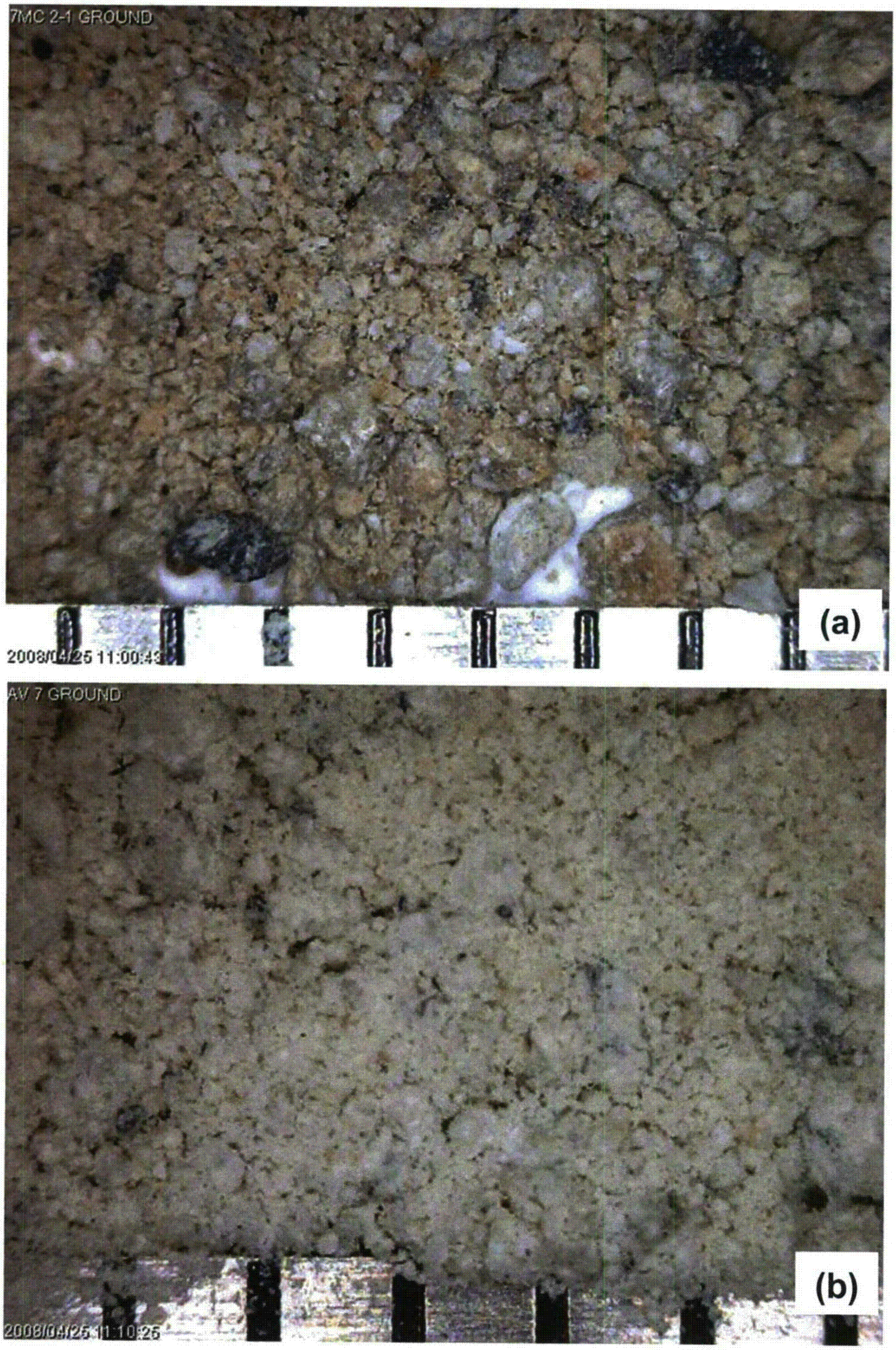

Fig. N. 5. Ground bentonite passing No. 20 sieve from Site E (a) and Site A (b).

Fig. N. 6. Bentonite from Site E TP1 during bound cation testing. Dark material is visible through the specimen.

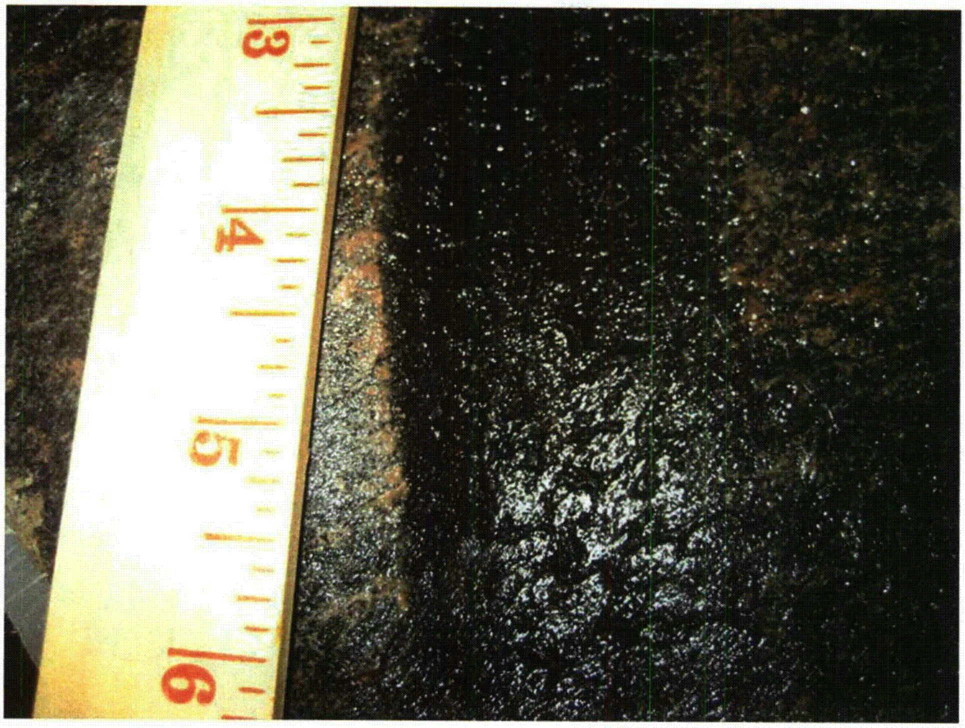

Fig. N. 7. Additional moisture visible under folds in GM exhumed from Site F TP1.

APPENDIX O - EXPLORATION OF GCL LABORATORY TESTING METHODS

O-1 EFFECT OF INCREASED EFFECTIVE STRESS DURING PERMEABILITY TESTING

After completion of permeability testing at an effective stress representative of field conditions (18 kPa), cell pressures were increased to ascertain the possible effect of increased overlying cover material. The average hydraulic gradient was maintained at approximately 150 for the duration of testing. Hydraulic conductivity is plotted versus pore volumes of flow for duplicate Site E-6 GCL specimens in Fig. O.1. The average hydraulic conductivity is also presented in Table O.1 with corresponding hydraulic conductivity at effective stress of 18 kPa (k_{18}) over hydraulic conductivity at increased effective stress ($k_{effective\ increased}$).

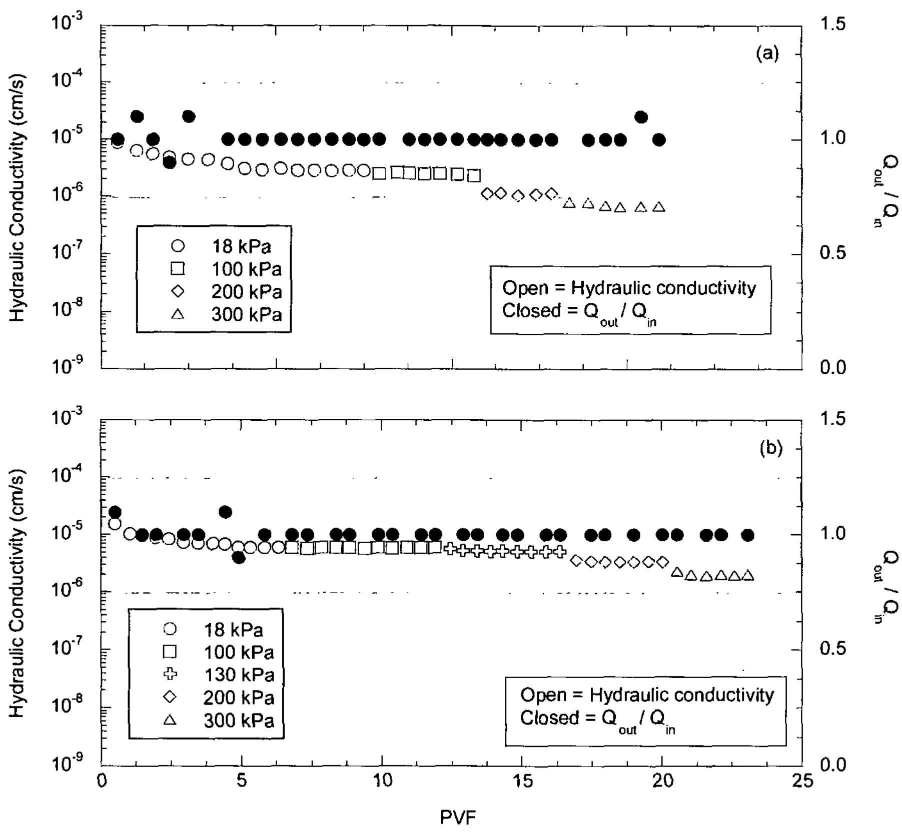

Fig. O. 1. Hydraulic conductivity and Q_{out} / Q_{in} as a function of pore volumes of flow for duplicate Site E-6 GCL permeated with standard water (Site E-6a (a), Site E-6b (b)).

Table O. 1. Final average hydraulic conductivity and $k_{18}/k_{ffective\ increased}$ at varying effective stresses for Site E-6 a & b GCLs.

	Site E-6a		Site E-6b	
Effective stress (kPa)	Final hydraulic conductivity (cm/s)	$k_{18}/k_{effective}$	Final hydraulic conductivity (cm/s)	$k_{18}/k_{effective}$
18	2.84E-06	1.0	5.99E-06	1.0
100	2.43E-06	1.2	5.88E-06	1.0
130	-	-	5.06E-06	1.2
200	1.11E-06	2.6	3.34E-06	1.8
300	6.81E-07	4.2	1.99E-06	3.0

O-2 EFFECT OF EDGE PASTE DEFECT IN PERMEABILITY TESTING

For all hydraulic conductivity tests, bentonite paste hydrated in the permeant liquid was frosted around the perimeter of the GCL specimen. The intention of this perimeter pasting is to eliminate possible flow paths the latex membrane. A hydraulic conductivity test was assembled with a generated gap in perimeter bentonite paste to asses the sensitivity of the perimeter bentonite paste assembly method. A 1 cm gap was place in the bentonite specimen pasting of Site E Test Pit 1 GCL specimen with a free swell index of 8 mL/2g (essentially calcium bentonite). A Site E GCL was chosen to provide a worst-case scenario where minimal self healing is possible. A profile of the assemble permeameter with bentonite paste gap is presented in Fig. O.2. Hydraulic conductivity profiles for a matching Site E Test Pit 1 specimen (same sample) and for the gap-pasted specimen are plotted versus PVF in Fig. O.3. The latex membrane closely formed over the bentonite paste gap after application of effective stress as shown in Fig. O.4. Both GCLs were permeated with standard water.

Fig. O. 2. GCL assembled with missing perimeter bentonite paste.

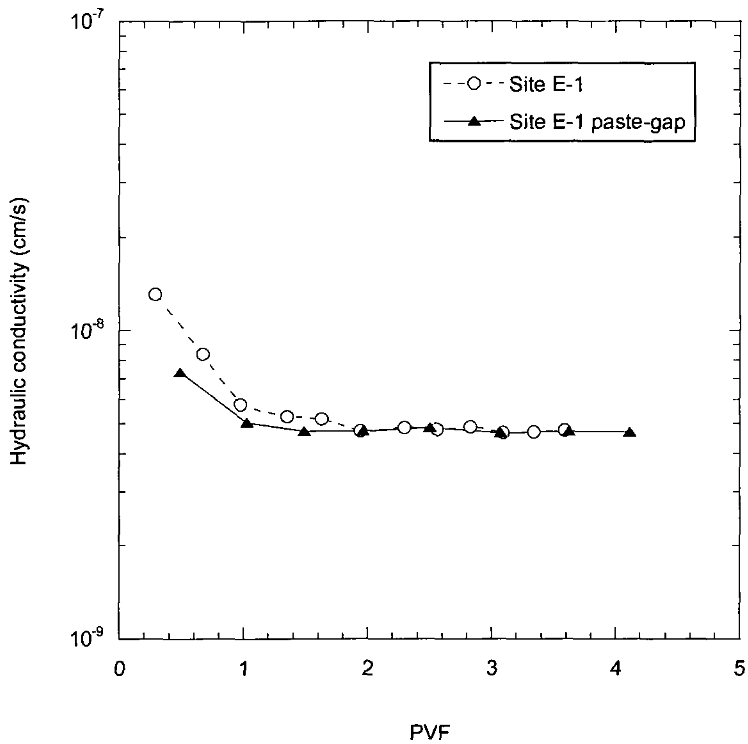

Fig. O. 3. Hydraulic conductivity versus pore volumes of flow for Site E-1 GCL and matching bentonite paste-gap specimen.

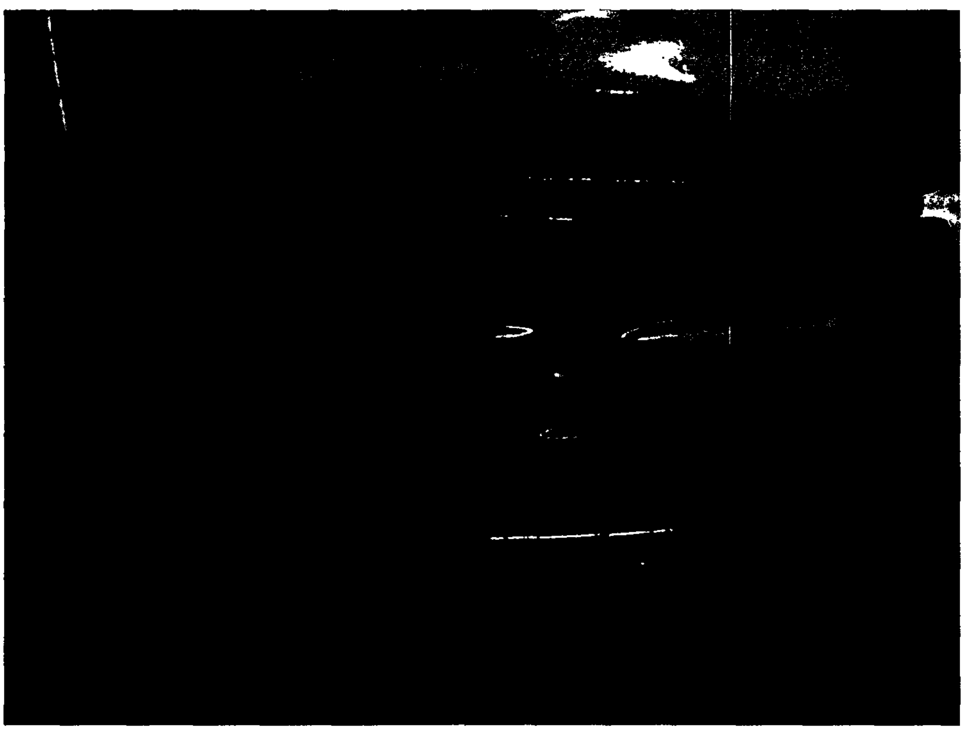

Fig. O. 4. Latex membrane over internal bentonite paste gap after application of effective stress, permeation, and disassembly.

O-3 MANUFACTURER VERSUS UNIVERSITY OF WISCONSIN EXHUMED COMPOSTIE COVER GCL HYDRAULIC CONDUCTIVITIES

Duplicate GCL specimens were exhumed from each sampling location at Site B (4 samples) and from Test Pit 1 at Site E by the University of Wisconsin and the Manufacturer. University of Wisconsin hydraulic conductivity testing was conducted as detailed in Chapters 2,3 and 4. Manufacturer hydraulic conductivity testing was performed on 10.2 cm diameter specimen with de-aired deionized water as the permeant. A maximum effective stress of 34.4 kPa was employed with an initial head of 140.6 kPa. All tests were run until the flux ratio ASTM termination criterion was met. Hydraulic conductivities from the University of Wisconsin permeating with AW or DW are plotted versus hydraulic conductivities from the manufacturer in Fig. O.5.

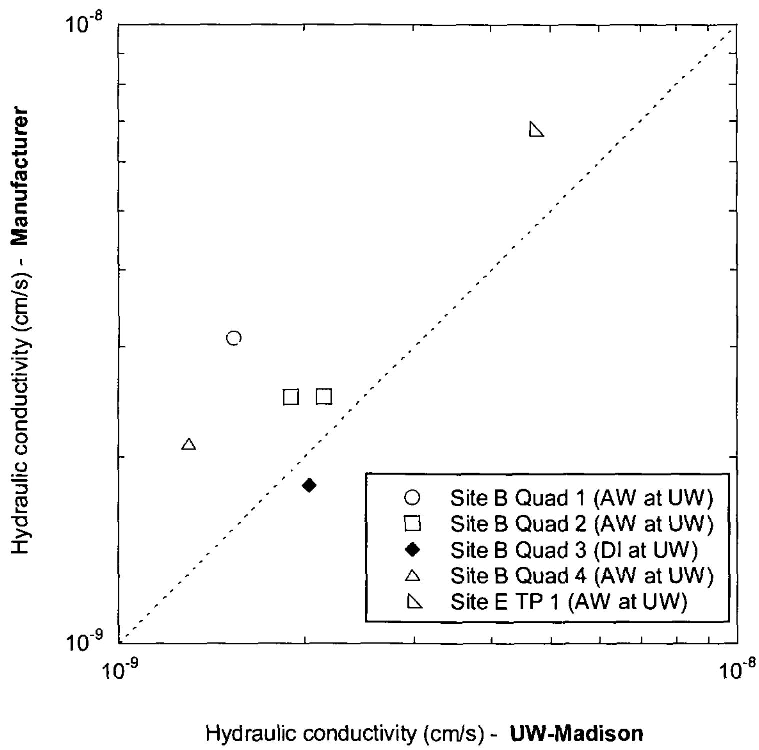

Fig. O. 5. Site B hydraulic conductivity versus testing facility for Site B GCL duplicate samples.

O-4. EFFECTS OF DESSICATION CYCLES ON EXHUMED COMPOSITE COVER GCLs.

Desiccation tests were conducted on Site A and Site E GCL specimens after permeation with SW. GCLs were removed from their permeameter, and the surrounding bentonite paste was manually removed with a small spatula. The GCL specimen was then placed between 2 geotextiles, 2 geocomposite drainage layers, and 2 rigid HDPE plates. The upper HDPE plate was then loaded vertically until a pressure (18-24 kPa) equal to the in-situ effective stress was achieved. GCLs were allowed to air dry for until their daily mass reached a steady state.

The saturated hydraulic conductivity before and after application of desiccation cycle(s) is plotted in Fig. O.6.

