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Variability and Scaling of Hydraulic Properties for 200 Area Soils, Hanford Site

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EXECUTIVE SUMMARY

Over the years, data have been obtained on soil hydraulic properties at the Hanford Site. Much of these data have been obtained as part of recent site characterization activities for the Environmental Restoration Program. The existing data on vadose zone soil properties are, however, fragmented and documented in reports that have not been formally reviewed and released. This study helps to identify, compile, and interpret all available data for the principal soil types in the 200 Areas plateau. Information on particle-size distribution, moisture retention, and saturated hydraulic conductivity (K_s) is available for 183 samples from 12 sites in the 200 Areas. Data on moisture retention and K_s are corrected for gravel content. After the data are corrected and cataloged, hydraulic parameters are determined by fitting the van Genuchten soil-moisture retention model to the data. A nonlinear parameter estimation code, RETC, is used. The unsaturated hydraulic conductivity relationship can subsequently be predicted using the van Genuchten parameters, Mualem's model, and laboratory-measured saturated hydraulic conductivity estimates. Alternatively, provided unsaturated conductivity measurements are available, the moisture retention curve-fitting parameters, Mualem's model, and a single unsaturated conductivity measurement can be used to predict unsaturated conductivities for the desired range of field moisture regime.

The database comprised of six soil categories and 176 samples is used as the basis for describing the probability distribution for the five hydraulic parameters (i.e., α, n, θ_r, θ_s, and K_s). Empirical cumulative distribution functions (CDF) are derived for all five parameters, and hypothesized distributions fitted. The Kolmogorov-Smirnov (K-S) goodness-of-fit statistic

D (maximum absolute deviation between the empirical and fitted CDFs) is used to select the best fit distribution. Although the database is limited, the CDFs for all five parameters can be described using a normal distribution based on either the untransformed or the transformed variables.

A scaling technique for similar media having linearly variable hydraulic properties is applied to simplify the description of the spatial variability of 200 Area soils. Separate scaling factors α_h, α_θ, and α_K associated with pressure head, moisture content, and hydraulic conductivity, respectively, for each sample, are determined for 176 samples. Comparisons made between the best fit van Genuchten curves for the unscaled data and those for the scaled data show that scaling reduces the sums of squares by amounts varying from 63 to 89%. Based on K-S statistic D, the scaling factors α_h, α_θ, and α_K are found to be either normally or lognormally distributed for the six soil categories considered. Results suggest that, for the soil types being considered, scaling can be successfully used to describe the variability of soil hydraulic properties in the 200 Areas plateau.

Both unscaled and scaled data parameter statistics can play an important role in characterizing the spatial variability of the hydraulic properties for a given soil horizon and between soil horizons. It is, therefore, important to update the database as more data become available across the Hanford Site on soil physical properties and moisture retention characteristics.

ACKNOWLEDGMENTS

A major portion of the database used in this report has been generated as part of recent site characterization activities for the Environmental Restoration Program for the Hanford Site. The authors wish to acknowledge the support provided by Westinghouse Hanford Company Geotechnical Engineering Laboratory personnel and, in particular, John Relyea and Paula Heller. Much of the recent data on soil properties has been made available to the authors by John Relyea and Paula Heller. An earlier version of the report was reviewed by Rien van Genuchten (U.S. Salinity Laboratory, Riverside, CA) and Mark Rockhold (Pacific Northwest National Laboratory, Richland, Washington). Charissa Chou provided help with the statistical analysis.

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VARIABILITY AND SCALING OF HYDRAULIC PROPERTIES FOR 200 AREA SOILS, HANFORD SITE

1.0 INTRODUCTION

Performance assessment models that simulate water flow and solute transport within the geologic media at the Hanford Site are being used to investigate the potential impact of contaminants to human health and the environment. A number of parameters are needed to model the vadose zone hydrology and transport of contaminants from a waste disposal site. The hydrologic data that are essential in quantifying the water storage and flow properties of unsaturated soils include a characterization of heterogeneities of various soil layers, and the soil hydraulic functions (i.e., moisture content versus pressure head and unsaturated hydraulic conductivity versus moisture content relationships) of the various layers.

1.1 SCOPE AND OBJECTIVES

The primary objective of this study is to summarize existing data on particle-size distribution, moisture retention, and saturated hydraulic conductivity (K_s) for various geologic formations and soil types in the 200 Areas (Figure 1). A total of 183 moisture retention data sets taken from 12 sites in the 200 Areas plateau were evaluated (Figure 2). The procedures used to correct the laboratory-measured moisture retention data for gravel content are briefly described. Summary tables are provided by soil type and formation, and the van Genuchten parameters and laboratory-measured K_s values are cataloged. Cumulative distribution functions are derived for the van Genuchten parameters and K_s. An additional objective is to apply the scaling theory (e.g., Miller and Miller 1956; Warrick et al. 1977; Simmons et al. 1978; Vogel et al. 1991) to characterize the spatial variability of soil hydraulic properties in the 200 Areas.

1.2 SITE GEOLOGY AND SAMPLING LOCATIONS

At the Hanford Site (Figure 1), geologic profiles within the vadose zone differ between the 200 East (200E) and 200 West (200W) Areas because of different erosional and depositional episodes that occurred at the two Areas; despite the fact that the two Areas are only a few miles apart. The two major formations in the vadose zone in both the 200 East and West Areas are the Hanford formation (informal designation) and the Ringold Formation. The Ringold underlies the Hanford formation and consists of fluvial and lacustrine sediments. The overlying Hanford formation was laid down by cataclysmic floods and consists of a variety of sub-facies ranging from coarse gravels in the high energy areas of deposition (flood channels) to fine-grained silts in the low-energy areas of deposition. In the 200W Area, the Hanford and Ringold formations bracket the Plio-Pleistocene and Early Palouse units. The Plio-Pleistocene unit is an alluvial and colluvial deposit and consists of a fine-grained, calcareous, weakly to strongly cemented mixture of mud and sand, whereas; the Early Palouse is a pedogenic deposit consisting of fine-grained sand and silt. The Plio-Pleistocene and Early Palouse units are present in the 200W Area but were removed during flooding in the 200E Area.

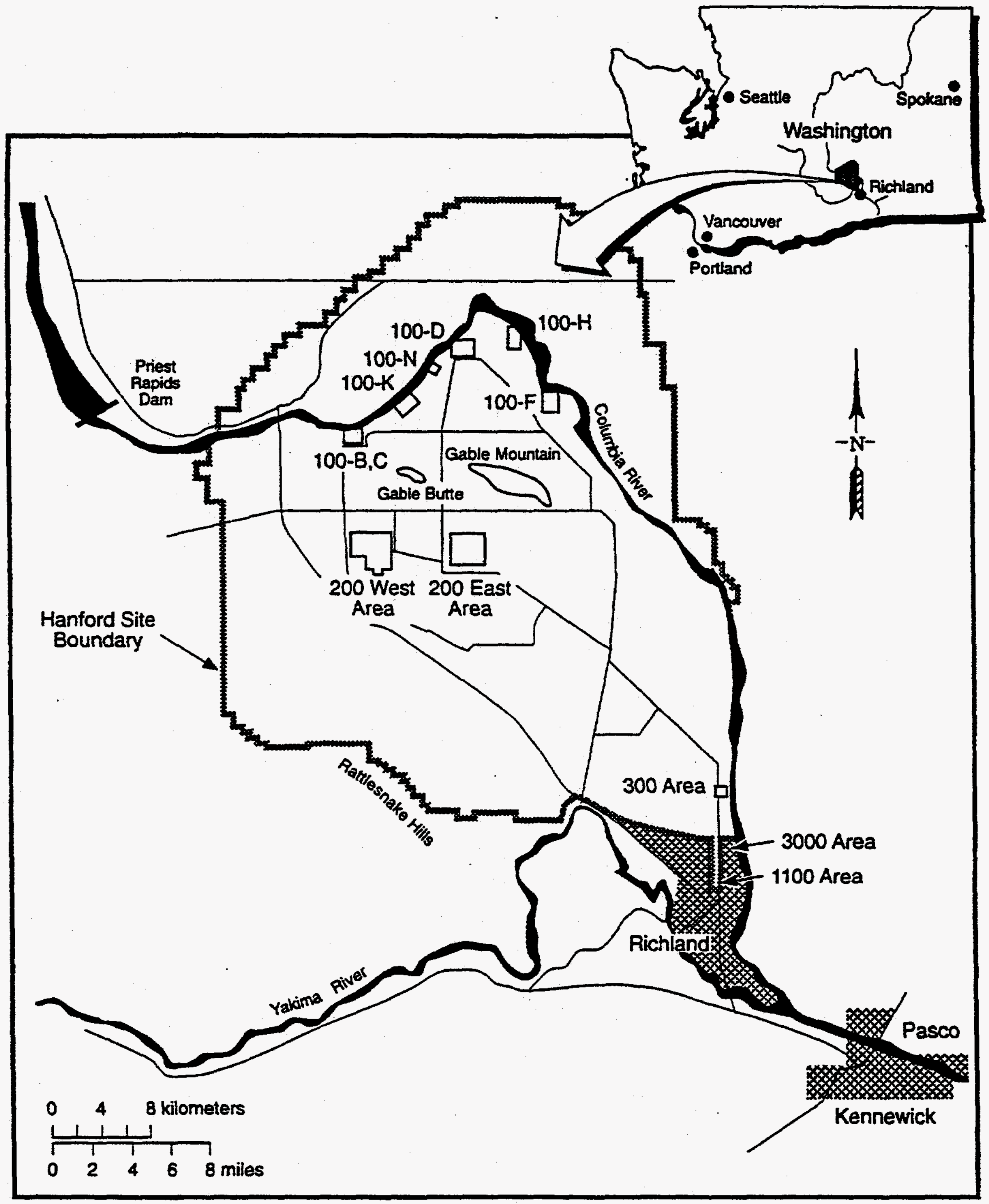

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Figure 1. Hanford Site Map

Information on particle-size distribution, moisture retention, and saturated hydraulic conductivity is available from 12 sites in the 200 Areas. A map showing the location of these sites is shown in Figure 2. A brief description of the individual sites is provided below.

1.2.1 200-BP-1 Site

The 200-BP-1 Operable Unit (Figure 2) is located at the north-central boundary of the 200E Area. Soils beneath this site are predominantly sandy gravels with interspersed sand lenses. Samples are available at the site up to a depth of about 65 m below land surface (bls).

1.2.2 218-W-5 Burial Ground

The 218-W-5 Burial Ground (Figure 2) is located in the northwest quadrant of the 200W Area. The soils beneath the site range from a gravelly to a sandy loam type. Samples were retrieved at the site up to a depth of about 70 m. K_s measurements are not available for two samples.

1.2.3 241-T-106 Tank Site

The T-106 tank site (Figure 2) lies in the north-central part of the 200W Area. Soil textures range from sandy gravel to sandy loam. Samples were retrieved at the site up to a depth of about 54 m. K_s measurements are not available for three samples.

1.2.4 AP Tank Farm Site

The AP Tank Farm (Figure 2) is located on the eastern boundary of the 200E Area. The soils around the AP Tank Farm are predominantly sands with some lenses of gravelly sand and silt. Samples were collected from an excavation site rather than from boreholes as is the case with most other samples.

1.2.5 C-018-H Site

The State Approved Land Disposal Site (SALDS) (Figure 2) is located about 210 m north of the 200W Area. Soil texture is characterized as gravelly sand to sand. Samples were retrieved from the upper 35 m.

1.2.6 Environmental Restoration Disposal Facility (ERDF) Site

The ERDF site (Figure 2) is located to the southeast of 200W and west of the U.S. Ecology site. Based on available sieve analysis of samples recovered from boreholes at the site, soil textures range from silty sand to sandy gravel. Samples were retrieved at the site up to a depth of about 94 m. K_s measurements are not available for a number of samples.

1.2.7 Field Lysimeter Test Facility (FLTF) Site

The Field Lysimeter Test Facility (Figure 2) is located between the 200E and 200W Areas. Soil textures are uniformly distributed between silt loam and loam.

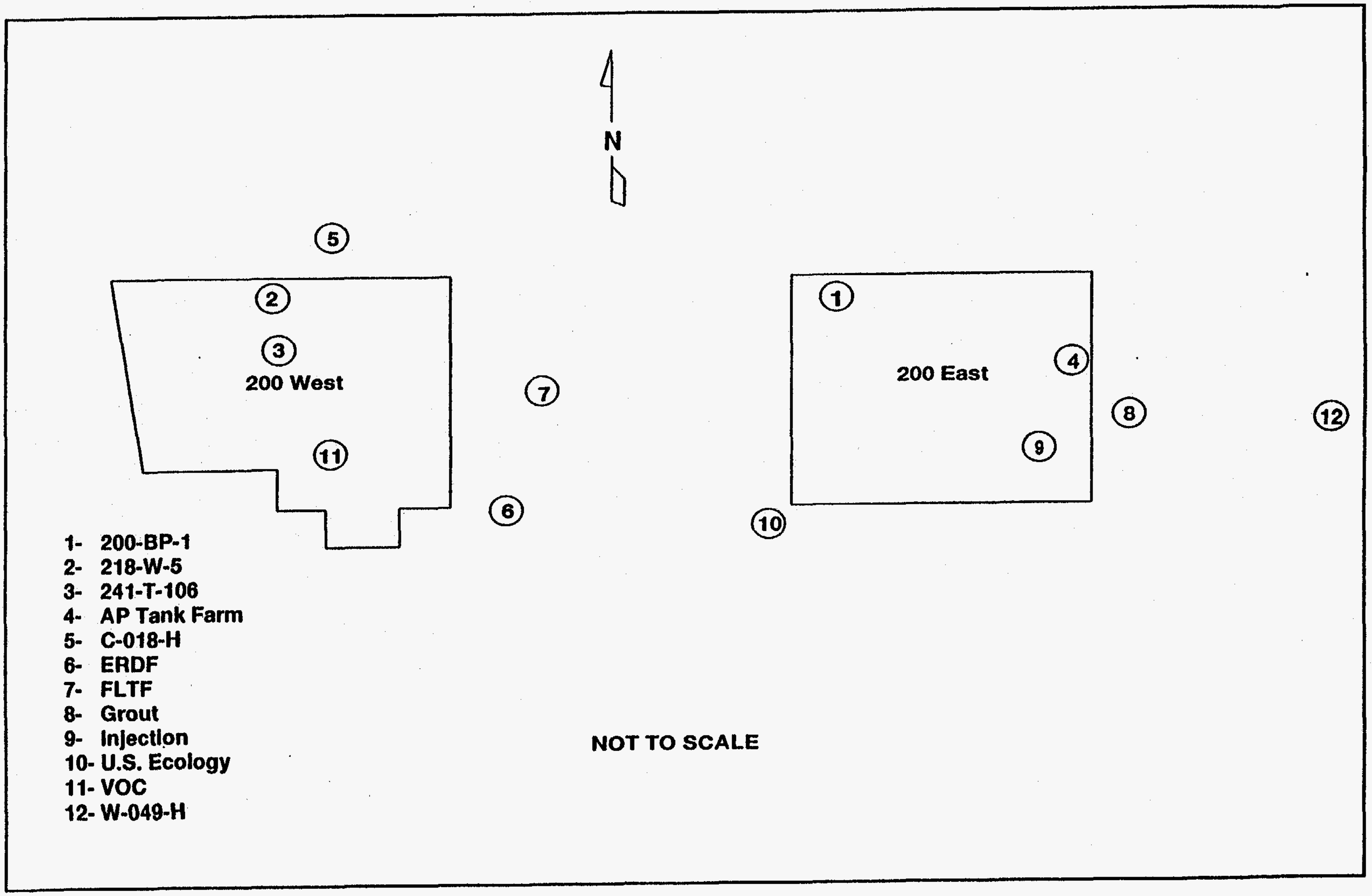

Figure 2. Location of Sampling Sites, 200 Area plateau.

The FLTF is an experimental facility designed to measure infiltration characteristics for the Hanford Barrier. Samples were obtained from a repacked soil profile within a vertically oriented corrugated pipe.

1.2.8 Grout Facility Site

The grout facility (Figure 2) is located directly east of the 200E Area. Sample depth is limited to 14.5 m bls; loamy sand dominates the upper 10 m and the lower 1.5 m are gravelly sands.

1.2.9 Injection Test Site

The Injection Test Site (Figure 2) is located in the southeast quadrant of the 200E Area. The stratigraphy beneath the site is predominantly medium to coarse sand and pea gravels with some silt lenses. Samples were retrieved at the site up to a depth of about 41 m.

1.2.10 U.S. Ecology (MW-5, MW-8, MW-10) Site

The U.S. Ecology site (Figure 2) is approximately 460 m south of the 200E Area. The soils beneath this facility are predominantly sands with interbedded gravel lenses. Samples were retrieved from up to 91 m.

1.2.11 VOC Site

The Volatile Organic Carbon (VOC) site (Figure 2) containing carbon tetrachloride is located in the southwest quadrant of the 200W Area. Soil textures range from sandy gravel to sandy loam. Beside the Pacific Northwest National Laboratory (PNL) data, the VOC site represents the only moisture retention data set not requiring correction for vacuum saturation (see Section 3.4). Samples were retrieved at the site up to a depth of about 60 m. One sample from the W-049-H site had a very high measured saturated moisture content; this is attributed to the presence of swelling clays. K_s measurements are not available for one sample.

1.2.12 Treated Effluent Disposal Facility (W-049-H) Site

The W-049-H site (Figure 2) is located approximately 2 km due east of the 200E Area. Soil textures of samples collected at this site are approximately evenly divided between sandy gravel and sandy loam. Samples were retrieved at the site up to a depth of about 54 m. Three samples from the W-049-H site had very high measured saturated moisture contents; this is attributed to the presence of swelling clays. Although included in appendices A and B, the samples having swelling clays were not included in the analysis.

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2.0 SAMPLING AND EXPERIMENTAL METHODS

Soil samples are collected at the Hanford Site primarily in conjunction with drilling activities. The prevalent method of drilling is cable tool. In most cases, cable tool and splitspoon coring techniques were used to obtain as continuous a record of sediment from each borehole as possible. Compared to core barrel, a splitspoon sampling device is presumed to recover intact, relatively undisturbed, and representative samples from the entire length of borehole.

The samples were analyzed either at the Westinghouse Hanford Company (WHC) Geotechnical Engineering Laboratory (GEL) or at PNL. At the WHC GEL, the moisture retention data were obtained using Tempe cells from saturation to -1000 cm; the rest of data up to -15,000 cm were obtained using the pressure plate extraction method (Klute 1986). At the PNL, three different methods were used to determine moisture retention data: (1) the hanging water column method (Klute 1986), (2) the pressure plate extraction method (Klute 1986), and (3) the vapor equilibrium (or thermocouple psychrometer) method (Rawlins and Campbell 1986). The methods used for various samples are identified in Appendix A.

Both wetting and drainage curves are generated at the GEL. Prior to April 1993, the GEL first vacuum-saturated a soil sample and then applied suction to produce a drainage curve. This curve is not the main drainage curve (MDC), rather a primary drainage curve (PDC) (Luckner et al. 1989). For most modeling applications, the MDC is of particular interest. A correction is therefore used to obtain the MDC from the PDC; this correction is described later (section 3.4). The PNL procedures immediately yield the main drainage curve, and therefore do not need any correction. The sites for which no correction for the MDC is needed are AP Tank Farm, ERDF, FLTF, Grout, U.S. Ecology, and VOC (Figure 2).

Two different methods were used to determine saturated hydraulic conductivities. At the WHC GEL, a constant head permeameter (Klute and Dirksen 1986) was used. At the PNL, a falling head permeameter (Klute and Dirksen 1986) was used. Particle-size distribution was determined on the < 0.075 mm size fraction of each sample using the hydrometer (Gee and Bauder 1986); for size fraction > 0.075 mm to < 2 mm, dry sieving methods were used.

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3.0 PROCEDURES FOR CORRECTION OF SATURATED CONDUCTIVITY AND MOISTURE RETENTION MEASUREMENTS

3.1 BACKGROUND

The textural designation used in this study to describe soils conforms with the International Soil Science Society classification (Hillel 1982).

- Gravel: >2 mm
- Coarse sand; cs: 2 mm to 0.2 mm
- Fine sand; fs: 0.2 mm to 0.02 mm
- Silt: 0.02 mm to 0.002 mm
- Clay: <0.002 mm.

The soils at the Hanford site can contain a high percentage of gravel (>2 mm). Bouwer and Rice (1983) demonstrated that gravel content can have considerable influence on soil moisture characteristics. The approach taken by Bouwer and Rice to correct for gravel assumes that all moisture in the soil is contained in the <2 mm size fraction and that the gravel fraction simply reduces the volume of material available to retain and conduct moisture.

The gravel correction approach of Bouwer and Rice (1983) is being used by both WHC and PNL to correct both the laboratory-measured moisture retention and saturated hydraulic conductivity estimates.

3.2 CORRECTING THE SATURATED HYDRAULIC CONDUCTIVITY FOR GRAVEL CONTENT

In many instances, hydraulic conductivity is measured for a soil sample which has been collected during splitspoon sampling. As was discussed earlier, compared to other techniques, the splitspoon sleeve contains what is considered to be a reasonably representative sample of the formation that has been drilled, and its hydraulic conductivity therefore does not require a correction for gravel content. This is the case with most of the samples analyzed at the GEL. Those samples for which the gravel fraction was removed prior to hydraulic conductivity determination in the laboratory, must be corrected to account for the effect of gravel within the sample. The equation used by Bouwer and Rice to arrive at a corrected hydraulic conductivity, K_b, is

$$K_b = K_s \left(\frac{e_b}{e_f} \right) \qquad (1)$$

where K_s is the saturated hydraulic conductivity of the <2 mm fraction (fines), e_b is the void ratio of the complete sample, and e_f is the void ratio of the fines (<2 mm) only. The void ratios e_b and e_f are defined as:

$$e_b = \frac{\theta_{b,s}}{1-\theta_{b,s}} \qquad (2)$$

$$e_f = \frac{\theta_{f,s}}{1-\theta_{f,s}} \tag{3}$$

where $\theta_{b,s}$ is the saturated (subscript s) volumetric moisture content of the bulk soil (subscript b) which includes gravel and $\theta_{f,s}$ is the saturated volumetric moisture content of the fines (subscript f) as measured in the laboratory on the fraction < 2 mm. The moisture contents $\theta_{b,s}$ and $\theta_{f,s}$ are related through

$$\theta_{b,s} = F_f\theta_{f,s} = (1-F_g)\theta_{f,s} \tag{4}$$

in which F_f is the volumetric fraction of the bulk soil sample passing through the number 10 sieve (<2 mm), and F_g is the volumetric gravel fraction of the bulk sample as used by Bouwer and Rice (1983). Equation (4) also holds for moisture contents less than saturation, i.e., with the subscripts s on θ removed.

3.3 CORRECTING THE MOISTURE RETENTION CURVES FOR GRAVEL CONTENT

The laboratory-measured moisture retention curve (MRC) is based on the soil fine fraction (<2 mm) and does not account for the gravel fraction. The laboratory-measured MRC therefore needs to be corrected for any gravel that may be present in a soil sample. The correction can be done using either a mass-based approach (i.e., Gardner 1986) or a volume-based approach (i.e., Bouwer and Rice 1983).

The gravimetric or mass-based procedure presented by Gardner is

$$\theta_b = \frac{W_f\rho_b/\rho_w}{1 + m_g/m_f} \tag{5}$$

where θ_b is the volumetric moisture content of the bulk soil including gravel, w_f is the laboratory-measured gravimetric moisture content of the fine fraction (< 2 mm), ρ_b is the bulk density of the entire sample (including gravel), ρ_w is the density of water, and m_f and m_g are, respectively, the dry masses of the fines and gravel as recovered from the bulk field soil sample.

The volume-based correction procedure described by Bouwer and Rice (1983) is based on the same general principles as equation (5), leading to an equation similar to (4) but with the subscript s removed, i.e., equation (4) is applicable to all moisture contents. The mass-based approach was used in this study since all parameters in (5) were directly measured in the laboratory.

In the remainder of the report, it is assumed that all volumetric moisture contents have been appropriately corrected for gravel content, and henceforth will drop the subscript b on θ. Thus, all values for θ specify volumetric moisture contents of the bulk soil sample including gravel where present.

3.4 CORRECTING FOR THE MAIN DRAINAGE CURVE

Luckner et al. (1989) proposed scaling functions to correct the PDC to the MDC. These functions may be used to scale moisture contents on the PDC to moisture contents on the MDC at the same pressure heads. When this procedure was applied to some of the GEL-measured moisture retention data, a shift in the data was noted thereby resulting in a reversal of the laboratory-measured main wetting curve (MWC) and the corrected MDC. To remedy the situation, an alternate approach was implemented. The wet end of the moisture retention curve is corrected for vacuum saturation by assigning an upper limit based on the saturated moisture content measured for the MWC. Using analytical models (described in Section 4.0), curves are fitted through the modified data. During the fitting procedure, four parameters (Θ_r, Θ_s, α, and n; Section 4.1) are based on the best fit curve through the measured data.

The MWC is available for all WHC samples and is considered to be accurate. The MDCs derived by this method appear to give a good description of the hysteretic soil moisture retention data.

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4.0 DATA EVALUATION

4.1 VAN GENUCHTEN-MUALEM MODEL AND RETC CODE

Van Genuchten (1980) derived an empirical relationship to describe the moisture retention data

$$\theta = \theta_r + \frac{(\theta_s - \theta_r)}{[1+|\alpha h|^n]^m} \tag{6}$$

where θ = Volumetric moisture content
θ_s = Saturated moisture content
θ_r = Residual moisture content
α = van Genuchten curve fitting parameter (1/cm)
h = Matric potential or pressure head (-cm)
n = van Genuchten curve fitting parameter
m = 1 - 1/n.

The RETC code (van Genuchten et al. 1991) is used for curve fitting. The Mualem (1976) model is used to predict the hydraulic conductivity from moisture retention data

$$K(S_e) = K_s S_e^{\ell} \left[\frac{f(S_e)}{f(1)} \right]^2 \tag{7}$$

$$\text{where} \qquad f(S_e) = \int_0^{S_e} \frac{1}{h(x)} dx \tag{8}$$

and

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} \tag{9}$$

and ℓ is a pore-connectivity parameter estimated by Mualem (1976) to be about 0.5 as being optimum for many soils.

Using Mualem's model, van Genuchten (1980) derived a closed-form analytic solution to equation (7) to predict the relative hydraulic conductivity (K_r)

$$K_r(h) = \frac{\{1-(\alpha h)^{mn}[1+(\alpha h)^n]^{-m}\}^2}{[1+(\alpha h)^n]^{m\ell}} \qquad (m = 1 - \frac{1}{n}) \tag{10}$$

$$K(h) = K_s * K_r \tag{11}$$

4.2 SCALING RELATIONSHIPS

To describe the hydraulic variability for texturally similar soils, a set of linear scaling transformations are used to relate the individual soil moisture characteristics $\theta(h)$ and K(h) to reference characteristics $\theta^*(h^*)$ and $K^*(h^*)$ (Vogel et al. 1991). The technique is based on the similar media concept (Miller and Miller 1956) for porous media which differ only in the scale of their internal geometry. Three scaling parameters are used to define a linear model characterizing variability in the soil hydraulic properties (Vogel et al. 1991).

$$\begin{aligned} K(h) &= \alpha_k K^*(h^*) \\ \theta(h) &= \theta_r + \alpha_\theta[\theta^*(h^*) - \theta_r^*] \\ h &= \alpha_h h^* \end{aligned} \tag{12}$$

where, for the most general case, α_θ, α_h and α_k are mutually independent scaling factors for the moisture content, the pressure head and the hydraulic conductivity, respectively. Less general scaling methods arise by invoking certain relationships between α_θ, α_h and/or α_k. For example, the original Miller-Miller scaling procedure is obtained by assuming $\alpha_\theta = 1$ (with $\theta_r^* = \theta_r$), and $\alpha_k = \alpha_h^{-2}$. A detailed discussion of the linear scaling relationships is given by Vogel et al. (1991).

For texturally similar soils, scaling factors are calculated from the relationships

$$\begin{aligned} \alpha_k &= K_s/K_s^* \\ \alpha_\theta &= (\theta_s - \theta_r)/(\theta_s^* - \theta_r^*) \\ \alpha_h &= h_c/h_c^* \end{aligned} \tag{13}$$

where the reference saturated hydraulic conductivity K_s^*, $(\theta_s^* - \theta_r^*)$ and h_c^* are arithmetic means of the respective values of K_s, $(\theta_s - \theta_r)$ and h_c. The value of h_c is computed for each moisture retention curve from

$$h_c = \frac{1}{(\theta_s - \theta_c)} \int_{\theta_c}^{\theta_s} h(\theta)\, d\theta \tag{14}$$

where θ_c is selected so that the majority of measured data points for texturally similar soils lie in the interval (θ_c, θ_s). A value near the middle of the interval (θ_r, θ_s) is recommended for θ_c (Vogel et al. 1991). In (14), h_c denotes the average h value within the interval (θ_c, θ_s).

After the scaling factors for each sample are determined, the scaled hydraulic properties $K^*(h^*)$, $\theta(h)$ and h^* for each measured data point are obtained via (12). Van Genuchten models are then fitted through the scaled data sets, and the resulting fitted parameters are referred to as the scaled mean hydraulic parameters.

5.0 RESULTS AND DISCUSSION

5.1 DATA CORRECTION AND COMPILATION

The laboratory-measured moisture retention data and K_s were first corrected, if necessary, for gravels and MDC using the procedures outlined in Section 3. The moisture retention data from the Tempe cell or hanging water column experiments for each individual sample were combined with the pressure-plate and vapor equilibrium data (where available) to estimate the van Genuchten parameters. When data from the different measurement techniques overlapped, the overlapping data from the wetter matric potential range only were included during curve fitting. The van Genuchten parameters θ_r, θ_s, α and n were fitted to the moisture retention data using RETC (van Genuchten et al. 1991), a computer program that uses a nonlinear, least squares curve fitting procedure. The fitted parameters θ_r, θ_s, α and n for all samples are listed in Appendix A, in addition to sample-specific physical and descriptive information. Appendix B contains the moisture retention plots that are generated from the RETC runs. For the majority of samples, all four van Genuchten parameters (i.e., θ_r, θ_s, α and n) were fitted to the data. In some cases, however, a better fit to the data was obtained by fixing the θ_r parameter during curve-fitting; these samples are identified in Appendix A. As shown by the plots in Appendix B, the fit between the measured moisture retention data and the van Genuchten model is excellent for all samples.

The data in Appendices A and B represent sediment characteristics for 183 samples collected throughout the 200 Areas. Note that the particle-size distribution information is missing on a few samples. In addition to Eolian Sand (surface horizon soils; 12 samples), the following formations are represented by the data: Hanford Sand (91 samples), Hanford Gravel (17 samples), Palouse (2 samples), Plio-Pleistocene (16 samples), Upper Ringold (9 samples), Middle Ringold (17 samples), and Lower Ringold (3 samples).

Some of the moisture retention curves in Appendix B do not show measured moisture retention data points (squares) for pressure heads that are typically greater than -100 cm. This is an artifact of the correction procedure applied to the laboratory-measured primary drainage curve (PDC) for the desired main drainage curve (MDC). As was discussed earlier, the wet end of the moisture retention curve is corrected for vacuum saturation by assigning, prior to curve-fitting, an upper limit based on the saturated moisture content measured for the MWC. PDC measurements which are greater than the measured θ_s for the MWC are then deleted during the curve-fitting procedure. All four parameters are, however, fitted through the corrected data for the MDC. In some cases, this resulted in somewhat of a flat segment of the moisture retention curve between the last measured point for the MDC and the saturated moisture content derived from the wetting curve. No correction for the MDC was needed for samples from AP Tank Farm, ERDF, FLTF, Grout, U.S. Ecology, and VOC sites (Appendix A).

For samples which required correction for MDC, an assessment of the procedure is made through a comparison of samples requiring corrections with those requiring no corrections; the samples being compared should have nearly the identical particle-size distribution. For example, sample 2-2271 (200-BP-1 site), requiring corrections for MDC, has nearly the identical particle-size distribution as sample 4-1012 (ERDF site) that needed no corrections for MDC (Appendix B). During curve-fitting, sample 2-2271 had its PDC measurements deleted for h >-50 cm. However, the shape of the MDC and the fitted van Genuchten parameters for sample 2-2271 are remarkably similar to those of sample 4-1012 that has measurements in the desired range of h >-50 cm (Appendix B). Similar conclusions can be drawn by comparing the fitted curve for the corrected sample 3-0690 (241-T-106 site) with that for sample 3-0689 (241-T-106) that needed no corrections, and comparing sample 3-0668 (241-T-106) with sample 4-1080 (ERDF).

Some of the samples having a relatively high gravel content (>50%) exhibit a fairly flat moisture retention curve relative to other samples (Appendix B). This is due to the gravel correction procedure that was followed. The wet and dry ends of the retention curve are reduced by the weight percent gravel in the sample. However, the correction will have a greater impact at the wet end of the retention curve than it will at the dry end. For example, if the saturated moisture content of the sample (<2 mm size fraction) is 0.25 and the residual moisture content is 0.05, a 50% gravel content would result in adjusted saturated and residual moisture contents of 0.125 and 0.025, respectively. The absolute change for θ_s is much greater than that for θ_r.