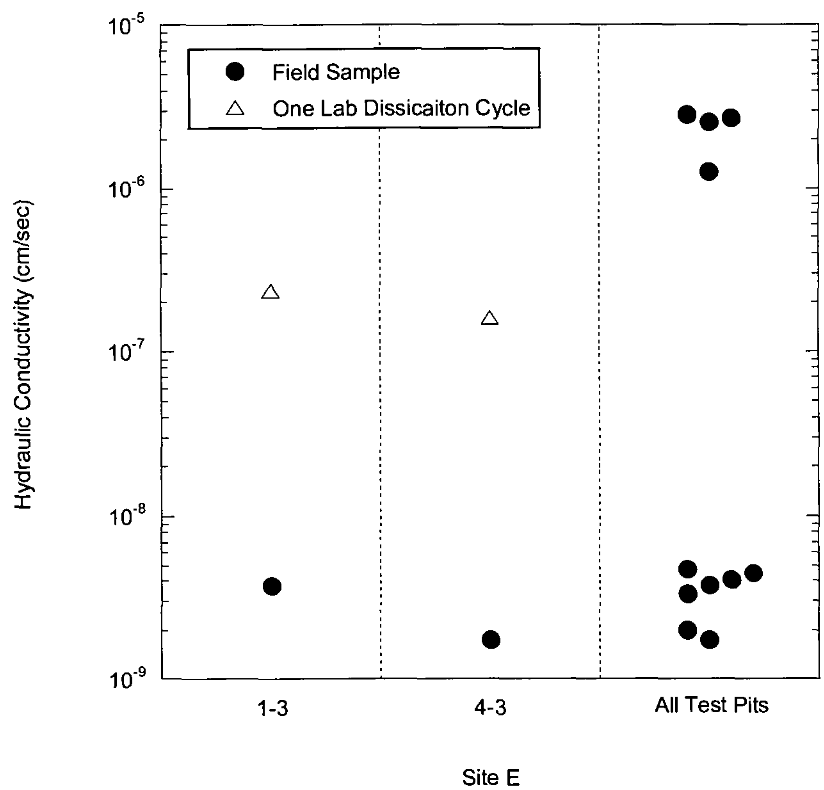

Fig. O. 6. Hydraulic conductivity after exhumation and application of desiccation cycle(s).

APPENDIX P – SUPPLEMENTAL GRAPHS AND TABLES FROM GEOSYNTHETIC MEMBRANE (GM) AND GEOSYNTHETIC DRAINAGE LAYER (GDL) TESTS

Table P1. Coefficient of variation (CoV) for each engineering property of exhumed geosynthetics.

	Altamont, CA	Apple Valley, CA	Boardman, OR	Cedar Rapids, IA	Eau Claire, WI	Helena, MT	Omaha, NE	Polson, MT	Underwood, ND
Wide Strip Yield Strength	2.3	3.8	4.1	1.8	5.1	3.0	8.7	10.2	2.6
Narrow Strip Yield Strength	7.3	10.7	9.5	12.9	15.7	2.4	17.0	6.2	9.4
Narrow Strip Break Strength	9.7	25.4	15.4	8.6	22.8	14.9	32.7	37.0	8.0
Wide Strip Yield Strain	3.0	2.6	4.0	12.6	23.2	4.4	28.8	8.3	26.1
Narrow Strip Yield Strain	10.8	8.8	16.0	9.6	34.7	9.4	22.8	16.9	7.8
Narrow Strip Break Strain	8.5	31.2	9.8	6.1	36.7	11.3	32.1	66.1	5.1
Ply Adhesion	27.3	19.8	30.2	47.0	43.0	66.4	34.9	-	58.9
Permittivity at 10 mm	15.4	10.1	30.4	35.3	43.3	57.1	47.7	-	23.3
Permittivity at 50 mm	22.1	5.8	25.7	20.7	41.2	46.1	42.4	-	35.9
Transmissivity (24 kPa)	80.0	-	55.8	23.7	64.5	4.2	23.1	-	41.9
Transmissivity (48 kPa)	66.8	-	48.5	23.9	-	3.4	27.3	-	38.8
Transmissivity (480 kPa)	82.4	-	46.8	29.2	38.6	5.3	34.3	-	41.9

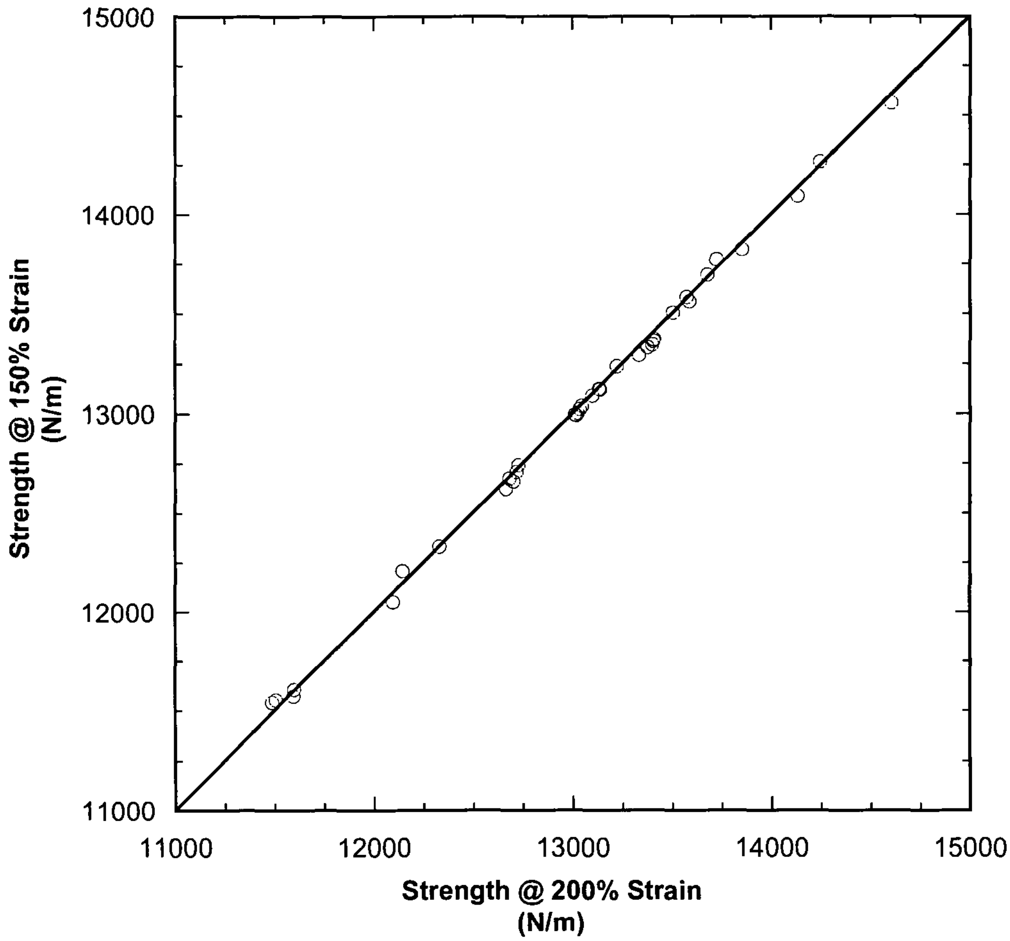

Fig. P1. Comparison of wide-width tensile strengths corresponding to 150 and 200% strain for Eau Claire samples.

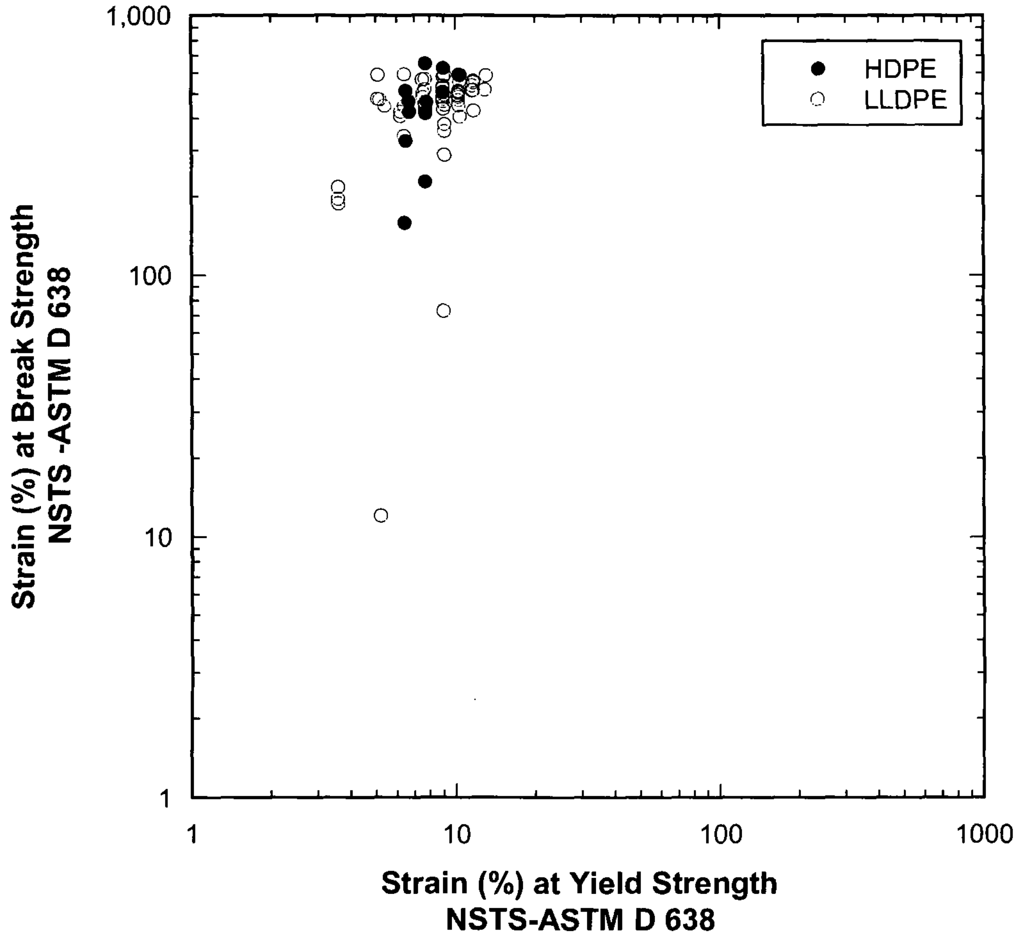

Fig. P2. Comparison between strains at narrow strip break strength and yield strength.

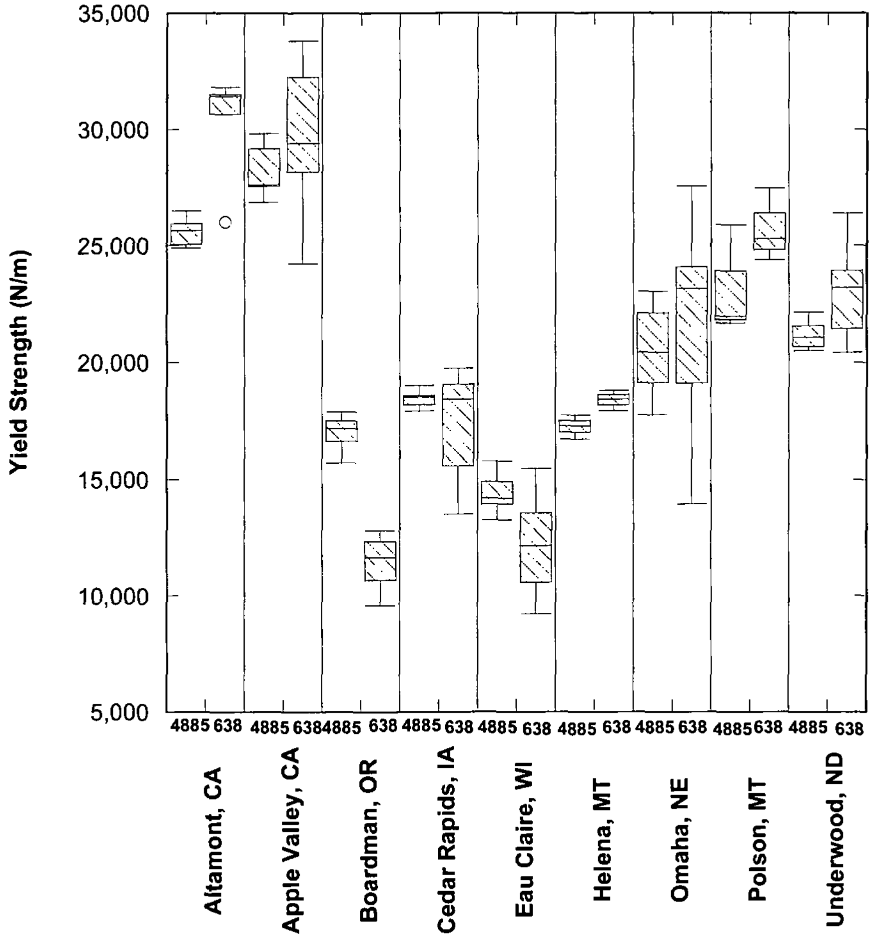

Fig. P3. Box plots comparing wide-strip and narrow-strip dumbbell tensile strengths.

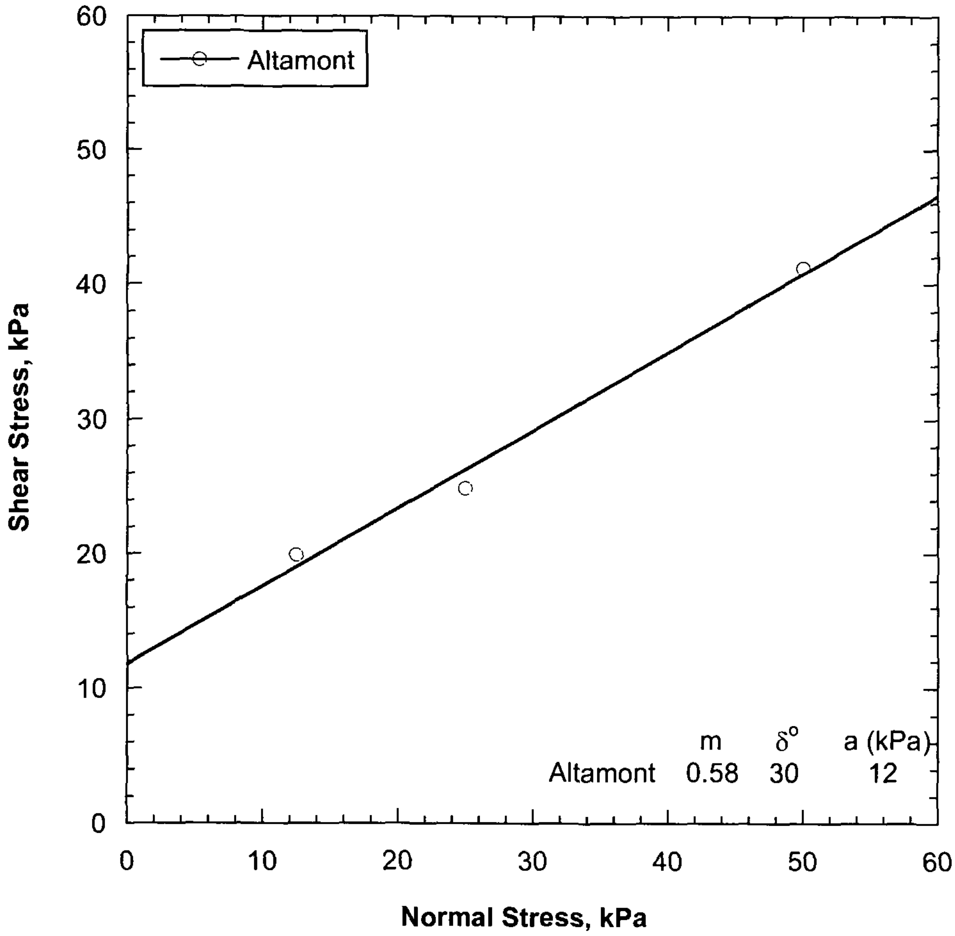

Fig. P4. Peak interface shear strength envelope for GM-GDL interface at Altamont.

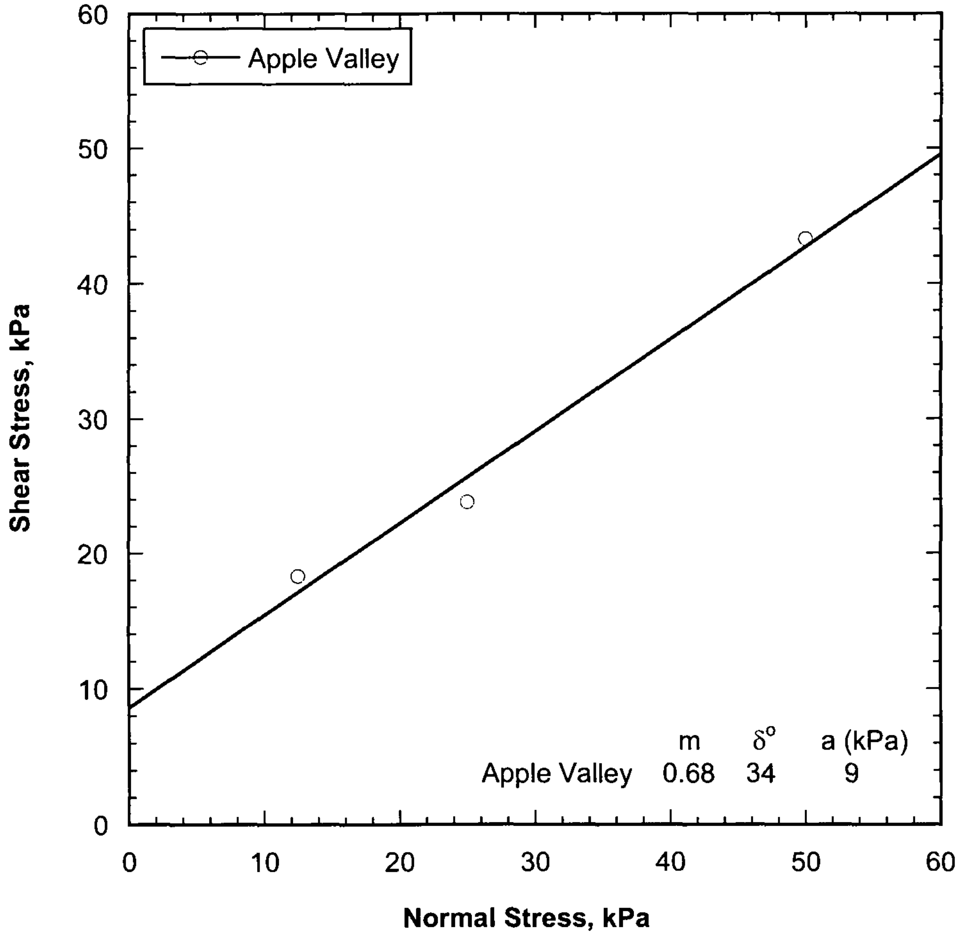

Fig. P5. Peak interface shear strength envelope for GM-GDL interface at Apple Valley.

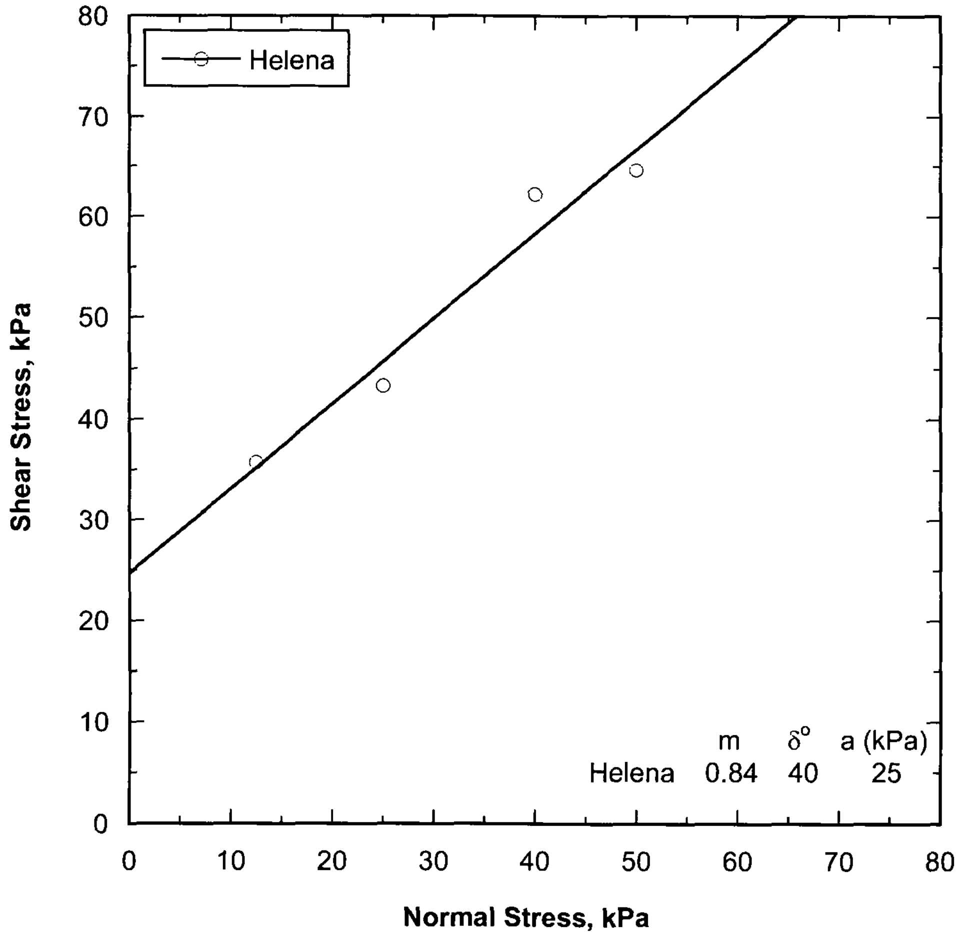

Fig. P6. Peak interface shear strength envelope for GM-GDL interface at Helena.

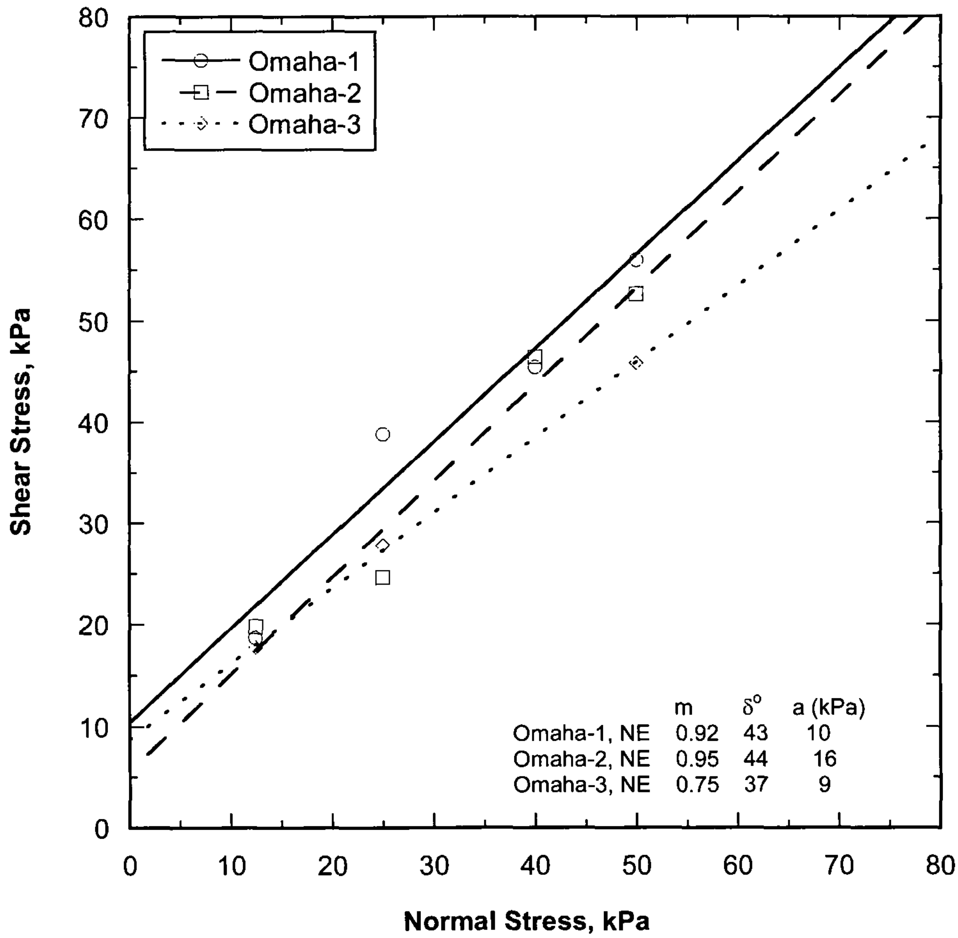

Fig. P7. Peak interface shear strength envelopes for GM-GDL interface at Omaha.

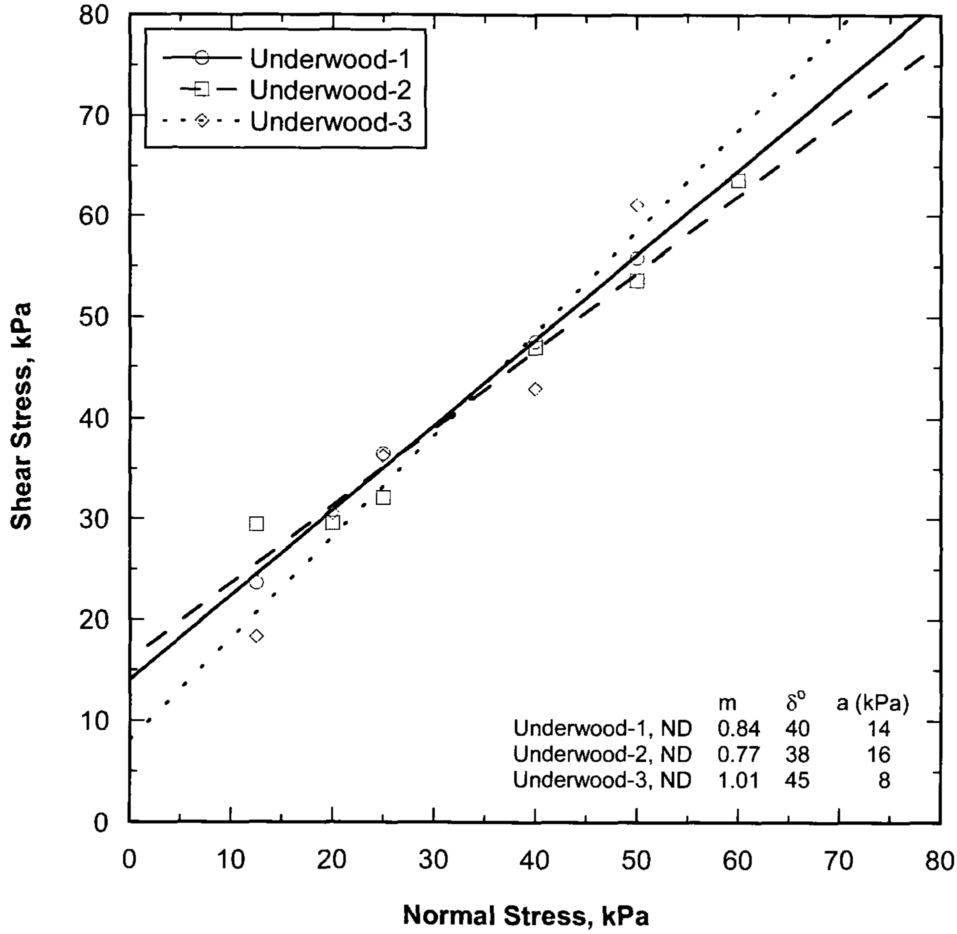

Fig. P8. Peak interface shear strength envelopes for GM-GDL interface at Underwood.

APPENDIX Q – PHOTOGRAPHS OF GM AND GDL TESTING

Fig. Q1. MTS Sintech 10/GL load frame equipped with Curtis Geo-Grips used for tensile testing.

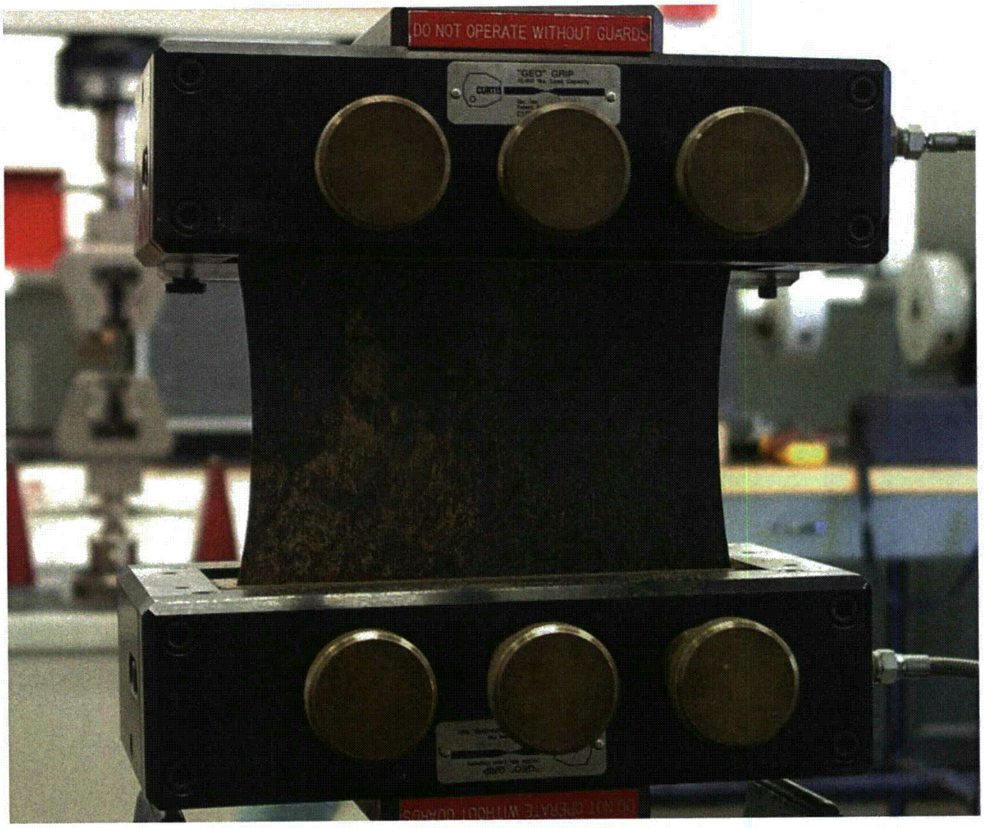

Fig. Q2. Close up of a wide-strip tensile testing of GM.

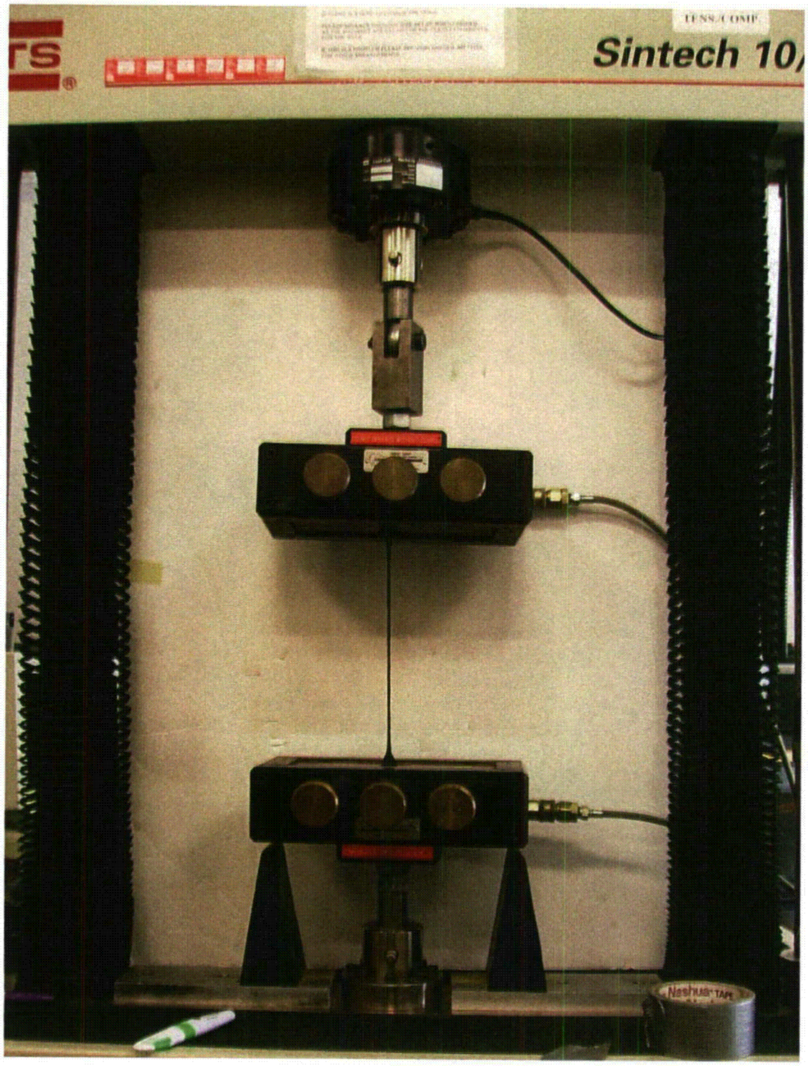

Fig. Q3. Photograph showing narrow strip specimen under tension.

Fig. Q4. Photograph of large-scale direct shear box used for interface shear tests.

Fig. Q5. Photograph of permittivity device.

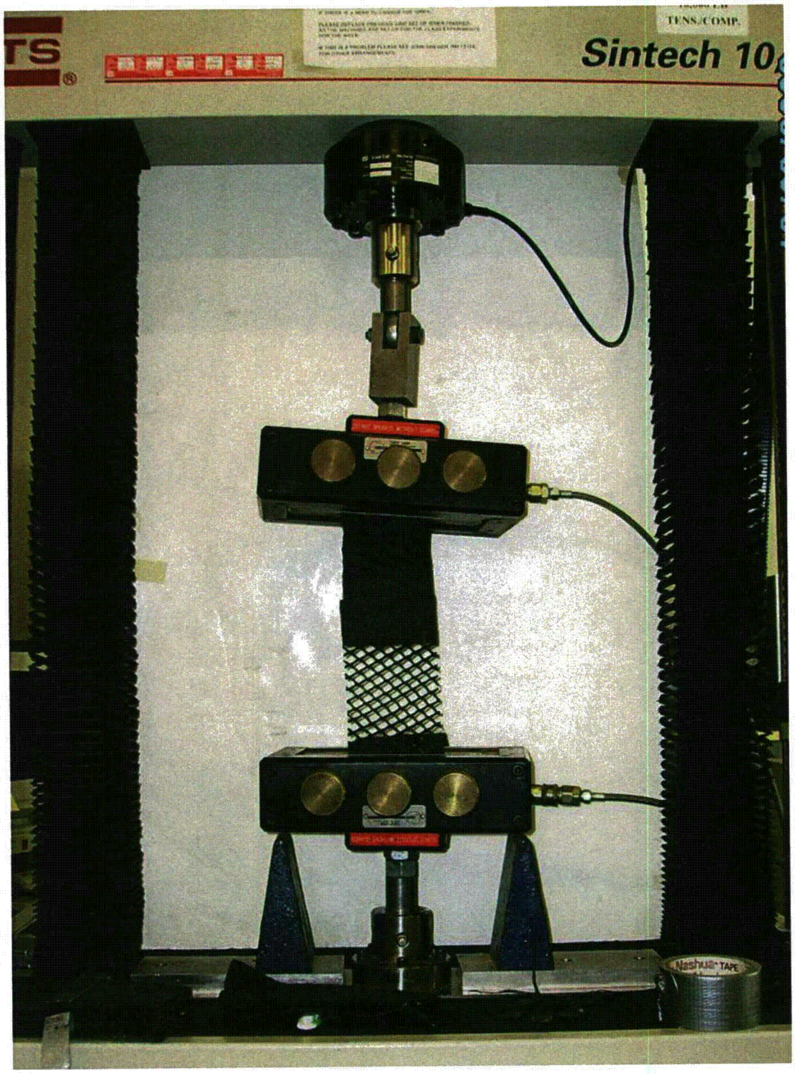

Fig. Q6. Photograph of ply adhesion test.

APPENDIX R – GM TEST DATA

Table R1. Wide-strip yield strengths (ASTM D 4885).

Identification		Wide Strip Yield Strength (N/m)					
		Specimen #					
		1	2	3	Mean	Max.	Min.
Altamont, CA	CMP - GM2	26491	25946	25718	**26052**	26491	25718
	CMP - GM3	25049	25577	24898	**25175**	25577	24898
Apple Valley, CA	GM1	29407	29833	29179	**29473**	29833	29179
	GM6	26864	27241	27618	**27241**	27618	26864
	GM8	27654	27546	28303	**27834**	28303	27546
Boardman, OR	GM1	17895	17872	17423	**17730**	17895	17423
	GM4	17815	17062	17512	**17463**	17815	17062
	Thin Cover	16480	15728	16625	**16278**	16625	15728
Cedar Rapids, IA	Bottom Comp.1	18764	18599	18424	**18596**	18764	18424
	Bottom Comp.3	19037	18583	18532	**18717**	19037	18532
	Clay Bottom 2	18203	18204	17927	**18111**	18204	17927
Eau Claire, WI	TP1	13046	12868	13169	**13028**	13169	12868
	TP2	14407	14600	14120	**14376**	14600	14120
	TP3	14910	14861	14471	**14747**	14910	14471
	TP4	13720	13132	12994	**13282**	13720	12994
Helena, MT	GM-AB	17281	16723	17747	**17250**	17747	16723
Omaha, NE	GM-A1B	22454	23009	22169	**22544**	23009	22169
	GM-A2B	20620	19960	20220	**20267**	20620	19960
	GM-CB	19976	22026	21728	**21243**	22026	19976
	GM-CM	18252	17758	18311	**18107**	18311	17758
Polson, MT	GM-CM	21647	25878	21949	**23158**	25878	21647
Underwood, ND	GM-CC3	21076	21112	20945	**21044**	21112	20945
	GM-CC5	20515	20675	20582	**20591**	20675	20515
	GM-ET	21758	22133	21548	**21813**	22133	21548

Table R2. Narrow-strip yield and break strengths (ASTM D 638).