5.2 UNSCALED DATA VARIABILITY

As is clear from appendices A and B, the data exhibit a high degree of variability. The first step in evaluating variability in unscaled data (Appendix A) was to ascertain the usefulness of grouping various soil types into common categories having similar physical characteristics. The moisture retention data (Appendix A) were sorted by texture based on sieve analysis and ISSS classification scheme. Retention curves having similar textures were then plotted on a single plot to evaluate if they indeed display common characteristics. Those displaying common characteristics were grouped so that an "average" curve could be defined. This led to a grouping of the moisture retention data for 176 samples by six categories: (1) sand mixed with finer fraction (SS; 48 samples), (2) sand (S; 76 samples), (3) sand and gravel mixed with finer fraction (SSG; 6 samples), (4) gravelly sand (GS; 10 samples), (5) sandy gravel for which gravel content is approximately less than 60% of the sample weight (SG1; 25 samples), and (6) sandy gravel for which gravel content is approximately greater than 60% by weight (SG2; 11 samples). Note that, because of incomplete or lack of particle-size distribution data, some of the moisture retention data sets listed in Appendix A could not be used. Also, four samples, although listed in Appendix A, were not included in analyzing variability since these samples were of the swelling clay type. The soil types and their grouping by categories are indicated for each sample in Appendix A.

The database comprised of six soil categories was used as the basis for characterizing the variability in parameters θ_s, θ_r, α, n, and K_s. Descriptive statistics are provided in Table 1. Among the five parameters, the variability is highest for K_s and least for parameter n; the coefficient of variation (CV) for K_s varies from about 104 to 293 percent, whereas the CV for the parameter n varies from only 9 to about 39%. The high variability exhibited by K_s is not unexpected given the highly heterogeneous nature of Hanford sediments and is consistent with values reported elsewhere (e.g.,

Table 1. Descriptive Statistics for van Genuchten Parameters θ_s, θ_r, α, n, and Saturated Hydraulic Conductivity K_s for the six Soil Categories. SS, Sand Mixed with Finer Fraction; S, Sand; SSG, Sand and Gravel Mixed with Finer Fraction; GS, Gravelly Sand; SG1, Sandy Gravel with Gravel Fraction < 60%; SG2, Sandy Gravel with Gravel Fraction > 60%.

Soil Category	Parameter	Number of samples	Low	High	Mean	Standard deviation	Coefficient of variation (%)
SS	θ_s	48	0.321	0.566	0.438	0.059	14
	θ_r	48	0.016	0.110	0.062	0.027	43
	α (1/cm)	48	8.0E-4	0.387	0.034	0.072	210
	n	48	1.262	2.894	1.824	0.344	19
	K_s (cm/s)	40	5.8E-6	0.017	0.001	0.003	278
S	θ_s	76	0.197	0.519	0.346	0.073	21
	θ_r	76	0	0.148	0.029	0.023	81
	α (1/cm)	76	0.004	0.861	0.108	0.164	151
	n	76	1.193	4.914	2.111	0.817	39
	K_s (cm/s)	71	1.38E-6	0.058	0.006	0.011	190
SSG	θ_s	6	0.187	0.375	0.262	0.072	28
	θ_r	6	0	0.064	0.030	0.029	95
	α (1/cm)	6	0.003	0.103	0.032	0.036	114
	n	6	1.256	1.629	1.400	0.131	9
	K_s (cm/s)	6	2.76E-5	0.068	0.015	0.027	183
GS	θ_s	10	0.203	0.334	0.272	0.048	18
	θ_r	10	0.010	0.069	0.040	0.019	48
	α (1/cm)	10	0.004	0.074	0.027	0.023	88
	n	10	1.529	2.537	1.994	0.315	16
	K_s (cm/s)	10	5.43E-5	0.008	0.003	0.003	104
SG1	θ_s	25	0.113	0.260	0.166	0.036	22
	θ_r	25	0	0.062	0.023	0.015	65
	α (1/cm)	25	0.002	0.919	0.083	0.204	247
	n	25	1.262	2.947	1.660	0.355	21
	K_s (cm/s)	24	1.9E-7	0.037	0.005	0.009	194
SG2	θ_s	11	0.056	0.107	0.077	0.016	21
	θ_r	11	0	0.020	0.010	0.007	75
	α (1/cm)	11	0.003	0.028	0.009	0.009	95
	n	11	1.347	1.885	1.621	0.178	11
	K_s (cm/s)	10	2.83E-5	0.130	0.014	0.041	293

Carsel and Parrish 1988). The variability exhibited by θ_s was minimal; the CV for θ_s was less than 25% for most soil categories. This is also consistent with data reported by other investigators (e.g., Carsel and Parrish 1988; Jury 1985). The CV for θ_r ranged from about 43 to 95%, whereas the CV for α ranged from about 95 to 247% (Table 1).

Figure 3 shows the unscaled data for the six soil categories. For each category, the solid line represents the best fit van Genuchten curve through the unscaled data. Table 2 provides the fitted van Genuchten parameters. A clear progression of the moisture retention data and the best fit curves from fine (SS) to coarse (SG2) categories is apparent from Figure 3.

Table 2. Van Genuchten Model Parameters Describing the Unscaled Mean Hydraulic Curve.

Soil Category	α	n	θ_r	θ_s	r^2	Sum of Squares (SS)
SS	0.0204	1.3179	0.0100	0.4329	0.6843	5.2739
S	0.0626	1.5820	0.0295	0.3665	0.7381	5.4937
SSG	0.0455	1.2003	0.0000	0.2407	0.7211	0.1265
GS	0.0588	1.3510	0.0123	0.2839	0.7558	0.3537
SG1	0.0594	1.2199	0.0000	0.1640	0.6343	0.4109
SG2	0.0098	1.3465	0.0020	0.0761	0.6989	0.0363

An attempt was made to examine the underlying probability distribution for the van Genuchten parameters and K_s. The database comprised of six soil categories and 176 samples was used as the basis for describing the probability distribution for the five parameters (i.e., θ_s, θ_r, α, n, and K_s). Empirical cumulative distribution functions (CDF) were derived for all five parameters, and hypothesized distributions were fitted. Best fit distributions that provided an adequate approximation to the empirical CDFs were sought. In particular, the available database was analyzed to see if the parameters fit a normal distribution. In cases where the normal distribution (NO) was inadequate for the representation of a given data set, other types of transformations that might produce a normal distribution were considered. The class of transformations used is the Johnson system as described in Carsel and Parrish (1988). The Johnson system involves three primary distribution types: lognormal (LN), log ratio (LR), and hyperbolic arcsine (SN).

$$\begin{aligned} &LN:\quad Y=\ln(X) \\ &LR:\quad Y=\ln\left[\frac{(X-A)}{(B-X)}\right] \qquad (15) \\ &SN:\quad \sinh^{-1}[U] = \ln[U+(1+U^2)^{\frac{1}{2}}] \end{aligned}$$

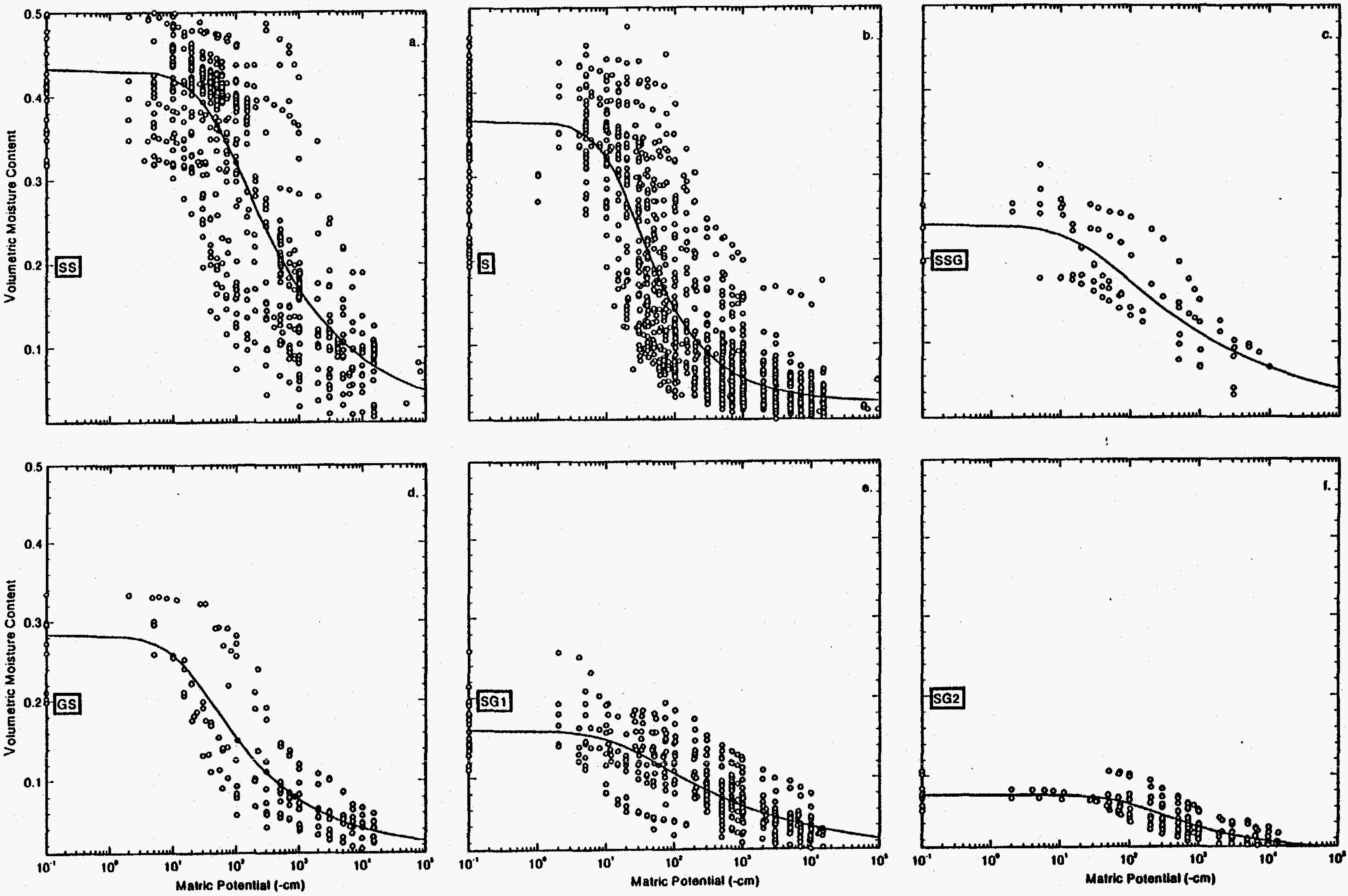

Figure 3. Unscaled Moisture Retention Data and Best Fit van Genuchten Curves for the six Soil Categories (SS, sand mixed with finer fraction; S, sand; SSG, sand and gravel mixed with finer fraction; GS, gravelly sand; SG1, sandy gravel with gravel content approximately < 60%; SG2, sandy gravel with gravel content approximately > 60%).

Table 3. Statistical Parameters Used for Cumulative Distribution Function Approximation (NO, Normal; LN, Lognormal; LR, Log Ratio; SN, Hyperbolic Arcsine) for θ_s, θ_r, α, n, and Saturated Hydraulic Conductivity K_s for the six Soil Categories. SS, Sand Mixed with Finer Fraction; S, Sand; SSG, Sand and Gravel Mixed with Finer Fraction; GS, Gravelly Sand; SG1, Sandy Gravel with Gravel Fraction < 60%; SG2, Sandy Gravel with Gravel Fraction > 60%.

Soil Category	Hydraulic Property	Lower Limit	Upper Limit	Transform	Statistics		
					Mean	Standard Deviation	D_{max}
SS	θ_s	0.321	0.566	NO	0.438	0.059	0.103
	θ_r	0.000	0.881	SN	0.458	0.255	0.148
	α	-7.131	-0.949	LN	-4.489	1.352	0.164
	n	1.262	2.894	NO	1.824	0.344	0.064
	K_s	-12.058	-4.057	LN	-8.487	1.813	0.144
S	θ_s	0.197	0.519	NO	0.346	0.073	0.050
	θ_r	0.000	0.881	SN	0.189	0.146	0.134
	α	-5.547	-0.149	LN	-3.097	1.347	0.057
	n	-5.756	4.330	LR	-1.459	1.523	0.080
	K_s	-11.191	-2.847	LN	-6.849	2.129	0.089
SSG	θ_s	0.187	0.375	NO	0.262	0.072	0.178
	θ_r	0.000	0.064	NO	0.030	0.029	0.202
	α	-5.843	-2.276	LN	-3.957	1.166	0.153
	n	1.256	1.629	NO	1.400	0.131	0.233
	K_s	-10.854	2.995	LR	-5.262	5.499	0.198
GS	θ_s	0.203	0.334	NO	0.272	0.048	0.182
	θ_r	0.010	0.069	NO	0.040	0.019	0.226
	α	0.004	0.074	NO	0.027	0.023	0.191
	n	1.529	2.537	NO	1.994	0.315	0.176
	K_s	-7.966	2.989	LR	-1.569	3.582	0.159
SG1	θ_s	0.113	0.260	NO	0.166	0.036	0.071
	θ_r	0.000	0.062	NO	0.023	0.015	0.134
	α	-6.075	-0.084	LN	-4.086	1.550	0.232
	n	0.233	1.081	LN	0.489	0.184	0.169
	K_s	-15.476	-3.297	LN	-7.932	3.322	0.150
SG2	θ_s	-2.888	-2.234	LN	-2.590	0.216	0.226
	θ_r	0.000	0.0197	NO	0.010	0.007	0.171
	α	-5.952	-3.590	LN	-5.008	0.882	0.187
	n	1.347	1.885	NO	1.621	0.178	0.162
	K_s	-10.473	-2.040	LN	-7.137	2.332	0.145

where Y denotes the transformed variable, X denotes the untransformed variable and corresponds to any of the variables θ_s, θ_r, α, n, and K_s with limits of variation from A to B (A < X < B), and U = (X - A)/(B - A). LR is bounded between limits A and B, whereas SN is unbounded.

The Kolmogorov-Smirnov (K-S) goodness-of-fit statistic D (maximum absolute deviation between the empirical and fitted CDFs) was used to select the best fit distribution among the four distributions (NO, LN, LR, SN). Figure 4 shows plots of empirical and best fit CDFs for transformed variables θ_s, θ_r, α, n, and K_s for one soil category (i.e., sand). The standardized normal distribution $[Z = (Y - \mu)/\sigma]$, having zero mean and unit variance, is used to represent the transformed variables (Figure 4). Results of comparison between the empirical and best fit CDFs are provided in Table 3. The smallest value of D signifies the most appropriate distribution in any given case. For each parameter of interest and for each soil category, the K-S statistic D was used to test whether the empirical and fitted CDFs are significantly different at a 5% level of significance. Results indicate that the majority of parameters for all six soil categories can be represented by either the normal or lognormal distribution. In a few cases where the normal or lognormal distribution was inadequate, the data can be adequately represented by using one of the other Johnson transformations (i.e, LR or SN). It should be noted that except for soil categories S and SS, the power of the statistical goodness-of-fit test is poor because the sample size is limited.

5.3 SCALED DATA

Following scaling procedures described in section 4.2, the identical unscaled database comprised of 176 samples and six soil categories was used to obtain the scaling factors α_h, α_θ, and α_K for each sample. The scaled moisture retention data for the six categories are shown in Figure 5. The scaled mean curve (shown as a solid line) is a best fit van Genuchten curve through the scaled data. Table 4 provides best fit van Genuchten parameters for the scaled data. In all cases, the scaled data forms a narrow band about the scaled mean curve. Again, similar to unscaled data, a clear progression of the moisture retention data and the best fit mean curves from fine (SS) to coarse (SG2) categories is evident from Figure 5.

A measure of the degree of success of scaling is the percentage reduction in sum of squares (SS) of deviations between the mean curves and the individual data, before and after scaling. Tables 2 and 4 provide information on SS as well as coefficient of determination (r^2) for unscaled and scaled data, respectively. The reduction in SS ranged from about 63 to 89 percent (Tables 2 and 4). Such a reduction is comparable to those reported by other investigators (e.g., Warrick et al. 1977), although different techniques are being used. Another measure of success due to scaling is the r^2 values for the best fit van Genuchten curves, before and after scaling (Tables 2 and 4). As discussed earlier, for each soil category, the unscaled and scaled mean curves are best fit van Genuchten curves through the unscaled and scaled data, respectively. For unscaled data, the r^2 values ranged from 0.63 to 0.76 (Table 2), whereas for scaled data, the values ranged from 0.91 to 0.97 (Table 4).

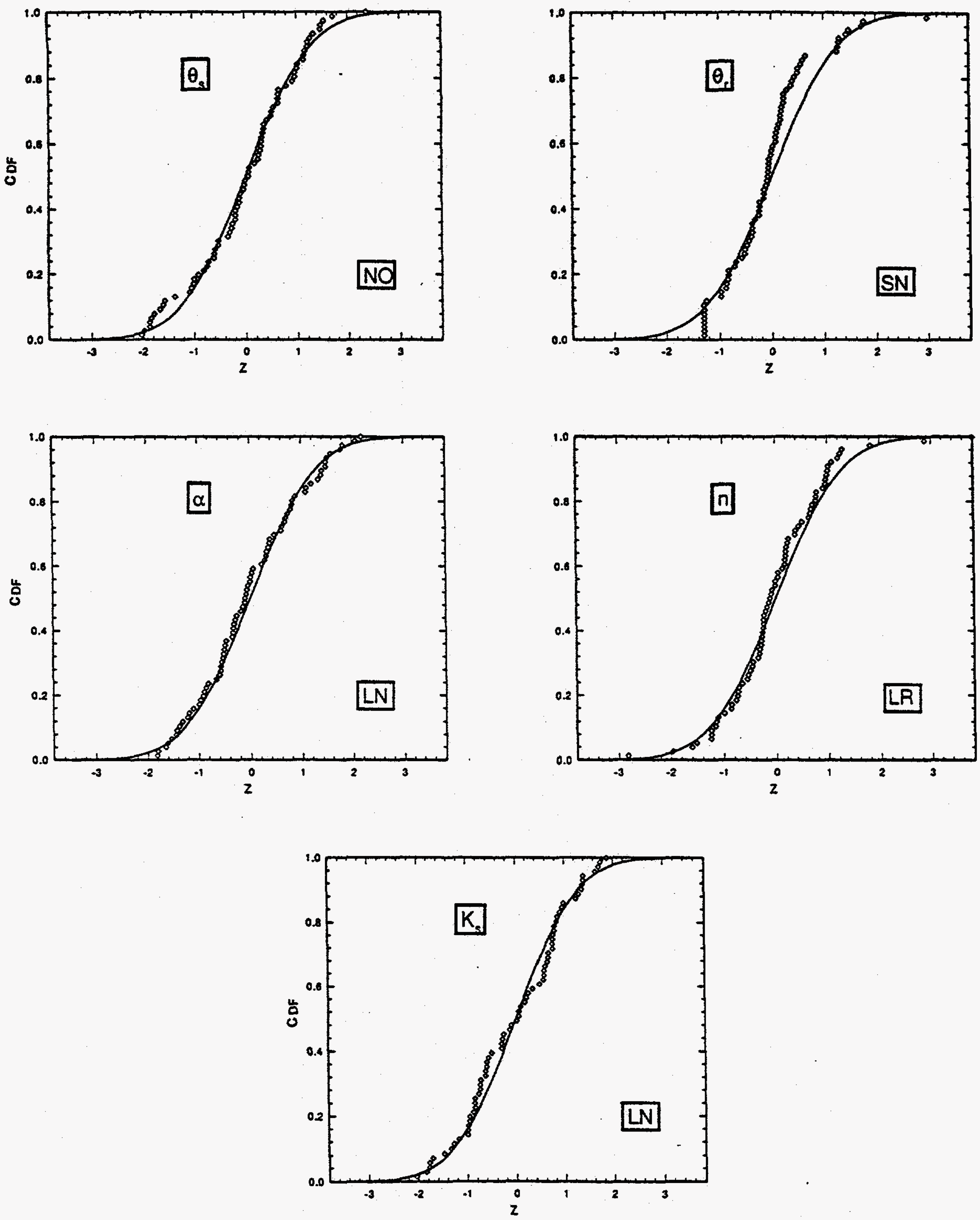

Figure 4. Empirical and Best Fit Cumulative Distribution Functions (CDF) for van Genuchten Parameters θ_S, θ_r, α, n and Saturated Hydraulic Conductivity K_S for Sand (S). NO, Normal; LN, Lognormal; LR, Log Ratio; SN, Hyperbolic Arcsine.

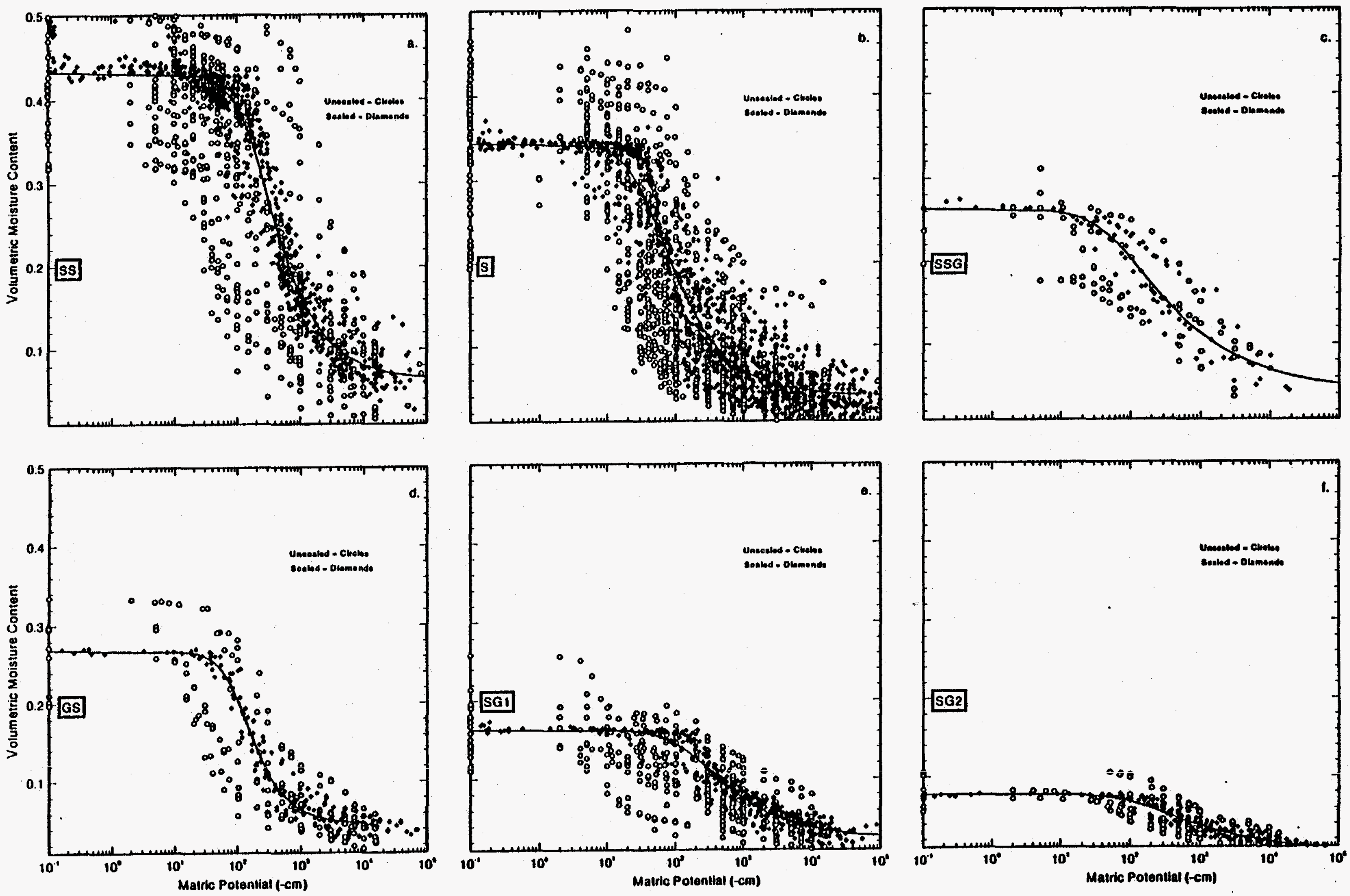

Figure 5. Scaled Moisture Retention Data and Best fit van Genuchten Curves for six Soil Categories (SS, sand mixed with finer fraction; S, sand; SSG, sand and gravel mixed with finer fraction; GS, gravelly sand; SG1, sandy gravel with gravel content approximately < 60%; SG2, sandy gravel with gravel content approximately > 60%).

Table 4. Van Genuchten Model Parameters Describing the Scaled Mean Hydraulic Curve.

Soil Category	α	n	θ_r	θ_s	r^2	Sum of Squares (SS)
SS	0.0052	1.7583	0.0627	0.4334	0.9543	0.6931
S	0.0246	1.1707	0.0391	0.3443	0.9050	1.5830
SSG	0.0164	1.3917	0.0391	0.2632	0.8992	0.0473
GS	0.0096	2.0892	0.0461	0.2688	0.9663	0.0408
SG1	0.0064	1.5147	0.0216	0.1630	0.9249	0.0766
SG2	0.0071	1.3333	0.0007	0.0785	0.9175	0.0096

Empirical CDFs were derived for the three scaling factors α_h, α_θ, and α_K. Again, similar to unscaled data, best fit distributions that provided an adequate approximation to the empirical CDFs were sought. In cases where the normal distribution (NO) was inadequate for the representation of a given data set, Johnson system of transformations was used. Again, the K-S statistic D was used to select the best fit distribution among the four distributions (NO, LN, LR, SN). Figure 6 shows plots of empirical and best fit CDFs for α_h, α_θ, and α_K for the sand category. Results of comparison between the empirical and best fit CDFs are provided in Table 5. Results indicate that, based on K-S statistic D, the scaling factors α_h, α_θ, and α_K are either normally or lognormally distributed for the six soil categories considered.

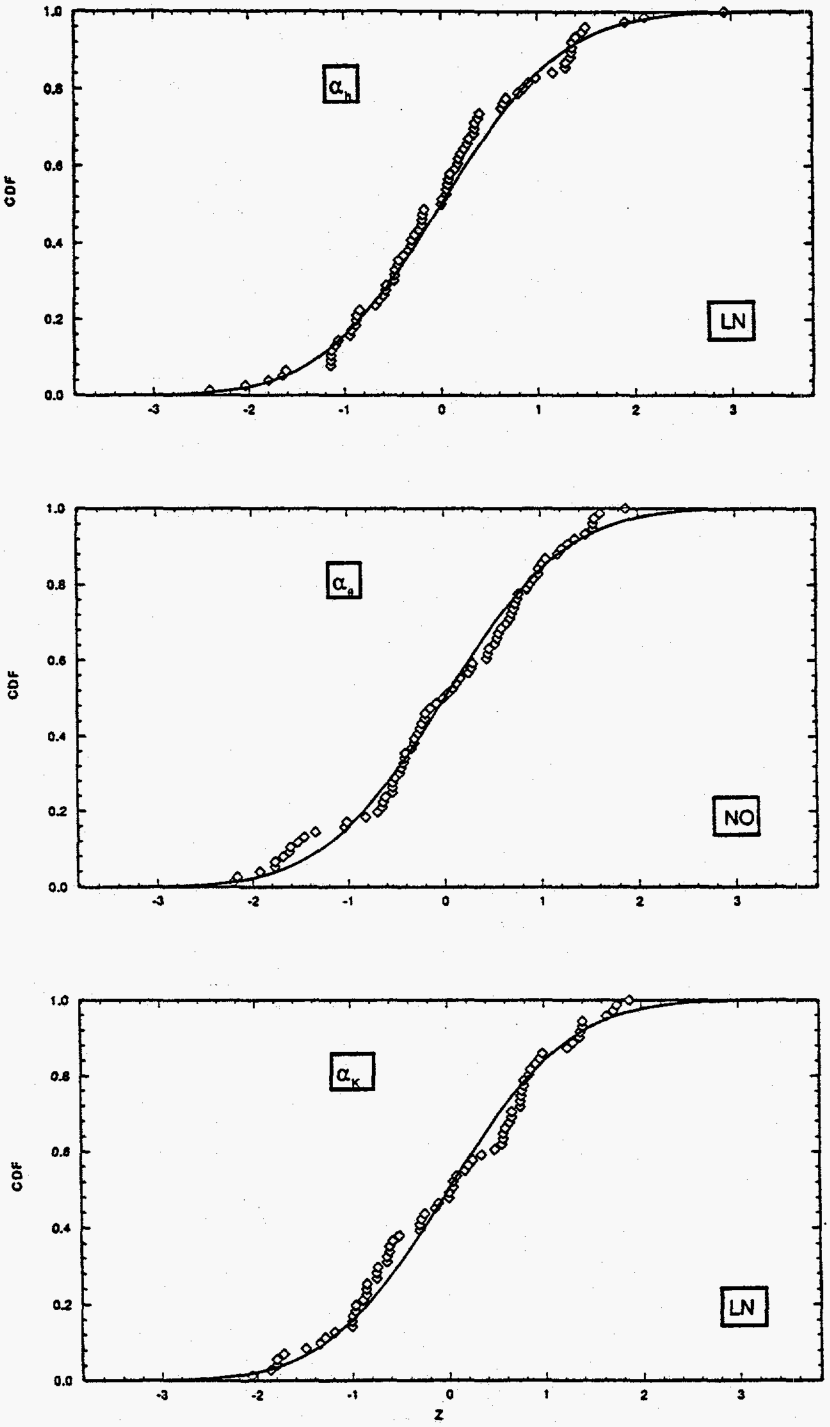

Figure 6. Empirical and Best Fit Cumulative Distribution Functions (CDF) for Scaling Factors α_h, α_θ, α_K for Sand (S). NO, Normal; LN, Lognormal.

Table 5. Statistical Parameters Used for Cumulative Distribution Function Approximation (NO, Normal; LN, Lognormal) for the Scaling Factors α_h, α_θ, and α_K for the six Soil Categories. SS, Sand Mixed with Finer Fraction; S, Sand; SSG, Sand and Gravel Mixed with Finer Fraction; GS, Gravelly Sand; SG1, Sandy Gravel with Gravel Fraction < 60%; SG2, Sandy Gravel with Gravel Fraction > 60%.

Soil Category	Scaling Factor	Lower Limit	Upper Limit	Transform	Statistics		
					Mean	Standard Deviation	D_{max}
SS	α_h	-3.503	1.949	LN	-0.599	1.172	0.154
	α_θ	0.709	1.409	NO	1.000	0.163	0.096
	α_K	-6.502	1.505	LN	-2.924	1.813	0.131
S	α_h	-3.572	2.686	LN	0.742	1.171	0.035
	α_θ	0.480	1.441	NO	1.000	0.236	0.070
	α_K	-5.991	2.357	LN	-1.621	2.120	0.094
SSG	α_h	-1.184	1.249	LN	-0.651	1.215	0.164
	α_θ	-0.213	0.296	LN	-0.022	0.227	0.283
	α_K	-6.266	1.517	LN	-3.204	3.348	0.253
GS	α_h	-2.039	0.961	LN	-0.510	1.108	0.136
	α_θ	0.684	1.409	NO	1.000	0.227	0.105
	α_K	-4.300	0.921	LN	-1.138	2.069	0.216
SG1	α_h	-4.465	2.199	LN	-0.967	1.559	0.129
	α_θ	0.655	1.668	NO	1.000	0.266	0.057
	α_K	-9.210	1.920	LN	-2.581	3.303	0.160
SG2	α_h	-1.881	0.938	LN	-0.365	0.939	0.073
	α_θ	0.675	1.300	NO	1.000	0.192	0.091
	α_K	-6.119	2.320	LN	-2.777	2.332	0.173

6.0 SUMMARY AND CONCLUSIONS

The primary objective of this study was to summarize existing data on particle-size distribution, moisture retention, and saturated hydraulic conductivity (K_s) for various geologic formations and soil types in the 200 Areas. A total of 183 moisture retention data sets taken from 12 sites in the 200 Areas plateau are evaluated. The laboratory-measured moisture retention data are corrected for gravel content and the main drainage curve. Summary tables are provided by soil type and formation, and the fitted van Genuchten parameters and laboratory-measured K_s values are cataloged.

To describe the variability, the moisture retention data were grouped by six categories: (1) sand mixed with finer fraction, (2) sand, (3) sand and gravel mixed with finer fraction, (4) gravelly sand, (5) sandy gravel with a gravel fraction of less than 60%, and (6) sandy gravel with a gravel fraction of greater than 60%. Descriptive statistics are provided describing the variability of unscaled moisture retention data and K_s. A progression of the moisture retention data and the best fit curves from fine to coarse categories is apparent from a plot of the unscaled data. Empirical cumulative distribution functions (CDFs) are derived for all five parameters (i.e., θ_s, θ_r, α, n, and K_s), and statistical distributions fitted. The Kolmogorov-Smirnov (K-S) goodness-of-fit statistic is used to select the best fit distribution. The CDFs for the vast majority of data can be described using either a normal or a lognormal distribution. In some cases, a log ratio or hyperbolic arcsine function is used to obtain a better fit to the data.

An alternate representation of hydraulic properties is the use of scaling technique to simplify the description of the spatial variability of the 200 Area soils. Separate scaling factors α_h, α_θ, and α_K associated with pressure head, moisture content, and hydraulic conductivity, respectively, for each sample, are obtained for the identical database used to describe variability in unscaled data. Comparisons made between the best fit van Genuchten curves for the unscaled data and those for the scaled data show that scaling reduces the sums of squares by amounts varying from 63 to 89%. Based on K-S statistic, the scaling factors α_h, α_θ, and α_K are found to be either normally or lognormally distributed for the six soil categories considered.

The information on unscaled and scaled data variability can potentially be used to propagate uncertainties in parameter estimates for 200 Area soils through numerical models of vadose zone flow and transport. However, since the existing database is limited, it would be useful to update the database as more data become available.

The analysis is based on the premise that the unsaturated hydraulic conductivity relationships can be predicted using the van Genuchten parameters, Mualem's model, and laboratory-measured saturated hydraulic conductivity estimates. Alternatively, provided unsaturated conductivity measurements are available, the moisture retention curve-fitting parameters and a single unsaturated conductivity measurement can be used to predict unsaturated conductivities for the desired range of field moisture regime.