Identification		Strenght (N/m)	Narrow Strip Test					
			Specimen #					
			1	2	3	Mean	Max.	Min.
Altamont, CA	CMP - GM2	@ Yield	26000	31833	31500	**29778**	31833	26000
		@ Break	44383	38133	47800	**43439**	47800	38133
	CMP - GM3	@ Yield	30650	31517	31367	**31178**	31517	30650
		@ Break	50900	46700	48750	**48783**	50900	46700
Apple Valley, CA	GM1	@ Yield	26667	30133	32250	**29683**	32250	26667
		@ Break	32266	39416	35466	**35716**	39416	32266
	GM6	@ Yield	33550	33817	28833	**32067**	33817	28833
		@ Break	39550	36900	21266	**32572**	39550	21266
	GM8	@ Yield	29400	28167	24217	**27261**	29400	24217
		@ Break	22033	30433	20316	**24261**	30433	20316
Boardman, OR	GM1	@ Yield	11183	9600	10683	**10489**	11183	9600
		@ Break	29633	24683	20700	**25005**	29633	20700
	GM4	@ Yield	10323	11783	11633	**11246**	11783	10323
		@ Break	27150	27533	25983	**26889**	27533	25983
	Thin Cover	@ Yield	12650	12333	12800	**12594**	12800	12333
		@ Break	24800	29133	35850	**29928**	35850	24800
Cedar Rapids, IA	Bottom Comp.1	@ Yield	19083	18683	19083	**18950**	19083	18683
		@ Break	40233	38216	36166	**38205**	40233	36166
	Bottom Comp.3	@ Yield	19767	18417	15567	**17917**	19767	15567
		@ Break	32250	40200	33750	**35400**	40200	32250
	Clay Bottom 2	@ Yield	15967	15050	13500	**14839**	15967	13500
		@ Break	32600	33933	34850	**33794**	34850	32600

Table R2. Narrow-strip yield and break strengths (ASTM D 638) (Continued).

Identification		Strenght (N/m)	Narrow Strip Test					
			Specimen #					
			1	2	3	Mean	Max.	Min.
Eau Claire, WI	TP1	@ Yield	12433	10550	9216	**10733**	12433	9216
		@ Break	21850	20283	20916	**21016**	21850	20283
	TP2	@ Yield	15466	13600	14750	**14605**	15466	13600
		@ Break	30366	33733	29166	**31088**	33733	29166
	TP3	@ Yield	11516	13500	13266	**12761**	13500	11516
		@ Break	30100	29450	16200	**25250**	30100	16200
	TP4	@ Yield	10283	11850	10583	**10905**	11850	10283
		@ Break	33266	34033	34866	**34055**	34866	33266
Helena, MT	GM-AB	@ Yield	17933	18417	18800	**18383**	18800	17933
		@ Break	22866	20766	27666	**23766**	27666	20766
Omaha, NE	GM-A1B	@ Yield	24433	23717	21450	**23200**	24433	21450
		@ Break	42633	43033	36250	**40639**	43033	36250
	GM-A2B	@ Yield	18650	19000	19271	**18974**	19271	18650
		@ Break	41416	46383	42683	**43494**	46383	41416
	GM-CB	@ Yield	22683	23583	23683	**23316**	23683	22683
		@ Break	44366	44133	53383	**47294**	53383	44133
	GM-CM	@ Yield	13950	16250	17300	**15833**	17300	13950
		@ Break	6983	25950	27550	**20161**	27550	6983
Polson, MT	GM-CM	@ Yield	27467	24383	25283	**25711**	27467	24383
		@ Break	14483	30133	31100	**25239**	31100	14483
Underwood, ND	GM-CC3	@ Yield	23917	21183	21417	**22172**	23917	21183
		@ Break	55033	54133	46166	**51777**	55033	46166
	GM-CC5	@ Yield	20417	21533	20833	**20928**	21533	20417
		@ Break	48050	56166	47566	**50594**	56166	47566
	GM-ET	@ Yield	26000	26383	23767	**25383**	26383	23767
		@ Break	53700	58183	53466	**55116**	58183	53466

Table R3. Wide-strip yield strains (ASTM D 638).

Identification		Wide Strip Yield Strain (%) Specimen # 1	2	3	Mean	Max.	Min.
Altamont, CA	CMP - GM2	16.7	17.3	17.4	**17.1**	17.4	16.7
	CMP - GM3	17.0	18.0	18.0	**17.7**	18.0	17.0
Apple Valley, CA	GM1	14.7	15.1	15.7	**15.2**	15.7	14.7
	GM6	15.6	15.2	15.6	**15.5**	15.6	15.2
	GM8	14.9	15.8	15.7	**15.5**	15.8	14.9
Boardman, OR	GM1	17.1	18.6	19.0	**18.2**	19.0	17.1
	GM4	19.8	18.9	18.5	**19.1**	19.8	18.5
	Thin Cover	18.3	18.7	17.9	**18.3**	18.7	17.9
Cedar Rapids, IA	Bottom Comp.1	23.1	26.3	33.5	**27.6**	33.5	23.1
	Bottom Comp.3	24.4	23.2	26.9	**24.8**	26.9	23.2
	Clay Bottom 2	26.5	27.3	30.6	**28.1**	30.6	26.5
Eau Claire, WI	TP1	23.5	30.4	34.9	**29.6**	34.9	23.5
	TP2	19.7	19.2	17.9	**18.9**	19.7	17.9
	TP3	21.0	19.8	18.5	**19.8**	21.0	18.5
	TP4	19.8	21.2	21.2	**20.7**	21.2	19.8
Helena, MT	GM-AB	18.3	16.9	18.2	**17.8**	18.3	16.9
Omaha, NE	GM-A1B	23.6	20.7	19.8	**21.4**	23.6	19.8
	GM-A2B	22.7	22.4	30.0	**25.0**	30.0	22.4
	GM-CB	20.2	21.6	20.5	**20.8**	21.6	20.2
	GM-CM	11.3	11.2	11.6	**11.4**	11.6	11.2
Polson, MT	GM-CM	18.0	16.0	15.4	**16.5**	18.0	15.4
Underwood, ND	GM-CC3	24.7	32.0	36.9	**31.2**	36.9	24.7
	GM-CC5	40.5	46.8	49.5	**45.6**	49.5	40.5
	GM-ET	23.6	28.5	41.8	**31.3**	41.8	23.6

Table R4. Narrow-strip yield and break strains (ASTM D 638).

Identification		Strain (%)	Narrow Strip Test					
			Specimen #					
			1	2	3	Mean	Max.	Min.
Altamont, CA	CMP - GM2	@ Yield	7.7	9.0	9.0	**8.6**	9.0	7.7
		@ Break	651.3	507.4	627.8	**595.5**	651.3	507.4
	CMP - GM3	@ Yield	9.0	10.4	10.3	**9.9**	10.4	9.0
		@ Break	627.7	589.8	591.1	**602.9**	627.7	589.8
Apple Valley, CA	GM1	@ Yield	6.7	6.5	6.7	**6.6**	6.7	6.5
		@ Break	468.4	511.4	424.0	**467.9**	511.4	424.0
	GM6	@ Yield	7.8	7.7	7.7	**7.7**	7.8	7.7
		@ Break	464.3	423.7	227.5	**371.8**	464.3	227.5
	GM8	@ Yield	6.4	7.7	6.5	**6.9**	7.7	6.4
		@ Break	158.2	418.5	327.0	**301.2**	418.5	158.2
Boardman, OR	GM1	@ Yield	7.6	5.4	6.2	**6.4**	7.6	5.4
		@ Break	502.1	446.2	407.8	**452.0**	502.1	407.8
	GM4	@ Yield	5.2	7.6	6.4	**6.4**	7.6	5.2
		@ Break	473.5	483.8	445.9	**467.7**	483.8	445.9
	Thin Cover	@ Yield	6.2	5.1	7.5	**6.3**	7.5	5.1
		@ Break	423.5	476.0	562.1	**487.2**	562.1	423.5
Cedar Rapids, IA	Bottom Comp.1	@ Yield	10.3	9.0	10.3	**9.9**	10.3	9.0
		@ Break	491.7	477.3	449.9	**473.0**	491.7	449.9
	Bottom Comp.3	@ Yield	10.4	10.3	7.7	**9.5**	10.4	7.7
		@ Break	406.7	493.0	455.1	**451.6**	493.0	406.7
	Clay Bottom 2	@ Yield	9.1	10.3	10.2	**9.9**	10.3	9.1
		@ Break	452.5	472.0	495.5	**473.3**	495.5	452.5

Table R4. Narrow-strip yield and break strains (ASTM D 638) (Continued).

Identification		Strain (%)	Narrow Strip Test					
			Specimen #					
			1	2	3	Mean	Max.	Min.
Eau Claire, WI	TP1	@ Yield	11.7	9.0	9.0	**9.9**	11.7	9.0
		@ Break	428.9	436.8	466.8	**444.2**	466.8	428.9
	TP2	@ Yield	3.6	3.6	3.6	**3.6**	3.6	3.6
		@ Break	194.6	216.8	187.9	**199.8**	216.8	187.9
	TP3	@ Yield	9.0	9.0	9.1	**9.0**	9.1	9.0
		@ Break	524.4	485.2	289.0	**432.9**	524.4	289.0
	TP4	@ Yield	9.0	10.4	9.1	**9.5**	10.4	9.0
		@ Break	582.0	554.5	587.2	**574.6**	587.2	554.5
Helena, MT	GM-AB	@ Yield	9.1	9.1	7.7	**8.6**	9.1	7.7
		@ Break	380.6	357.0	443.3	**393.6**	443.3	357.0
Omaha, NE	GM-A1B	@ Yield	10.3	10.3	7.7	**9.4**	10.3	7.7
		@ Break	485.2	508.7	449.8	**481.2**	508.7	449.8
	GM-A2B	@ Yield	7.7	7.7	9.0	**8.1**	9.0	7.7
		@ Break	516.6	566.3	534.8	**539.2**	566.3	516.6
	GM-CB	@ Yield	10.3	9.1	9.1	**9.5**	10.3	9.1
		@ Break	511.3	494.3	593.8	**533.1**	593.8	494.3
	GM-CM	@ Yield	5.2	5.1	6.4	**5.6**	6.4	5.1
		@ Break	12.0	588.5	591.1	**397.2**	591.1	12.0
Polson, MT	GM-CM	@ Yield	9.0	6.4	7.7	**7.7**	9.0	6.4
		@ Break	73.1	341.1	431.5	**281.9**	431.5	73.1
Underwood, ND	GM-CC3	@ Yield	10.7	11.7	10.3	**10.9**	11.7	10.3
		@ Break	550.9	550.6	500.9	**534.1**	550.9	500.9
	GM-CC5	@ Yield	13.0	13.1	11.6	**12.6**	13.1	11.6
		@ Break	517.9	584.8	512.6	**538.4**	584.8	512.6
	GM-ET	@ Yield	11.7	11.7	11.6	**11.7**	11.7	11.6
		@ Break	515.3	559.8	533.6	**536.2**	559.8	515.3

APPENDIX S – GDL TEST DATA

Table S1. Transmissivity of GDLs (ASTM D 4716).

			σ = 24 kPa		σ = 48 kPa		σ = 480 kPa	
Sample ID	**Sample #**	**Specimen #**	**Transmissivity θ (m^2/s)**	**Mean θ (m^2/s)**	**Transmissivity θ (m^2/s)**	**Mean θ (m^2/s)**	**Transmissivity θ(m^2/s)**	**Mean θ (m^2/s)**
ALTAMONT, CA	**Alt. Bottom of Lysimeter**	1	2.1E-04	2.1E-04	7.9E-05	8.1E-05	2.1E-05	2.0E-05
			2.2E-04		8.4E-05		2.0E-05	
			2.0E-04		8.1E-05		1.9E-05	
		2	8.5E-05	8.4E-05	5.6E-05	5.5E-05	2.0E-05	2.0E-05
			8.3E-05		5.5E-05		2.0E-05	
			8.3E-05		5.3E-05		1.9E-05	
		3	8.2E-05	8.1E-05	5.2E-05	5.0E-05	1.3E-05	1.2E-05
			8.0E-05		5.0E-05		1.2E-05	
			8.0E-05		4.9E-05		1.2E-05	
	CMP-GC3	1	2.6E-04	2.6E-04	1.5E-04	1.4E-04	2.3E-05	2.2E-05
			2.6E-04		1.5E-04		2.2E-05	
			2.6E-04		1.4E-04		2.1E-05	
		2	2.9E-04	2.8E-04	1.5E-04	1.5E-04	2.3E-05	2.2E-05
			2.8E-04		1.5E-04		2.2E-05	
			2.8E-04		1.4E-04		2.2E-05	
		3	3.4E-04	3.3E-04	1.5E-04	1.5E-04	3.1E-05	3.0E-05
			3.2E-04		1.5E-04		3.0E-05	
			3.2E-04		1.5E-04		2.9E-05	

Table S1. Transmissivity of GDLs (ASTM D 4716) (Continued).

			σ = 24 kPa		σ = 48 kPa		σ = 480 kPa	
Sample ID	**Sample #**	**Specimen #**	**Transmissivity θ (m^2/s)**	**Mean θ (m^2/s)**	**Transmissivity θ (m^2/s)**	**Mean θ (m^2/s)**	**Transmissivity θ(m^2/s)**	**Mean θ (m^2/s)**
ALTAMONT, CA	CMP-Bottom of Lysimeter	1	2.4E-04	2.4E-04	1.7E-04	1.7E-04	9.7E-05	9.7E-05
			2.4E-04		1.7E-04		9.7E-05	
			2.4E-04		1.7E-04		9.7E-05	
		2	4.9E-05	4.8E-05	4.4E-05	4.4E-05	2.9E-05	2.8E-05
			4.8E-05		4.4E-05		2.8E-05	
			4.8E-05		4.3E-05		2.8E-05	
		3	4.2E-05	4.2E-05	3.7E-05	3.7E-05	2.1E-05	2.1E-05
			4.2E-05		3.7E-05		2.1E-05	
			4.1E-05		3.6E-05		2.1E-05	
	CMP-GC2	1	3.6E-05	3.5E-05	3.1E-05	3.1E-05	1.7E-05	1.7E-05
			3.5E-05		3.1E-05		1.7E-05	
			3.4E-05		3.1E-05		1.7E-05	
		2	3.8E-05	3.8E-05	3.5E-05	3.4E-05	2.1E-05	2.1E-05
			3.8E-05		3.4E-05		2.1E-05	
			3.7E-05		3.4E-05		2.0E-05	
		3	4.7E-05	4.6E-05	3.6E-05	3.6E-05	1.8E-05	1.7E-05
			4.6E-05		3.6E-05		1.7E-05	
			4.5E-05		3.6E-05		1.7E-05	

Table S1. Transmissivity of GDLs (ASTM D 4716) (Continued).

			σ = 24 kPa		σ = 48 kPa		σ = 480 kPa	
Sample ID	**Sample #**	**Specimen #**	**Transmissivity θ (m^2/s)**	**Mean θ (m^2/s)**	**Transmissivity θ (m^2/s)**	**Mean θ (m^2/s)**	**Transmissivity θ(m^2/s)**	**Mean θ (m^2/s)**
BOARDMAN, OR	LOWER GEOCOMPOSITE	1	1.7E-04	1.8E-04	1.6E-04	1.6E-04	8.0E-05	7.9E-05
			1.8E-04		1.6E-04		7.9E-05	
			1.8E-04		1.6E-04		7.7E-05	
		2	3.3E-04	3.4E-04	5.5E-05	5.5E-05	2.8E-05	2.8E-05
			3.4E-04		5.5E-05		2.8E-05	
			3.4E-04		5.5E-05		2.7E-05	
		3	7.2E-05	7.2E-05	5.8E-05	5.8E-05	2.9E-05	2.9E-05
			7.2E-05		5.8E-05		2.9E-05	
			7.1E-05		5.8E-05		2.8E-05	
	GEOCOMPOSITE 1 UPPER	1	1.9E-04	1.9E-04	1.5E-04	1.5E-04	5.6E-05	5.3E-05
			1.9E-04		1.5E-04		5.3E-05	
			1.8E-04		1.5E-04		5.2E-05	
		2	1.7E-04	1.6E-04	1.3E-04	1.3E-04	6.2E-05	6.1E-05
			1.6E-04		1.3E-04		6.1E-05	
			1.6E-04		1.2E-04		6.0E-05	
		3	1.6E-04	1.6E-04	1.2E-04	1.2E-04	5.9E-05	5.7E-05
			1.6E-04		1.2E-04		5.7E-05	
			1.5E-04		1.2E-04		5.5E-05	

Table S1. Transmissivity of GDLs (ASTM D 4716) (Continued).

			σ = 24 kPa		σ = 48 kPa		σ = 480 kPa	
Sample ID	**Sample #**	**Specimen #**	**Transmissivity θ (m^2/s)**	**Mean θ (m^2/s)**	**Transmissivity θ (m^2/s)**	**Mean θ (m^2/s)**	**Transmissivity θ(m^2/s)**	**Mean θ (m^2/s)**
BOARDMAN, OR	Thick Cover 3	1	6.8E-05	6.6E-05	4.7E-05	4.7E-05	2.4E-05	2.3E-05
			6.6E-05		4.6E-05		2.3E-05	
			6.5E-05		4.6E-05		2.3E-05	
		2	1.9E-04	1.9E-04	1.5E-04	1.5E-04	7.7E-05	7.5E-05
			1.9E-04		1.5E-04		7.4E-05	
			1.9E-04		1.5E-04		7.3E-05	
		3	5.5E-05	5.7E-05	4.3E-05	4.3E-05	2.3E-05	2.3E-05
			5.8E-05		4.3E-05		2.3E-05	
			5.7E-05		4.3E-05		2.3E-05	
CEDAR RAPIDS, IA	CLAY BOTTOM 1	1	3.1E-04	3.0E-04	1.8E-04	1.8E-04	8.5E-05	8.4E-05
			3.0E-04		1.8E-04		8.3E-05	
			3.0E-04		1.8E-04		8.3E-05	
		2	2.7E-04	2.8E-04	2.7E-04	2.7E-04	1.6E-04	1.6E-04
			2.8E-04		2.7E-04		1.6E-04	
			2.8E-04		2.6E-04		1.6E-04	
		3	2.8E-04	2.8E-04	2.8E-04	2.8E-04	1.8E-04	1.8E-04
			2.8E-04		2.8E-04		1.8E-04	
			2.7E-04		2.7E-04		1.7E-04	

Table S1. Transmissivity of GDLs (ASTM D 4716) (Continued).