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APPENDIX A

SUMMARY OF PHYSICAL AND HYDRAULIC PARAMETERS

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Site	sample no.	borehole	depth (m)	Sieve Analysis					soil type$^{\#}$	formation	alpha (1/cm)	n	theta_r	theta_s	Ks (cm/s)	sampling technique	Source
				gr	cs	fs	silt	clay									
200-BP-1 ^{2,4}	1-0526	299-E33-38	1.9	47	18	15	10	0	sandy gravel (5)	Hanford Gravel	0.0164	1.5448	0.0229	0.2144	2.00E-05	splitspoon	Hoffman, 1992
	1-0527	299-E33-38	15.1	42	50	8	0	0	sandy gravel (6)	Hanford Gravel	0.0255	1.6222	0.015^{f}	0.0773	5.70E-05	splitspoon	Relyea, 1995
	1-0528	299-E33-38	51.0	42	50	8	0	0	sandy gravel (6)	Hanford Sand	0.0045	1.8509	0.0105	0.0746	5.00E-04	splitspoon	"
	1-0529	299-E33-38	62.3	79	14	7	0	0	sandy gravel (6)	Hanford Gravel	0.0026	1.4909	0.0000	0.0557	4.20E-03	splitspoon	"
	1-0530	299-E33-38	57.1	0	60	35	5	0	sand (2)	Hanford Sand	0.0123	1.6899	0.0098	0.2663	7.10E-05	splitspoon	"
	1-0531	299-E33-38	57.9	-----	-----	N/A	-----	-----	sand (2)	Hanford Sand	0.0017	1.8438	0.0400^{f}	0.4863	2.10E-06	splitspoon	"
	1-0550	299-E33-40	14.0	63	32	5	0	0	sandy gravel (6)	Hanford Gravel	0.0037	1.4567	0.0000	0.0757	6.00E-04	splitspoon	"
	1-1133	216-B-61A	4.1	76	13	11	0	0	sandy gravel (6)	Hanford Gravel	0.0028	1.8847	0.0162	0.0781	1.80E-03	splitspoon	"
	1-1134	216-B-61A	5.8	55	24	13	8	0	sandy gravel (5)	Hanford Gravel	0.0034	1.6905	0.0322	0.1409	2.80E-03	splitspoon	"
	1-1136	216-B-61A	7.0	68	20	12	0	0	sandy gravel (6)	Hanford Gravel	0.0056	1.4945	0.0187	0.1043	4.00E-04	splitspoon	"
	1-1137	216-B-61A	8.8	38	49	13	0	0	sandy gravel (5)	Hanford Gravel	0.0139	1.4207	0.0210	0.1542	1.80E-05	splitspoon	"
	2-2244	216-B-49A	26.5	1	49	48	2	0	sand (2)	Hanford Sand	0.0135	2.0185	0.0270	0.2687	4.60E-05	splitspoon	"
	2-2253	216-B-49A	35.5	2	85	13	0	0	sand (2)	Hanford Sand	0.0205	1.7138	0.0308	0.2284	8.80E-05	splitspoon	"
	2-2258	216-B-43A	41.3	1	84	15	0	0	sand (2)	Hanford Sand	0.0373	1.7815	0.0271	0.2306	2.80E-05	splitspoon	"
	2-2261	216-B-49A	48.6	12	76	12	0	0	gravelly sand (4)	Hanford Sand	0.0410	1.6885	0.0303	0.2026	1.80E-04	splitspoon	"
	2-2271	216-B-57A	60.5	50	28	14	6	2	sandy gravel (5)	Hanford Gravel	0.0074	1.4319	0.0145	0.1636	1.40E-05	splitspoon	"
	2-2283	216-B-57A	13.9	6	83	11	0	0	sand (2)	Hanford Sand	0.0298	1.6757	0.0269	0.2005	2.10E-05	splitspoon	"
	2-2286	216-B-49A	14.9	0	4	92	3	1	sand (2)	Hanford Sand	0.0077	3.0137	0.0569	0.4712	6.30E-05	splitspoon	"
	2-2289	216-B-43A	51.4	4	84	12	0	0	sand (2)	Hanford Sand	0.0131	1.6351	0.0409	0.1968	1.30E-04	splitspoon	"
	2-2294	216-B-43A	61.4	39	33	17	7	4	sandy gravel (5)	Hanford Gravel	0.0051	1.4514	0.0066	0.2006	4.40E-05	splitspoon	"
	2-2297	216-B-57A	65.4	80	20	0	0	0	sandy gravel (6)	Hanford Gravel	0.0059	1.8562	0.0074	0.0641	4.10E-04	splitspoon	"
218-W-5 ^{2,4}	0-073	299-W7-9	20.3	0	27	54	10	9	loamy sand (1)	Hanford sand	0.0008	1.9785	0.0600^{f}	0.4134	N/A	splitspoon	"
	0-082	299-W7-9	24.5	2	38	47	8	5	sand (2)	Plio-Pleistocene	0.0064	1.7084	0.1483	0.3336	6.30E-04	splitspoon	"
	0-085	299-W7-9	26.9	0	50	37	5	8	sand (2)	Plio-Pleistocene	0.0049	2.1261	0.0578	0.2105	1.30E-04	splitspoon	"
	0-101	299-W7-9	31.6	0	85	8	2	5	sand (2)	Upper Ringold	0.0695	1.4447	0.0228	0.2082	2.10E-04	splitspoon	"
	0-104	299-W7-9	34.2	0	72	24	3	1	sand (2)	Upper Ringold	0.0849	1.3106	0.0000	0.2082	1.10E-03	splitspoon	"
	5-0001	299-W7-9	21.6	4	4	79	8	5	sand (2)	Palouse paleosol	0.0057	2.8152	0.0200^{f}	0.3727	1.40E-04	splitspoon	Relyea, 1995
	5-0002	299-W7-9	24.9	2	38	47	8	5	sand (2)	Plio-Pleistocene	0.0039	1.9321	0.0678	0.3454	1.32E-04	splitspoon	"
	5-0003	299-W7-9	43.2	0	74	22	1	3	sand (2)	Upper Ringold	0.0414	1.9382	0.0211	0.3004	1.80E-04	splitspoon	"
	5-0004	299-W7-9	30.3	0	58	30	7	5	sand (2)	Upper Ringold	0.0102	1.5737	0.0267	0.3256	1.65E-04	splitspoon	"
	5-0005	299-W7-9	21.1	0	0	73	22	5	sandy loam (1)	Palouse paleosol	0.0069	2.2430	0.0400^{f}	0.3851	6.70E-05	splitspoon	"
	5-0006	299-W7-9	19.9	0	27	54	10	9	loamy sand (1)	Hanford sand	0.0064	2.2593	0.0584	0.3274	N/A	splitspoon	"

	5-0007	299-W7-9	40.3	0	80	13	5	2	sand (2)	Upper Ringold	0.1308	1.7017	0.0231	0.3502	3.00E-03	splitspoon	"
218-W-5[1,5]	W7-2-65	299-W07-02	19.8	35	38	11	16	0	silty sandy gravel (3)	Plio-Pleistocene	0.02102	1.4563	0.064	0.3752	6.80E-02	splitspoon	Bjornstad, 1990
	W7-2-94	299-W07-02	28.6	48	39	7	6	0	sandy gravel (5)	Upper Ringold	0.0557	1.9669	0.0223	0.2168	3.70E-02	splitspoon	"
	W7-2-154	299-W07-02	46.9	32	36	15	17	0	silty sandy gravel (3)	Middle Ringold	0.1027	1.3782	0.0150[f]	0.3071	2.10E-02	splitspoon	"
	W7-2-219	299-W07-02	66.8	39	35	18	8	0	sandy gravel (5)	Middle Ringold	0.068	1.7788	0.0617	0.1594	2.70E-03	splitspoon	"
	W10-13-45	299-W10-13	13.7	0	62	33	5	0	sand (2)	Hanford Sand	0.0408	2.0672	0.0396	0.3915	5.80E-02	splitspoon	"
	W10-13-80	299-W10-13	24.4	64	25	6	5	0	sandy gravel (5)	Hanford Gravel	0.2758	1.3718	0.0367	0.1781	2.70E-02	splitspoon	"
241-T-106[2,4]	3-0210	299-W10-196	3.1	48	30	22	0	0	sandy gravel (5)	Hanford gravel	0.0115	2.2692	0.0450	0.1854	1.00E-03	splitspoon	Relyea, 1995
	3-0213	299-W10-196	5.6	31	33	36	0	0	gravelly sand (4)	Hanford gravel	0.0040	2.4233	0.0494	0.2083	1.02E-03	splitspoon	"
	3-0279	299-W10-196	1.8	46	32	20	2	0	sandy gravel (5)	Hanford gravel	0.0061	2.1046	0.0337	0.1492	N/A	splitspoon	"
	3-0589	299-W10-196	25.5	2	56	42	0	0	sand (2)	Hanford sand	0.0040	2.0685	0.0575	0.3443	1.38E-05	splitspoon	"
	3-0667	299-W10-196	42.2	80	13	7	0	0	sandy gravel (6)	Middle Ringold	0.0115	1.3466	0.0000	0.0718	2.83E-05	splitspoon	"
	3-0668	299-W10-196	38.9	63	15	12	10	0	sandy gravel (5)	Middle Ringold	0.0023	1.5765	0.0100[f]	0.1470	1.60E-03	splitspoon	"
	3-0682	299-W10-196	46.1	0	54	35	10	1	sand (1)	Middle Ringold	0.0128	2.0864	0.0519	0.4334	4.57E-05	splitspoon	"
	3-0688	299-W10-196	48.5	0	38	28	28	6	sandy loam (1)	Middle Ringold	0.0036	1.6568	0.0302	0.3230	N/A	splitspoon	"
	3-0689	299-W10-196	52.2	0	36	30	25	9	sandy loam (1)	Middle Ringold	0.0022	1.6651	0.0300[f]	0.3208	N/A	splitspoon	"
	3-0690	299-W10-196	53.7	0	39	31	23	7	sandy loam (1)	Middle Ringold	0.0042	1.6376	0.0564	0.3683	6.55E-06	splitspoon	"
APTANK[1,5]	241-AP1G	N/A	N/A	38	58	3	1	0	sandy gravel (5)	Hanford sand	0.1018	2.9473	0.0212	0.2599	1.24E-03	excavation	Heller., 1989
	241-AP-2	N/A	N/A	0	68	26	3	3	sand (2)	Hanford sand	0.0309	3.0872	0.0994	0.519	5.97E-04	excavation	"
	241-AP-3	N/A	N/A	0	85	12	2	1	sand (2)	Hanford sand	0.0494	3.4878	0.062	0.4348	8.10E-04	excavation	"
	241-AP-4G	N/A	N/A	10	83	5	2	0	sand (2)	Hanford sand	0.0698	2.6694	0.0416	0.4162	1.87E-03	excavation	"
	241-AP-5	N/A	N/A	0	7	49	36	8	sandy loam (1)	Hanford sand	0.0108	1.4367	0.0268	0.4293	4.94E-05	excavation	"
	241-AP-6	N/A	N/A	1	36	43	14	6	loamy sand (1)	Hanford sand	0.0053	1.9484	0.068	0.4049	8.60E-05	excavation	"
C-018-H[2,4]	2-1169	699-48-77	8.1	14	40	44	2	0	gravelly sand (4)	Plio-Pliestocene	0.0076	2.5367	0.0569	0.3069	5.30E-03	splitspoon	Relyea, 1995
	2-1170	699-48-77	8.9	22	42	33	3	0	gravelly sand (4)	Plio-Pliestocene	0.0048	1.9770	0.0635	0.3011	1.30E-04	splitspoon	"
	2-1176	699-48-77	13.0	1	79	20	0	0	sand (2)	Plio-Pliestocene	0.0223	1.7587	0.0262	0.2230	2.00E-02	splitspoon	"
	2-1181	699-48-77	14.1	8	82	10	0	0	sand (2)	Plio-Pliestocene	0.0728	1.3096	0.0230	0.2147	8.20E-03	splitspoon	"
	2-1431	699-48-77A	20.6	------	-----	N/A	----	-----	sand (2)	Plio-Pliestocene	0.0227	1.5859	0.0432	0.2346	1.80E-02	splitspoon	"
	2-1432	699-48-77A	27.6	51	30	15	4	0	sandy gravel (5)	Middle Ringold	0.0083	1.5938	0.0191	0.1128	1.40E-02	splitspoon	"
ERDF[2,6]	4-0637	699-36-63A	74.9	------	-----	N/A	-----	-----	sand (2)	Hanford sand	0.0261	3.2937	0.0278	0.3743	N/A	splitspoon	Relyea, 1995
	4-0642	699-35-69A	25.7	0	60	30	10	0	sand (2)	Hanford sand	0.0119	1.6727	0.0566	0.3513	N/A	splitspoon	Weekes and Borghese, 1994
	4-0644	699-35-69A	49.8	0	27	56	12	5	loamy sand (1)	Hanford sand	0.0069	2.2673	0.0828	0.3922	N/A	splitspoon	"

	4-0791	699-35-65A	63.2	0	50	50	0	0	sand (2)	Hanford sand	0.0217	2.4513	0.0303	0.3371	N/A	splitspoon	"
	4-0792	699-35-65A	75.4	70	21	8	1	0	sandy gravel (6)	Middle Ringold	0.0276	1.6636	0.0091	0.0825	N/A	splitspoon	"
	4-0855	699-35-66B	12.2	0	7	83	5	5	sand (2)	Hanford sand	0.0088	3.2652	0.0689	0.3936	N/A	splitspoon	"
	4-0973	699-35-68A	37.0	0	21	64	12	3	loamy sand (1)	Hanford sand	0.0169	2.0085	0.0190^{f}	0.3525	1.27E-04	splitspoon	"
	4-0983	699-35-68A	82.9	17	35	42	4	2	gravelly sand (4)	Upper Ringold	0.0156	2.0226	0.0100^{f}	0.3373	5.43E-05	splitspoon	"
	4-1011	699-35-69A	73.0	0	4	60	28	8	loamy sand (1)	Plio-Pleistocene	0.0042	1.5218	0.0450^{f}	0.4913	1.00E-05	splitspoon	"
	4-1012	699-35-69A	73.9	50	20	20	7	3	sandy gravel (5)	Middle Ringold	0.0062	1.6452	0.0100^{f}	0.1643	5.10E-05	splitspoon	"
	4-1013	699-35-69A	77.9	77	6	12	3	2	sandy gravel (5)	Middle Ringold	0.0064	1.6574	0.0214	0.1397	1.90E-07	splitspoon	"
	4-1056	699-32-72B	61.7	0	6	88	4	2	sand (2)	Hanford sand	0.0071	2.7253	0.0350^{f}	0.4288	N/A	splitspoon	"
	4-1057	699-32-72B	49.5	0	2	68	24	6	loamy sand (1)	Hanford sand	0.0046	2.2861	0.0890	0.4877	N/A	splitspoon	"
	4-1058	699-32-72B	64.7	0	1	41	43	15	loam (1)	Hanford sand	0.0029	1.5267	0.1023	0.5661	N/A	splitspoon	"
	4-1076	699-35-61A	76.4	0	75	25	0	0	sand (2)	Hanford sand	0.0235	2.0956	0.0265	0.3433	N/A	splitspoon	"
	4-1079	699-35-61A	90.9	65	24	11	0	0	sandy gravel (5)	Middle Ringold	0.0073	1.6668	0.0295	0.1236	1.30E-03	splitspoon	"
	4-1080	699-35-61A	93.5	63	24	10	3	0	sandy gravel (5)	Middle Ringold	0.0062	1.6601	0.0302	0.1316	3.30E-06	splitspoon	"
FLTF[1,5]	D02-10	N/A	<6.1	0	2	54	34	10	sandy loam (1)	Warden silt loam	0.0049	1.9773	0.0778	0.4531	1.20E-04	excavation	Gee et al., 1989
	D02-16	N/A	<6.1	0	2	63	25	10	sandy loam (1)	Warden silt loam	0.0035	2.4632	0.0820^{f}	0.4630	1.20E-04	excavation	Volk, 1993
	D04-04	N/A	<6.1	0	4	58	28	10	sandy loam (1)	Warden silt loam	0.0072	1.6501	0.0700^{f}	0.4508	1.20E-04	excavation	"
	D04-10	N/A	<6.1	0	3	58	30	9	sandy loam (1)	Warden silt loam	0.0066	1.7574	0.0800^{f}	0.4428	2.90E-04	excavation	"
	D05-03	N/A	<6.1	0	4	63	23	10	sandy loam (1)	Warden silt loam	0.0055	1.8647	0.0860^{f}	0.4332	2.90E-04	excavation	"
	D07-04	N/A	<6.1	0	3	58	30	9	sandy loam (1)	Warden silt loam	0.0051	1.9424	0.0820^{f}	0.4435	1.20E-04	excavation	"
	D08-15	N/A	<6.1	0	2	57	31	10	sandy loam (1)	Warden silt loam	0.0059	1.8533	0.0850^{f}	0.4543	1.20E-04	excavation	"
	D09-01	N/A	<6.1	0	3	51	37	9	sandy loam (1)	Warden silt loam	0.0066	1.7677	0.0800^{f}	0.4544	1.20E-04	excavation	"
	D09-02	N/A	<6.1	0	2	57	31	10	sandy loam (1)	Warden silt loam	0.0069	1.8498	0.0825	0.4559	1.20E-04	excavation	"
	D09-05	N/A	<6.1	0	7	60	29	4	sandy loam (1)	Warden silt loam	0.0088	1.6183	0.0681	0.4461	2.90E-04	excavation	"
	D10-04	N/A	<6.1	0	6	59	30	5	sandy loam (1)	Warden silt loam	0.0064	1.7899	0.0850^{f}	0.4481	1.20E-04	excavation	"
	D11-06	N/A	<6.1	0	4	57	33	6	sandy loam (1)	Warden silt loam	0.0061	1.8575	0.0850^{f}	0.4308	1.20E-04	excavation	"
	D11-08	N/A	<6.1	0	5	58	32	5	sandy loam (1)	Warden silt loam	0.0061	1.7567	0.0850^{f}	0.4312	1.20E-04	excavation	"
	D12-14	N/A	<6.1	0	3	52	34	11	sandy loam (1)	Warden silt loam	0.0063	1.7576	0.0980^{f}	0.4686	1.20E-04	excavation	"
	D13-08	N/A	<6.1	0	4	52	35	9	sandy loam (1)	Warden silt loam	0.0070	1.7677	0.0820^{f}	0.4513	1.20E-04	excavation	"
	D14-04	N/A	<6.1	0	3	56	36	5	sandy loam (1)	Warden silt loam	0.0065	1.8553	0.0837	0.4586	1.20E-04	excavation	"
GROUT[1,5]	5A	299-E25-234	1.5	1	73	17	5	4	sand (2)	Eolian sand	0.1480	1.3087	0.0187	0.4131	5.73E-04	splitspoon	Rockhold et al., 1993
	5B	299-E25-234	1.5						sand (2)	Eolian sand	0.0211	1.5360	0.0336	0.3367	5.73E-04	splitspoon	"
	19A	299-E25-234	5.8	2	28	53	12	5	loamy sand (1)	Eolian sand	0.3870	1.2615	0.0461	0.4860	8.88E-04	splitspoon	"
	19B	299-E25-234	5.8						loamy sand (1)	Eolian sand	0.2729	1.5326	0.0363	0.5026	8.88E-04	splitspoon	"
	25A	299-E25-234	7.6	0	49	36	10	5	loamy sand (1)	Eolian sand	0.0473	2.0595	0.0539	0.4407	1.80E-03	splitspoon	"

	25B	299-E25-234	7.6						loamy sand (1)	Eolian sand	0.0519	1.3421	0.0342	0.5228	1.80E-03	splitspoon	"
	25C	299-E25-234	7.6						loamy sand (1)	Eolian sand	0.0287	1.3529	0.0280^{f}	0.5062	1.80E-03	splitspoon	"
	25D	299-E25-234	7.6						loamy sand (1)	Eolian sand	0.0700	1.8780	0.0800^{f}	0.4822	1.80E-03	splitspoon	"
	29A	299-E25-234	8.8	0	60	31	6	3	sand (2)	Eolian sand	0.2718	1.1928	0.0000	0.4341	2.41E-05	splitspoon	"
	29B	299-E25-234	8.8						sand (2)	Eolian sand	0.1033	1.2242	0.0000	0.4387	2.41E-05	splitspoon	"
	37A	299-E25-234	11.3	1	43	39	10	7	loamy sand (1)	Eolian sand	0.0775	1.2921	0.0703	0.5114	5.77E-04	splitspoon	"
	37B	299-E25-234	11.3						loamy sand (1)	Eolian sand	0.0914	1.3319	0.0844	0.5304	5.77E-04	splitspoon	"
	46A	299-E25-234	14	0	73	22	2	3	sand (2)	Hanford sand	0.2923	1.3658	0.0000	0.4581	2.99E-04	splitspoon	"
	46B	299-E25-234	14						sand (2)	Hanford sand	0.0613	1.4343	0.0000	0.3708	2.99E-04	splitspoon	"
	54A	299-E25-234	16.5	1	51	32	9	7	loamy sand (1)	Hanford sand	0.1524	1.4137	0.0262	0.4488	1.38E-05	splitspoon	"
	54B	299-E25-234	16.5						loamy sand (1)	Hanford sand	0.1451	1.4419	0.0216	0.4543	1.38E-05	splitspoon	"
	69A	299-E25-234	21	3	71	19	5	2	sand (2)	Hanford sand	0.3357	1.2658	0.0000	0.3721	1.21E-03	splitspoon	"
	69B	299-E25-234	21						sand (2)	Hanford sand	0.2269	1.6572	0.0288	0.4042	1.21E-03	splitspoon	"
	83A	299-E25-234	25.3	4	70	19	5	2	sand (2)	Hanford sand	0.2979	1.3300	0.0070^{f}	0.3915	1.78E-04	splitspoon	"
	83B	299-E25-234	25.3						sand (2)	Hanford sand	0.1157	1.4027	0.0070^{f}	0.3696	1.78E-04	splitspoon	"
	99A	299-E25-234	30.2	0	34	60	4	2	sand (2)	Hanford sand	0.7417	1.2557	0.0000	0.3692	2.24E-04	splitspoon	"
	99B	299-E25-234	30.2						sand (2)	Hanford sand	0.3823	1.3262	0.0100	0.3765	2.24E-04	splitspoon	"
	110A	299-E25-234	33.5	6	64	23	5	2	sand (2)	Hanford sand	0.1964	1.8193	0.0324	0.4293	2.82E-04	splitspoon	"
	110B	299-E25-234	33.5						sand (2)	Hanford sand	0.1991	1.8015	0.0326	0.4201	2.82E-04	splitspoon	"
	117A	299-E25-234	35.7	3	62	26	5	4	sand (2)	Hanford sand	0.1114	1.6538	0.0259	0.4538	3.63E-03	splitspoon	"
	117B	299-E25-234	35.7						sand (2)	Hanford sand	0.0230	1.5237	0.0011	0.3831	3.63E-03	splitspoon	"
	126A	299-E25-234	38.4	51	33	14	1	1	sandy gravel (5)	Hanford sand	0.9193	1.3700	0.0106	0.1755	1.98E-03	splitspoon	"
	126B	299-E25-234	38.4						sandy gravel (5)	Hanford sand	0.4783	1.4639	0.0127	0.1823	1.98E-03	splitspoon	"
	133A	299-E25-234	40.5	30	33	25	9	3	silty sandy gravel (3)	Hanford sand	0.0163	1.3134	0.0000	0.1877	2.76E-05	splitspoon	"
	133B	299-E25-234	40.5						silty sandy gravel (3)	Hanford sand	0.0331	1.2555	0.0000	0.1871	2.76E-05	splitspoon	"
Injection [2,4]	1-1417	299-E24-95	1.8	1	23	68	7	1	sand (2)	Hanford sand	0.0051	1.6827	0.0200^{f}	0.3501	1.40E-04	core barrel	Relyea, 1995
	1-1418	299-E24-95	3.0	18	56	26	0	0	gravelly sand (4)	Hanford sand	0.0310	1.5289	0.0336	0.2152	1.80E-04	core barrel	"
	1-1419	299-E24-95	4.9	2	88	10	0	0	sand (2)	Hanford sand	0.4984	1.4065	0.0090	0.3013	3.20E-04	core barrel	"
	2-1636	299-E24-95	4.9	2	84	14	0	0	sand (2)	Hanford sand	0.1385	1.7079	0.0228	0.3073	8.70E-04	core barrel	"
	2-1637	299-E24-79	9.8	0	80	20	0	0	sand (2)	Hanford sand	0.0760	1.8863	0.0248	0.3026	4.20E-03	core barrel	"
	2-1638	299-E24-79	12.2	0	81	19	0	0	sand (2)	Hanford sand	0.1016	1.3365	0.0000	0.2720	5.80E-03	core barrel	"
	2-1639	299-E24-79	18.3	0	93	7	0	0	sand (2)	Hanford sand	0.3333	1.5801	0.0179	0.3206	1.30E-03	core barrel	"
	2-2225	299-E24-92	9.8	0	80	20	0	0	sand (2)	Hanford sand	0.0242	4.1695	0.0335	0.3309	5.50E-03	core barrel	"
	2-2226	299-E24-92	15.2	6	90	4	0	0	sand (2)	Hanford sand	0.5282	1.4780	0.0168	0.2861	1.50E-02	core barrel	"
	2-2227	299-E24-92	18.3	2	92	6	0	0	sand (2)	Hanford sand	0.1216	1.7364	0.0154	0.3271	8.70E-03	core barrel	"
	2-2228	299-E24-95	15.2	1	97	2	0	0	sand (2)	Hanford sand	0.8612	1.4523	0.0092	0.2925	2.10E-02	core barrel	"

	2-2229	299-E24-95	18.3	1	94	5	0	0	sand (2)	Hanford sand	0.1358	1.8345	0.0197	0.3070	6.40E-03	core barrel	"
	2-2230	299-E24-79	1.8	2	32	52	11	3	sand (2)	Hanford sand	0.0066	2.1407	0.0608	0.3309	2.30E-04	core barrel	"
	2-2231	299-E24-79	3.0	12	52	36	0	0	gravelly sand (4)	Hanford sand	0.0063	1.7824	0.0685	0.2811	7.50E-03	core barrel	"
	2-2232	299-E24-79	4.9	4	88	8	0	0	sand (2)	Hanford sand	0.0452	2.0873	0.0279	0.2450	4.10E-02	core barrel	"
	2-2233	299-E24-79	7.9	2	90	8	0	0	sand (2)	Hanford sand	0.3460	1.4491	0.0130	0.2906	1.70E-02	core barrel	"
	2-2234	299-E24-79	11.0	0	86	14	0	0	sand (2)	Hanford sand	0.0664	1.5548	0.0123	0.2782	2.10E-02	core barrel	"
US ECOLOGY [1,3]																	
MW-5	50	699-35-58	15.2	1	75	18	6	0	sand (2)	Hanford sand	0.0395	2.6308	0.0367	0.3309	3.53E-02	splitspoon	Bergeron et al., 1987
	70	699-35-58	21.3	0	38	51	11	0	sand (2)	Hanford sand	0.0142	4.7700	0.0300[f]	0.4431	1.57E-03	splitspoon	"
	90	699-35-58	27.4	0	81	15	4	0	sand (2)	Hanford sand	0.0454	3.0831	0.0250	0.3854	2.26E-03	splitspoon	"
	130	699-35-58	39.6	0	28	68	4	0	sand (2)	Hanford sand	0.0150	4.9138	0.0250[f]	0.4163	4.42E-02	splitspoon	"
	170	699-35-58	51.8	0	52	42	6	0	sand (2)	Hanford sand	0.0226	3.5355	0.0334	0.3927	3.81E-03	splitspoon	"
	190	699-35-58	57.9	1	84	11	4	0	sand (2)	Hanford sand	0.0473	2.8261	0.0200[f]	0.4532	5.78E-03	splitspoon	"
	210	699-35-58	64.0	3	85	8	4	0	sand (2)	Hanford sand	0.0751	2.2980	0.0321	0.2724	5.42E-03	splitspoon	"
	230	699-35-58	70.1	0	77	18	5	0	sand (2)	Hanford sand	0.0393	3.1424	0.0100[f]	0.4193	5.31E-03	splitspoon	"
	270	699-35-58	82.3	0	62	23	15	0	loamy sand (1)	Hanford sand	0.0244	1.5601	0.0200[f]	0.3270	5.54E-04	splitspoon	"
	300	699-35-58	91.4	59	19	13	9	0	sandy gravel (5)	*Middle Ringold*	0.0105	1.6304	0.0123	0.1190	7.66E-04	splitspoon	"
MW-8	14.5	699-36-58B	4.4	0	78	18	4	0	sand (2)	Hanford sand	0.0425	3.1199	0.0395	0.4308	1.70E-03	splitspoon	"
	145	699-36-58B	44.2	0	2	58	40	0	sandy loam (1)	Hanford sand	0.0110	2.8937	0.0200[f]	0.4233	8.86E-04	splitspoon	"
	185	699-36-58B	56.4	22	68	7	3	0	gravelly sand (4)	Hanford sand	0.0735	2.0899	0.0288	0.3074	7.19E-03	splitspoon	"
MW-10	45	699-36-58A	13.7	1	69	20	10	0	sand (2)	Hanford sand	0.0288	2.2830	0.0382	0.3385	5.31E-03	splitspoon	"
	86	699-36-58A	26.2	0	55	38	7	0	sand (2)	Hanford sand	0.0355	2.0852	0.0314	0.3822	1.97E-02	splitspoon	"
	105	699-36-58A	32.0	1	62	24	13	0	loamy sand (1)	Hanford sand	0.0233	1.9835	0.0408	0.3267	1.73E-02	splitspoon	"
	125	699-36-58A	38.1	1	59	30	10	0	sand (2)	Hanford sand	0.0210	2.8388	0.0429	0.3638	4.39E-03	splitspoon	"
	165	699-36-58A	50.3	1	59	30	10	0	sand (2)	Hanford sand	0.0186	3.4294	0.0373	0.3233	6.63E-03	splitspoon	"
	195	699-36-58A	59.4	24	57	13	6	0	gravelly sand (4)	Hanford sand	0.0312	2.0934	0.0298	0.2621	2.65E-03	splitspoon	"
	205	699-36-58A	62.5	10	71	12	7	0	gravelly sand (4)	Hanford sand	0.0503	1.7946	0.0258	0.2969	6.63E-03	splitspoon	"
	245	699-36-58A	74.7	0	71	20	9	0	sand (2)	Hanford sand	0.0319	2.3729	0.0321	0.3686	7.39E-03	splitspoon	"
	265	699-36-58A	80.8	0	64	25	11	0	sand (1)	Hanford sand	0.0259	2.5903	0.0160[f]	0.3589	2.65E-03	splitspoon	"
	285	699-36-58A	86.9	0	64	26	10	0	sand (2)	Hanford sand	0.0282	2.6922	0.0170[f]	0.3648	3.54E-03	splitspoon	"
	300	699-36-58A	91.4	0	71	22	7	0	sand (2)	Hanford sand	0.0291	3.1582	0.0281	0.3668	4.42E-03	splitspoon	"
VOC [2,4]	3-0647	299-W18-246	42.9	0	2	78	14	6	loamy sand (1)	Plio-Pleistocene	0.0051	2.0531	0.0400[f]	0.4995	2.00E-04	splitspoon	Relyea, 1995
	3-0648	299-W18-246	59.6	62	18	20	0	0	sandy gravel (5)	Middle Ringold	0.0124	1.6450	0.0000	0.1462	8.70E-03	splitspoon	

	3-0649	299-W18-247	41.1	0	10	38	40	12	loam (1)	Plio-Peistocene	0.0010	1.7024	0.0600[f]	0.5331	N/A	splitspoon	"
	3-0650	299-W18-247	45.1	0	46	28	15	11	sandy loam (1)	Plio-Peistocene	0.0120	1.5539	0.2412	0.6306	2.60E-07	splitspoon	"
	3-0651	299-W18-247	46.9	0	58	24	9	9	loamy sand (1)	Plio-Peistocene	0.0286	1.9721	0.1006	0.3728	9.40E-03	splitspoon	"
	3-0652	299-W18-248	38.4	0	40	52	4	4	sand (2)	Hanford Sand	0.0092	1.8848	0.0300[f]	0.3586	3.70E-04	splitspoon	"
	3-0653	299-W18-248	42.5	0	24	54	14	8	loamy sand (1)	Plio-Peistocene	0.0067	1.8378	0.1096	0.4223	5.80E-06	splitspoon	"
	3-0654	299-W15-216	35.6	59	30	3	4	4	sandy gravel (5)	Plio-Peistocene	0.0119	1.2618	0.0186	0.1933	2.70E-04	splitspoon	"
	3-0655	299-W15-216	36.9	34	28	8	24	6	silty sandy gravel (3)	Upper Ringold	0.0029	1.6285	0.0559	0.2625	1.58E-04	splitspoon	"
	3-0656	299-W15-216	39.0	42	40	18	0	0	sandy gravel (5)	Middle Ringold	0.0166	1.3941	0.0090	0.1814	1.36E-02	splitspoon	"
	3-0657	299-W15-217	37.4	34	38	10	10	8	silty sandy gravel (3)	Hanford Sand	0.0145	1.3692	0.0469	0.2505	2.67E-04	splitspoon	"
W-049-H[2,4]	2-2865	699-42-37	38.7	0	22	58	14	6	loamy sand (1)	Lower Ringold	0.0038	2.0069	0.1612	0.5868	2.30E-06	splitspoon	Delaney, 1992
	2-3084	699-41-39	24.7	82	14	4	0	0	sandy gravel (6)	Upper Ringold	0.0097	1.5700	0.0125	0.0579	1.30E-01	splitspoon	
	2-3085	699-41-35	31.5	0	55	25	10	10	sandy loam (1)	Lower Ringold	0.0142	1.2598	0.2705	0.6772	1.40E-08	splitspoon	"
	2-3088	699-42-37	4.6	65	20	12	3	0	sandy gravel (6)	Hanford Gravels	0.0038	1.5977	0.0197	0.1071	1.30E-03	splitspoon	"
	2-3089	699-42-37	28.3	0	35	30	27	8	sandy loam (1)	Hanford sand	0.0035	1.3657	0.1808	0.5336	3.20E-07	splitspoon	"
	3-0001	699-40-36	29.3	68	19	6	7	0	sandy gravel (5)	Hanford Gravels	0.0095	1.5556	0.0156	0.1128	1.82E-04	splitspoon	"
	3-0003	699-40-36	65.8	65	21	14	0	0	sandy gravel (5)	Basal Ringold	0.0054	1.4011	0.0538	0.1953	6.30E-07	splitspoon	"