			σ = 24 kPa		σ = 48 kPa		σ = 480 kPa	
Sample ID	**Sample #**	**Specimen #**	**Transmissivity θ (m^2/s)**	**Mean θ (m^2/s)**	**Transmissivity θ (m^2/s)**	**Mean θ (m^2/s)**	**Transmissivity θ(m^2/s)**	**Mean θ (m^2/s)**
CEDAR RAPIDS, IA	**BOTTOM COMPOSITE 2**	1	3.1E-04	3.1E-04	2.8E-04	2.8E-04	1.5E-04	1.5E-04
			3.1E-04		2.7E-04		1.5E-04	
			3.0E-04		2.7E-04		1.5E-04	
		2	3.2E-04	3.2E-04	3.1E-04	3.1E-04	1.8E-04	1.7E-04
			3.2E-04		3.1E-04		1.7E-04	
			3.2E-04		3.1E-04		1.7E-04	
		3	4.9E-04	4.8E-04	3.9E-04	3.9E-04	2.3E-04	2.3E-04
			4.9E-04		3.8E-04		2.3E-04	
			4.7E-04		3.9E-04		2.3E-04	
EAU CLAIRE, WI	**TP1-GC-1**	1	4.6E-04	4.4E-04	N/A		2.1E-04	2.0E-04
			4.5E-04				2.0E-04	
			4.7E-04				2.0E-04	
		2	2.5E-04				1.2E-04	
			2.4E-04				1.2E-04	
			2.4E-04				1.2E-04	
		3	6.2E-04				2.9E-04	
			6.0E-04				2.8E-04	
			5.9E-04				2.8E-04	

Table S1. Transmissivity of GDLs (ASTM D 4716) (Continued).

			σ = 24 kPa		σ = 48 kPa		σ = 480 kPa	
Sample ID	**Sample #**	**Specimen #**	**Transmissivity θ (m^2/s)**	**Mean θ (m^2/s)**	**Transmissivity θ (m^2/s)**	**Mean θ (m^2/s)**	**Transmissivity θ(m^2/s)**	**Mean θ (m^2/s)**
EAU CLAIRE, WI			5.6E-04				2.2E-04	
		1	5.7E-04				2.2E-04	
			5.6E-04				2.2E-04	
			5.1E-04				2.5E-04	
	TP1-GC-2	2	5.2E-04	5.4E-04	N/A		2.5E-04	2.3E-04
			5.1E-04				2.4E-04	
			5.4E-04				2.3E-04	
		3	5.6E-04				2.2E-04	
			5.3E-04				2.2E-04	
			2.3E-04				1.1E-04	
		1	2.3E-04				1.1E-04	
			2.3E-04				1.0E-04	
			4.2E-04				1.6E-04	
	TP1-GC-3	2	4.3E-04	3.4E-04	N/A		1.6E-04	1.4E-04
			4.2E-04				1.6E-04	
			3.8E-04				1.5E-04	
		3	3.7E-04				1.5E-04	
			3.7E-04				1.5E-04	

Table S1. Transmissivity of GDLs (ASTM D 4716) (Continued).

			σ = 24 kPa		σ = 48 kPa		σ = 480 kPa	
Sample ID	**Sample #**	**Specimen #**	**Transmissivity θ (m²/s)**	**Mean θ (m²/s)**	**Transmissivity θ (m²/s)**	**Mean θ (m²/s)**	**Transmissivity θ(m²/s)**	**Mean θ (m²/s)**
EAU CLAIRE, WI	**TP2-GC-1**	1	3.2E-04	2.8E-04	N/A		1.1E-04	1.1E-04
			3.2E-04				1.1E-04	
			3.3E-04				1.0E-04	
		2	2.8E-04				1.2E-04	
			2.9E-04				1.1E-04	
			2.9E-04				1.1E-04	
		3	2.2E-04				1.1E-04	
			2.3E-04				1.0E-04	
			2.2E-04				1.0E-04	
	TP2-GC-2	1	1.0E-03	6.1E-04	N/A		2.6E-04	1.7E-04
			1.1E-03				2.7E-04	
			1.0E-03				2.6E-04	
		2	5.0E-04				1.3E-04	
			5.1E-04				1.3E-04	
			4.9E-04				1.2E-04	
		3	2.9E-04				1.2E-04	
			2.9E-04				1.2E-04	
			3.0E-04				1.2E-04	

Table S1. Transmissivity of GDLs (ASTM D 4716) (Continued).

			σ = 24 kPa		σ = 48 kPa		σ = 480 kPa	
Sample ID	**Sample #**	**Specimen #**	**Transmissivity θ (m²/s)**	**Mean θ (m²/s)**	**Transmissivity θ (m²/s)**	**Mean θ (m²/s)**	**Transmissivity θ(m²/s)**	**Mean θ (m²/s)**
EAU CLAIRE, WI	**TP2-GC-3**	1	3.7E-04	4.0E-04	N/A		1.5E-04	1.5E-04
			3.7E-04				1.4E-04	
			3.7E-04				1.4E-04	
		2	3.7E-04				1.2E-04	
			3.6E-04				1.2E-04	
			3.6E-04				1.2E-04	
		3	4.7E-04				1.9E-04	
			4.8E-04				1.8E-04	
			4.7E-04				1.8E-04	
	TP3-GC-1	1	2.0E-04	3.0E-04	N/A		7.5E-05	1.2E-04
			1.9E-04				7.8E-05	
			1.9E-04				7.7E-05	
		2	4.7E-04				2.0E-04	
			4.6E-04				2.0E-04	
			4.7E-04				2.0E-04	
		3	2.4E-04				7.3E-05	
			2.3E-04				7.3E-05	
			2.3E-04				7.2E-05	

Table S1. Transmissivity of GDLs (ASTM D 4716) (Continued).

			σ = 24 kPa		σ = 48 kPa		σ = 480 kPa	
Sample ID	**Sample #**	**Specimen #**	**Transmissivity θ (m^2/s)**	**Mean θ (m^2/s)**	**Transmissivity θ (m^2/s)**	**Mean θ (m^2/s)**	**Transmissivity θ(m^2/s)**	**Mean θ (m^2/s)**
EAU CLAIRE, WI	**TP3-GC-2**	1	1.6E-03	7.2E-04	N/A		1.6E-04	1.4E-04
			1.6E-03				1.6E-04	
			1.6E-03				1.6E-04	
		2	2.1E-04				9.9E-05	
			2.0E-04				9.8E-05	
			2.1E-04				9.8E-05	
		3	3.7E-04				1.6E-04	
			3.7E-04				1.6E-04	
			3.7E-04				1.6E-04	
	TP3-GC-3	1	3.4E-04	3.6E-04	N/A		1.5E-04	1.3E-04
			3.4E-04				1.5E-04	
			3.4E-04				1.5E-04	
		2	4.1E-04				1.2E-04	
			4.2E-04				1.2E-04	
			4.1E-04				1.2E-04	
		3	3.3E-04				1.2E-04	
			3.4E-04				1.2E-04	
			3.5E-04				1.2E-04	

Table S1. Transmissivity of GDLs (ASTM D 4716) (Continued).

			σ = 24 kPa		σ = 48 kPa		σ = 480 kPa	
Sample ID	**Sample #**	**Specimen #**	**Transmissivity θ (m^2/s)**	**Mean θ (m^2/s)**	**Transmissivity θ (m^2/s)**	**Mean θ (m^2/s)**	**Transmissivity θ(m^2/s)**	**Mean θ (m^2/s)**
EAU CLAIRE, WI	**TP3-GC-4**	1	5.3E-04	5.7E-04	N/A		1.7E-04	1.4E-04
			5.3E-04				1.6E-04	
			5.3E-04				1.6E-04	
		2	3.1E-04				1.3E-04	
			3.0E-04				1.3E-04	
			3.1E-04				1.2E-04	
		3	8.9E-04				1.5E-04	
			8.7E-04				1.4E-04	
			8.7E-04				1.4E-04	
	TP4-GC-1	1	4.5E-04	3.3E-04	N/A		2.0E-04	1.2E-04
			4.3E-04				2.0E-04	
			4.2E-04				1.9E-04	
		2	3.9E-04				1.6E-04	
			3.8E-04				1.5E-06	
			3.8E-04				1.5E-04	
		3	1.9E-04				6.5E-05	
			1.9E-04				6.5E-05	
			1.8E-04				6.4E-05	

Table S1. Transmissivity of GDLs (ASTM D 4716) (Continued).

			σ = 24 kPa		σ = 48 kPa		σ = 480 kPa	
Sample ID	**Sample #**	**Specimen #**	**Transmissivity θ (m^2/s)**	**Mean θ (m^2/s)**	**Transmissivity θ (m^2/s)**	**Mean θ (m^2/s)**	**Transmissivity θ(m^2/s)**	**Mean θ (m^2/s)**
EAU CLAIRE, WI	**TP4-GC-2**	1	1.2E-03	5.7E-04	N/A		2.2E-04	1.2E-04
			1.2E-03				2.2E-04	
			1.3E-03				2.2E-04	
		2	2.4E-04				6.2E-05	
			2.4E-04				6.2E-05	
			2.4E-04				6.1E-05	
		3	2.4E-04				7.3E-05	
			2.4E-04				7.2E-05	
			2.4E-04				7.0E-05	
	TP4-GC-3	1	4.5E-04	5.6E-04	N/A		8.9E-05	1.0E-04
			4.3E-04				8.9E-05	
			4.4E-04				8.8E-05	
		2	2.8E-04				1.4E-04	
			2.8E-04				1.4E-04	
			2.9E-04				1.4E-04	
		3	9.5E-04				7.4E-05	
			1.0E-03				7.4E-05	
			9.6E-04				7.4E-05	

Table S1. Transmissivity of GDLs (ASTM D 4716) (Continued).

			σ = 24 kPa		σ = 48 kPa		σ = 480 kPa	
Sample ID	**Sample #**	**Specimen #**	**Transmissivity θ (m^2/s)**	**Mean θ (m^2/s)**	**Transmissivity θ (m^2/s)**	**Mean θ (m^2/s)**	**Transmissivity θ(m^2/s)**	**Mean θ (m^2/s)**
EAU CLAIRE, WI	**TP4-GC-4**	1	2.6E-04	2.7E-04	N/A		1.1E-04	1.2E-04
			2.6E-04				1.1E-04	
			2.6E-04				1.1E-04	
		2	3.0E-04				1.4E-04	
			3.0E-04				1.4E-04	
			3.0E-04				1.4E-04	
		3	2.7E-04				1.2E-04	
			2.7E-04				1.2E-04	
			2.6E-04				1.2E-04	
HELENA, MT	**GC-AB**	1	2.3E-04	2.3E-04	2.2E-04	2.2E-04	1.3E-04	1.3E-04
			2.4E-04		2.2E-04		1.3E-04	
			2.3E-04		2.2E-04		1.3E-04	
		2	2.5E-04	2.5E-04	2.3E-04	2.3E-04	1.4E-04	1.4E-04
			2.5E-04		2.4E-04		1.4E-04	
			2.5E-04		2.3E-04		1.4E-04	
		3	2.3E-04	2.3E-04	2.2E-04	2.2E-04	1.3E-04	1.3E-04
			2.3E-04		2.2E-04		1.3E-04	
			2.3E-04		2.2E-04		1.2E-04	

Table S1. Transmissivity of GDLs (ASTM D 4716) (Continued).

			σ = 24 kPa		σ = 48 kPa		σ = 480 kPa	
Sample ID	**Sample #**	**Specimen #**	**Transmissivity θ (m^2/s)**	**Mean θ (m^2/s)**	**Transmissivity θ (m^2/s)**	**Mean θ (m^2/s)**	**Transmissivity θ(m^2/s)**	**Mean θ (m^2/s)**
OMAHA, NE	GC-A1B	1	1.7E-04	1.7E-04	1.5E-04	1.5E-04	7.0E-05	6.8E-05
			1.7E-04		1.5E-04		6.7E-05	
			1.7E-04		1.5E-04		6.6E-05	
		2	1.7E-04	1.7E-04	1.6E-04	1.5E-04	9.0E-05	8.9E-05
			1.7E-04		1.5E-04		9.0E-05	
			1.7E-04		1.5E-04		8.9E-05	
		3	1.5E-04	1.4E-04	1.3E-04	1.3E-04	8.4E-05	8.3E-05
			1.4E-04		1.3E-04		8.3E-05	
			1.4E-04		1.3E-04		8.2E-05	
	GC-A2B	1	1.8E-04	1.8E-04	1.5E-04	1.5E-04	7.7E-05	7.5E-05
			1.8E-04		1.5E-04		7.5E-05	
			1.8E-04		1.5E-04		7.3E-05	
		2	1.2E-04	1.1E-04	8.3E-05	8.2E-05	4.1E-05	4.0E-05
			1.1E-04		8.2E-05		4.0E-05	
			1.1E-04		8.1E-05		3.9E-05	
		3	1.0E-04	1.0E-04	9.1E-05	9.1E-05	4.1E-05	3.9E-05
			1.0E-04		9.1E-05		3.9E-05	
			9.9E-05		8.9E-05		3.7E-05	

Table S1. Transmissivity of GDLs (ASTM D 4716) (Continued).

			σ = 24 kPa		σ = 48 kPa		σ = 480 kPa	
Sample ID	**Sample #**	**Specimen #**	**Transmissivity θ (m^2/s)**	**Mean θ (m^2/s)**	**Transmissivity θ (m^2/s)**	**Mean θ (m^2/s)**	**Transmissivity θ(m^2/s)**	**Mean θ (m^2/s)**
OMAHA, NE	GC-CB	1	1.7E-04	1.7E-04	1.5E-04	1.5E-04	8.2E-05	8.1E-05
			1.7E-04		1.5E-04		8.1E-05	
			1.7E-04		1.5E-04		8.1E-05	
		2	1.9E-04	1.8E-04	1.7E-04	1.7E-04	9.1E-05	9.0E-05
			1.8E-04		1.7E-04		9.0E-05	
			1.8E-04		1.7E-04		8.8E-05	
		3	2.2E-04	2.2E-04	2.2E-04	2.2E-04	1.2E-04	1.2E-04
			2.3E-04		2.1E-04		1.2E-04	
			2.2E-04		2.1E-04		1.2E-04	
	GC-CM	1	1.2E-04	1.2E-04	1.0E-04	1.0E-04	5.2E-05	5.2E-05
			1.2E-04		1.0E-04		5.2E-05	
			1.2E-04		1.0E-04		5.1E-05	
		2	1.5E-04	1.5E-04	1.3E-04	1.3E-04	5.4E-05	5.2E-05
			1.5E-04		1.3E-04		5.1E-05	
			1.5E-04		1.3E-04		5.0E-05	
		3	2.0E-04	2.0E-04	1.9E-04	1.9E-04	1.1E-04	1.1E-04
			2.0E-04		1.9E-04		1.1E-04	
			2.0E-04		1.8E-04		1.0E-04	

Table S1. Transmissivity of GDLs (ASTM D 4716) (Continued).

			σ = 24 kPa		σ = 48 kPa		σ = 480 kPa	
Sample ID	**Sample #**	**Specimen #**	**Transmissivity θ (m^2/s)**	**Mean θ (m^2/s)**	**Transmissivity θ (m^2/s)**	**Mean θ (m^2/s)**	**Transmissivity θ(m^2/s)**	**Mean θ (m^2/s)**
UNDERWOOD, ND	GC-CC3	1	2.4E-04	2.4E-04	2.3E-04	2.3E-04	1.0E-04	9.7E-05
			2.4E-04		2.3E-04		9.6E-05	
			2.4E-04		2.3E-04		9.2E-05	
		2	3.5E-04	3.4E-04	3.0E-04	3.0E-04	1.4E-04	1.4E-04
			3.5E-04		3.0E-04		1.3E-04	
			3.4E-04		3.0E-04		1.3E-04	
		3	4.1E-04	4.2E-04	3.6E-04	3.6E-04	1.6E-04	1.6E-04
			4.1E-04		3.5E-04		1.6E-04	
			4.3E-04		3.6E-04		1.5E-04	
	GC-CC5	1	1.3E-04	1.4E-04	1.2E-04	1.2E-04	4.7E-05	4.6E-05
			1.4E-04		1.2E-04		4.5E-05	
			1.3E-04		1.2E-04		4.4E-05	
		2	1.3E-04	1.3E-04	1.2E-04	1.2E-04	5.1E-05	4.9E-05
			1.3E-04		1.2E-04		4.8E-05	
			1.3E-04		1.2E-04		4.7E-05	
		3	1.6E-04	1.6E-04	1.4E-04	1.4E-04	6.6E-05	6.4E-05
			1.5E-04		1.4E-04		6.4E-05	
			1.6E-04		1.4E-04		6.1E-05	

Table S1. Transmissivity of GDLs (ASTM D 4716) (Continued).

			σ = 24 kPa		σ = 48 kPa		σ = 480 kPa	
Sample ID	**Sample #**	**Specimen #**	**Transmissivity θ (m^2/s)**	**Mean θ (m^2/s)**	**Transmissivity θ (m^2/s)**	**Mean θ (m^2/s)**	**Transmissivity θ(m^2/s)**	**Mean θ (m^2/s)**
UNDERWOOD, ND	GC-ET	1	2.0E-04	2.0E-04	1.9E-04	1.8E-04	8.8E-05	8.5E-05
			2.0E-04		1.8E-04		8.5E-05	
			2.0E-04		1.6E-04		8.2E-05	
		2	2.0E-04	2.0E-04	2.0E-04	1.9E-04	8.8E-05	8.5E-05
			2.1E-04		1.9E-04		8.5E-05	
			2.0E-04		1.9E-04		8.3E-05	
		3	2.2E-04	2.2E-04	2.1E-04	2.1E-04	8.9E-05	8.6E-05
			2.3E-04		2.1E-04		8.6E-05	
			2.2E-04		2.1E-04		8.3E-05	

Table S2. Permittivity of GDLs (ASTM D 4491).

ID		#	Date	50 mm constant head					10 mm constant head				
				Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.	Time (s)	Volume (cm^3)	Permitt-ivity ψ (s^{-1})	Mean	Std. Dev.
ALTAMONT	CMP - Bottom of Lysimeter	1	11/19/07	12.03	552.4	0.43	0.40	1.8E-02	23.81	372.7	0.74	0.72	1.3E-02
				8.73	366.9	0.40			20.92	325.1	0.73		
				9.96	418.3	0.39			21.77	334.6	0.72		
				10.68	448.1	0.39			27.36	417.3	0.72		
				8.98	370.4	0.39			22.27	333.2	0.70		
		2	05/28/08	9.77	596.1	0.57	0.57	1.3E-02	36.05	556.3	0.73	0.71	9.7E-03
				7.09	435.7	0.58			30.87	471.2	0.72		
				6.57	401.5	0.57			23.78	362.2	0.72		
				6.44	383.3	0.56			25.18	378.2	0.71		
				8.07	470.2	0.55			23.97	357.4	0.70		
		3	05/28/08	7.42	418.8	0.53	0.52	8.3E-03	23.31	326.9	0.66	0.65	7.1E-03
				6.88	380.0	0.52			22.48	310.1	0.65		
				7.43	410.2	0.52			22.30	308.4	0.65		
				8.78	479.8	0.51			21.30	291.3	0.64		
				6.77	366.1	0.51			21.84	297.9	0.64		
		4	05/28/08	9.41	515.8	0.52	0.50	1.0E-02	23.19	290.2	0.59	0.57	2.7E-02
				8.14	443.6	0.51			22.63	281.2	0.58		
				8.01	423.8	0.50			26.08	289.8	0.52		
				7.18	383.7	0.50			29.83	365.6	0.58		
				7.68	401.4	0.49			25.97	317.2	0.57		

Table S2. Permittivity of GDLs (ASTM D 4491) (Continued).

ID		#	Date	50 mm constant head					10 mm constant head				
				Time (s)	**Volume (cm^3)**	**Permittivity ψ (s^{-1})**	**Mean**	**Std. Dev.**	**Time (s)**	**Volume (cm^3)**	**Permitt-ivity ψ (s^{-1})**	**Mean**	**Std. Dev.**
ALTAMONT	CMP - GC3	1	05/28/08	7.44	415.0	0.52	0.48	2.7E-02	21.86	320.8	0.69	0.66	2.3E-02
				8.03	418.7	0.49			23.29	336.9	0.68		
				7.82	395.6	0.48			22.97	324.5	0.66		
				7.67	380.6	0.47			23.90	332.0	0.65		
				7.23	350.4	0.46			25.83	346.3	0.63		
		2	05/28/08	7.63	408.7	0.50	0.45	4.9E-02	27.91	291.2	0.49	0.48	1.3E-02
				12.70	666.4	0.49			21.33	220.3	0.49		
				14.77	681.9	0.43			23.37	237.2	0.48		
				9.17	400.7	0.41			28.36	281.8	0.47		
				7.29	305.5	0.39			27.90	272.4	0.46		
		3	05/28/08	5.58	316.2	0.53	0.50	2.5E-02	30.23	537.0	0.84	0.80	2.8E-02
				8.91	483.0	0.51			21.19	373.3	0.83		
				9.43	495.1	0.49			25.23	431.2	0.80		
				6.05	312.0	0.49			25.22	423.0	0.79		
				7.87	390.1	0.47			24.03	392.8	0.77		
		4	05/28/08	11.00	695.1	0.59	0.55	2.9E-02	30.43	470.5	0.73	0.68	4.7E-02
				9.09	549.5	0.57			24.29	373.0	0.72		
				8.87	514.9	0.55			22.14	332.8	0.71		
				8.46	482.3	0.54			24.77	335.6	0.64		
				10.60	587.1	0.52			25.69	345.1	0.63		

Table S2. Permittivity of GDLs (ASTM D 4491) (Continued).

ID		#	Date	50 mm constant head: Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.	10 mm constant head: Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.
ALTAMONT	Alt - Bottom of Lysimeter	1	05/28/08	9.97	442.6	0.42	0.39	1.7E-02	29.37	524.4	0.84	0.82	1.8E-02
				9.72	417.6	0.40			28.58	504.5	0.83		
				6.68	280.0	0.39			22.31	385.2	0.81		
				9.14	371.3	0.38			22.60	394.9	0.82		
				9.27	371.2	0.38			20.93	353.3	0.79		
		2	05/28/08	8.93	579.2	0.61	0.56	4.4E-02	27.62	366.1	0.62	0.60	2.5E-01
				7.19	449.3	0.59			25.64	303.0	0.56		
				6.52	396.9	0.57			25.05	257.5	0.48		
				9.52	526.1	0.52			33.01	231.4	0.33		
				8.33	450.3	0.51			18.02	388.0	1.01		
		3	05/28/08	12.07	335.5	0.26	0.20	4.3E-02	20.52	405.9	0.93	0.83	8.9E-02
				18.68	451.7	0.23			19.38	366.4	0.89		
				9.10	199.5	0.21			22.35	397.9	0.84		
				13.08	246.4	0.18			20.72	341.4	0.77		
				14.23	227.6	0.15			21.19	318.5	0.71		
		4	05/28/08	8.04	534.3	0.62	0.58	4.3E-02	21.88	365.3	0.78	0.75	2.7E-02
				7.83	504.8	0.61			21.37	350.2	0.77		
				8.51	521.7	0.58			23.67	377.2	0.75		
				8.33	485.6	0.55			30.94	478.6	0.73		
				7.81	431.6	0.52			24.00	368.2	0.72		

Table S2. Permittivity of GDLs (ASTM D 4491) (Continued).

ID		#	Date	50 mm constant head					10 mm constant head				
				Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.	Time (s)	Volume (cm^3)	Permit-tivity ψ (s^{-1})	Mean	Std. Dev.
APPLE VALLEY	Lysimeter Base	1	05/29/08	7.45	606.2	0.77	0.74	2.7E-02	22.89	502.5	1.03	1.03	3.2E-02
				4.92	394.2	0.75			23.61	545.6	1.09		
				6.12	484.6	0.74			14.87	324.4	1.03		
				5.55	438.6	0.74			18.34	395.7	1.01		
				10.12	747.2	0.69			15.77	337.4	1.01		
		2	05/29/08	9.84	867.2	0.83	0.76	4.4E-02	15.70	294.2	0.88	0.87	8.0E-03
				6.37	515.5	0.76			18.02	336.4	0.88		
				7.23	576.9	0.75			14.58	272.4	0.88		
				6.58	514.5	0.74			20.34	374.6	0.87		
				6.67	504.8	0.71			18.20	334.2	0.86		
		3	05/29/08	6.80	598.5	0.83	0.80	2.0E-02	26.23	628.8	1.13	1.11	1.8E-02
				10.67	922.4	0.81			15.86	380.5	1.13		
				5.98	512.8	0.81			15.14	363.2	1.13		
				6.83	575.5	0.79			17.77	416.0	1.10		
				7.36	607.3	0.78			15.89	368.4	1.09		
		4	05/29/08	7.62	743.7	0.92	0.84	5.0E-02	18.20	384.3	0.99	0.99	4.6E-03
				6.02	553.0	0.86			16.55	349.9	0.99		
				8.52	739.1	0.82			17.28	363.5	0.99		
				5.87	510.7	0.82			19.61	411.1	0.99		
				8.00	673.4	0.79			16.67	348.5	0.98		

Table S2. Permittivity of GDLs (ASTM D 4491) (Continued).

ID		#	Date	50 mm constant head: Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.	10 mm constant head: Time (s)	Volume (cm^3)	Permit-tivity ψ (s^{-1})	Mean	Std. Dev.
BOARDMAN	Geocomposite 1 Upper	1	05/29/08	6.77	494.3	0.69	0.66	1.7E-02	38.02	731.8	0.90	0.87	5.4 E-02
				8.79	626.1	0.67			29.71	573.5	0.91		
				11.37	789.4	0.65			31.67	601.5	0.89		
				7.37	510.4	0.65			32.68	615.9	0.89		
				6.33	433.5	0.64			26.20	433.8	0.78		
		2	05/29/08	6.73	555.2	0.78	0.70	5.0E-02	45.88	751.8	0.77	0.76	1.8 E-02
				7.25	551.3	0.72			28.35	464.2	0.77		
				12.15	885.7	0.69			22.85	380.1	0.78		
				8.49	593.7	0.66			24.25	388.0	0.75		
				7.03	488.1	0.65			35.23	552.0	0.74		
		3	05/29/08	8.11	599.9	0.70	0.67	2.2E-02	45.73	894.7	0.92	0.90	1.9 E-02
				8.70	636.4	0.69			24.89	480.4	0.91		
				7.39	524.1	0.67			21.37	406.4	0.89		
				7.94	555.0	0.66			20.21	380.8	0.89		
				13.07	892.1	0.64			23.05	427.0	0.87		
		4	05/29/08	9.97	744.5	0.70	0.66	3.4E-02	34.31	522.7	0.72	0.70	1.2 E-02
				6.59	475.4	0.68			31.87	479.8	0.71		
				7.62	530.4	0.65			31.67	469.7	0.70		
				7.70	520.9	0.64			26.16	386.6	0.69		
				9.15	597.8	0.61			28.94	422.1	0.69		

Table S2. Permittivity of GDLs (ASTM D 4491) (Continued).

				50 mm constant head					10 mm constant head				
ID		#	Date	Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.	Time (s)	Volume (cm^3)	Permit -tivity ψ (s^{-1})	Mean	Std. Dev.
BOARDMAN	Thcik Cover	1	05/29/08	10.30	456.3	0.42	0.41	5.6E-03	28.64	320.7	0.53	0.52	7.7E-03
				14.98	652.0	0.41			24.23	267.9	0.52		
				10.42	453.2	0.41			24.40	268.6	0.52		
				8.42	364.5	0.41			39.11	423.3	0.51		
				12.27	523.1	0.40			24.70	267.1	0.51		
		2	05/29/08	10.92	465.5	0.40	0.39	8.3E-03	32.53	290.9	0.42	0.42	5.2E-03
				15.89	665.8	0.39			31.83	285.3	0.42		
				13.52	561.2	0.39			38.20	337.7	0.42		
				14.30	577.2	0.38			37.48	330.1	0.41		
				8.48	346.5	0.38			27.05	235.1	0.41		
		3	05/29/08	12.98	591.6	0.43	0.42	1.1E-02	31.25	336.5	0.51	0.50	4.6E-03
				10.98	497.5	0.43			50.27	536.8	0.50		
				9.58	431.1	0.42			28.33	301.7	0.50		
				21.11	918.8	0.41			31.48	333.9	0.50		
				13.14	564.0	0.40			33.36	350.3	0.49		
		4	05/29/08	8.05	390.0	0.46	0.43	1.6E-02	24.02	236.4	0.46	0.44	2.2E-02
				18.48	862.4	0.44			33.17	289.0	0.41		
				10.36	466.2	0.42			25.27	246.5	0.46		
				8.70	394.6	0.43			29.20	271.7	0.44		
				11.95	527.6	0.42			31.55	288.7	0.43		

Table S2. Permittivity of GDLs (ASTM D 4491) (Continued).

				50 mm constant head					10 mm constant head				
ID		#	Date	Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.	Time (s)	Volume (cm^3)	Permitt -ivity ψ (s^{-1})	Mean	Std. Dev.
CEDAR RAPIDS	Clay Bottom 1	1	05/29/08	6.14	523.9	0.80	0.77	2.9E-02	13.31	337.7	1.19	1.16	2.5E-02
				6.69	570.6	0.80			14.66	368.3	1.18		
				5.09	420.1	0.78			11.95	297.9	1.17		
				7.50	600.9	0.75			14.68	355.5	1.14		
				8.08	632.9	0.74			14.29	346.2	1.14		
		2	05/29/08	6.93	541.8	0.74	0.62	8.6E-02	39.88	505.8	0.60	0.57	2.2E-02
				9.84	714.4	0.68			70.82	868.4	0.58		
				6.71	419.7	0.59			41.33	498.9	0.57		
				8.54	504.6	0.56			70.22	820.4	0.55		
				8.66	491.5	0.53			43.69	503.7	0.54		
		3	05/29/08	6.57	716.4	1.03	1.01	1.5E-02	20.47	658.6	1.51	1.47	2.7E-02
				5.93	643.1	1.02			20.03	627.5	1.47		
				5.76	624.8	1.02			17.10	534.1	1.47		
				5.99	641.9	1.01			15.99	497.2	1.46		
				6.99	734.1	0.99			18.63	569.6	1.44		
		4	05/29/08	6.62	683.9	0.97	0.92	3.3E-02	19.57	446.1	1.07	1.06	6.3E-03
				4.87	478.9	0.92			15.51	351.8	1.07		
				7.06	691.6	0.92			16.78	378.0	1.06		
				8.87	834.7	0.88			15.23	344.5	1.06		
				6.16	590.7	0.90			16.89	379.2	1.06		

Table S2. Permittivity of GDLs (ASTM D 4491) (Continued).

ID		#	Date	50 mm constant head Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.	10 mm constant head Time (s)	Volume (cm^3)	Permitt-ivity ψ (s^{-1})	Mean	Std. Dev.
EAU CLAIRE	TP1 GC-1	1	11/19/07	13.98	308.1	0.21	0.20	4.1E-03	78.27	416.4	0.25	0.25	3.6E-03
				14.42	311.4	0.20			64.67	345.2	0.25		
				14.20	304.5	0.20			60.33	319.5	0.25		
				14.70	309.5	0.20			58.98	307.2	0.24		
				14.23	298.3	0.20			59.52	307.3	0.24		
		2	11/19/07	13.53	507.3	0.35	0.34	1.3E-02	54.11	553.7	0.48	0.48	1.2E-02
				12.86	482.6	0.35			47.25	505.3	0.50		
				10.12	365.8	0.34			42.42	434.9	0.48		
				12.39	436.9	0.33			38.50	390.2	0.48		
				15.11	518.0	0.32			38.09	383.3	0.47		
		3	11/19/07	23.18	412.2	0.17	0.16	3.9E-03	58.02	285.4	0.23	0.22	6.2E-03
				22.46	396.3	0.17			61.98	298.4	0.23		
				16.39	280.6	0.16			61.14	289.2	0.22		
				18.42	315.9	0.16			59.39	278.3	0.22		
				17.38	291.5	0.16			56.31	257.2	0.21		
		4	11/19/07	21.20	252.1	0.11	0.11	3.4E-03	78.92	425.7	0.25	0.26	1.4E-03
				20.03	238.2	0.11			60.30	327.9	0.26		
				22.61	262.9	0.11			55.59	303.7	0.26		
				21.39	249.4	0.11			58.83	320.8	0.26		
				21.05	263.9	0.12			64.60	353.1	0.26		

Table S2. Permittivity of GDLs (ASTM D 4491) (Continued).

				50 mm constant head					10 mm constant head				
ID		#	Date	Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.	Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.
EAU CLAIRE	TP1 GC-2	1	11/19/07	14.27	315.1	0.21	0.20	4.1E-03	61.61	368.9	0.28	0.28	4.5E-03
				15.36	332.8	0.20			62.75	368.4	0.28		
				13.70	293.8	0.20			53.52	315.6	0.28		
				15.27	323.0	0.20			52.36	303.1	0.27		
				13.45	282.3	0.20			52.92	303.8	0.27		
		2	11/19/07	8.77	420.4	0.45	0.42	1.7E-02	62.77	693.9	0.52	0.51	8.3E-03
				7.89	359.5	0.43			46.62	509.7	0.51		
				10.14	456.1	0.42			35.18	379.7	0.51		
				6.73	299.0	0.42			29.86	318.5	0.50		
				6.67	286.9	0.40			25.30	269.1	0.50		
		3	11/20/07	24.08	456.2	0.18	0.17	3.7E-03	58.89	274.3	0.22	0.22	3.2E-03
				17.95	337.9	0.18			61.30	284.3	0.22		
				17.75	328.7	0.17			62.30	282.4	0.21		
				16.84	311.0	0.17			65.55	298.2	0.21		
				14.65	262.9	0.17			59.42	267.4	0.21		
		4	11/20/07	11.58	524.9	0.43	0.43	1.5E-03	55.64	661.5	0.56	0.56	3.4E-03
				9.55	432.4	0.43			41.20	490.5	0.56		
				10.33	471.8	0.43			32.36	384.7	0.56		
				9.52	433.0	0.43			31.42	368.9	0.55		
				9.37	424.9	0.43			29.17	344.0	0.55		

Table S2. Permittivity of GDLs (ASTM D 4491) (Continued).

				50 mm constant head					**10 mm constant head**				
ID		**#**	**Date**	**Time (s)**	**Volume (cm^3)**	**Permittivity ψ (s^{-1})**	**Mean**	**Std. Dev.**	**Time (s)**	**Volume (cm^3)**	**Permittivity ψ (s^{-1})**	**Mean**	**Std. Dev.**
EAU CLAIRE	**TP1 GC-3**	1	11/20/07	10.33	435.5	0.40	0.39	7.3E-03	51.37	455.1	0.42	0.42	4.2E-03
				11.48	484.7	0.40			38.52	340.2	0.42		
				7.52	310.5	0.39			34.20	302.5	0.42		
				8.17	335.5	0.39			37.08	324.4	0.41		
				7.33	295.9	0.38			32.77	294.8	0.42		
		2	11/20/07	8.95	624.7	0.66	0.64	1.6E-02	29.42	498.5	0.80	0.79	8.6E-03
				6.70	468.7	0.66			29.34	493.9	0.79		
				5.77	392.7	0.64			25.61	428.6	0.79		
				5.33	355.3	0.63			21.15	353.6	0.79		
				5.37	356.6	0.62			21.08	346.8	0.77		
		3	11/20/07	6.61	371.4	0.53	0.51	1.4E-02	26.48	368.6	0.65	0.65	5.9E-03
				5.23	290.5	0.52			26.02	362.3	0.65		
				6.70	361.5	0.51			24.05	332.2	0.65		
				7.02	372.2	0.50			21.37	293.3	0.65		
				6.92	365.3	0.50			24.48	333.7	0.64		
		4	11/20/07	7.23	394.1	0.51	0.50	7.8E-03	30.23	384.6	0.60	0.60	2.9E-03
				12.64	670.7	0.50			26.20	333.9	0.60		
				6.36	344.3	0.51			23.89	302.8	0.60		
				7.21	383.9	0.50			25.70	325.1	0.59		
				7.92	415.6	0.49			28.08	353.4	0.59		

Table S2. Permittivity of GDLs (ASTM D 4491) (Continued).

ID		#	Date	50 mm constant head					10 mm constant head				
				Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.	Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.
EAU CLAIRE	TP2 GC-1	1	11/20/07	8.12	484.2	0.56	0.54	1.7E-02	24.69	485.8	0.93	0.87	3.5E-02
				7.62	445.1	0.55			22.14	418.6	0.89		
				8.22	469.7	0.54			20.10	371.8	0.87		
				6.03	341.0	0.53			20.81	374.1	0.85		
				5.23	287.1	0.52			18.70	333.4	0.84		
		2	11/20/07	9.60	349.4	0.34	0.33	7.4E-03	48.76	493.3	0.48	0.47	7.2E-03
				7.80	272.5	0.33			38.23	384.0	0.47		
				11.07	388.3	0.33			32.97	327.9	0.47		
				8.41	292.7	0.33			65.05	632.9	0.46		
				9.60	328.9	0.32			51.42	507.1	0.46		
		3	11/20/07	9.40	458.7	0.46	0.45	7.1E-03	33.69	465.9	0.65	0.64	9.7E-03
				10.85	516.7	0.45			29.49	402.6	0.64		
				7.16	344.2	0.45			28.46	383.1	0.63		
				9.85	460.9	0.44			30.07	401.4	0.63		
				6.17	292.4	0.45			26.47	353.6	0.63		
		4	11/20/07	7.21	299.6	0.39	0.37	1.2E-02	30.03	259.4	0.41	0.39	7.7E-03
				9.01	356.8	0.37			50.77	429.4	0.40		
				8.65	346.5	0.38			39.21	328.2	0.39		
				11.81	457.5	0.36			43.95	366.4	0.39		
				8.83	337.3	0.36			39.68	325.1	0.39		

Table S2. Permittivity of GDLs (ASTM D 4491) (Continued).

				50 mm constant head					10 mm constant head				
ID		#	Date	Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.	Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.
EAU CLAIRE	TP2 GC-2	1	11/21/07	10.14	335.3	0.31	0.31	3.4E-03	55.58	502.7	0.43	0.41	7.9E-03
				9.32	310.9	0.31			44.13	386.6	0.41		
				8.66	286.7	0.31			44.71	387.4	0.41		
				8.11	275.3	0.32			38.61	335.5	0.41		
				11.48	381.1	0.31			36.20	312.3	0.41		
		2	11/21/07	6.08	469.1	0.73	0.70	2.5E-02	45.10	803.3	0.84	0.81	1.9E-02
				5.93	452.9	0.72			23.80	415.7	0.82		
				5.26	396.2	0.71			24.31	416.1	0.80		
				5.89	435.8	0.70			17.72	299.3	0.79		
				5.52	388.8	0.66			19.37	325.9	0.79		
		3	11/21/07	8.12	538.6	0.62	0.60	1.5E-02	44.40	728.3	0.77	0.77	4.4E-03
				7.19	470.0	0.61			27.71	452.6	0.77		
				6.34	397.5	0.59			28.88	477.7	0.78		
				6.12	386.5	0.59			22.10	365.7	0.78		
				4.75	300.9	0.60			27.18	446.1	0.77		
		4	11/21/07	7.47	474.6	0.60	0.57	2.0E-02	25.35	406.4	0.75	0.74	1.2E-02
				6.68	415.1	0.58			21.34	341.8	0.75		
				5.31	329.7	0.58			22.27	352.9	0.75		
				5.59	332.7	0.56			20.54	316.4	0.72		
				5.61	326.6	0.55			20.56	325.2	0.74		

Table S2. Permittivity of GDLs (ASTM D 4491) (Continued).