[f] signifies that the residual moisture content has been fixed to improve the curve fit through the measured data

[#] soil category :

(1) - SS, sand mixed with finer fraction
(2) - S, sand
(3) - SSG, sand and gravel mixed with finer fraction
(4) - GS, gravelly sand
(5) - SG1, sandy gravel with gravel content approximately <60%
(6) - SG2, sandy gravel with gravel content approximately >60%

1 - K_s measured by falling head permeameter
2 - K_s measured by constant head permeameter

Moisture Retention Data Measurements

3 - 0 to -60 cm, hanging water column; -100 to -15300 cm, pressure plate extraction (Klute 1986)
4 - 0 to -1000 cm, Tempe cell; -500 to -15300 cm, pressure plate extraction
5 - 0 to -150 cm, hanging water column; -310 to -15300 cm, pressure plate extraction; <-15300 cm, thermocouple psychrometer (Rawlins and Campbell 1986)
6 - 0 to -1000 cm, Tempe cell; -500 to -10000 cm, pressure plate extraction; < -10000 cm, thermocouple psychrometer

APPENDIX B

MOISTURE RETENTION DATA AND FITTED PARAMETERS FOR 183 SOIL SAMPLES

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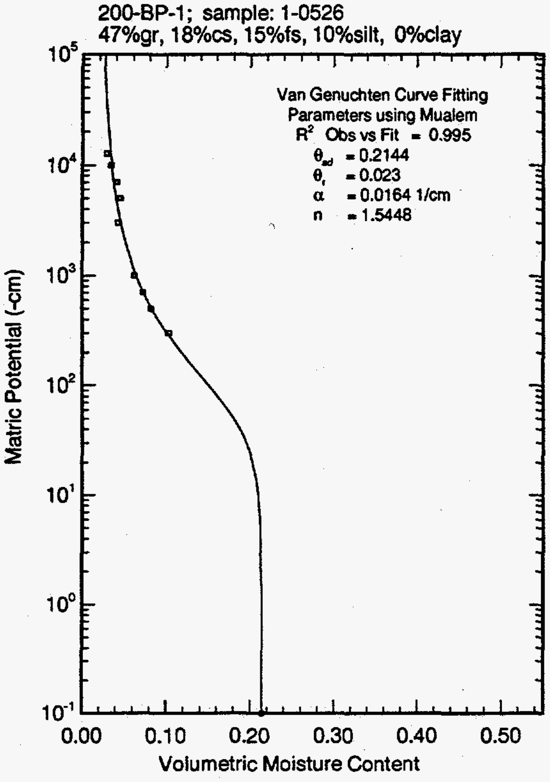
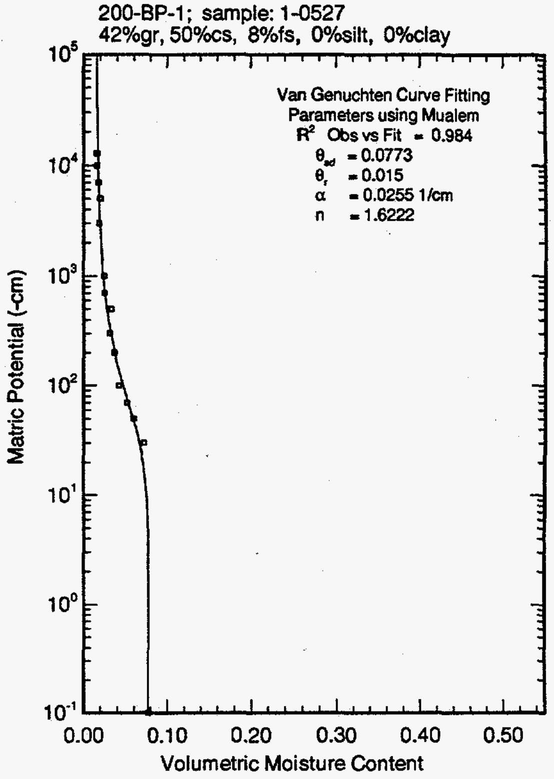
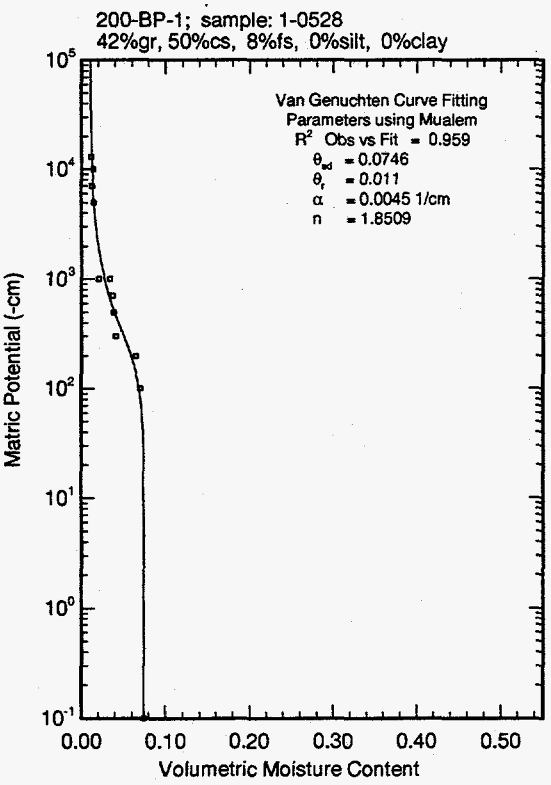
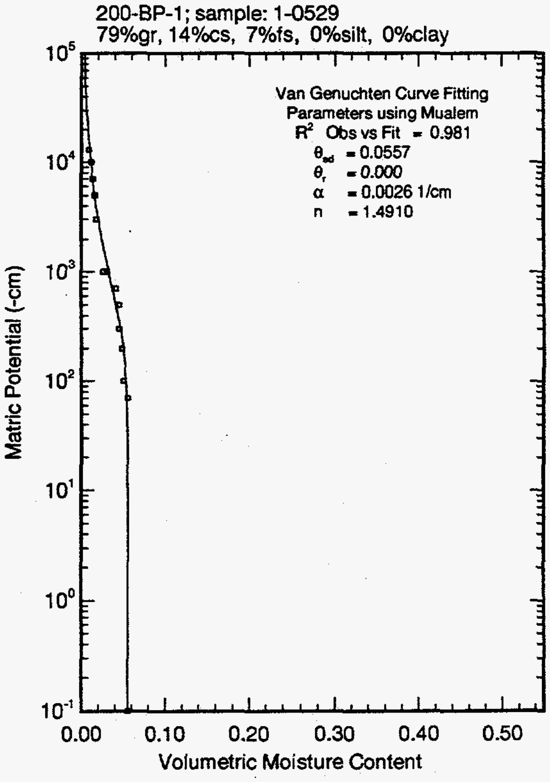
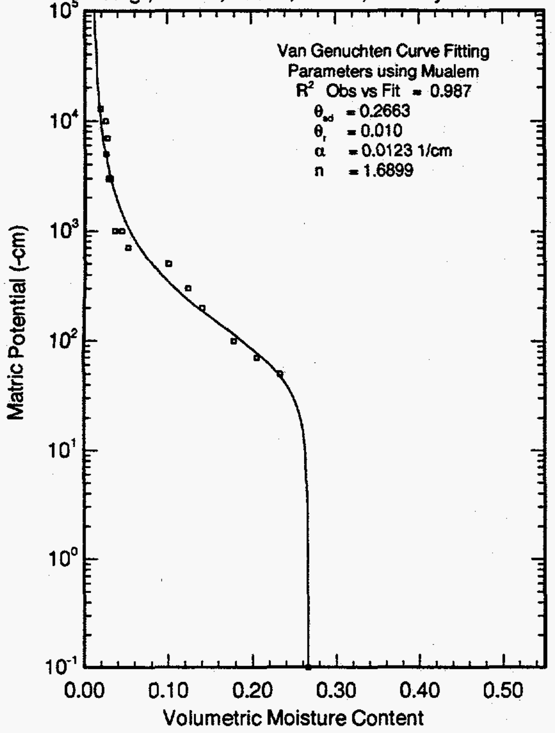
APPENDIX B

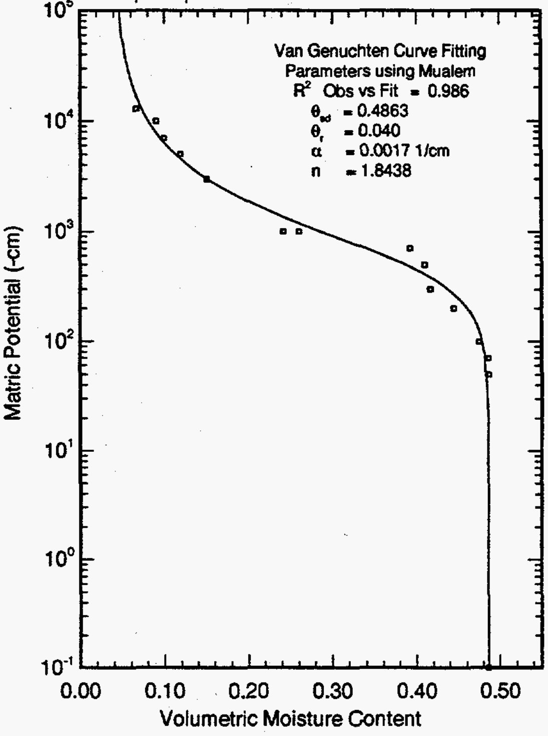

200-BP-1; sample: 1-0526
47%gr, 18%cs, 15%fs, 10%silt, 0%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R^2 Obs vs Fit = 0.995
θ_{sd} = 0.2144
θ_r = 0.023
α = 0.0164 1/cm
n = 1.5448
Matric Potential (-cm)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content

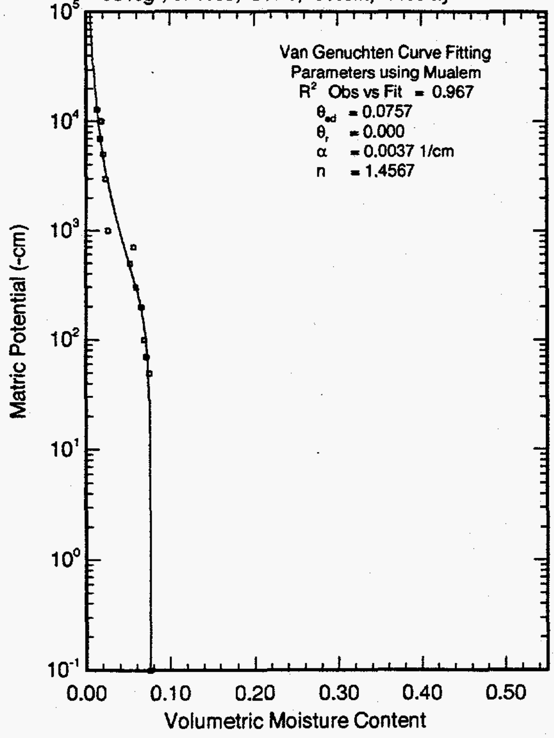

200-BP-1; sample: 1-0527
42%gr, 50%cs, 8%fs, 0%silt, 0%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R^2 Obs vs Fit = 0.984
θ_{sd} = 0.0773
θ_r = 0.015
α = 0.0255 1/cm
n = 1.6222
Matric Potential (-cm)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content

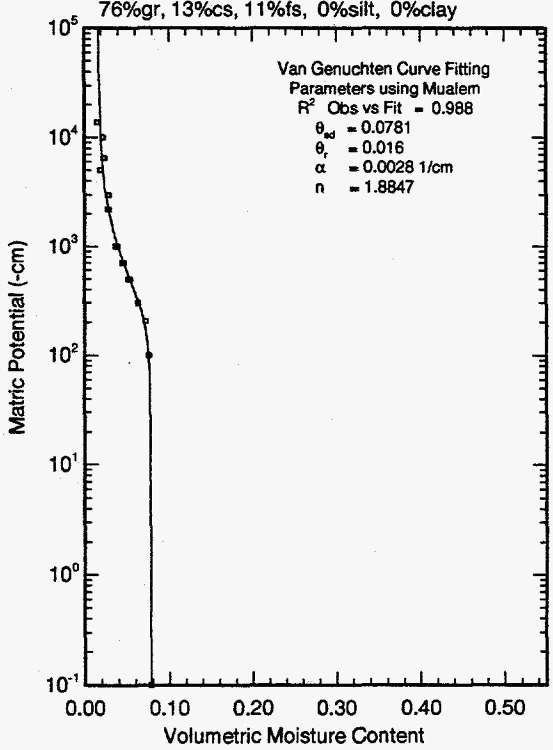

200-BP-1; sample: 1-0528
42%gr, 50%cs, 8%fs, 0%silt, 0%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R^2 Obs vs Fit = 0.959
θ_{sd} = 0.0746
θ_r = 0.011
α = 0.0045 1/cm
n = 1.8509
Matric Potential (-cm)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content

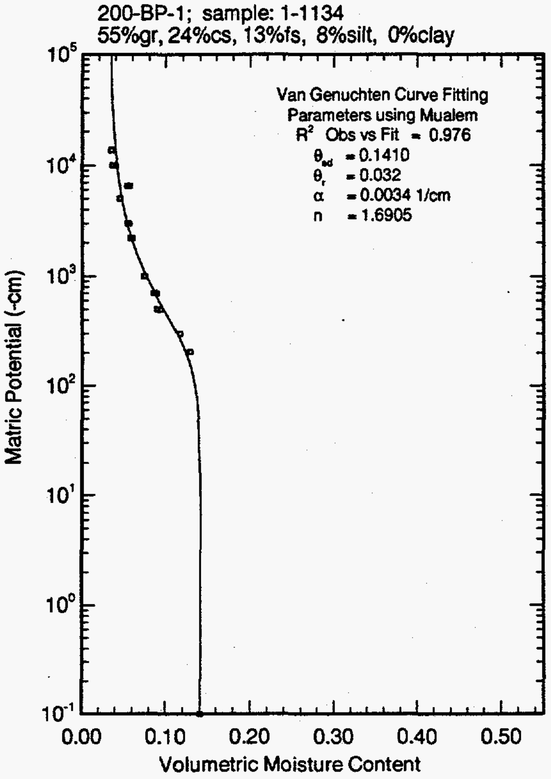

200-BP-1; sample: 1-0529
79%gr, 14%cs, 7%fs, 0%silt, 0%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R^2 Obs vs Fit = 0.981
θ_{sd} = 0.0557
θ_r = 0.000
α = 0.0026 1/cm
n = 1.4910
Matric Potential (-cm)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content

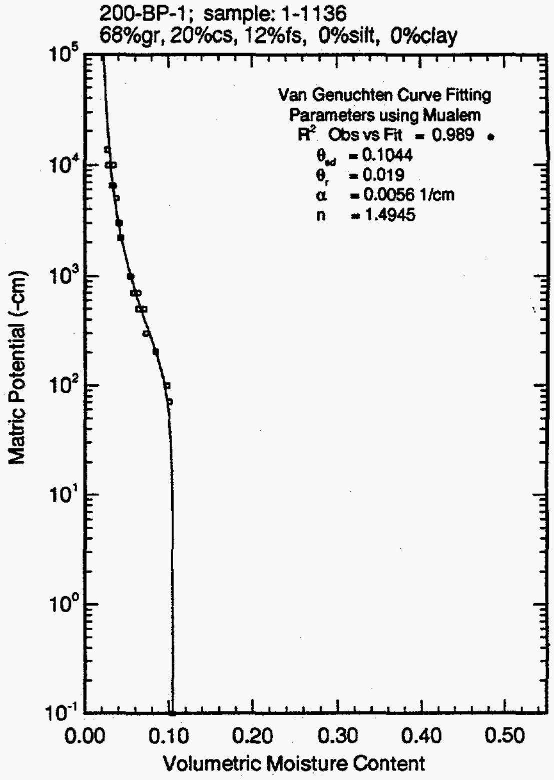

200-BP-1; sample: 1-0530
0%gr, 60%cs, 35%fs, 5%silt, 0%clay

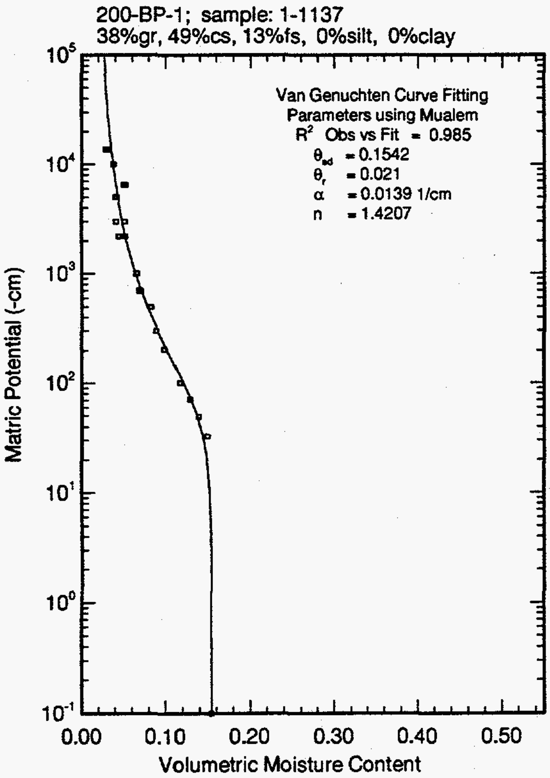

200-BP-1; sample: 1-0531
complete particle size distribution not available

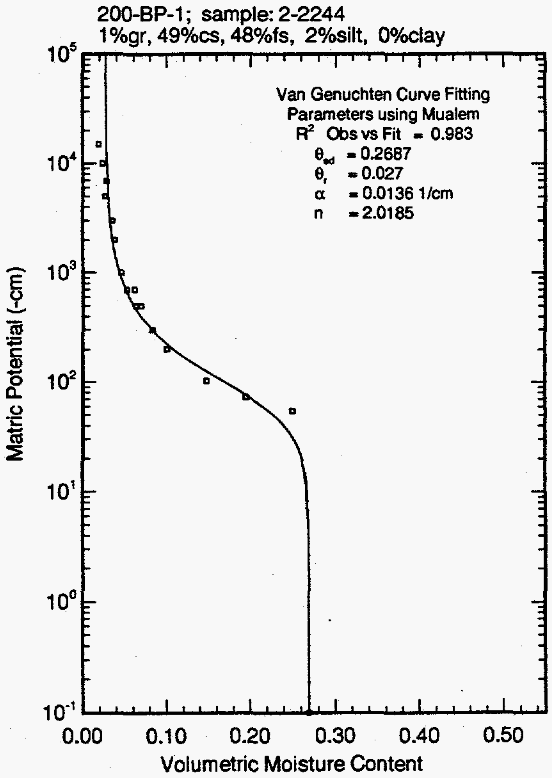

200-BP-1; sample: 1-0550
63%gr, 32%cs, 5%fs, 0%silt, 0%clay

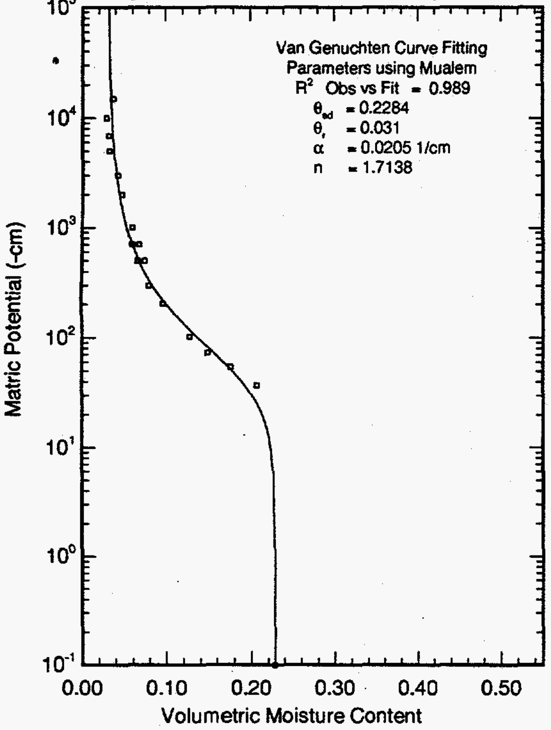

200-BP-1; sample: 1-1133
76%gr, 13%cs, 11%fs, 0%silt, 0%clay

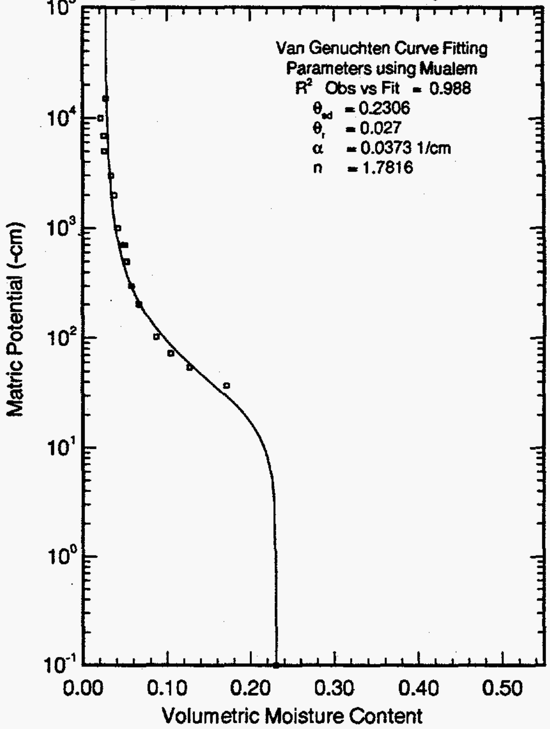

200-BP-1; sample: 1-1134
55%gr, 24%cs, 13%fs, 8%silt, 0%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R^2 Obs vs Fit = 0.976
θ_{sd} = 0.1410
θ_r = 0.032
α = 0.0034 1/cm
n = 1.6905
Matric Potential (-cm)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content

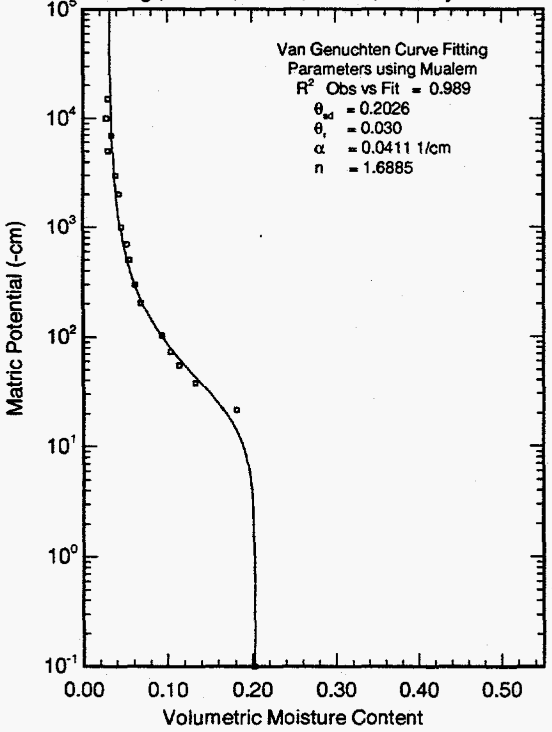

200-BP-1; sample: 1-1136
68%gr, 20%cs, 12%fs, 0%silt, 0%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R^2 Obs vs Fit = 0.989
θ_{sd} = 0.1044
θ_r = 0.019
α = 0.0056 1/cm
n = 1.4945
Matric Potential (-cm)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content

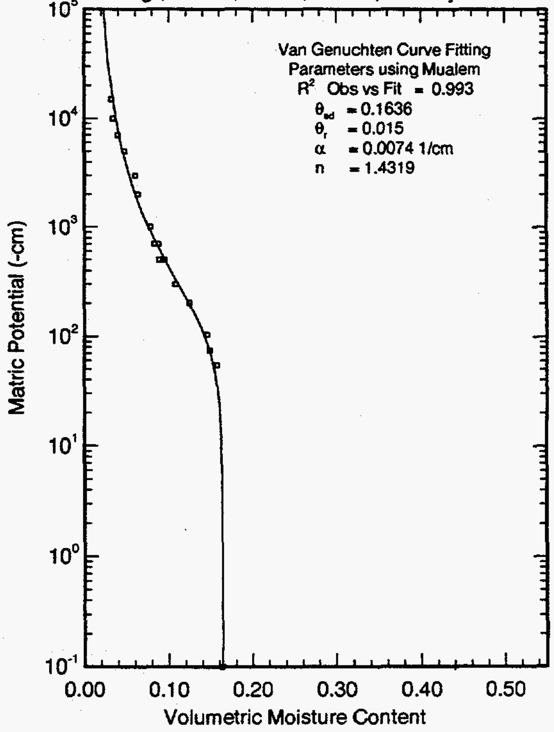

200-BP-1; sample: 1-1137
38%gr, 49%cs, 13%fs, 0%silt, 0%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R^2 Obs vs Fit = 0.985
θ_{sd} = 0.1542
θ_r = 0.021
α = 0.0139 1/cm
n = 1.4207
Matric Potential (-cm)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content


200-BP-1; sample: 2-2244
1%gr, 49%cs, 48%fs, 2%silt, 0%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R^2 Obs vs Fit = 0.983
θ_{sd} = 0.2687
θ_r = 0.027
α = 0.0136 1/cm
n = 2.0185
Matric Potential (-cm)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content

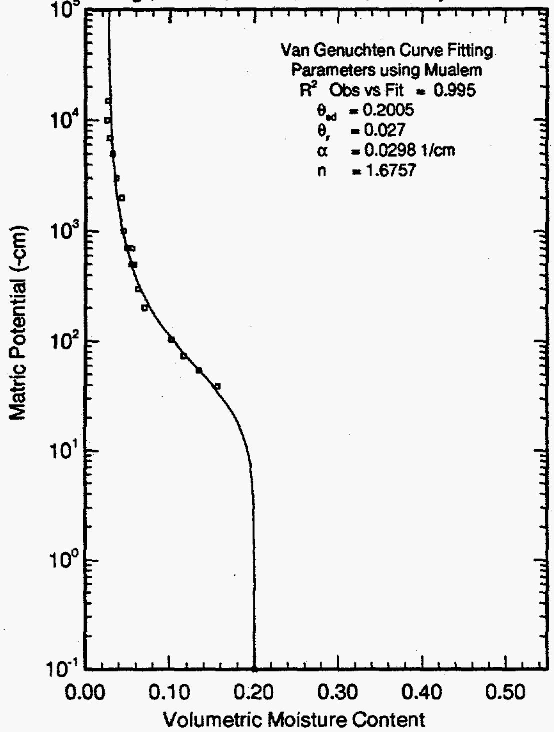

200-BP-1; sample: 2-2253
2%gr, 85%cs, 13%fs, 0%silt, 0%clay


200-BP-1; sample: 2-2258
1%gr, 84%cs, 15%fs, 0%silt, 0%clay

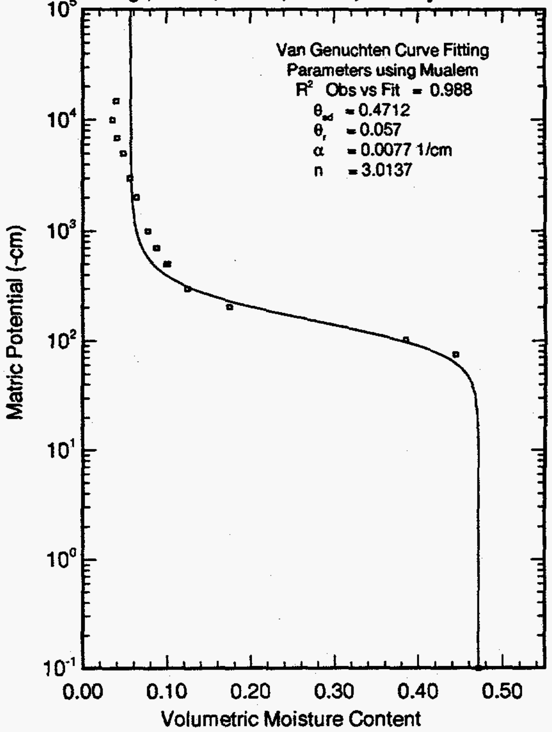

200-BP-1; sample: 2-2261
12%gr, 76%cs, 12%fs, 0%silt, 0%clay


200-BP-1; sample: 2-2271
50%gr, 28%cs, 14%fs, 6%silt, 2%clay

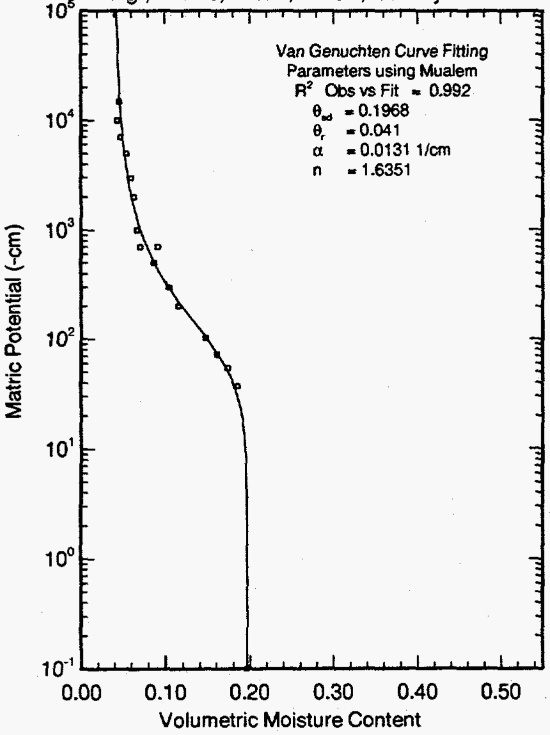
200-BP-1; sample: 2-2283
6%gr, 83%cs, 11%fs, 0%silt, 0%clay



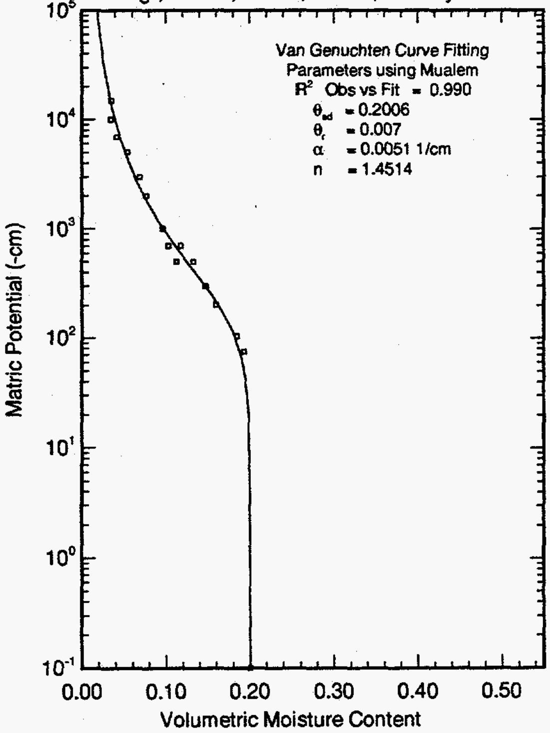
200-BP-1; sample: 2-2286
0%gr, 4%cs, 92%fs, 3%silt, 1%clay