ID		#	Date	50 mm constant head					10 mm constant head				
				Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.	Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.
EAU CLAIRE	TP2 GC-3	1	11/21/07	9.26	340.7	0.35	0.33	1.5E-02	53.16	415.1	0.37	0.35	1.1E-02
				11.73	415.3	0.33			47.52	360.2	0.36		
				14.48	506.5	0.33			42.43	319.2	0.35		
				15.24	511.3	0.32			39.39	290.2	0.35		
				14.25	464.4	0.31			46.78	337.5	0.34		
		2	11/21/07	10.98	398.8	0.34	0.32	1.4E-02	51.87	394.5	0.36	0.35	7.7E-03
				7.98	276.6	0.33			48.37	365.2	0.36		
				8.99	306.4	0.32			47.27	350.6	0.35		
				9.61	323.0	0.32			46.06	336.4	0.34		
				10.28	330.9	0.30			39.87	287.6	0.34		
		3	11/21/07	10.39	244.0	0.22	0.21	6.6E-03	53.94	344.2	0.30	0.29	4.7E-03
				12.12	276.2	0.21			51.68	322.2	0.29		
				23.43	552.6	0.22			53.27	331.0	0.29		
				20.24	449.1	0.21			50.28	311.2	0.29		
				12.61	278.6	0.21			50.92	310.8	0.29		
		4	11/21/07	19.04	415.4	0.21	0.19	1.2E-02	61.63	297.1	0.23	0.22	5.3E-03
				15.43	319.7	0.19			63.08	298.0	0.22		
				15.47	305.6	0.19			58.12	270.3	0.22		
				15.96	305.7	0.18			63.15	289.7	0.22		
				13.67	254.7	0.18			57.23	259.7	0.21		

Table S2. Permittivity of GDLs (ASTM D 4491) (Continued).

ID		#	Date	50 mm constant head					10 mm constant head				
				Time (s)	**Volume (cm^3)**	**Permittivity ψ (s^{-1})**	**Mean**	**Std. Dev.**	**Time (s)**	**Volume (cm^3)**	**Permitt -ivity ψ (s^{-1})**	**Mean**	**Std. Dev.**
EAU CLAIRE	TP3 GC-1	1	11/21/07	21.34	394.2	0.17	0.17	3.7E-03	81.66	487.6	0.28	0.27	8.1E-03
				21.98	402.2	0.17			62.57	364.4	0.27		
				16.73	303.7	0.17			52.96	302.4	0.27		
				17.73	313.8	0.17			54.82	307.5	0.26		
				17.00	298.7	0.17			51.79	287.0	0.26		
		2	11/21/07	20.20	336.9	0.16	0.15	4.7E-03	60.94	276.4	0.21	0.21	5.6E-03
				16.95	275.7	0.15			58.39	261.3	0.21		
				19.62	311.5	0.15			56.28	246.0	0.21		
				18.00	281.1	0.15			58.82	253.8	0.20		
				16.81	259.9	0.15			62.89	266.8	0.20		
		3	11/21/07	8.70	367.9	0.40	0.39	5.4E-03	49.95	536.1	0.50	0.51	6.5E-03
				7.44	310.5	0.39			40.17	441.4	0.52		
				6.76	283.6	0.39			34.98	378.2	0.51		
				7.85	325.1	0.39			30.58	326.3	0.50		
				7.50	305.8	0.38			35.74	380.5	0.50		
		4	11/21/07	10.54	440.3	0.39	0.38	1.2E-02	45.87	433.1	0.44	0.43	8.3E-03
				8.66	348.8	0.38			40.08	376.9	0.44		
				7.90	316.3	0.38			39.62	365.0	0.43		
				8.31	323.1	0.37			49.35	450.1	0.43		
				9.51	365.4	0.36			43.20	390.4	0.42		

Table S2. Permittivity of GDLs (ASTM D 4491) (Continued).

ID		#	Date	50 mm constant head					10 mm constant head				
				Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.	Time (s)	Volume (cm^3)	Permitt-ivity ψ (s^{-1})	Mean	Std. Dev.
EAU CLAIRE	TP3 GC-2	1	11/21/07	14.19	575.9	0.38	0.38	2.7E-03	80.48	1129.8	0.66	0.63	2.1E-02
				9.92	409.6	0.39			49.97	683.2	0.64		
				9.87	405.3	0.39			39.28	525.7	0.63		
				6.42	262.7	0.38			34.87	456.3	0.62		
				8.28	336.9	0.38			30.39	393.3	0.61		
		2	11/21/07	5.87	390.9	0.63	0.60	2.0E-02	43.56	663.2	0.72	0.73	3.0E-02
				5.02	321.2	0.60			35.75	540.6	0.71		
				6.74	421.9	0.59			23.43	351.6	0.71		
				4.76	307.8	0.61			22.95	378.9	0.78		
				5.66	345.4	0.57			21.06	333.4	0.74		
		3	11/21/07	7.50	335.0	0.42	0.41	8.0E-03	38.62	514.9	0.63	0.61	1.1E-02
				8.69	384.5	0.42			26.81	355.7	0.62		
				7.93	349.7	0.41			26.00	336.3	0.61		
				6.58	288.1	0.41			27.01	349.7	0.61		
				9.68	410.8	0.40			23.96	307.1	0.60		
		4	11/21/07	6.90	450.2	0.61	0.58	2.8E-02	28.85	484.9	0.79	0.78	1.4E-02
				7.05	446.1	0.60			21.49	360.8	0.79		
				6.87	426.9	0.58			20.23	337.1	0.78		
				7.74	468.1	0.57			54.38	881.5	0.76		
				6.83	391.5	0.54			21.61	350.1	0.76		

Table S2. Permittivity of GDLs (ASTM D 4491) (Continued).

ID		#	Date	50 mm constant head					10 mm constant head				
				Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.	Time (s)	Volume (cm^3)	Permitt -ivity ψ (s^{-1})	Mean	Std. Dev.
EAU CLAIRE	TP3 GC-3	1	11/26/07	12.67	341.3	0.25	0.24	1.2E-02	40.67	326.7	0.38	0.36	1.6E-02
				11.23	297.9	0.25			33.11	259.2	0.37		
				18.03	458.7	0.24			47.58	353.1	0.35		
				13.80	340.2	0.23			49.67	367.5	0.35		
				13.37	319.3	0.22			43.89	317.1	0.34		
		2	11/26/07	11.37	464.8	0.38	0.37	1.6E-02	45.17	424.2	0.44	0.42	1.3E-02
				10.23	410.8	0.38			39.15	361.6	0.43		
				9.23	362.7	0.37			43.95	396.1	0.42		
				8.36	316.9	0.36			40.77	361.5	0.42		
				9.87	363.3	0.35			42.61	369.9	0.41		
		3	11/26/07	7.87	570.5	0.68	0.66	2.3E-02	25.92	528.8	0.96	0.93	2.1E-02
				7.43	530.3	0.67			21.67	432.1	0.94		
				5.11	356.6	0.66			22.11	433.9	0.92		
				6.37	437.3	0.65			15.92	309.2	0.91		
				6.05	401.1	0.62			17.20	332.0	0.91		
		4	11/26/07	17.73	1114.4	0.59	0.57	2.6E-02	22.02	295.5	0.63	0.65	1.4E-02
				6.14	384.9	0.59			26.08	367.4	0.66		
				6.80	413.8	0.57			25.37	354.2	0.66		
				7.20	423.6	0.55			22.30	308.8	0.65		
				7.45	420.2	0.53			26.67	358.4	0.63		

Table S2. Permittivity of GDLs (ASTM D 4491) (Continued).

ID		#	Date	50 mm constant head					10 mm constant head				
ID		#	Date	Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.	Time (s)	Volume (cm^3)	Permit-tivity ψ (s^{-1})	Mean	Std. Dev.
EAU CLAIRE	TP3 GC-4	1	11/26/07	10.92	486.9	0.42	0.39	1.9E-02	31.03	473.5	0.72	0.68	2.9E-02
				10.58	451.4	0.40			22.43	330.4	0.69		
				8.98	374.6	0.39			41.98	606.9	0.68		
				8.61	347.0	0.38			38.70	540.0	0.66		
				8.92	351.9	0.37			22.95	314.5	0.64		
		2	11/26/07	11.89	265.4	0.21	0.23	2.1E-02	57.08	325.5	0.27	0.25	1.9E-02
				10.92	302.5	0.26			71.02	399.9	0.26		
				11.31	300.8	0.25			60.37	305.6	0.24		
				12.34	308.1	0.23			61.61	306.9	0.23		
				14.48	336.4	0.22			96.77	468.3	0.23		
		3	11/26/07	10.36	240.8	0.22	0.23	8.0E-03	45.67	387.0	0.40	0.38	1.6E-02
				21.96	556.6	0.24			40.55	338.8	0.39		
				10.52	261.2	0.23			42.18	339.8	0.38		
				12.45	304.4	0.23			40.61	321.2	0.37		
				12.77	302.5	0.22			37.89	289.3	0.36		
		4	11/26/07	18.80	414.7	0.21	0.19	1.1E-02	35.42	447.8	0.59	0.49	5.7E-02
				15.08	319.6	0.20			19.80	193.3	0.46		
				16.86	347.7	0.19			22.70	230.4	0.48		
				15.20	300.3	0.19			32.12	323.0	0.47		
				22.78	436.6	0.18			27.30	268.7	0.46		

Table S2. Permittivity of GDLs (ASTM D 4491) (Continued).

ID		#	Date	50 mm constant head					10 mm constant head				
ID		#	Date	Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.	Time (s)	Volume (cm^3)	Permitt-ivity ψ (s^{-1})	Mean	Std. Dev.
EAU CLAIRE	TP4 GC-1	1	11/26/07	5.89	392.9	0.63	0.60	2.6E-02	54.14	1154.5	1.00	0.94	4.7E-02
				5.48	355.8	0.61			26.30	542.3	0.97		
				5.30	335.7	0.60			24.05	479.5	0.94		
				5.95	373.0	0.59			25.98	503.4	0.91		
				7.08	419.9	0.56			27.61	518.1	0.88		
		2	11/26/07	11.96	842.8	0.66	0.59	5.4E-02	27.83	356.0	0.60	0.57	2.2E-02
				9.08	596.4	0.62			29.42	368.1	0.59		
				9.95	616.7	0.58			26.61	324.3	0.57		
				9.11	527.3	0.54			27.12	322.3	0.56		
				7.36	415.9	0.53			28.92	335.6	0.55		
		3	11/26/07	7.70	547.7	0.67	0.63	2.8E-02	28.89	628.5	1.02	0.98	3.3E-02
				6.42	433.6	0.64			20.11	430.6	1.01		
				7.45	489.8	0.62			18.08	380.1	0.99		
				6.48	423.3	0.61			21.11	430.8	0.96		
				7.81	493.9	0.59			20.05	401.4	0.94		
		4	11/26/07	6.70	445.6	0.63	0.58	3.7E-02	20.42	299.5	0.69	0.64	2.8E-02
				6.61	431.4	0.61			27.92	386.9	0.65		
				7.03	438.6	0.59			24.05	322.2	0.63		
				6.27	376.4	0.56			23.48	313.3	0.63		
				6.37	361.0	0.53			22.52	296.9	0.62		

Table S2. Permittivity of GDLs (ASTM D 4491) (Continued).

				50 mm constant head					10 mm constant head				
ID		#	Date	Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.	Time (s)	Volume (cm^3)	Permit -tivity ψ (s^{-1})	Mean	Std. Dev.
EAU CLAIRE	TP4 GC-2	1	11/27/07	5.02	419.2	0.79	0.76	1.3E-02	28.40	711.2	1.18	1.18	7.1E-03
				5.34	430.6	0.76			15.75	397.3	1.19		
				6.33	508.6	0.76			12.58	316.2	1.18		
				8.80	703.3	0.75			12.11	308.1	1.20		
				5.84	475.3	0.77			13.05	328.0	1.18		
		2	11/27/07	11.02	494.2	0.42	0.42	2.4E-03	30.12	442.4	0.69	0.71	1.3E-02
				11.34	506.3	0.42			31.55	483.7	0.72		
				8.27	366.1	0.42			27.05	413.2	0.72		
				9.77	436.3	0.42			20.23	309.7	0.72		
				8.08	357.7	0.42			22.75	347.8	0.72		
		3	11/27/07	10.55	727.5	0.65	0.64	4.8E-03	46.39	1068.2	1.08	1.07	1.3E-02
				9.40	640.7	0.64			27.39	629.2	1.08		
				6.53	447.0	0.64			20.23	458.6	1.07		
				5.67	384.0	0.64			22.67	509.3	1.06		
				5.33	361.3	0.64			21.20	475.7	1.06		
		4	11/27/07	14.89	372.5	0.24	0.23	6.1E-03	43.77	310.0	0.33	0.27	4.6E-02
				9.58	242.1	0.24			47.15	306.5	0.31		
				11.64	288.8	0.23			46.14	243.9	0.25		
				11.61	283.6	0.23			47.17	236.3	0.24		
				15.98	377.1	0.22			50.92	248.3	0.23		

Table S2. Permittivity of GDLs (ASTM D 4491) (Continued).

Identification		#	Date	50 mm constant head					10 mm constant head				
				Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.	Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.
EAU CLAIRE	TP4 GC-3	1	11/27/07	8.77	434.4	0.47	0.44	2.9E-02	33.53	693.3	0.97	0.92	3.9E-02
				8.78	425.0	0.46			14.27	288.2	0.95		
				8.33	391.8	0.44			18.42	360.0	0.92		
				7.55	338.1	0.42			19.36	368.7	0.90		
				10.61	444.6	0.39			17.89	333.4	0.88		
		2	11/27/07	7.95	558.2	0.66	0.62	3.8E-02	29.55	559.4	0.89	0.89	3.6E-03
				6.92	474.0	0.64			25.67	484.5	0.89		
				6.15	405.9	0.62			20.23	379.8	0.88		
				7.15	444.7	0.58			17.89	336.2	0.88		
				7.70	468.4	0.57			17.52	328.5	0.88		
		3	11/27/07	7.17	362.9	0.48	0.46	1.5E-02	29.67	598.5	0.95	0.89	3.9E-02
				17.36	839.2	0.45			19.23	375.3	0.92		
				10.48	515.6	0.46			22.30	421.1	0.89		
				7.14	343.3	0.45			17.77	327.2	0.87		
				8.05	371.4	0.43			18.33	332.4	0.85		
		4	11/27/07	7.08	485.2	0.64	0.60	3.6E-02	22.87	391.8	0.81	0.81	6.4E-03
				7.09	478.7	0.63			22.20	384.0	0.81		
				8.05	503.7	0.59			20.15	352.7	0.82		
				6.92	421.5	0.57			22.30	385.4	0.81		
				5.55	333.7	0.57			27.42	476.4	0.82		

Table S2. Permittivity of GDLs (ASTM D 4491) (Continued).

				50 mm constant head					10 mm constant head				
ID		#	Date	Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.	Time (s)	Volume (cm^3)	Permitt -ivity ψ (s^{-1})	Mean	Std. Dev.
EAU CLAIRE	TP4 GC-4	1	11/27/07	8.62	401.6	0.44	0.41	1.6E-02	33.23	541.6	0.77	0.71	4.8E-02
				16.55	727.5	0.41			20.30	321.0	0.74		
				9.09	392.9	0.41			22.95	354.6	0.73		
				8.05	345.8	0.40			17.81	249.5	0.66		
				8.73	367.3	0.40			23.02	326.2	0.67		
		2	11/27/07	11.61	718.8	0.58	0.54	3.7E-02	21.20	333.9	0.74	0.71	3.9E-02
				6.98	425.4	0.57			20.93	327.5	0.74		
				7.95	456.5	0.54			24.21	369.0	0.72		
				8.92	487.9	0.51			22.73	333.2	0.69		
				9.05	477.8	0.50			20.31	279.2	0.65		
		3	11/27/07	11.34	286.9	0.24	0.22	1.3E-02	39.61	439.1	0.52	0.49	2.2E-02
				15.80	369.8	0.22			28.02	299.3	0.50		
				15.55	351.8	0.21			42.98	451.3	0.49		
				15.09	332.4	0.21			33.59	352.2	0.49		
				12.25	265.9	0.20			28.14	275.8	0.46		
		4	11/27/07	11.02	474.7	0.41	0.36	3.5E-02	38.52	436.6	0.53	0.53	1.1E-02
				9.70	397.0	0.38			29.17	333.9	0.54		
				9.46	354.2	0.35			34.39	384.4	0.53		
				8.09	289.5	0.34			29.45	326.4	0.52		
				12.36	418.9	0.32			31.39	340.2	0.51		

Table S2. Permittivity of GDLs (ASTM D 4491) (Continued).

ID		#	Date	50 mm constant head					10 mm constant head				
				Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.	Time (s)	Volume (cm^3)	Permitt-ivity ψ (s^{-1})	Mean	Std. Dev.
HELENA	GC - AB	1	09/11/08	16.68	630.2	0.36	0.34	2.7E-02	28.45	535.5	0.89	0.83	4.4E-02
				12.48	457.5	0.34			23.05	416.8	0.85		
				16.87	584.5	0.33			24.45	429.6	0.83		
				14.61	482.0	0.31			24.84	426.2	0.81		
				13.67	550.8	0.38			31.83	519.7	0.77		
		2	09/11/08	12.48	921.2	0.69	0.65	3.9E-02	26.17	644.2	1.16	1.08	5.7E-02
				8.02	573.9	0.67			14.02	333.0	1.12		
				8.20	570.2	0.65			18.71	411.6	1.03		
				10.55	698.8	0.62			17.37	391.5	1.06		
				12.56	796.6	0.60			19.45	423.2	1.02		
		3	09/11/08	15.86	462.1	0.27	0.25	1.7E-02	10.23	514.5	2.36	2.23	1.1E-01
				17.33	489.5	0.27			14.89	725.1	2.29		
				16.52	453.8	0.26			7.78	377.1	2.28		
				14.53	371.6	0.24			12.08	546.0	2.13		
				13.40	334.4	0.23			12.39	554.0	2.10		
		4	09/11/08	8.83	734.1	0.78	0.70	6.9E-02	20.45	327.9	0.75	0.72	2.8E-02
				6.42	516.2	0.76			32.70	513.4	0.74		
				7.39	542.7	0.69			41.30	635.3	0.72		
				7.40	511.4	0.65			45.55	681.4	0.70		
				13.17	868.7	0.62			28.86	419.3	0.68		

Table S2. Permittivity of GDLs (ASTM D 4491) (Continued).