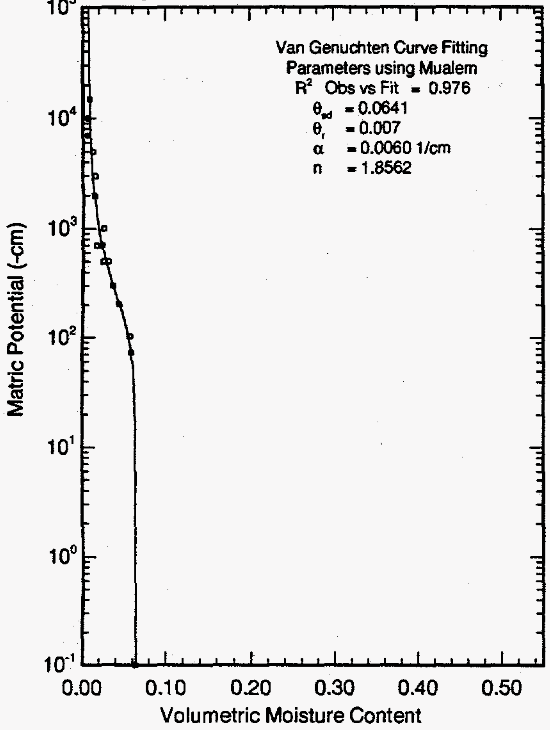


200-BP-1; sample: 2-2289
4%gr, 84%cs, 12%fs, 0%silt, 0%clay

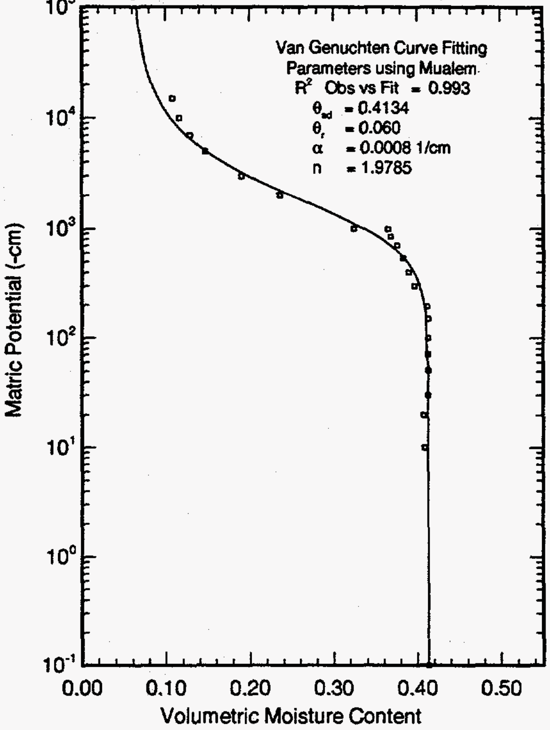


200-BP-1; sample: 2-2294
39%gr, 33%cs, 17%fs, 7%silt, 4%clay

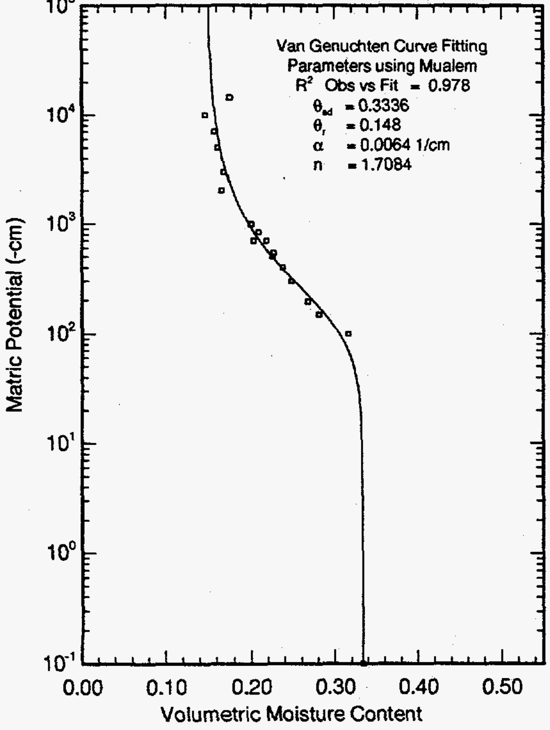




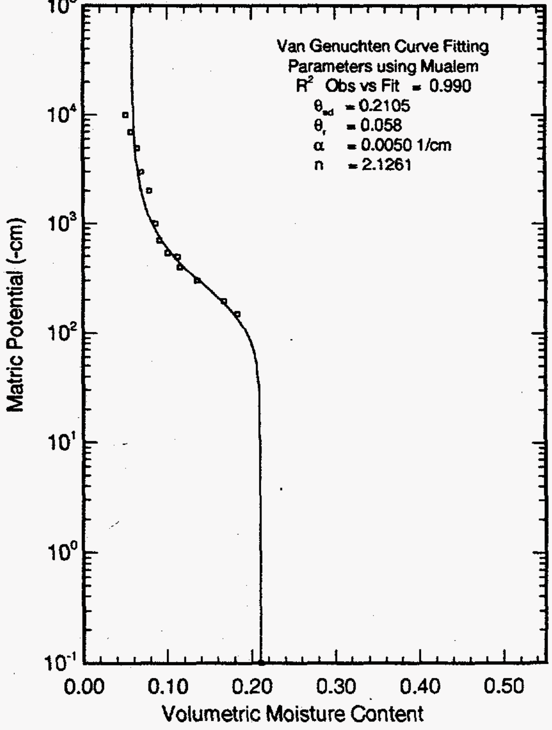
200-BP-1; sample: 2-2297
80%gr, 20%cs, 0%fs, 0%silt, 0%clay



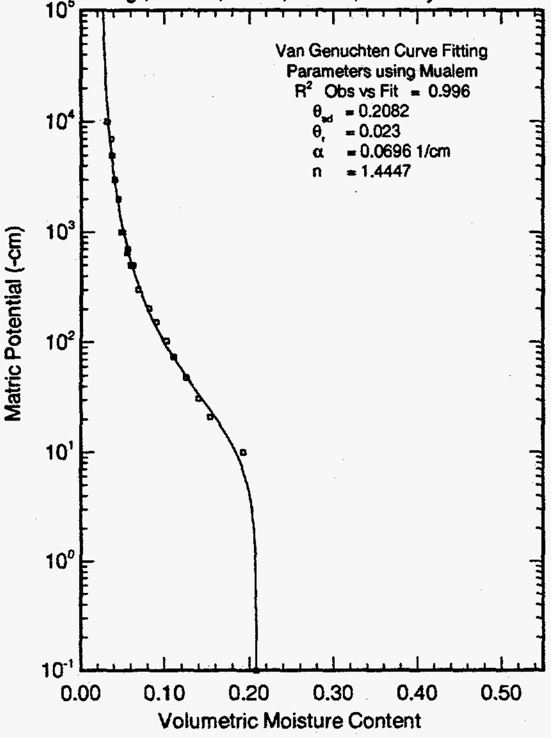
218-W-5; sample: 0-073
0%gr, 27%cs, 54%fs, 10%silt, 9%clay



218-W-5; sample: 0-082
2%gr, 38%cs, 47%fs, 8%silt, 5%clay

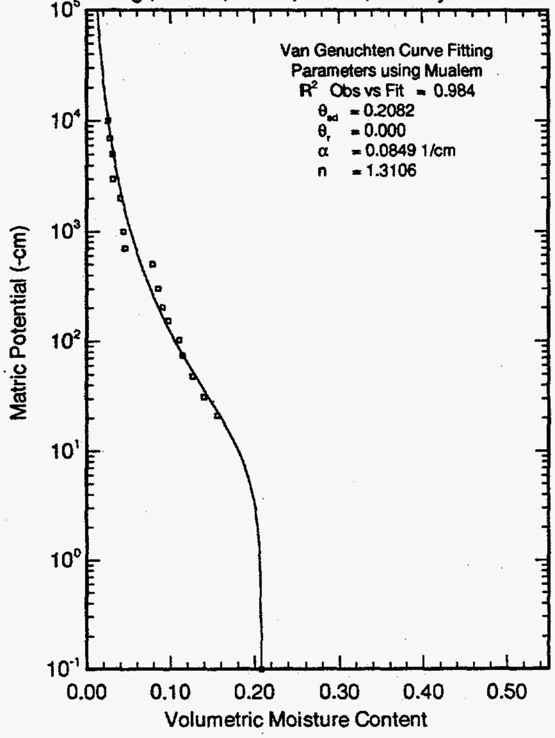


218-W-5; sample: 0-085
0%gr, 50%cs, 37%fs, 5%silt, 8%clay



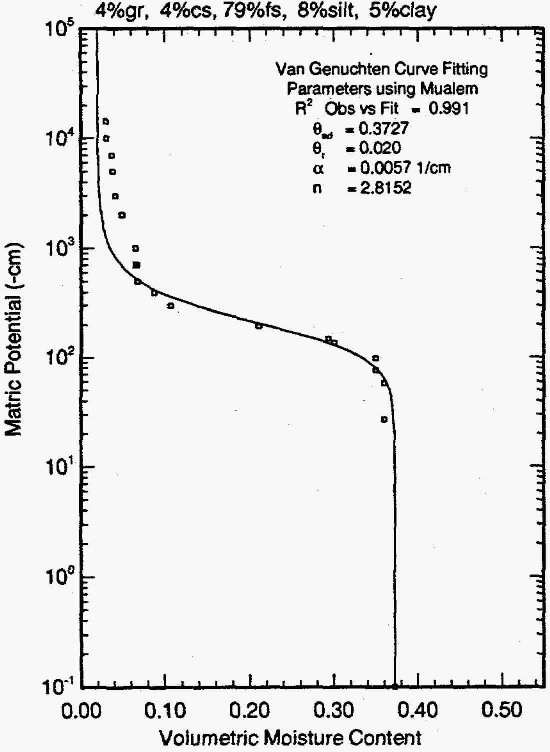
218-W-5; sample: 0-101

0%gr, 85%cs, 8%fs, 2%silt, 5%clay



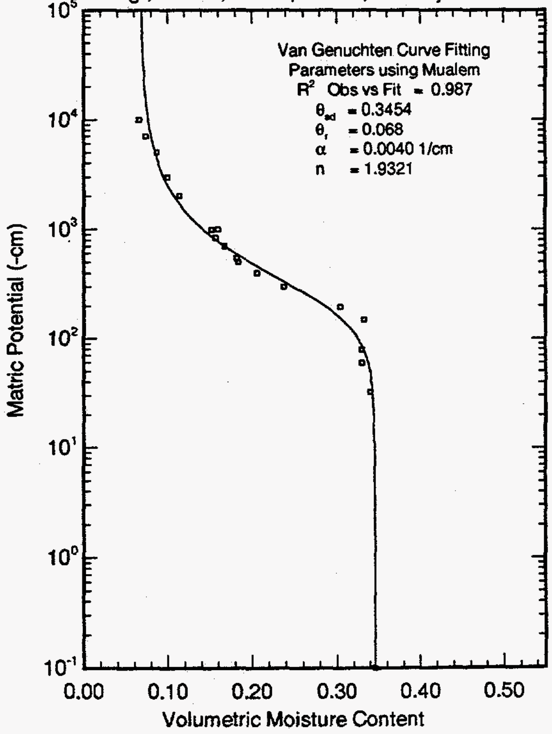
218-W-5; sample: 0-104

0%gr, 72%cs, 24%fs, 3%silt, 1%clay



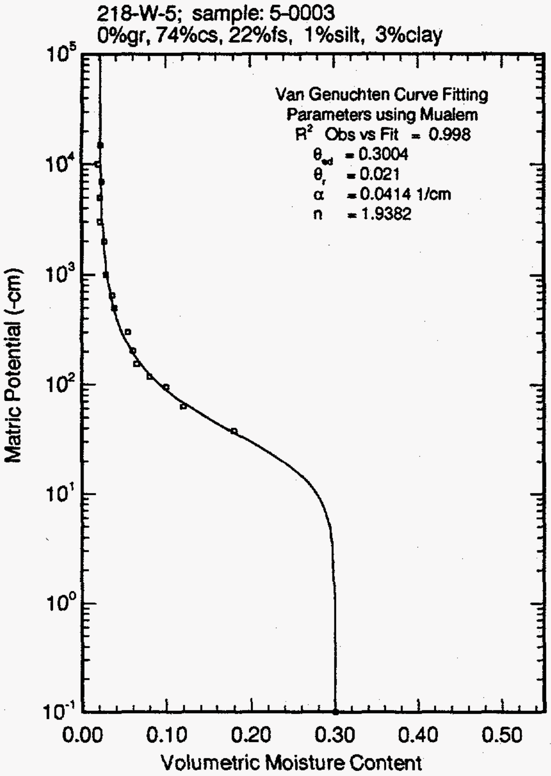
218-W-5; sample: 5-0001

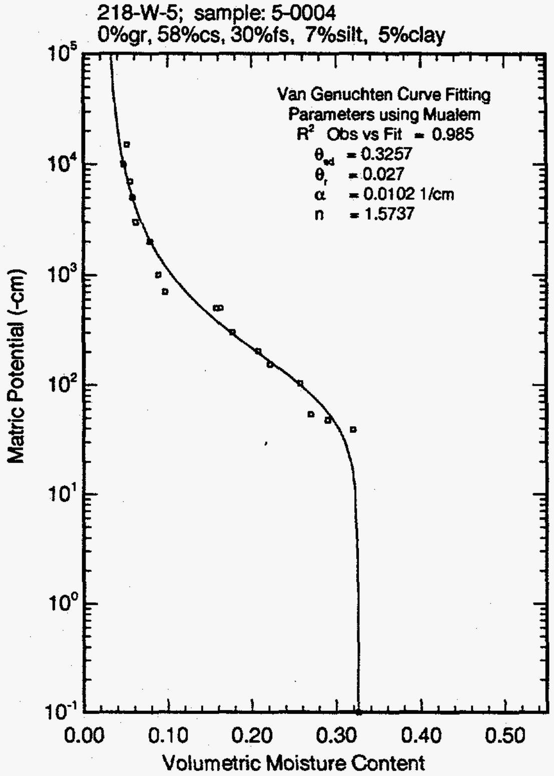
4%gr, 4%cs, 79%fs, 8%silt, 5%clay

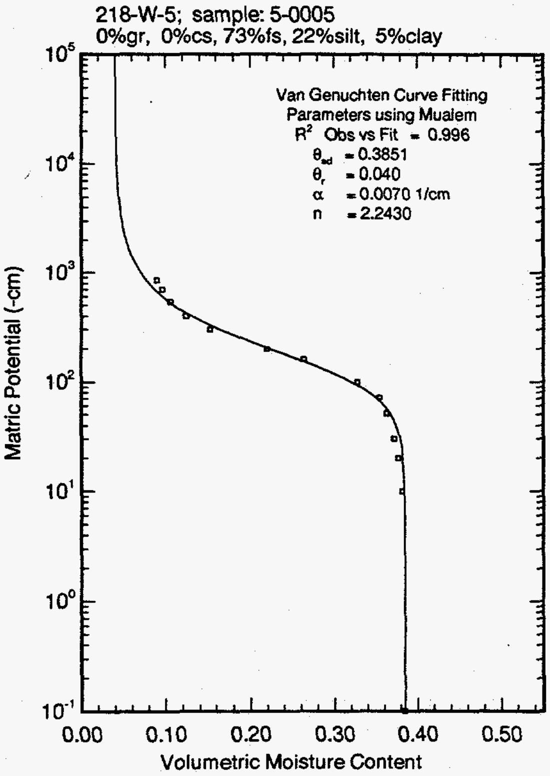


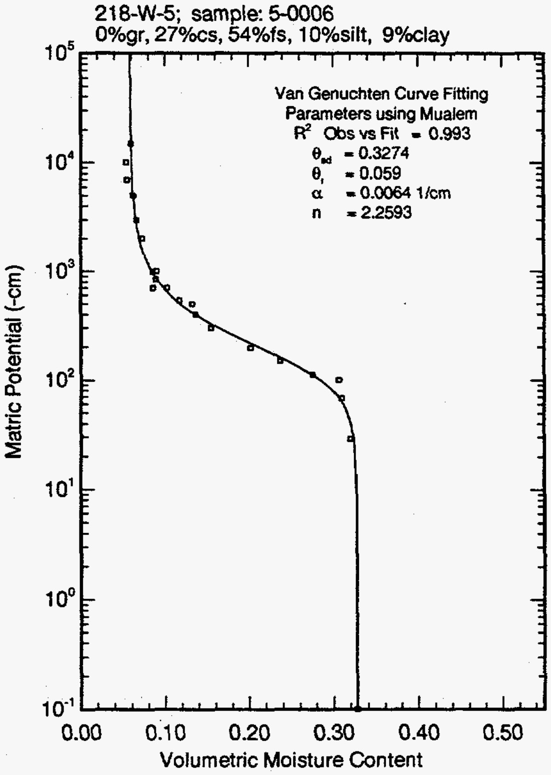
218-W-5; sample: 5-0002

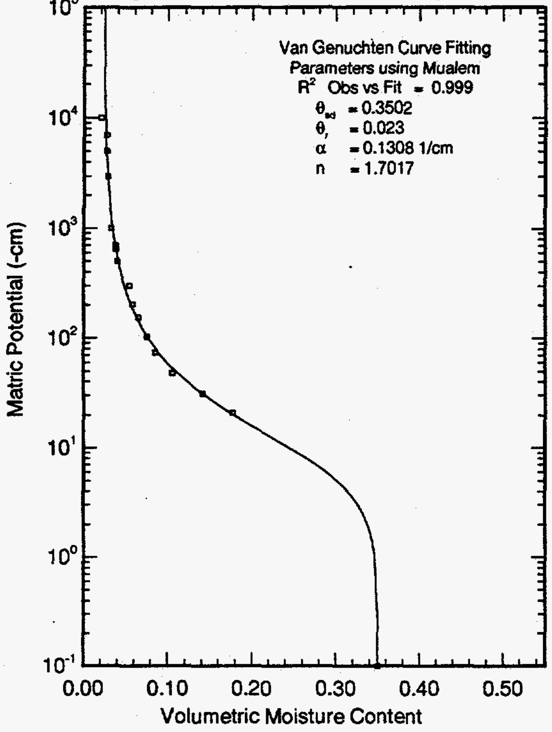
2%gr, 38%cs, 47%fs, 8%silt, 5%clay


218-W-5; sample: 5-0003
0%gr, 74%cs, 22%fs, 1%silt, 3%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R^2 Obs vs Fit = 0.998
θ_{sd} = 0.3004
θ_r = 0.021
α = 0.0414 1/cm
n = 1.9382
Matric Potential (-cm)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content

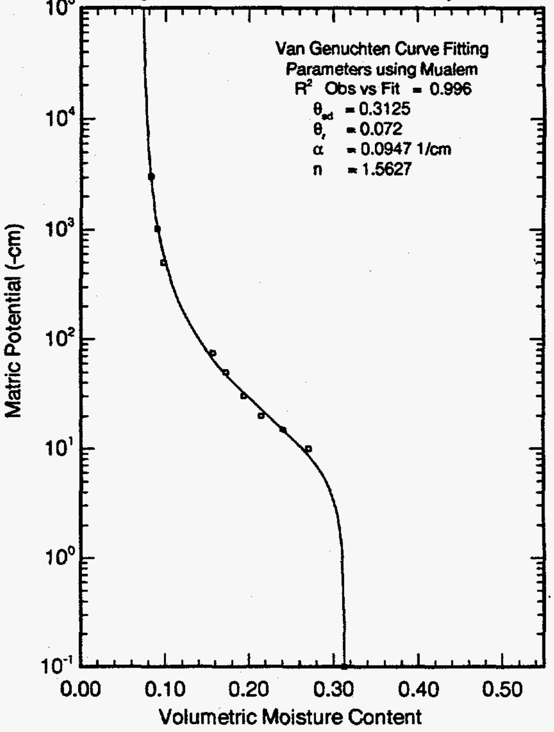

218-W-5; sample: 5-0004
0%gr, 58%cs, 30%fs, 7%silt, 5%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R^2 Obs vs Fit = 0.985
θ_{sd} = 0.3257
θ_r = 0.027
α = 0.0102 1/cm
n = 1.5737
Matric Potential (-cm)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content


218-W-5; sample: 5-0005
0%gr, 0%cs, 73%fs, 22%silt, 5%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R^2 Obs vs Fit = 0.996
θ_{sd} = 0.3851
θ_r = 0.040
α = 0.0070 1/cm
n = 2.2430
Matric Potential (-cm)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content

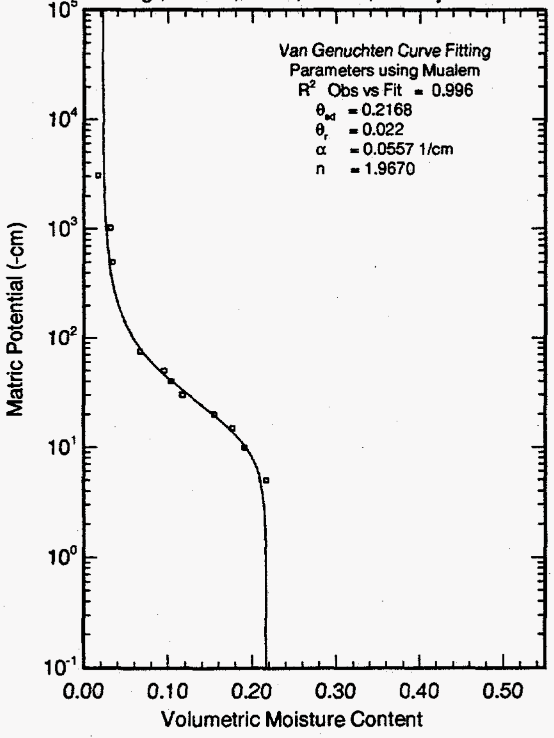

218-W-5; sample: 5-0006
0%gr, 27%cs, 54%fs, 10%silt, 9%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R^2 Obs vs Fit = 0.993
θ_{sd} = 0.3274
θ_r = 0.059
α = 0.0064 1/cm
n = 2.2593
Matric Potential (-cm)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content



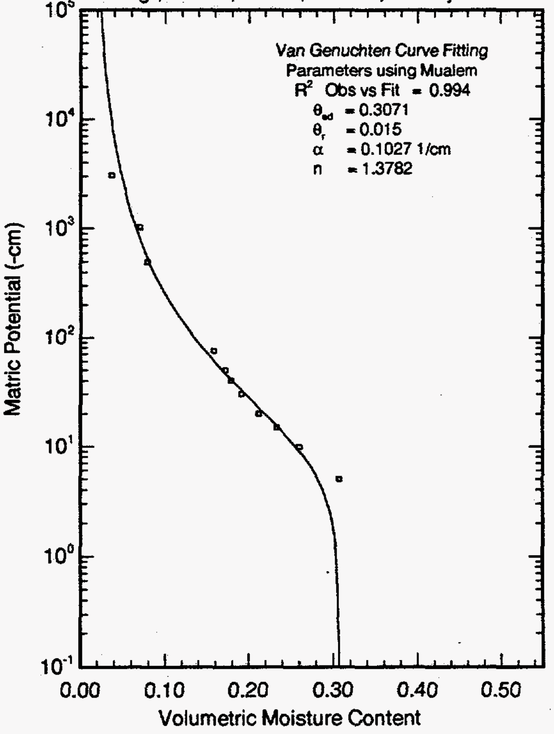
218-W-5; sample: 5-0007
0%gr, 80%cs, 13%fs, 5%silt, 2%clay



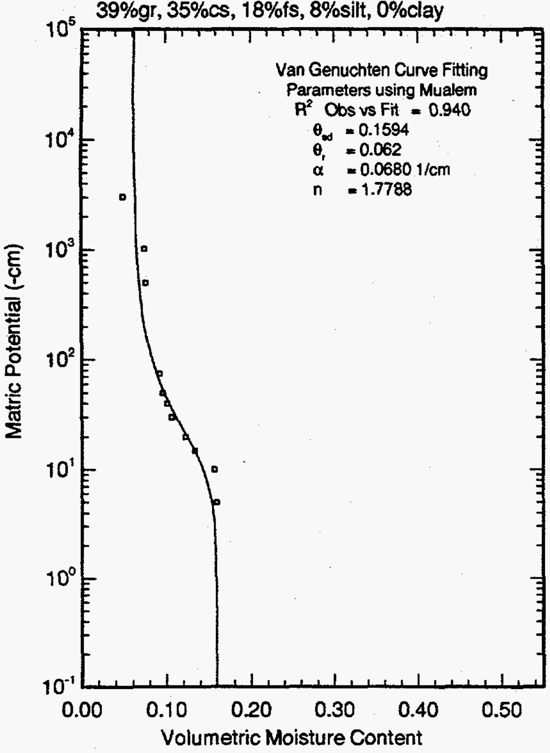
218-W-5; sample: w7-2-65
35%gr, 38%cs, 11%fs, 16%silt, 0%clay



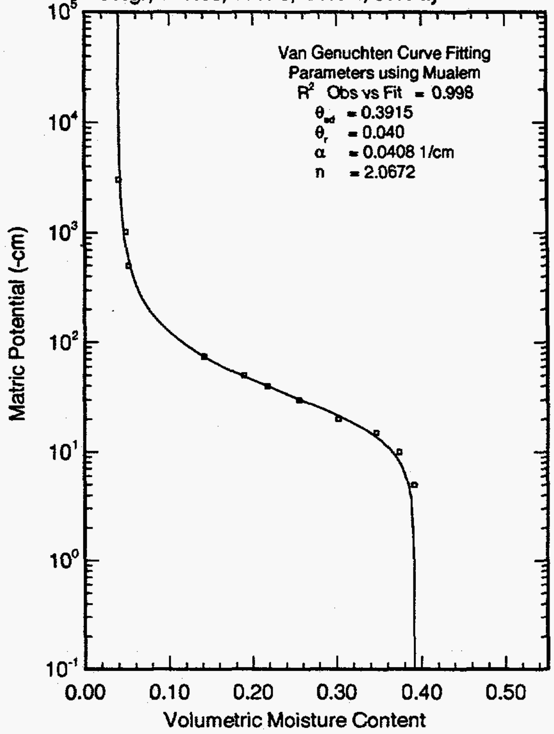
218-W-5; sample: w7-2-94
48%gr, 39%cs, 7%fs, 6%silt, 0%clay



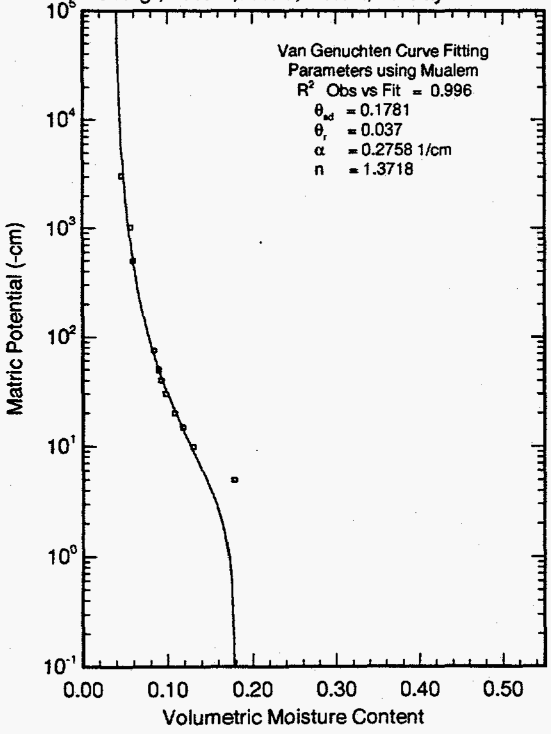
218-W-5; sample: w7-2-154
32%gr, 36%cs, 15%fs, 17%silt, 0%clay



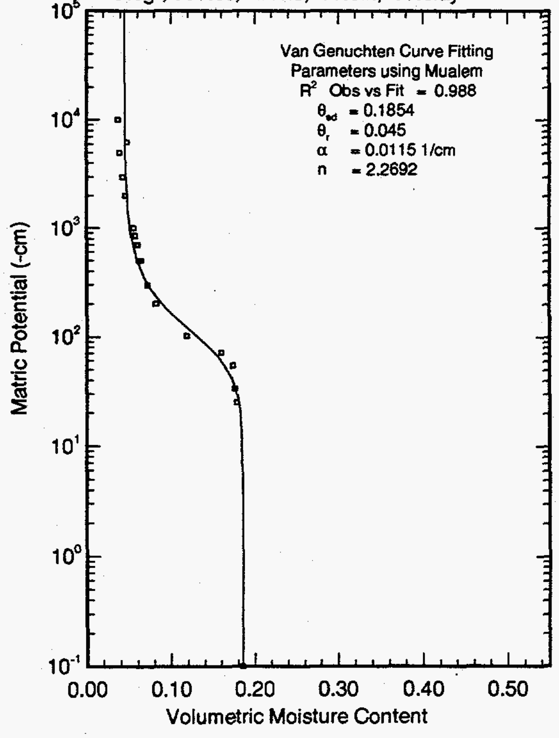
218-W-5; sample: w7-2-219
39%gr, 35%cs, 18%fs, 8%silt, 0%clay



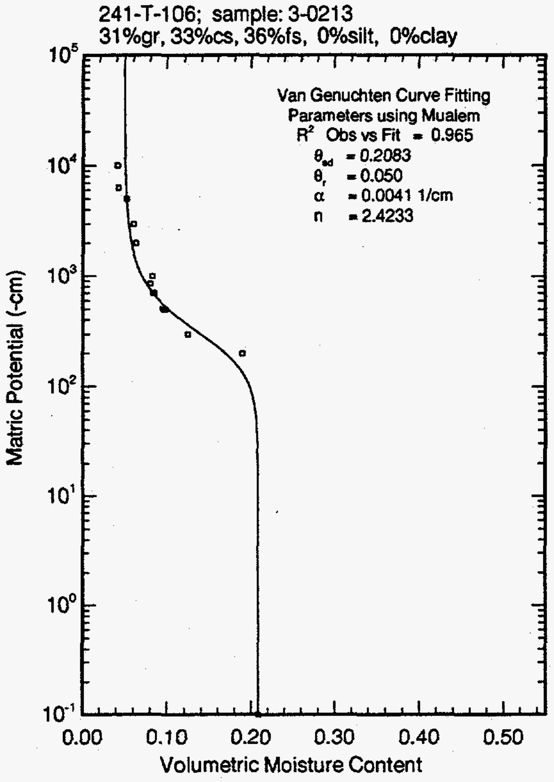
218-W-5; sample: w10-13-45
0%gr, 62%cs, 33%fs, 5%silt, 0%clay

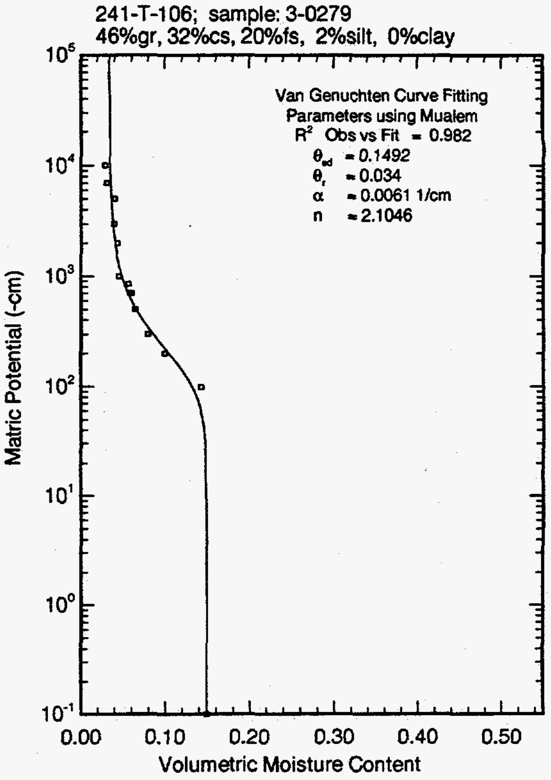


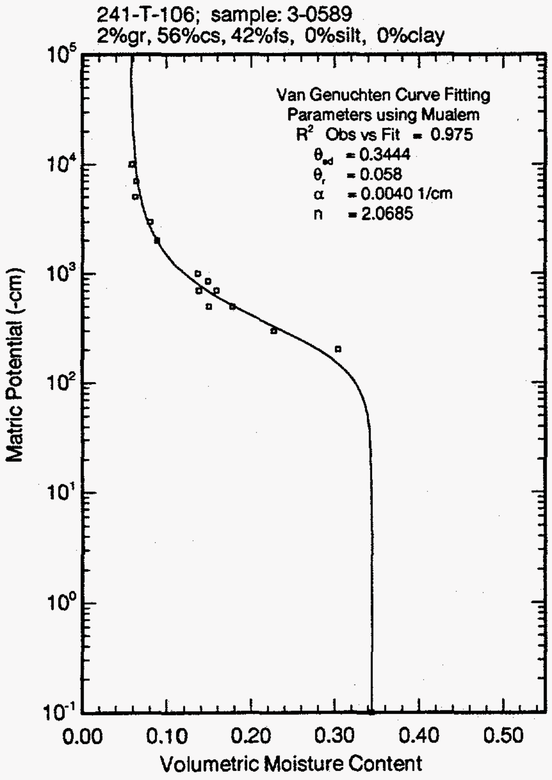
218-W-5; sample: w10-13-80
64%gr, 25%cs, 6%fs, 5%silt, 0%clay

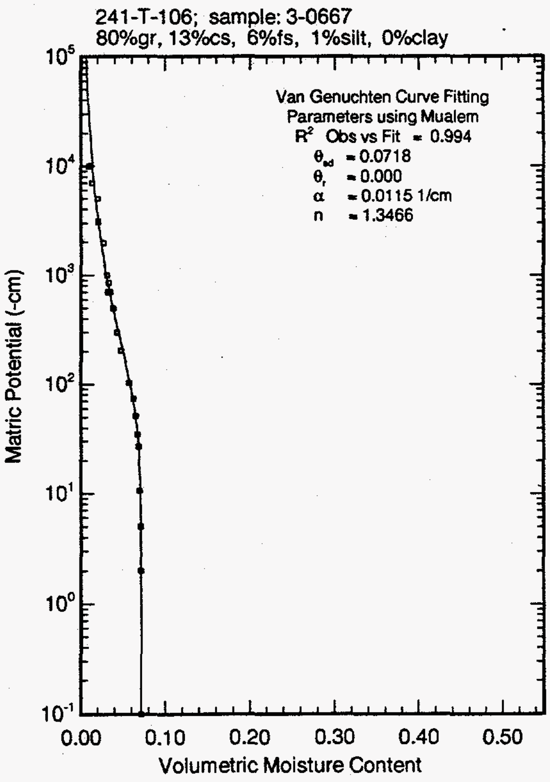


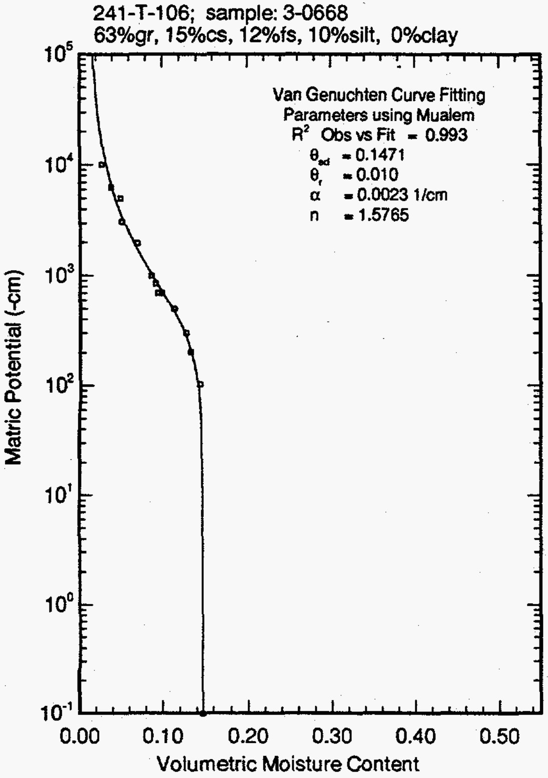
241-T-106; sample: 3-0210
48%gr, 30%cs, 22%fs, 0%silt, 0%clay

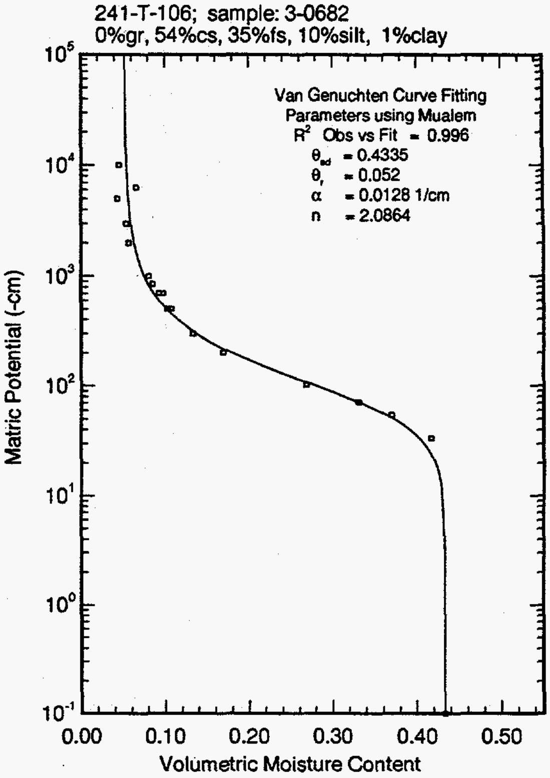

241-T-106; sample: 3-0213
31%gr, 33%cs, 36%fs, 0%silt, 0%clay

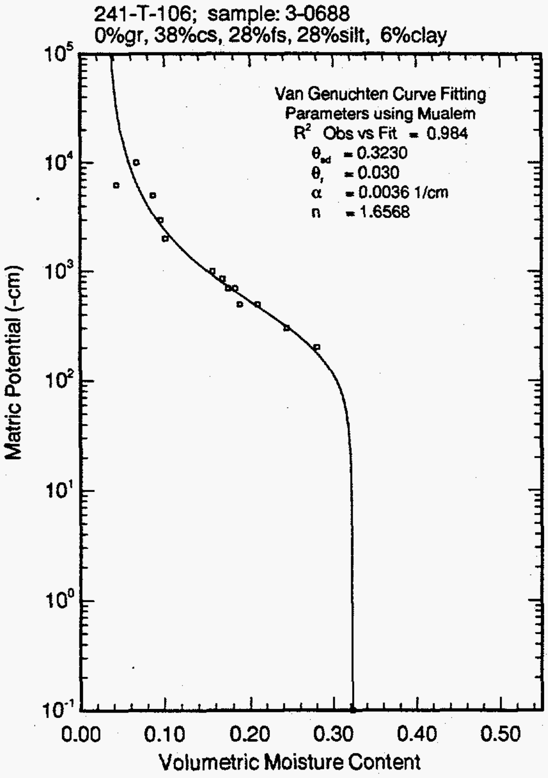

241-T-106; sample: 3-0279
46%gr, 32%cs, 20%fs, 2%silt, 0%clay

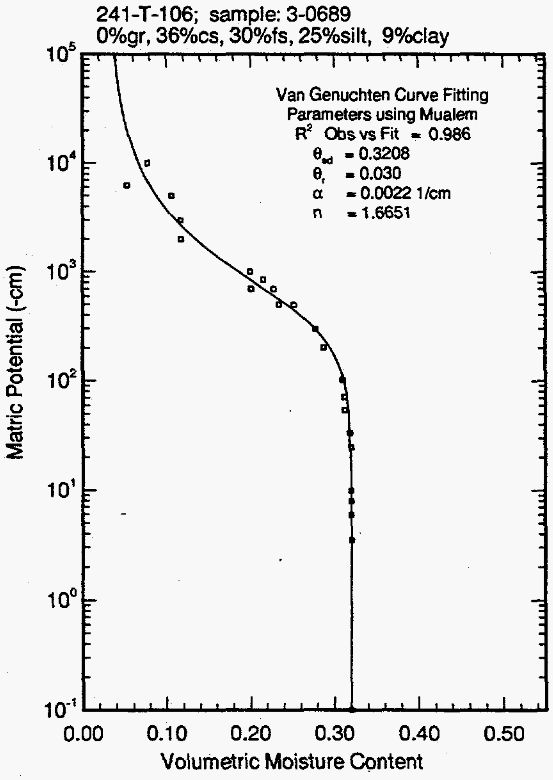

241-T-106; sample: 3-0589
2%gr, 56%cs, 42%fs, 0%silt, 0%clay


241-T-106; sample: 3-0667
80%gr, 13%cs, 6%fs, 1%silt, 0%clay

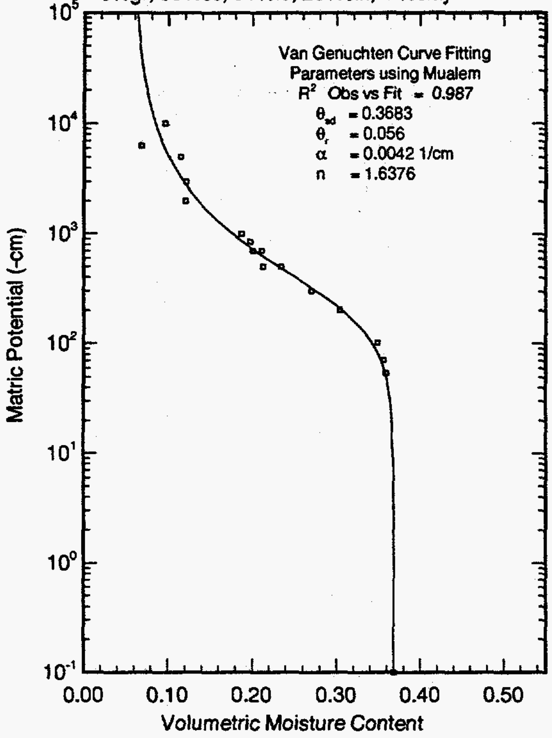

241-T-106; sample: 3-0668
63%gr, 15%cs, 12%fs, 10%silt, 0%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R^2 Obs vs Fit = 0.993
θ_{sd} = 0.1471
θ_r = 0.010
α = 0.0023 1/cm
n = 1.5765
Matric Potential (-cm)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content


241-T-106; sample: 3-0682
0%gr, 54%cs, 35%fs, 10%silt, 1%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R^2 Obs vs Fit = 0.996
θ_{sd} = 0.4335
θ_r = 0.052
α = 0.0128 1/cm
n = 2.0864
Matric Potential (-cm)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content

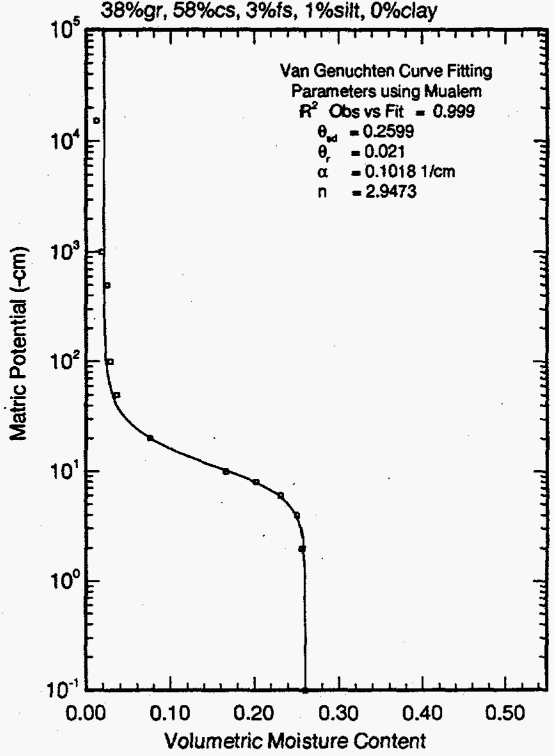

241-T-106; sample: 3-0688
0%gr, 38%cs, 28%fs, 28%silt, 6%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R^2 Obs vs Fit = 0.984
θ_{sd} = 0.3230
θ_r = 0.030
α = 0.0036 1/cm
n = 1.6568
Matric Potential (-cm)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content


241-T-106; sample: 3-0689
0%gr, 36%cs, 30%fs, 25%silt, 9%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R^2 Obs vs Fit = 0.986
θ_{sd} = 0.3208
θ_r = 0.030
α = 0.0022 1/cm
n = 1.6651
Matric Potential (-cm)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content

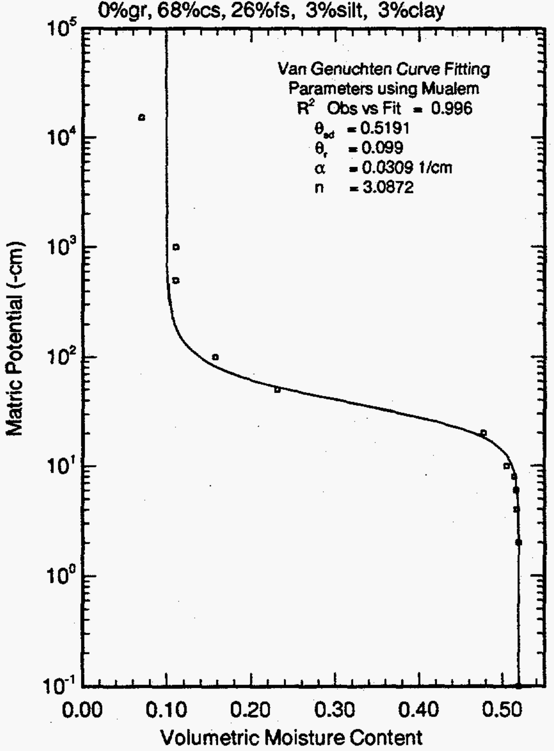
241-T-106; sample: 3-0690
0%gr, 39%cs, 31%fs, 23%silt, 7%clay



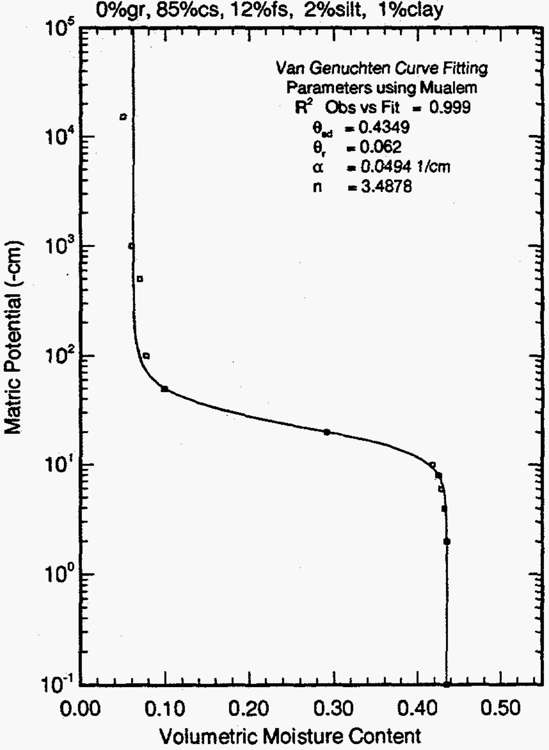
APTANK; sample: 241-AP1G
38%gr, 58%cs, 3%fs, 1%silt, 0%clay



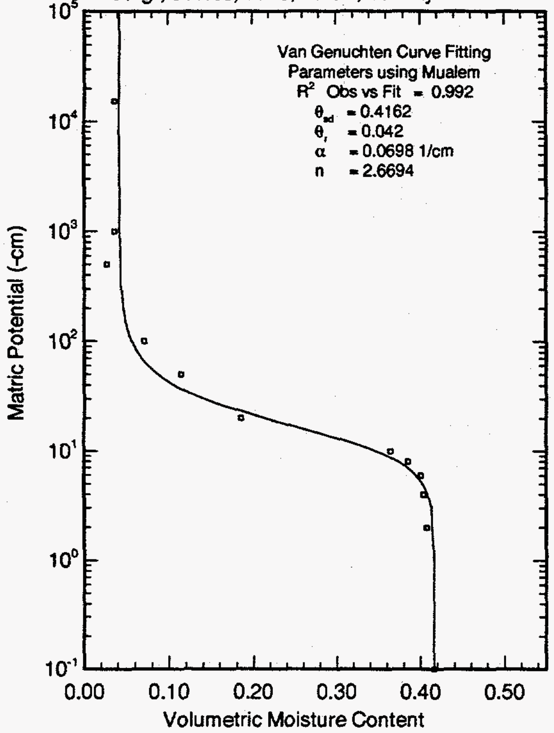
APTANK; sample: 241-AP2
0%gr, 68%cs, 26%fs, 3%silt, 3%clay



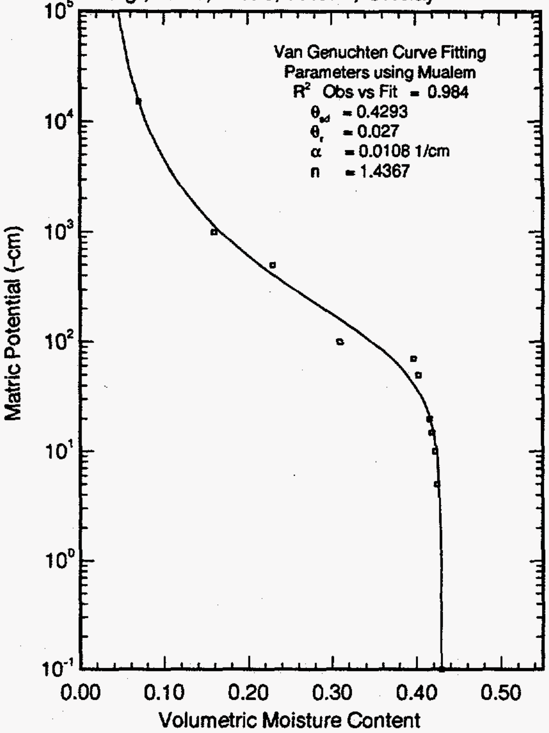
APTANK; sample: 241-AP3
0%gr, 85%cs, 12%fs, 2%silt, 1%clay



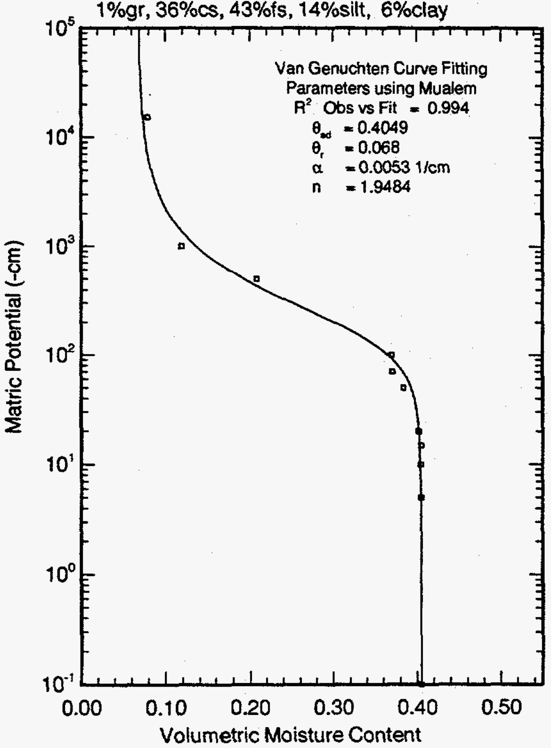
APTANK; sample: 241-AP4G
10%gr, 83%cs, 5%fs, 2%silt, 0%clay



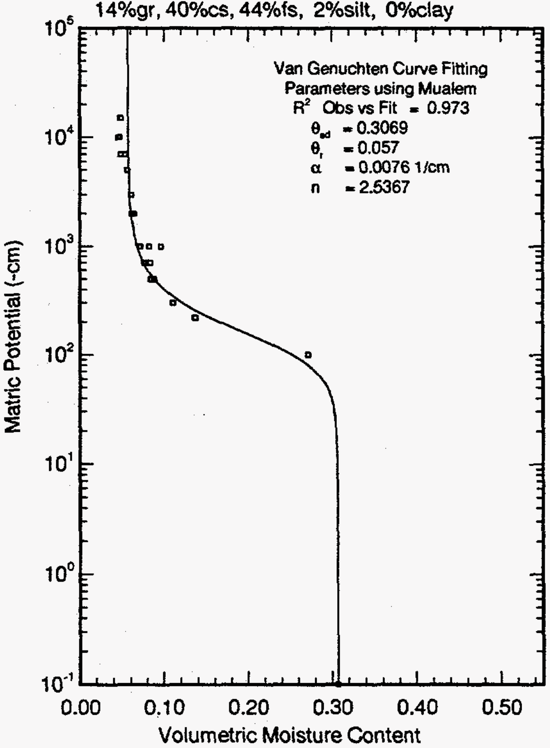
APTANK; sample: 241-AP5
0%gr, 7%cs, 49%fs, 36%silt, 8%clay

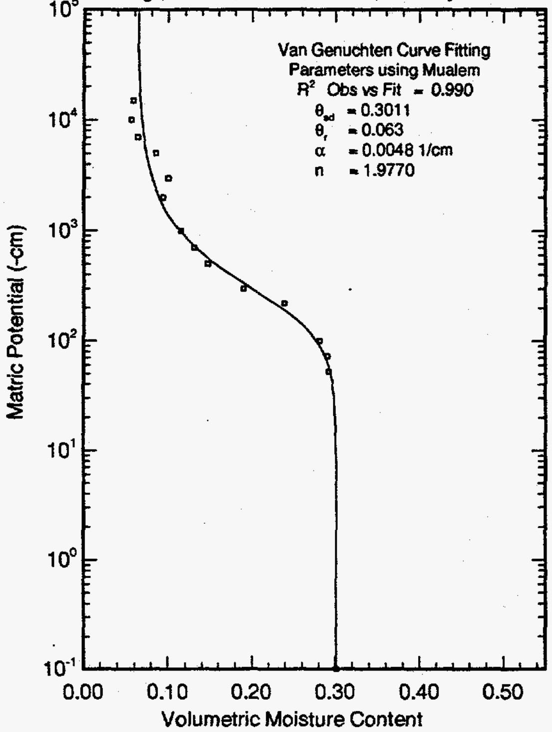


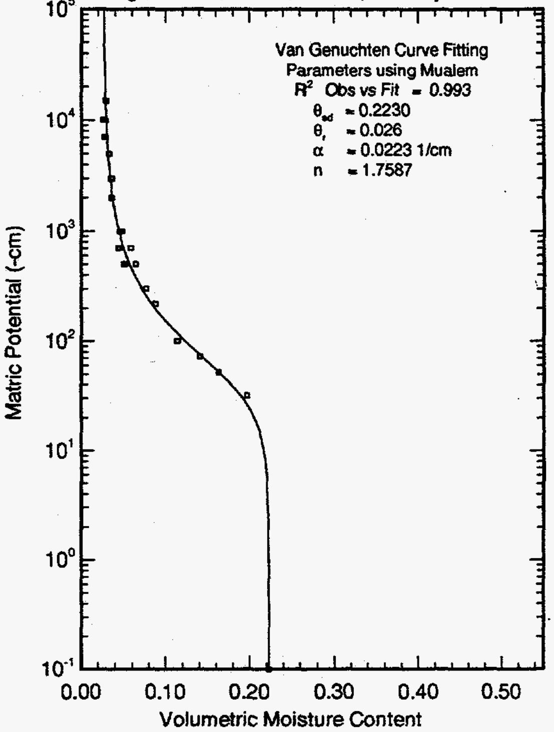
APTANK; sample: 241-AP6
1%gr, 36%cs, 43%fs, 14%silt, 6%clay

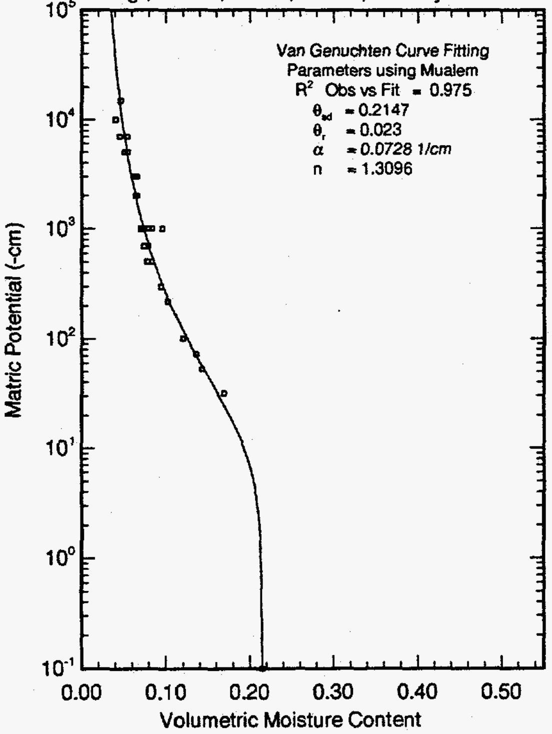


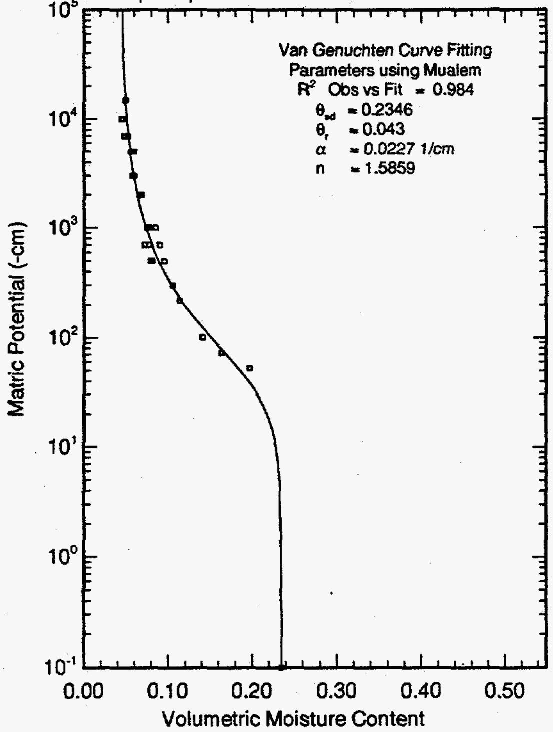
C-018-H; sample: 2-1169
14%gr, 40%cs, 44%fs, 2%silt, 0%clay



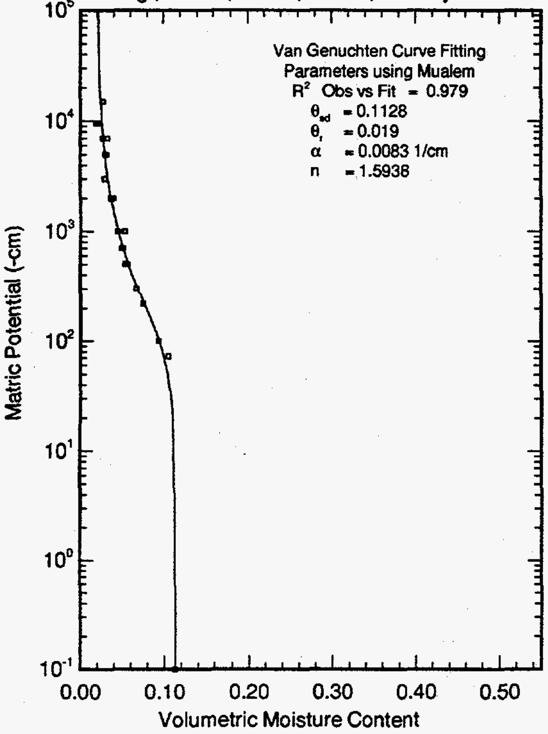

C-018-H; sample: 2-1170
22%gr, 42%cs, 33%fs, 3%silt, 0%clay


C-018-H; sample: 2-1176
1%gr, 79%cs, 20%fs, 0%silt, 0%clay

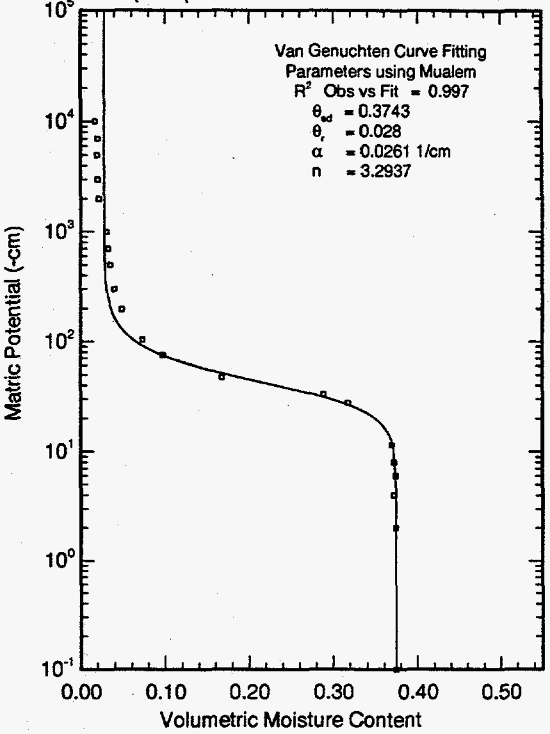

C-018-H; sample: 2-1181
8%gr, 82%cs, 10%fs, 0%silt, 0%clay


C-018-H; sample: 2-1431
complete particle size distribution not available

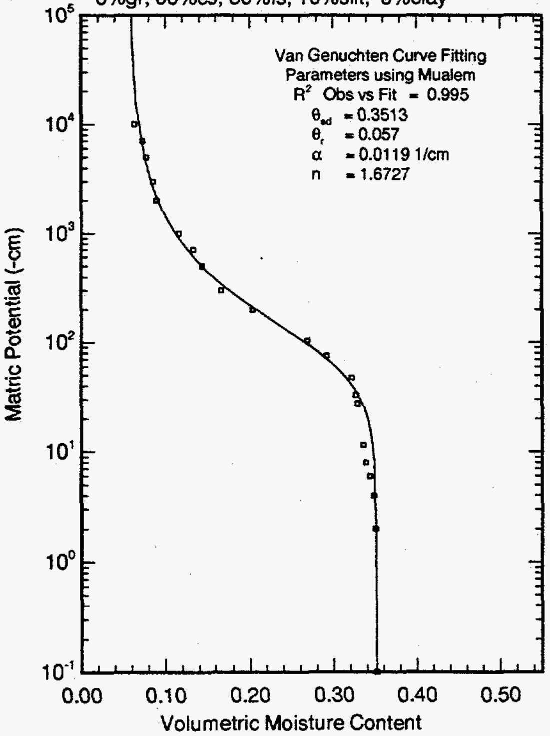
C-018-H; sample: 2-1432
51%gr, 30%cs, 15%fs, 4%silt, 0%clay



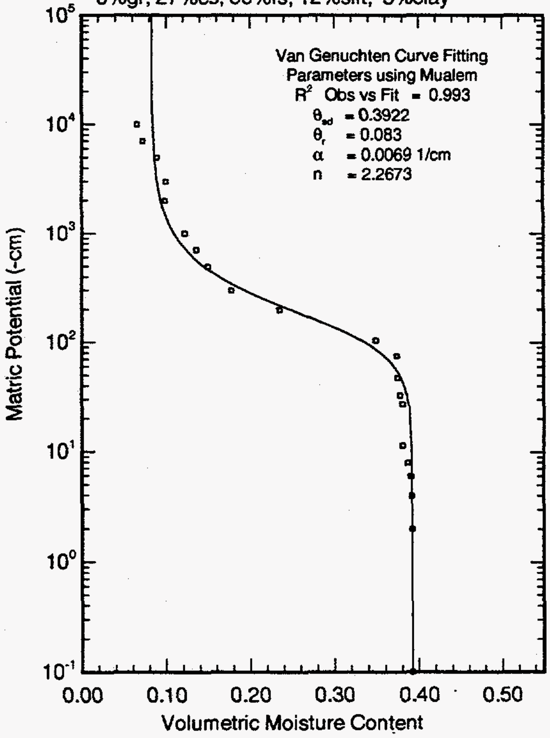
ERDF; sample: 4-0637
complete particle size distribution not available



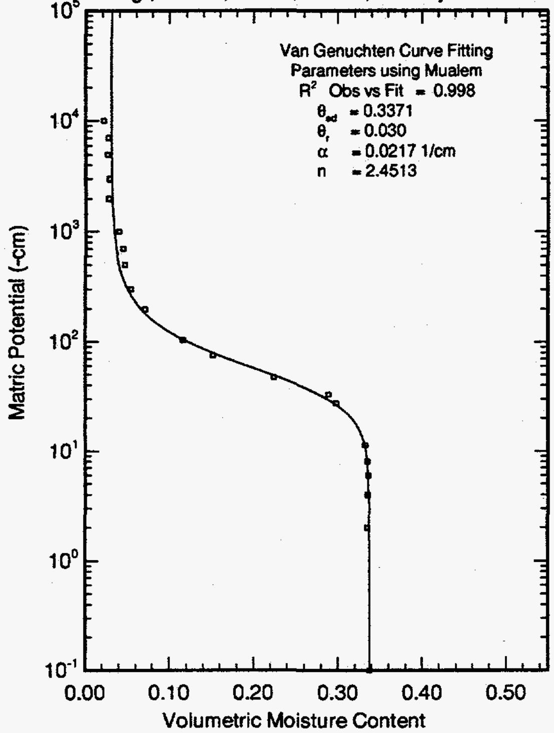
ERDF; sample: 4-0642
0%gr, 60%cs, 30%fs, 10%silt, 0%clay



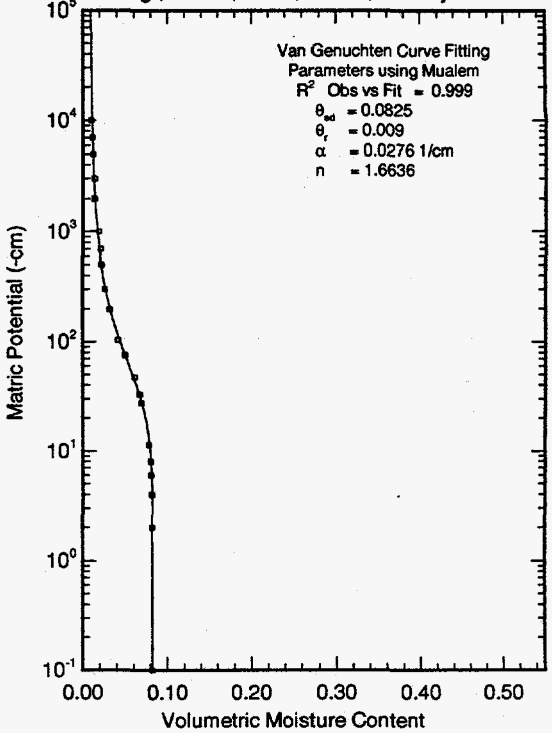
ERDF; sample: 4-0644
0%gr, 27%cs, 56%fs, 12%silt, 5%clay



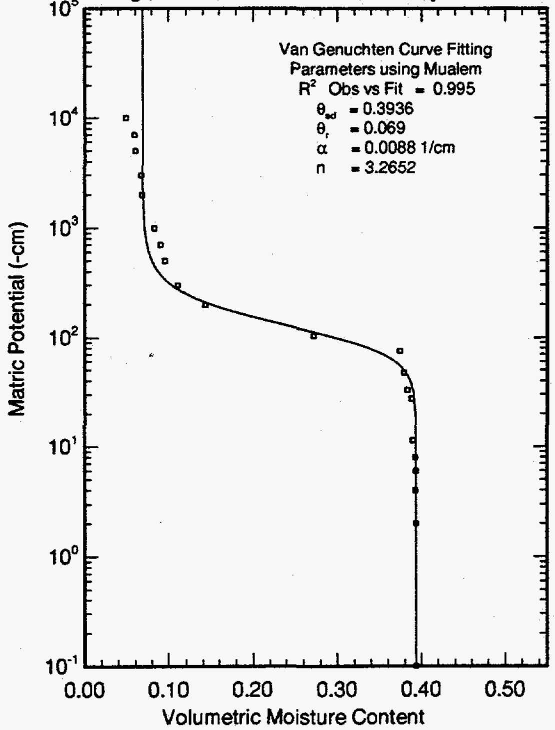
ERDF; sample: 4-0791
0%gr, 50%cs, 50%fs, 0%silt, 0%clay



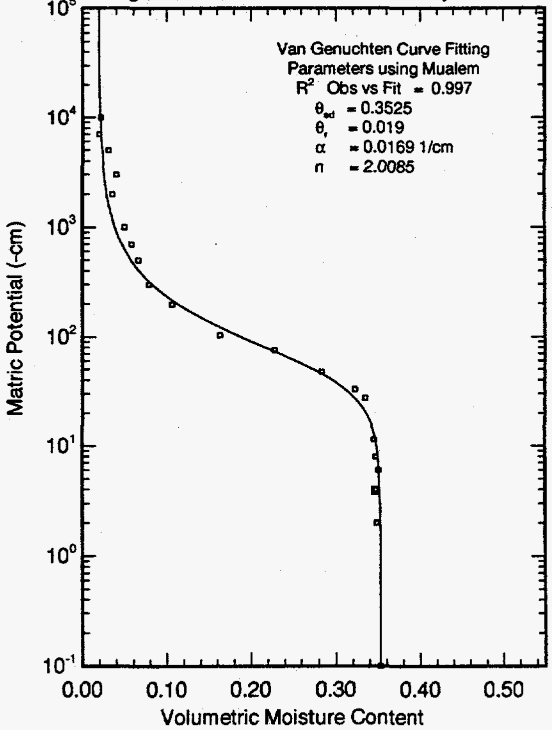
ERDF; sample: 4-0792
71%gr, 21%cs, 8%fs, 1%silt, 0%clay