ID		#	Date	50 mm constant head					10 mm constant head				
				Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.	Time (s)	Volume (cm^3)	Permitt-ivity ψ (s^{-1})	Mean	Std. Dev.
OMAHA	GC - CB	1	07/11/08	43.05	337.8	0.07	0.07	1.1E-03	38.08	218.5	0.27	0.23	3.2E-02
				53.08	421.3	0.07			51.96	283.7	0.26		
				43.10	345.6	0.08			39.71	190.7	0.23		
				37.80	299.5	0.07			41.11	182.4	0.21		
				51.03	393.2	0.07			43.59	181.0	0.20		
		2	07/11/08	12.14	424.0	0.33	0.28	3.9E-02	20.95	406.5	0.91	0.77	1.1E-01
				12.52	407.1	0.31			35.83	645.1	0.85		
				15.23	446.9	0.28			21.25	338.7	0.75		
				17.09	450.1	0.25			27.11	407.0	0.71		
				9.80	246.1	0.24			20.95	281.3	0.63		
		3	07/11/08	22.39	771.6	0.32	0.28	3.5E-02	40.36	271.3	0.32	0.30	1.3E-02
				13.80	450.6	0.31			46.05	301.0	0.31		
				11.17	336.9	0.28			61.11	386.5	0.30		
				13.02	371.1	0.27			33.58	208.9	0.29		
				15.30	379.6	0.23			30.46	183.5	0.28		
		4	07/11/08	10.36	754.2	0.68	0.60	5.8E-02	18.45	390.5	1.00	0.96	4.2E-02
				14.08	956.9	0.64			13.48	283.8	0.99		
				9.64	608.5	0.59			15.65	325.2	0.98		
				10.36	619.4	0.56			15.92	313.4	0.93		
				8.42	485.1	0.54			12.33	236.6	0.90		

Table S2. Permittivity of GDLs (ASTM D 4491) (Continued).

				50 mm constant head					10 mm constant head				
ID		#	Date	Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.	Time (s)	Volume (cm^3)	Permitt -ivity ψ (s^{-1})	Mean	Std. Dev.
OMAHA	GC - CM	1	07/11/08	11.42	742.4	0.61	0.52	6.5E-02	25.23	322.5	0.60	0.58	1.4E-02
				10.40	604.7	0.55			23.86	297.4	0.59		
				12.05	649.3	0.51			18.65	231.0	0.58		
				9.77	491.3	0.47			20.86	252.9	0.57		
				9.83	468.0	0.45			23.28	279.6	0.56		
		2	07/11/08	15.11	769.9	0.48	0.43	3.8E-02	24.70	407.5	0.78	0.74	2.6E-02
				7.05	336.3	0.45			19.80	316.1	0.75		
				10.59	479.6	0.43			24.89	381.2	0.72		
				10.52	446.7	0.40			19.18	298.7	0.73		
				9.86	403.5	0.38			20.86	314.5	0.71		
		3	07/11/08	7.98	545.7	0.64	0.56	5.8E-02	23.86	372.4	0.73	0.71	1.9E-02
				5.61	353.5	0.59			22.89	350.2	0.72		
				9.02	533.3	0.56			28.21	421.3	0.70		
				9.80	546.8	0.52			27.67	404.7	0.69		
				9.83	517.4	0.49			22.61	351.0	0.73		
		4	07/11/08	16.31	1079.9	0.62	0.56	4.4E-02	21.46	500.7	1.10	1.03	4.0E-02
				6.17	376.5	0.57			16.02	346.2	1.02		
				8.34	484.9	0.55			14.09	310.8	1.04		
				9.67	543.8	0.53			16.55	359.0	1.02		
				10.20	551.6	0.51			15.78	332.2	0.99		

Table S2. Permittivity of GDLs (ASTM D 4491) (Continued).

Identification		#	Date	50 mm constant head Time (s)	Volume (cm³)	Permittivity ψ (s⁻¹)	Mean	Std. Dev.	10 mm constant head Time (s)	Volume (cm³)	Permittivity ψ (s⁻¹)	Mean	Std. Dev.
OMAHA	GC - A1B	1	07/11/08	19.11	600.0	0.30	0.24	3.8E-02	47.89	215.2	0.21	0.20	7.5E-03
				14.42	394.8	0.26			59.36	255.1	0.20		
				14.56	366.7	0.24			44.30	185.5	0.20		
				15.58	357.3	0.22			51.58	210.8	0.19		
				15.45	325.0	0.20			52.11	228.2	0.21		
		2	07/11/08	13.93	454.2	0.31	0.27	2.5E-02	32.64	323.7	0.47	0.42	3.2E-02
				12.89	391.4	0.29			25.11	233.4	0.44		
				18.64	530.4	0.27			23.11	201.6	0.41		
				11.61	314.8	0.25			26.90	227.9	0.40		
				11.87	308.2	0.24			21.15	173.3	0.39		
		3	07/11/08	11.61	677.6	0.55	0.45	6.7E-02	24.17	330.4	0.64	0.57	4.3E-02
				9.95	506.2	0.48			69.08	856.6	0.58		
				9.84	455.0	0.43			28.81	343.3	0.56		
				7.55	329.8	0.41			26.92	311.3	0.54		
				9.67	384.5	0.37			25.64	292.1	0.54		
		4	07/11/08	12.40	686.1	0.52	0.48	3.6E-02	20.42	351.3	0.81	0.73	5.5E-02
				8.33	450.1	0.51			23.28	380.2	0.77		
				11.36	585.3	0.48			22.18	342.4	0.73		
				14.21	679.2	0.45			25.37	376.4	0.70		
				9.58	444.5	0.44			25.05	358.4	0.67		

Table S2. Permittivity of GDLs (ASTM D 4491) (Continued).

				50 mm constant head					10 mm constant head				
ID		#	Date	Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.	Time (s)	Volume (cm^3)	Permit -tivity ψ (s^{-1})	Mean	Std. Dev.
OMAHA	GC - A2B	1	07/11/08	15.86	521.4	0.31	0.23	5.6E-02	23.02	204.6	0.42	0.42	1.9E-02
				10.52	292.8	0.26			25.03	219.9	0.41		
				12.77	283.9	0.21			34.05	331.9	0.46		
				12.80	259.9	0.19			20.36	177.9	0.41		
				14.48	266.9	0.17			21.36	192.4	0.42		
		2	07/11/08	11.45	441.9	0.36	0.32	2.9E-02	22.45	378.6	0.79	0.71	5.7E-02
				9.80	354.8	0.34			20.27	323.9	0.75		
				11.70	399.8	0.32			24.73	367.1	0.70		
				15.23	489.1	0.30			34.89	501.3	0.68		
				9.70	300.7	0.29			15.30	212.8	0.65		
		3	07/11/08	13.28	668.5	0.47	0.36	7.4E-02	46.67	356.2	0.36	0.31	3.2E-02
				8.73	366.8	0.40			72.48	504.7	0.33		
				9.70	360.6	0.35			159.80	1017.4	0.30		
				9.67	324.5	0.32			26.42	162.5	0.29		
				10.68	324.0	0.29			37.03	221.3	0.28		
		4	07/11/08	8.78	500.0	0.54	0.48	4.7E-02	23.36	447.6	0.90	0.81	6.3E-02
				6.65	363.2	0.51			21.17	381.3	0.85		
				8.83	440.6	0.47			21.02	362.8	0.81		
				10.86	509.2	0.44			16.64	273.8	0.77		
				9.52	430.7	0.43			19.84	312.4	0.74		

Table S2. Permittivity of GDLs (ASTM D 4491) (Continued).

ID		#	Date	50 mm constant head					10 mm constant head				
				Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.	Time (s)	Volume (cm^3)	Permitt -ivity ψ (s^{-1})	Mean	Std. Dev.
UNDERWOOD	GC - CC3	1	08/07/08	13.65	462.9	0.32	0.25	5.5E-02	30.77	625.1	0.96	0.87	1.0E-01
				15.89	487.8	0.29			22.50	455.1	0.95		
				16.14	404.2	0.24			59.83	1154.3	0.91		
				24.52	544.1	0.21			24.14	431.1	0.84		
				18.56	370.0	0.19			25.18	382.6	0.71		
		2	08/07/08	12.43	568.0	0.43	0.37	4.7E-02	27.52	240.3	0.41	0.40	8.0E-03
				13.14	571.0	0.41			30.09	261.5	0.41		
				8.96	356.2	0.37			28.36	245.0	0.41		
				10.83	399.3	0.35			44.36	373.3	0.40		
				13.67	454.9	0.31			45.55	380.4	0.39		
		3	08/07/08	9.45	676.4	0.67	0.65	2.8E-02	44.27	987.6	1.05	0.98	5.2E-02
				9.73	698.4	0.67			22.11	473.1	1.01		
				8.92	627.2	0.66			17.14	351.3	0.96		
				8.89	606.9	0.64			19.27	388.3	0.95		
				9.83	635.4	0.61			17.12	333.6	0.92		
		4	08/07/08	32.30	516.5	0.15	0.15	2.2E-03	16.33	356.7	1.03	0.97	4.2E-02
				18.33	292.0	0.15			14.92	314.3	0.99		
				26.77	417.9	0.15			18.08	381.3	0.99		
				21.71	343.4	0.15			20.20	398.7	0.93		
				22.95	354.1	0.15			16.58	329.2	0.93		

Table S2. Permittivity of GDLs (ASTM D 4491) (Continued).

				50 mm constant head					10 mm constant head				
ID		#	Date	Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.	Time (s)	Volume (cm^3)	Permitt-ivity ψ (s^{-1})	Mean	Std. Dev.
UNDERWOOD	GC - CC5	1	08/07/08	6.71	441.3	0.62	0.60	2.6E-02	29.78	760.3	1.20	1.13	4.5E-02
				7.48	491.3	0.62			16.42	400.6	1.15		
				8.80	569.9	0.61			24.58	585.9	1.12		
				6.83	432.4	0.60			12.52	293.1	1.10		
				8.70	513.2	0.55			14.48	334.0	1.08		
		2	08/07/08	6.77	485.8	0.67	0.63	4.2E-02	19.52	335.9	0.81	0.78	1.9E-02
				10.77	758.6	0.66			23.48	389.8	0.78		
				9.61	638.0	0.62			17.12	284.2	0.78		
				8.05	516.1	0.60			19.77	322.5	0.77		
				7.58	460.9	0.57			19.17	309.6	0.76		
		3	08/07/08	7.90	412.4	0.49	0.47	2.1E-02	23.67	433.2	0.86	0.83	3.2E-02
				14.68	751.2	0.48			20.52	371.1	0.85		
				11.33	564.8	0.47			16.70	297.7	0.84		
				9.64	461.6	0.45			22.86	391.0	0.80		
				9.11	426.5	0.44			19.64	327.3	0.78		
		4	08/07/08	9.23	787.8	0.80	0.70	8.6E-02	22.05	370.6	0.79	0.77	2.0E-02
				10.83	882.7	0.77			17.83	300.2	0.79		
				8.40	622.4	0.70			17.14	283.6	0.78		
				8.68	594.5	0.64			27.02	440.9	0.77		
				8.14	512.2	0.59			21.78	343.8	0.74		

Table S2. Permittivity of GDLs (ASTM D 4491) (Continued).

ID		#	Date	50 mm constant head					10 mm constant head				
				Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.	Time (s)	Volume (cm^3)	Permittivity ψ (s^{-1})	Mean	Std. Dev.
UNDERWOOD	GC - ET	1	08/07/08	7.53	508.7	0.64	0.53	9.3E-02	21.08	521.4	1.16	1.13	3.4E-02
				8.67	554.0	0.60			11.89	282.2	1.12		
				10.27	593.0	0.54			15.78	366.5	1.09		
				10.45	521.6	0.47			16.67	412.3	1.16		
				9.87	428.6	0.41			17.77	415.2	1.10		
		2	08/07/08	7.73	685.8	0.83	0.77	5.6E-02	40.05	744.0	0.87	0.74	1.1E-01
				7.64	660.2	0.81			25.77	445.3	0.81		
				8.27	691.2	0.79			22.42	361.2	0.76		
				7.52	592.1	0.74			21.52	297.4	0.65		
				10.23	757.0	0.70			24.02	315.2	0.62		
		3	08/07/08	10.83	618.3	0.54	0.52	1.9E-02	23.95	594.4	1.17	1.08	5.6E-02
				10.20	580.4	0.54			16.77	392.8	1.10		
				7.30	407.8	0.53			16.83	385.1	1.08		
				9.87	530.4	0.51			14.83	327.6	1.04		
				9.58	501.8	0.49			16.67	364.1	1.03		
		4	08/07/08	14.31	1172.7	0.77	0.70	6.9E-02	30.52	545.8	0.84	1.00	1.9E-01
				5.73	465.2	0.76			68.45	1106.4	0.76		
				8.73	650.5	0.70			20.14	495.6	1.16		
				17.05	1179.0	0.65			13.11	317.8	1.14		
				7.77	505.6	0.61			11.67	274.4	1.11		

Table S3. Ply adhesion (N/m) of GDLs (ASTM D 7005).

	APPLE VALLEY				ALTAMONT	
	Composite Lys. Base		Clay-Lys. Base-1		CMP-GC3	
	A	B	A	B	A	B
1	241	276	314	388	935	844
2	383	228	312	298	1168	694
3	312	399	392	274	548	686
4	325	435	378	423	742	976
5	465	438	302	387	564	1179
	BOARDMAN					
	Composite 1 Upper		Thin Cover		Thick Cover 3	
	A	B	A	B	A	B
1	1199	1107	762	1038	870	947
2	873	796	771	795	724	833
3	563	266	769	755	719	610
4	288	451	696	838	871	779
5	219	763	757	652	576	769
	CEDAR RAPIDS					
	Clay Bottom 1		Composite Bottom		Bottom Composite 4	
	A	B	A	B	A	B
1	311	688	309	276	148	237
2	293	611	330	302	265	142
3	269	522	164	245	223	198
4	547	286	166	283	265	258
5	471	243	172	220	155	219
	EAU CLAIRE					
	TP1-GC-1		TP1-GC-2		TP1-GC-3	
	A	B	A	B	A	B
1	374	-	287	309	228	204
2	48	-	379	321	222	190
3	240	32	363	428	200	105
4	-	-	387	305	124	223
5	31	294	292	373	47	238

* All results are in N/m.

* A and B represent a randomly assigned top and bottom of the sample.

Table S3. Ply adhesion (N/m) of GDLs (ASTM D 7005) (Continued).

	EAU CLAIRE					
	TP2-GC-1		TP2-GC-2		TP2-GC-3	
	A	B	A	B	A	B
1	439	479	409	767	384	414
2	505	413	622	322	470	354
3	575	438	249	850	543	283
4	538	438	751	260	467	568
5	693	398	136	726	356	486
	EAU CLAIRE					
	TP3-GC-1		**TP3-GC-2**		**TP3-GC-3**	
	A	**B**	**A**	**B**	**A**	**B**
1	453	331	647	383	316	487
2	540	454	694	431	442	438
3	500	494	516	485	601	359
4	327	401	354	527	607	411
5	372	516	362	474	551	476
	EAU CLAIRE					
	TP3-GC-4		**TP4-GC-1**		**TP4-GC-2**	
	A	**B**	**A**	**B**	**A**	**B**
1	130	371	593	986	514	490
2	297	329	973	231	418	524
3	179	154	686	156	424	318
4	243	336	414	787	701	428
5	409	221	241	735	637	356
	EAU CLAIRE				**HELENA**	
	TP4-GC-3		**TP4-GC-4**		**GC-AB1**	
	A	**B**	**A**	**B**	**A**	**B**
1	639	640	600	484	171	703
2	638	397	685	506	109	779
3	536	848	485	464	1053	251
4	561	362	520	535	965	724
5	648	421	495	404	71	872

* All results are in N/m.
* A and B represent a randomly assigned top and bottom of the sample.

Table S3. Ply adhesion (N/m) of GDLs (ASTM D 7005) (Continued).

	OMAHA					
	GC-CB		GC-A1B		GC-A2B	
	A	B	A	B	A	B
1	297	216	337	514	312	124
2	322	226	472	308	395	254
3	193	287	398	444	260	365
4	345	217	362	562	415	266
5	336	218	504	562	359	129
	UNDERWOOD					
	GC-CC3		GC-CC5		GC-ET	
	A	B	A	B	A	B
1	666	338	356	533	1178	2065
2	101	725	270	548	1532	1234
3	533	665	858	379	1466	1595
4	792	962	909	347	1206	1252
5	658	391	647	191	1095	1609

* All results are in N/m.
* A and B represent a randomly assigned top and bottom of the sample.

NRC FORM 335 (12-2010) NRCMD 3.7

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER (Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, if any.)

NUREG/CR-7028
Volume 2

2. TITLE AND SUBTITLE

Engineered Covers for Waste Containment: Changes in Engineering Properties and Implications for Long-Term Performance Assessment - Appendices

3. DATE REPORT PUBLISHED

MONTH	YEAR
12	2011

4. FIN OR GRANT NUMBER

N 6366

5. AUTHOR(S)

C.H. Benson*, W.M. Albright**, D.O. Fratta*, J.M. Tinjum*, E. Kucukkirca*, S.H. Lee*, J. Scalia*, P.D. Schlicht*, and X. Wang*

6. TYPE OF REPORT

Technical

7. PERIOD COVERED (Inclusive Dates)

August 2006 - May 2009

8. PERFORMING ORGANIZATION - NAME AND ADDRESS (If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)

*Geological Engineering
University of Wisconsin-Madison
1415 Engineering Drive
Madison, WI 53706

**Desert Research Institute
2215 Raggio Parkway
Reno, NV 89512

9. SPONSORING ORGANIZATION - NAME AND ADDRESS (If NRC, type "Same as above", if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)

Division of Risk Analysis
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

10. SUPPLEMENTARY NOTES

Jacob Philip, Project Manager

11. ABSTRACT (200 words or less)

This study demonstrates that engineering properties of cover soils change while in service and that long-term engineering properties should be used as input to models employed for performance assessments. Recommendations for appropriate input are made based on the data that were collected. Increases in the saturated hydraulic conductivity, saturated volumetric water content, and the air entry suction (as characterized by van Genuchten's alpha parameter) occurred due to formation of soil structure, regardless of climate, cover design, or service life. Substantial changes in hydraulic conductivity were observed in some geosynthetic clay liners (GCLs) that did not hydrate completely and underwent cation exchange. Changes in geomembranes and geosynthetic drainage layers were modest or small, and computations based on antioxidant depletion rates suggest that the minimum service life of geomembranes is in the order of 50-125 years (the actual service life will be longer). The findings indicate that covers should be monitored to ensure that they are functioning as intended. Monitoring using pan lysimeters combined with secondary measurements collected for interpretive purposes is recommended. Future research investments should include an evaluation of remote sensing technologies for cover monitoring and analog studies to estimate properties of earthen and geosynthetic cover materials corresponding to service lives of 100s to 1000s of years.

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)

alternative cover assessment program (ACAP)
changes in engineering properties of soils
engineered barriers
geomembrane (GM)
geosynthetic clay liner (GCL)
geosynthetics
long-term performance assessments
pan lysimeters
waste containment

13. AVAILABILITY STATEMENT

unlimited

14. SECURITY CLASSIFICATION

(This Page) unclassified

(This Report) unclassified

15. NUMBER OF PAGES

16. PRICE

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, DC 20555-0001

OFFICIAL BUSINESS