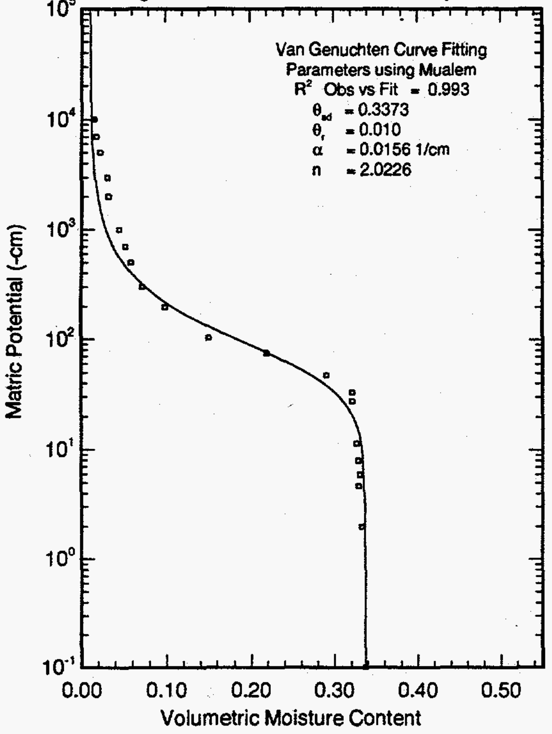
ERDF; sample: 4-0855
0%gr, 7%cs, 83%fs, 5%silt, 5%clay



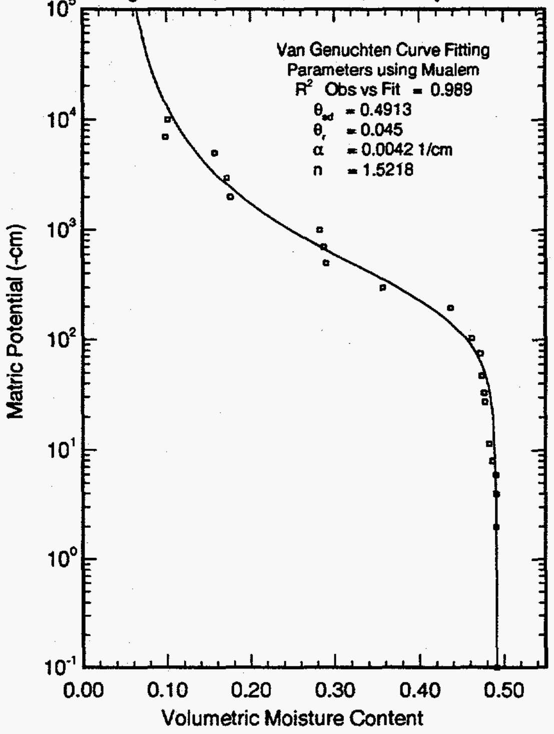
ERDF; sample: 4-0973
0%gr, 21%cs, 64%fs, 12%silt, 3%clay



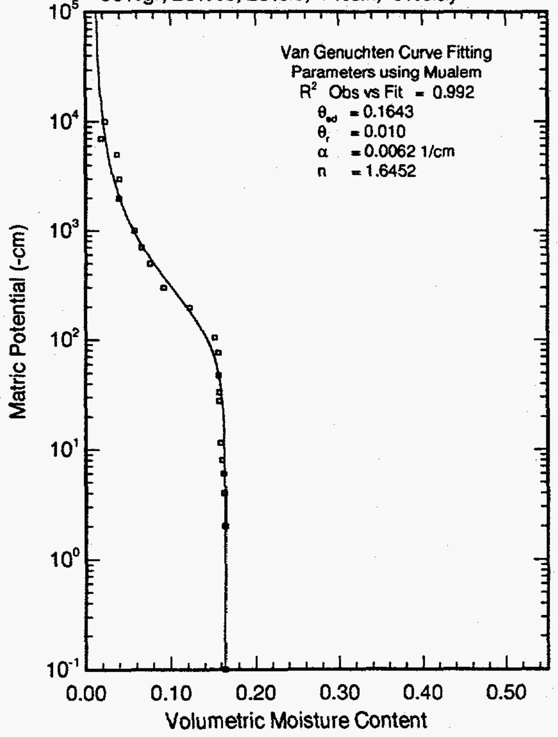
ERDF; sample: 4-0983
17%gr, 35%cs, 42%fs, 4%silt, 2%clay



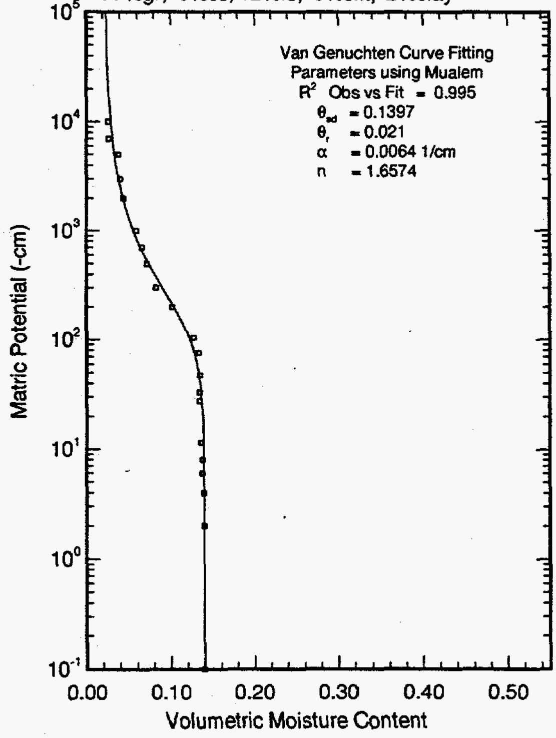
ERDF; sample: 4-1011
0%gr, 4%cs, 60%fs, 28%silt, 8%clay

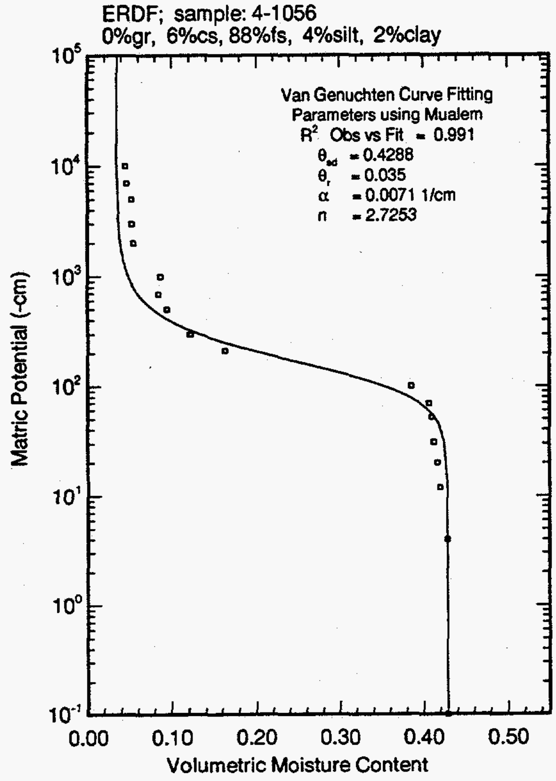


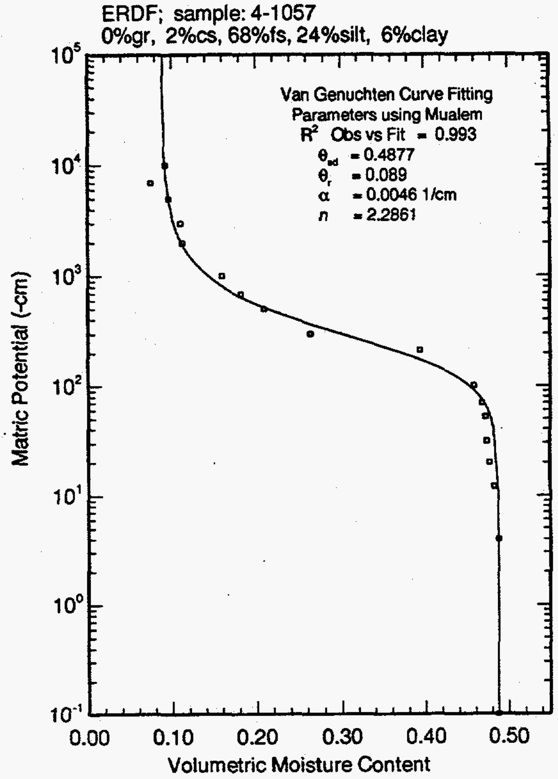
ERDF; sample: 4-1012
50%gr, 20%cs, 20%fs, 7%silt, 3%clay

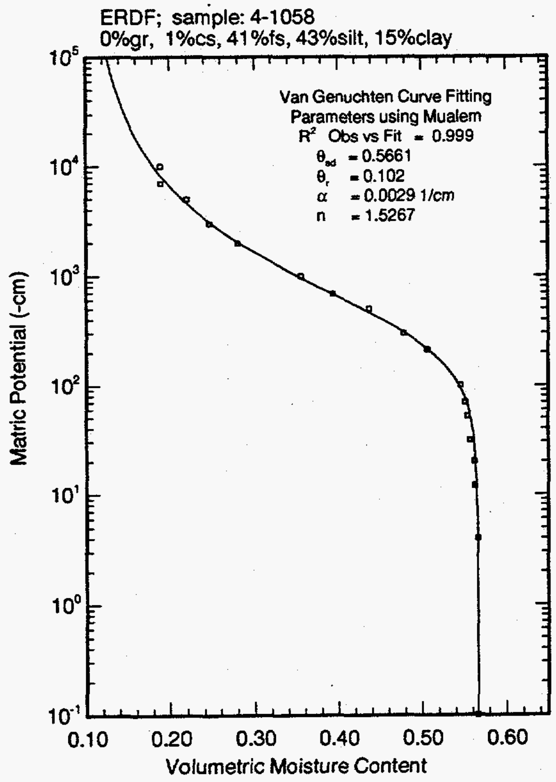


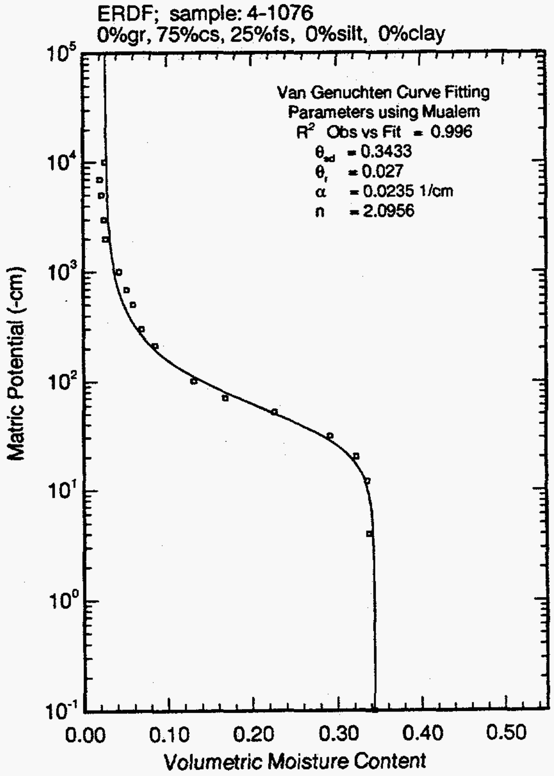
ERDF; sample: 4-1013
77%gr, 6%cs, 12%fs, 3%silt, 2%clay



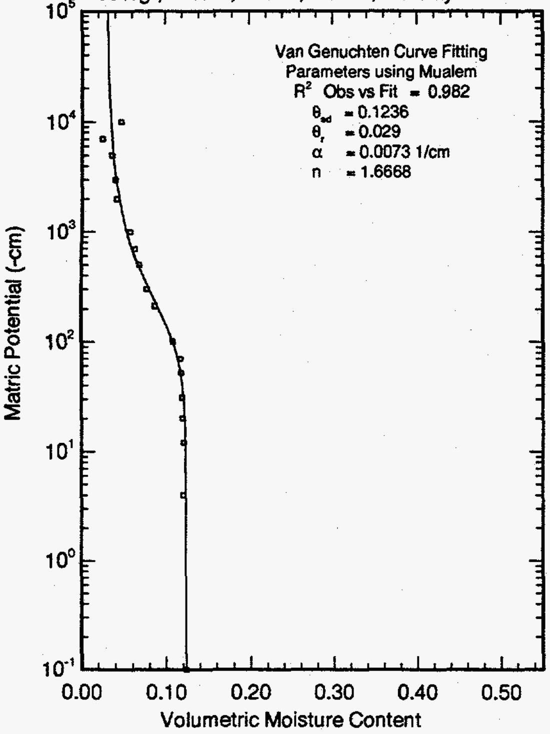

ERDF; sample: 4-1056
0%gr, 6%cs, 88%fs, 4%silt, 2%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R^2 Obs vs Fit = 0.991
θ_{sd} = 0.4288
θ_r = 0.035
α = 0.0071 1/cm
n = 2.7253
Matric Potential (-cm)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content


ERDF; sample: 4-1057
0%gr, 2%cs, 68%fs, 24%silt, 6%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R^2 Obs vs Fit = 0.993
θ_{sd} = 0.4877
θ_r = 0.089
α = 0.0046 1/cm
n = 2.2861
Matric Potential (-cm)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content

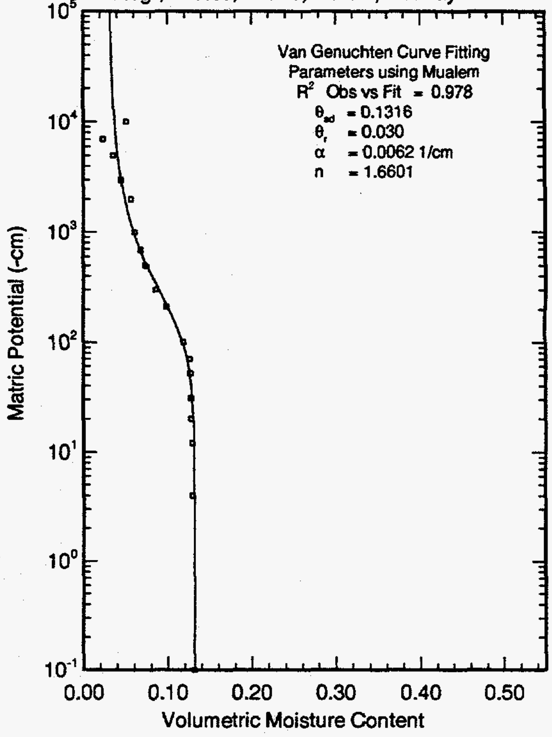

ERDF; sample: 4-1058
0%gr, 1%cs, 41%fs, 43%silt, 15%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R^2 Obs vs Fit = 0.999
θ_{sd} = 0.5661
θ_r = 0.102
α = 0.0029 1/cm
n = 1.5267
Matric Potential (-cm)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.10
0.20
0.30
0.40
0.50
0.60
Volumetric Moisture Content


ERDF; sample: 4-1076
0%gr, 75%cs, 25%fs, 0%silt, 0%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R^2 Obs vs Fit = 0.996
θ_{sd} = 0.3433
θ_r = 0.027
α = 0.0235 1/cm
n = 2.0956
Matric Potential (-cm)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content

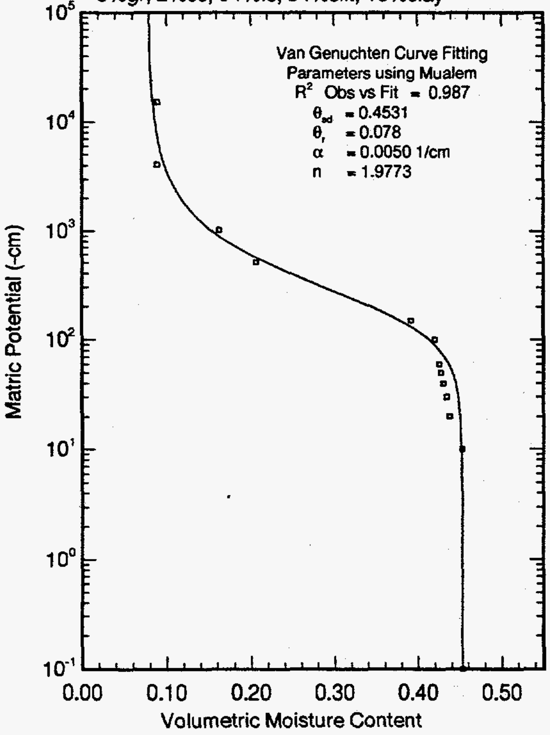
ERDF; sample: 4-1079
65%gr, 24%cs, 11%fs, 0%silt, 0%clay



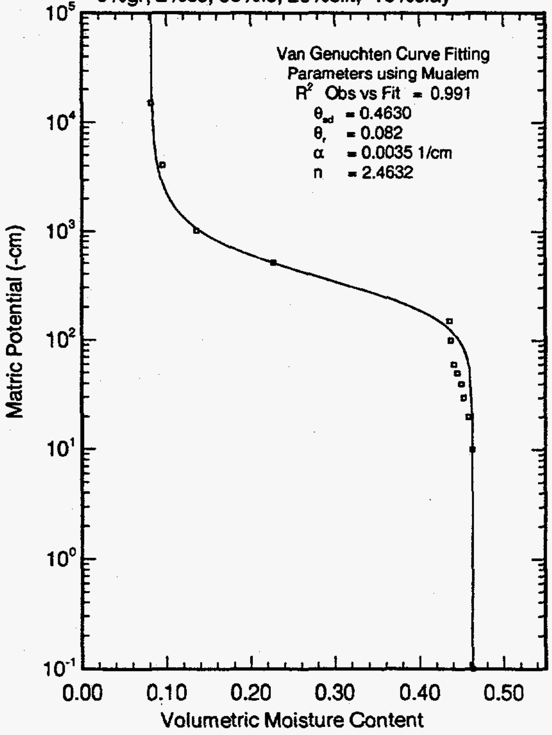
ERDF; sample: 4-1080
63%gr, 24%cs, 10%fs, 3%silt, 0%clay



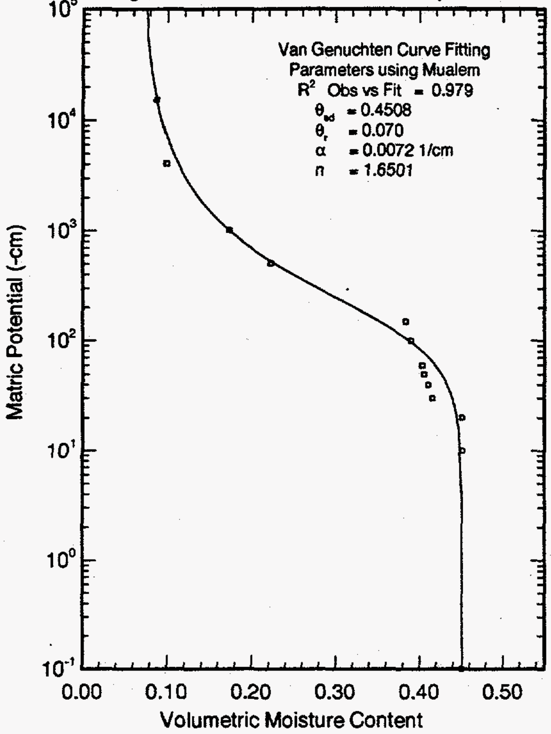
FLTF; sample: D02-10
0%gr, 2%cs, 54%fs, 34%silt, 10%clay



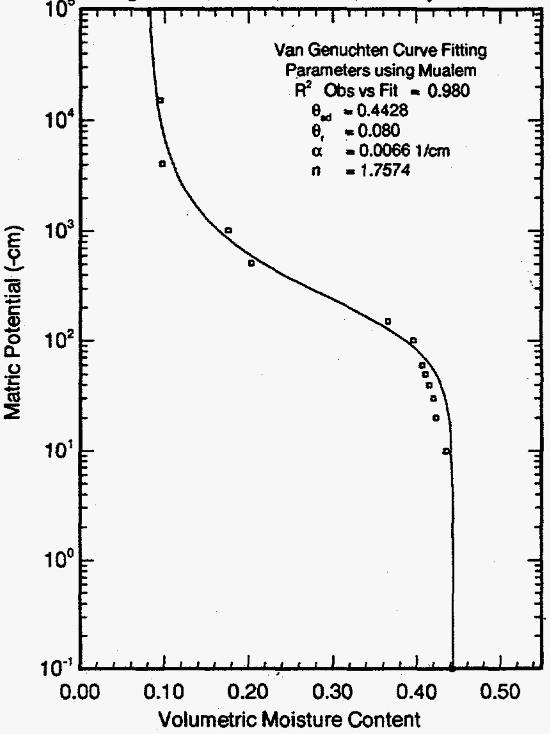
FLTF; sample: D02-16
0%gr, 2%cs, 63%fs, 25%silt, 10%clay



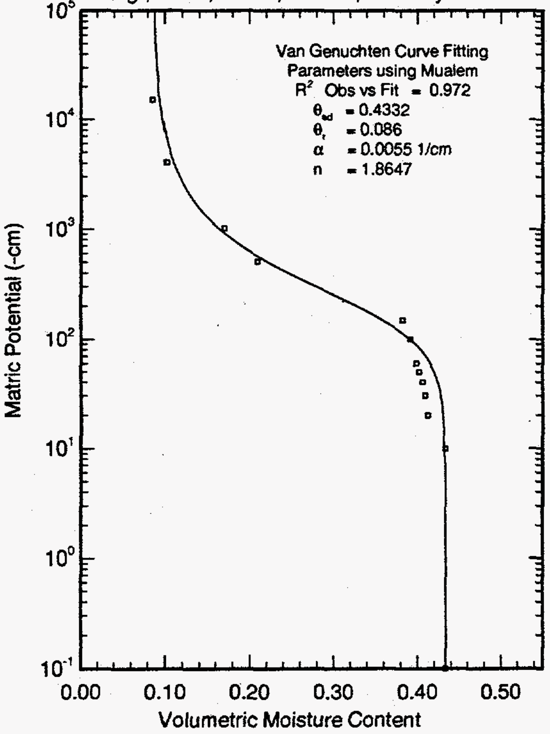
FLTF; sample: D04-04
0%gr, 4%cs, 58%fs, 28%silt, 10%clay



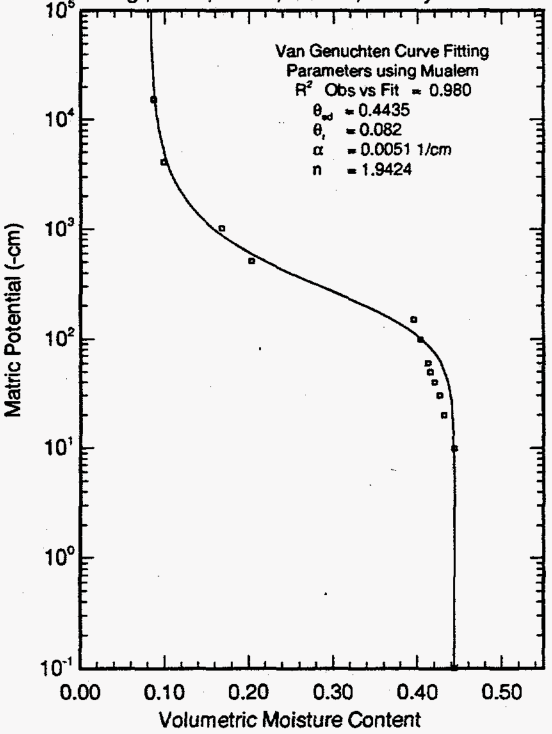
FLTF; sample: D04-10
0%gr, 3%cs, 58%fs, 30%silt, 9%clay

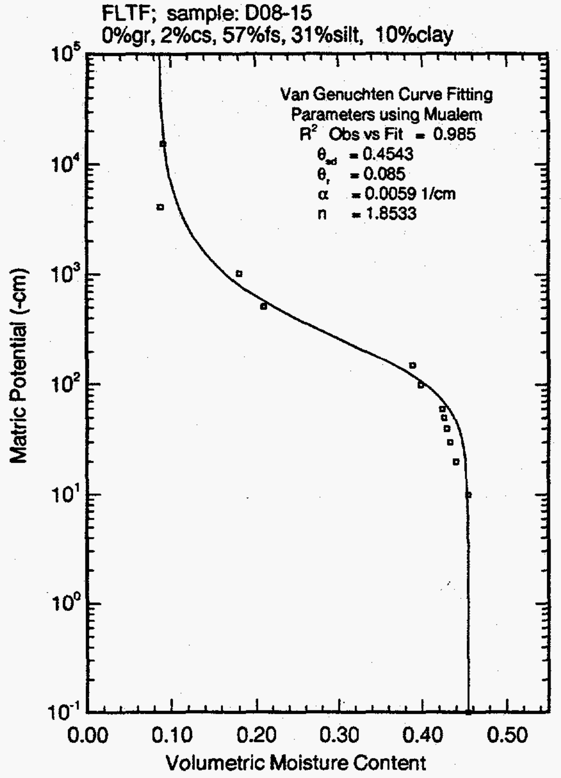


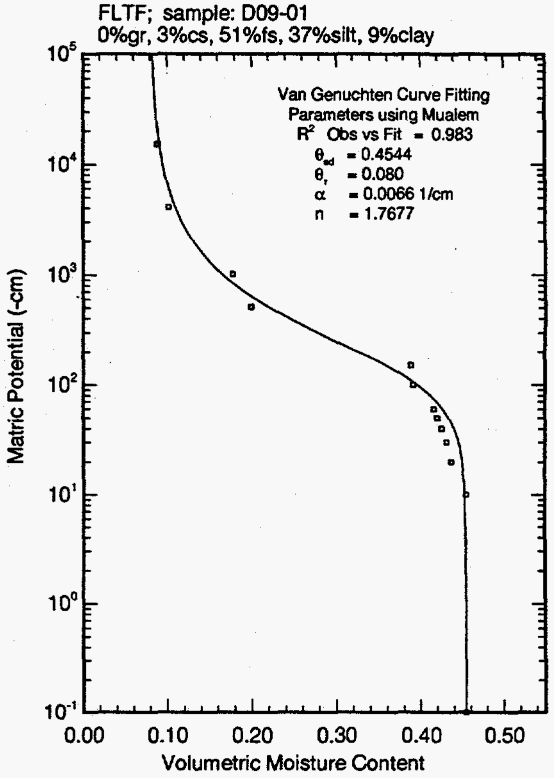
FLTF; sample: D05-03
0%gr, 4%cs, 63%fs, 23%silt, 10%clay

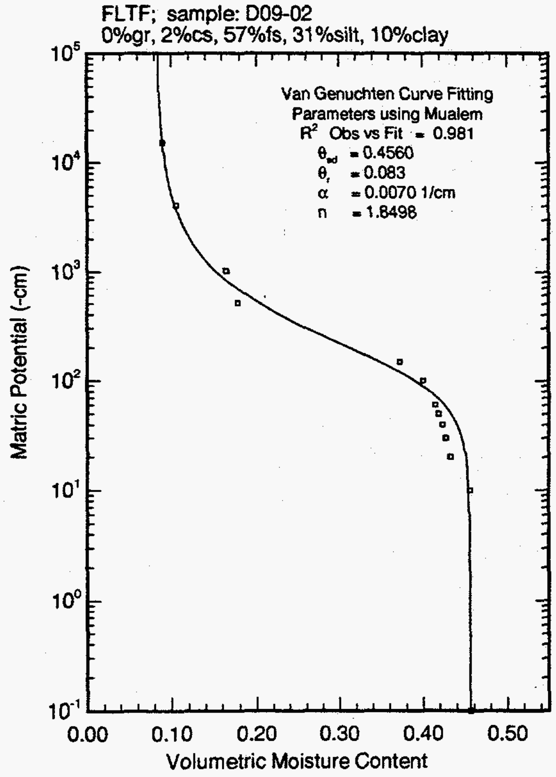


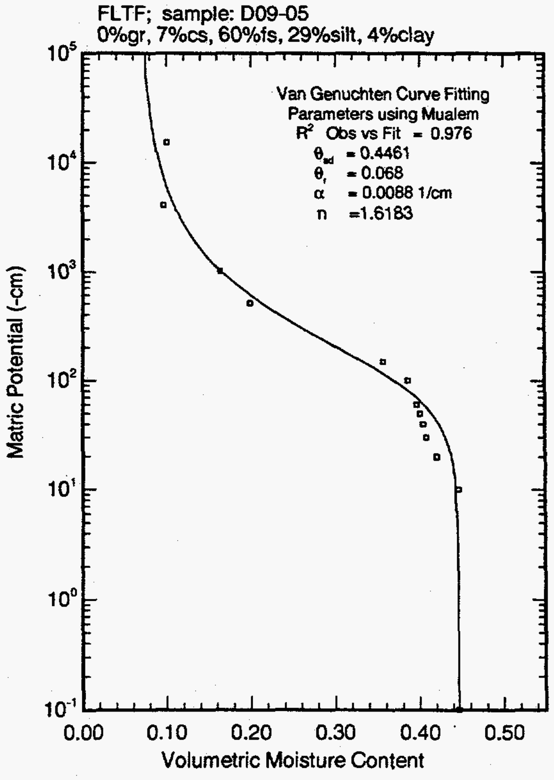
FLTF; sample: D07-04
0%gr, 3%cs, 58%fs, 30%silt, 9%clay

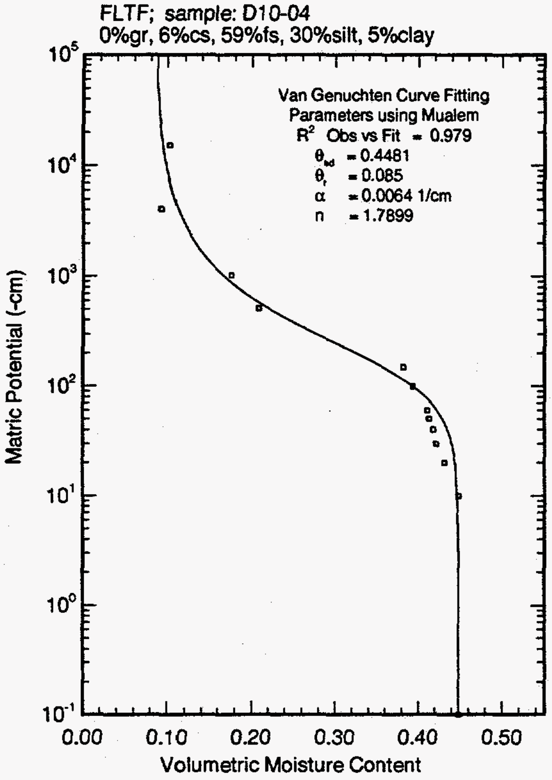


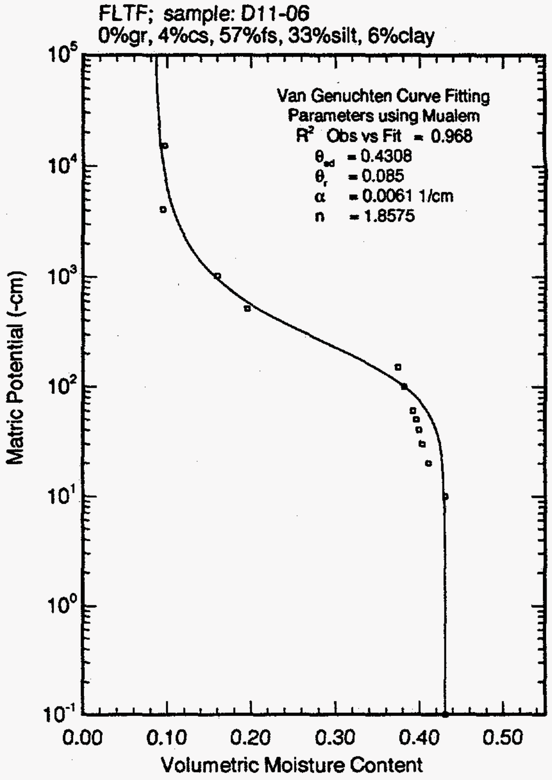

FLTF; sample: D08-15
0%gr, 2%cs, 57%fs, 31%silt, 10%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R² Obs vs Fit = 0.985
θsd = 0.4543
θr = 0.085
α = 0.0059 1/cm
n = 1.8533
Matric Potential (-cm)
10⁵
10⁴
10³
10²
10¹
10⁰
10⁻¹
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content

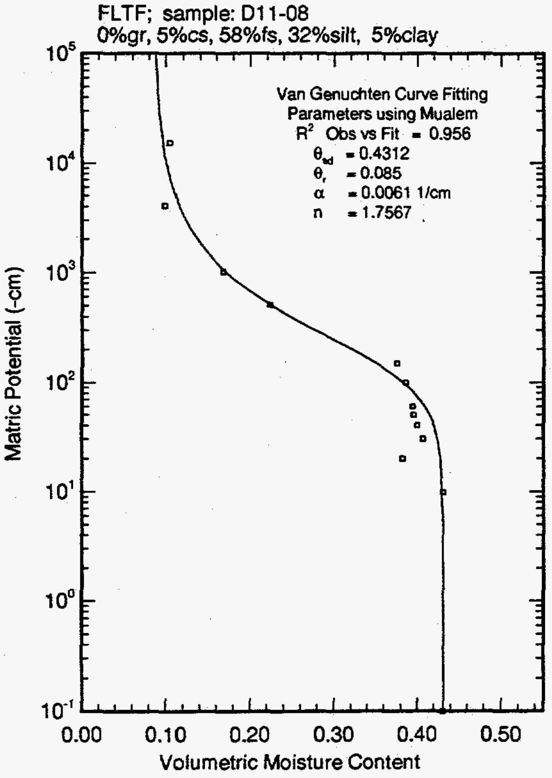

FLTF; sample: D09-01
0%gr, 3%cs, 51%fs, 37%silt, 9%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R² Obs vs Fit = 0.983
θsd = 0.4544
θr = 0.080
α = 0.0066 1/cm
n = 1.7677
Matric Potential (-cm)
10⁵
10⁴
10³
10²
10¹
10⁰
10⁻¹
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content

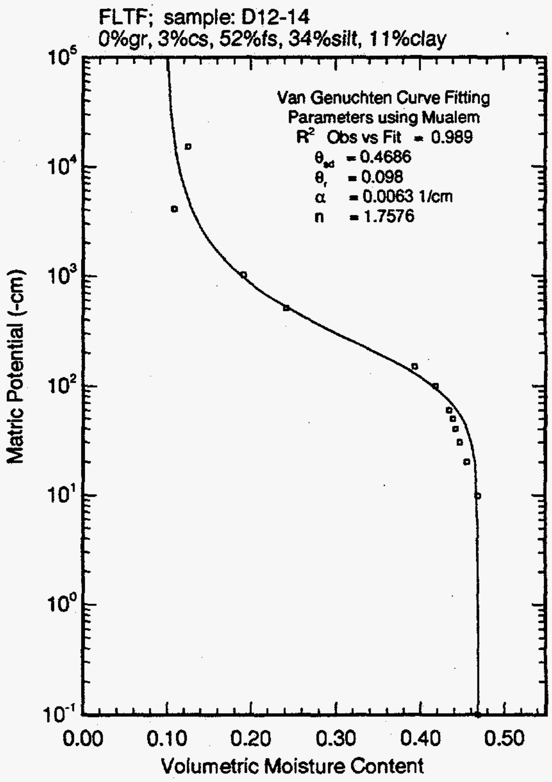

FLTF; sample: D09-02
0%gr, 2%cs, 57%fs, 31%silt, 10%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R² Obs vs Fit = 0.981
θsd = 0.4560
θr = 0.083
α = 0.0070 1/cm
n = 1.8498
Matric Potential (-cm)
10⁵
10⁴
10³
10²
10¹
10⁰
10⁻¹
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content

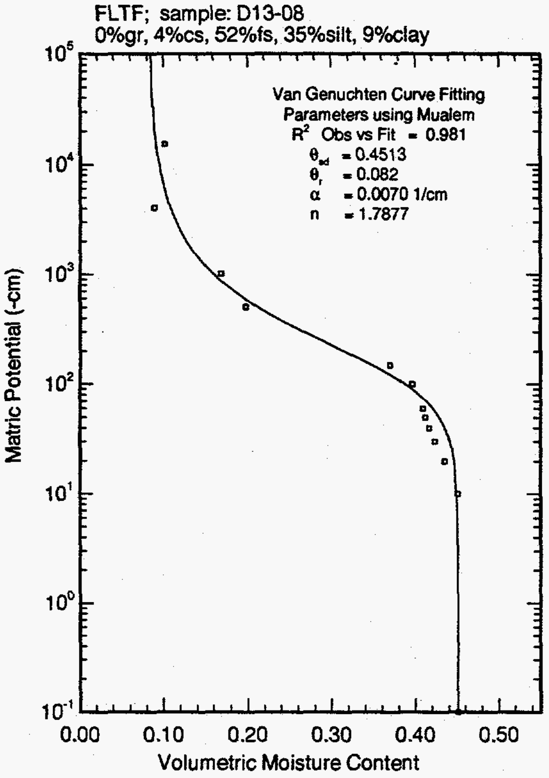

FLTF; sample: D09-05
0%gr, 7%cs, 60%fs, 29%silt, 4%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R² Obs vs Fit = 0.976
θsd = 0.4461
θr = 0.068
α = 0.0088 1/cm
n = 1.6183
Matric Potential (-cm)
10⁵
10⁴
10³
10²
10¹
10⁰
10⁻¹
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content

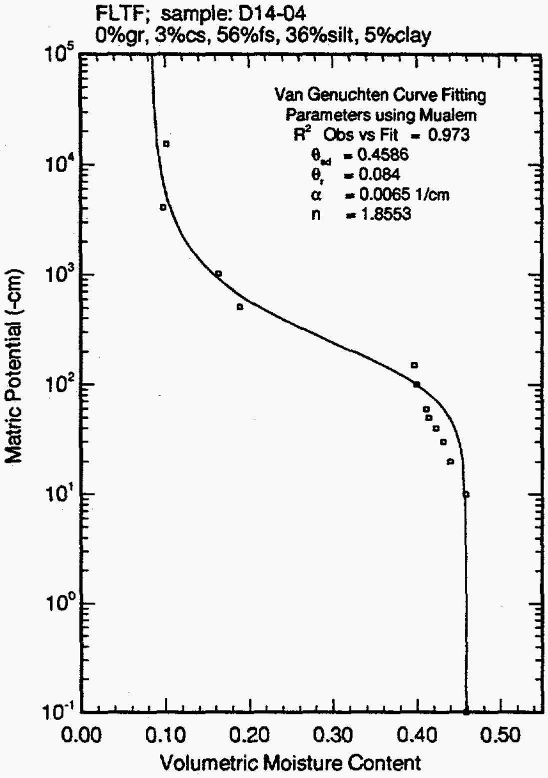

FLTF; sample: D10-04
0%gr, 6%cs, 59%fs, 30%silt, 5%clay

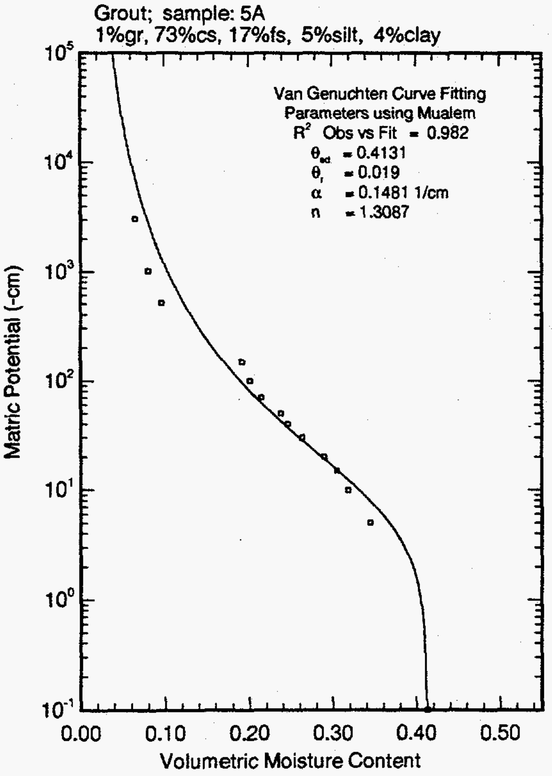

FLTF; sample: D11-06
0%gr, 4%cs, 57%fs, 33%silt, 6%clay

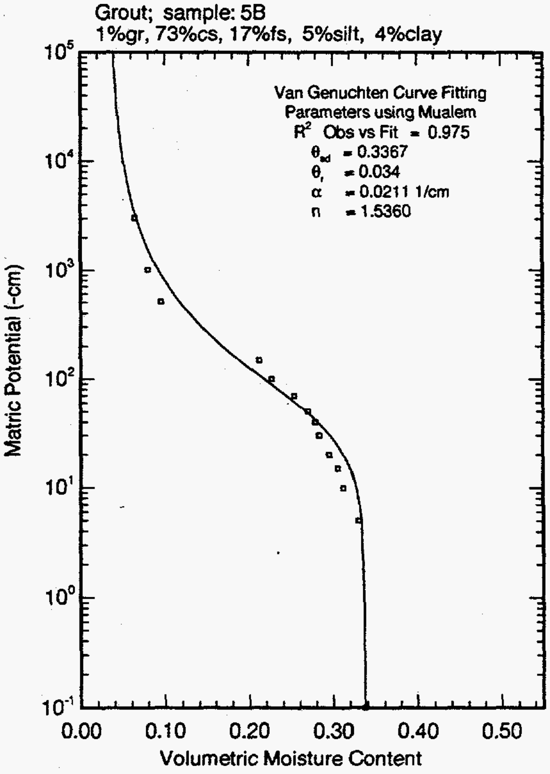

FLTF; sample: D11-08
0%gr, 5%cs, 58%fs, 32%silt, 5%clay

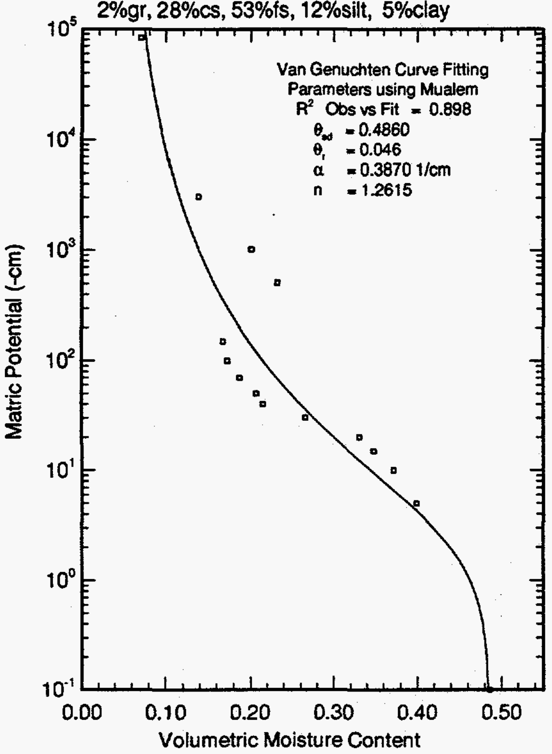

FLTF; sample: D12-14
0%gr, 3%cs, 52%fs, 34%silt, 11%clay

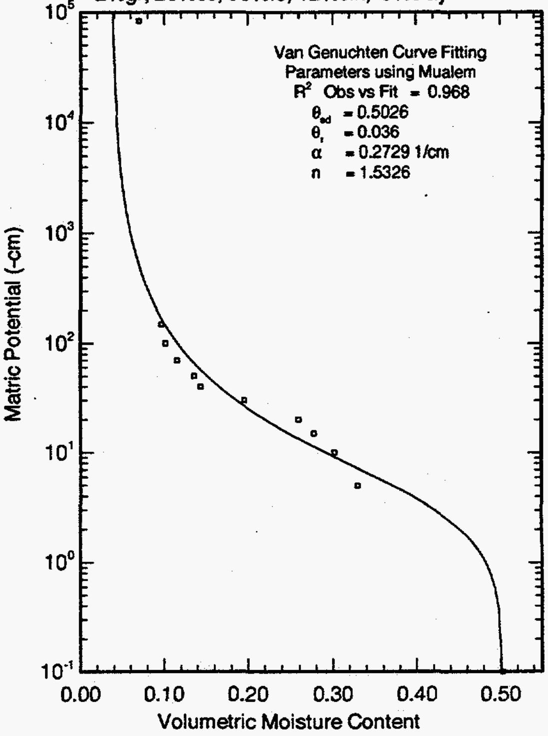

FLTF; sample: D13-08
0%gr, 4%cs, 52%fs, 35%silt, 9%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R^2 Obs vs Fit = 0.981
θ_{sd} = 0.4513
θ_r = 0.082
α = 0.0070 1/cm
n = 1.7877
Matric Potential (-cm)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content

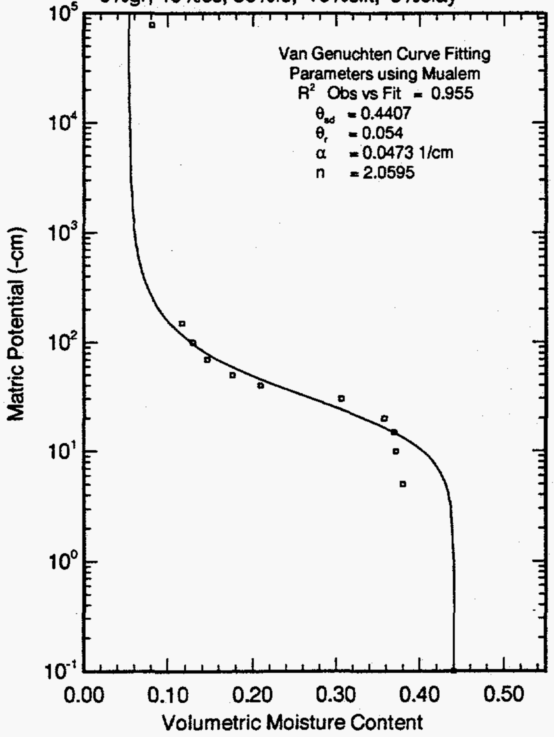

FLTF; sample: D14-04
0%gr, 3%cs, 56%fs, 36%silt, 5%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R^2 Obs vs Fit = 0.973
θ_{sd} = 0.4586
θ_r = 0.084
α = 0.0065 1/cm
n = 1.8553
Matric Potential (-cm)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content

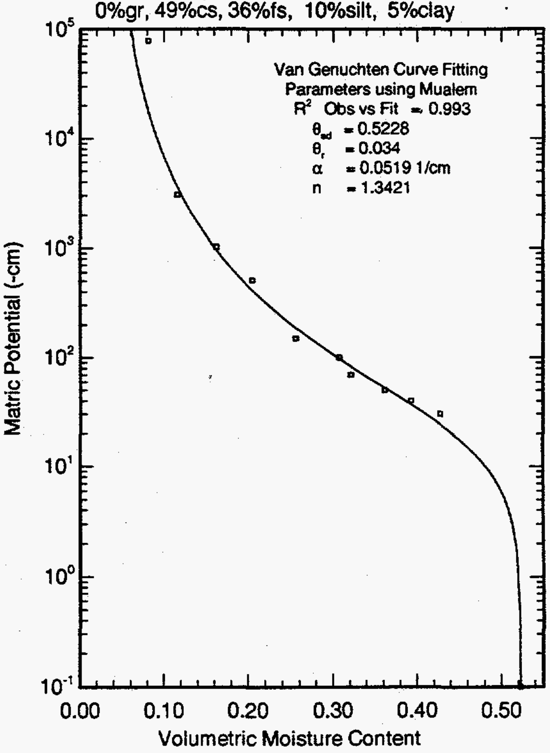

Grout; sample: 5A
1%gr, 73%cs, 17%fs, 5%silt, 4%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R^2 Obs vs Fit = 0.982
θ_{sd} = 0.4131
θ_r = 0.019
α = 0.1481 1/cm
n = 1.3087
Matric Potential (-cm)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content


Grout; sample: 5B
1%gr, 73%cs, 17%fs, 5%silt, 4%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R^2 Obs vs Fit = 0.975
θ_{sd} = 0.3367
θ_r = 0.034
α = 0.0211 1/cm
n = 1.5360
Matric Potential (-cm)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content

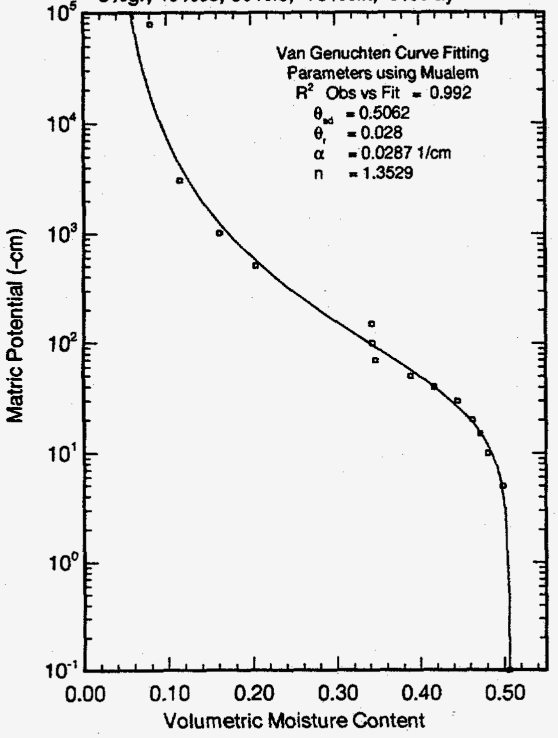

Grout; sample: 19A
2%gr, 28%cs, 53%fs, 12%silt, 5%clay


Grout; sample: 19B
2%gr, 28%cs, 53%fs, 12%silt, 5%clay

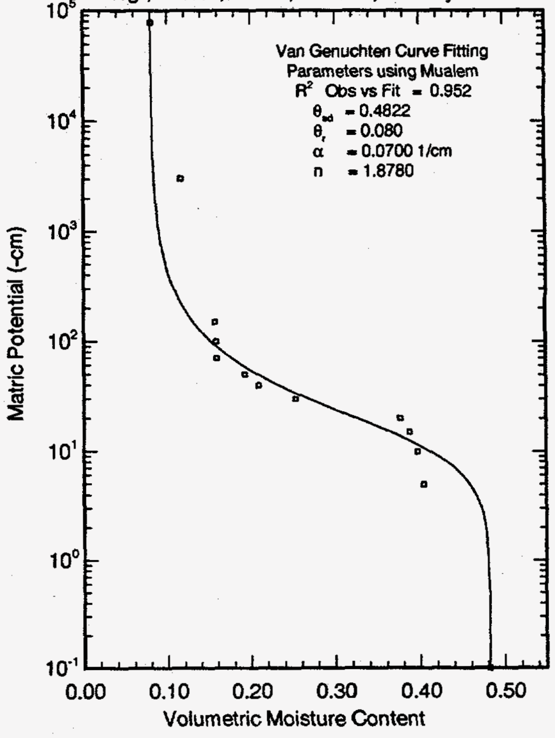

Grout; sample: 25A
0%gr, 49%cs, 36%fs, 10%silt, 5%clay


Grout; sample: 25B
0%gr, 49%cs, 36%fs, 10%silt, 5%clay

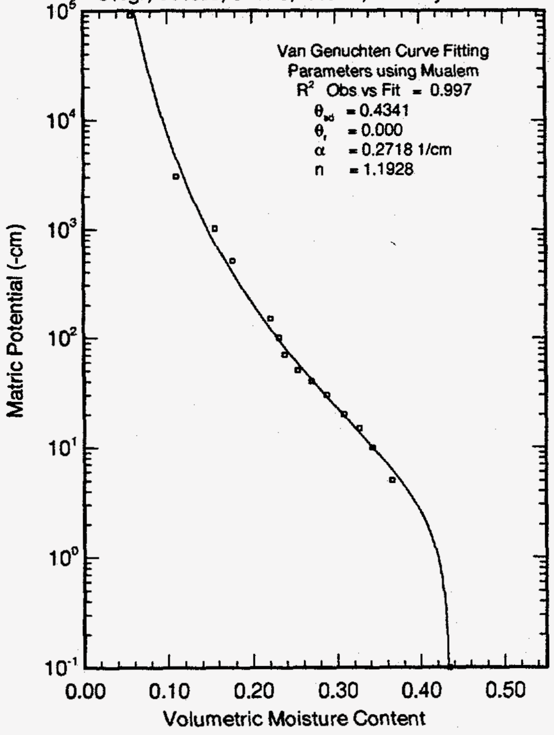
Grout; sample: 25C
0%gr, 49%cs, 36%fs, 10%silt, 5%clay



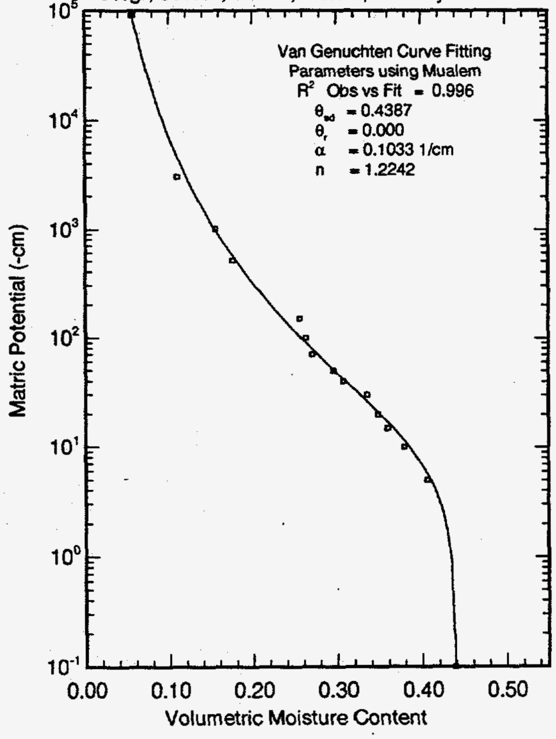
Grout; sample: 25D
0%gr, 49%cs, 36%fs, 10%silt, 5%clay

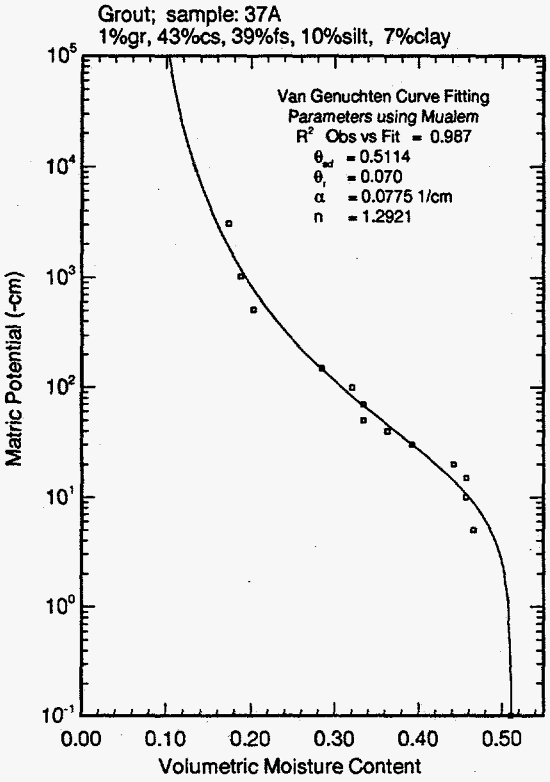


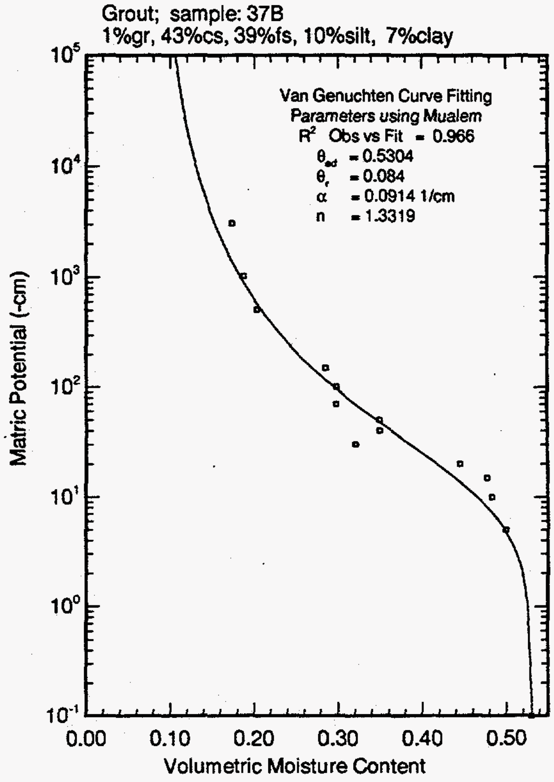
Grout; sample: 29A
0%gr, 60%cs, 31%fs, 6%silt, 3%clay

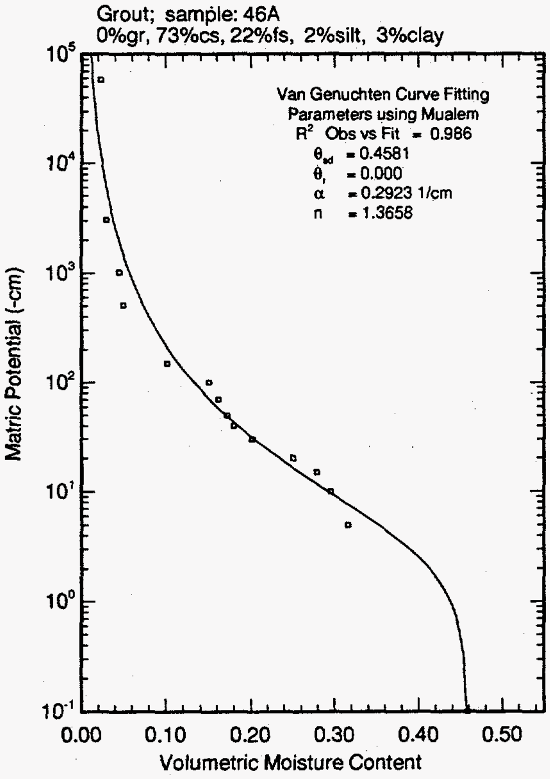


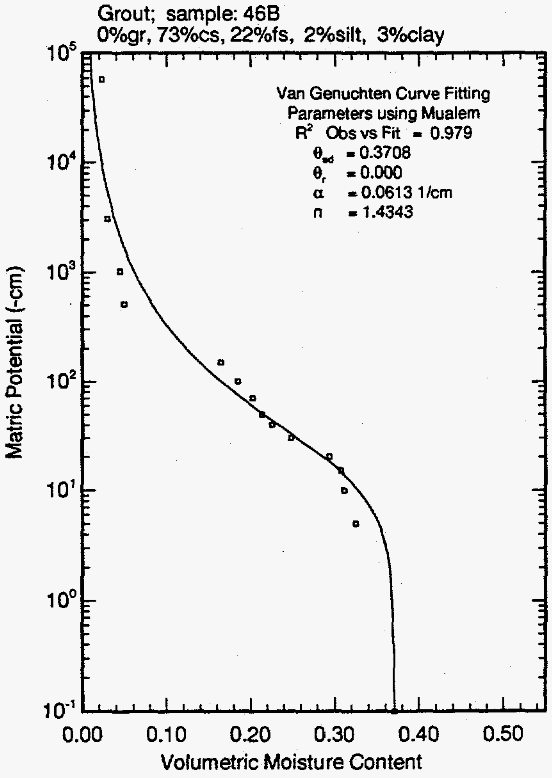
Grout; sample: 29B
0%gr, 60%cs, 31%fs, 6%silt, 3%clay

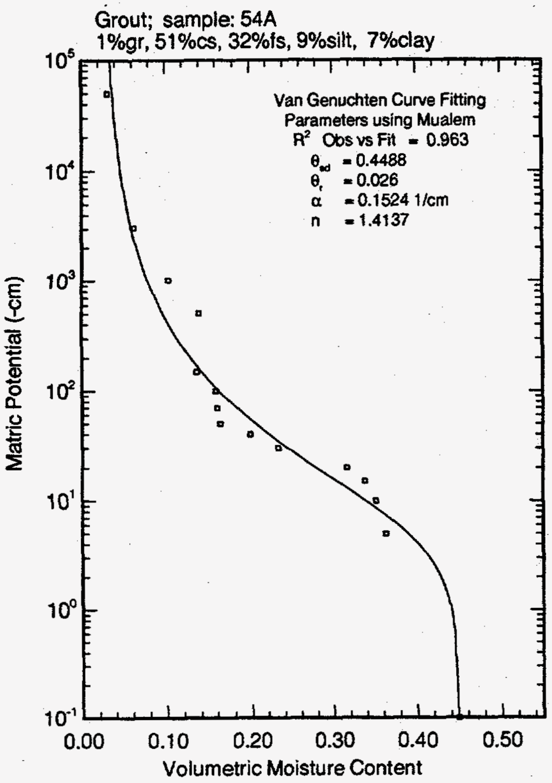


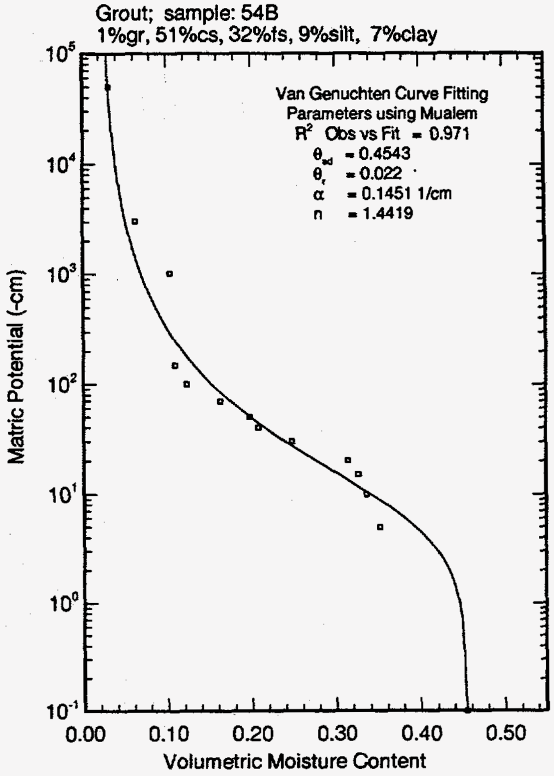

Grout; sample: 37A
1%gr, 43%cs, 39%fs, 10%silt, 7%clay

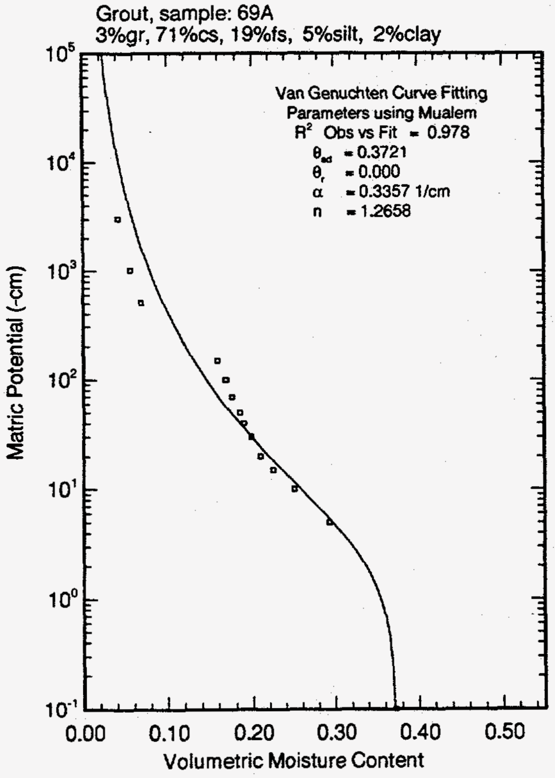

Grout; sample: 37B
1%gr, 43%cs, 39%fs, 10%silt, 7%clay

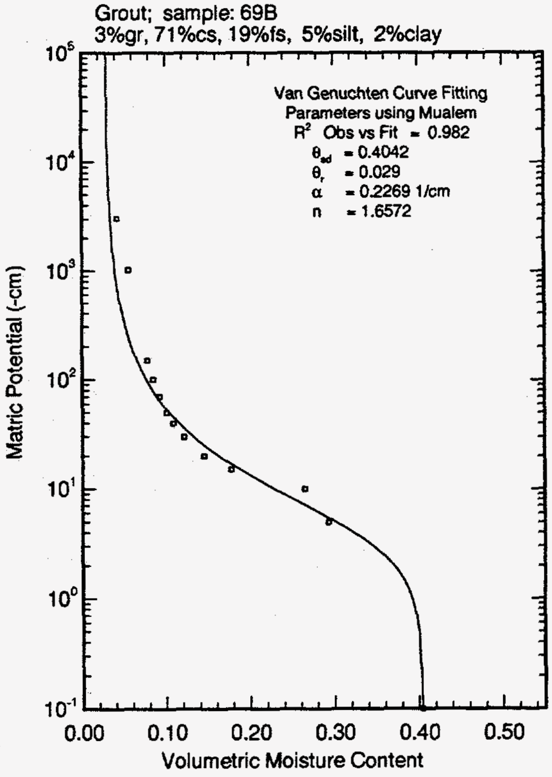

Grout; sample: 46A
0%gr, 73%cs, 22%fs, 2%silt, 3%clay


Grout; sample: 46B
0%gr, 73%cs, 22%fs, 2%silt, 3%clay

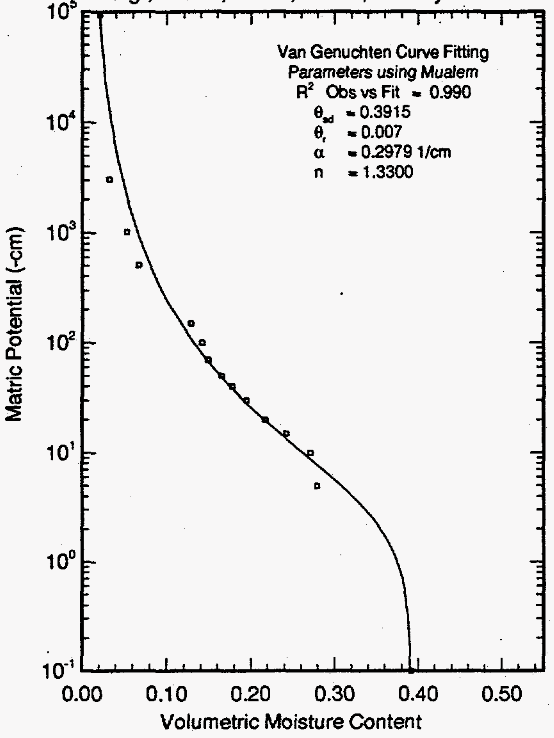

Grout; sample: 54A
1%gr, 51%cs, 32%fs, 9%silt, 7%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R^2 Obs vs Fit = 0.963
θ_{sd} = 0.4488
θ_r = 0.026
α = 0.1524 1/cm
n = 1.4137
Matric Potential (-cm)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content


Grout; sample: 54B
1%gr, 51%cs, 32%fs, 9%silt, 7%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R^2 Obs vs Fit = 0.971
θ_{sd} = 0.4543
θ_r = 0.022
α = 0.1451 1/cm
n = 1.4419
Matric Potential (-cm)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content

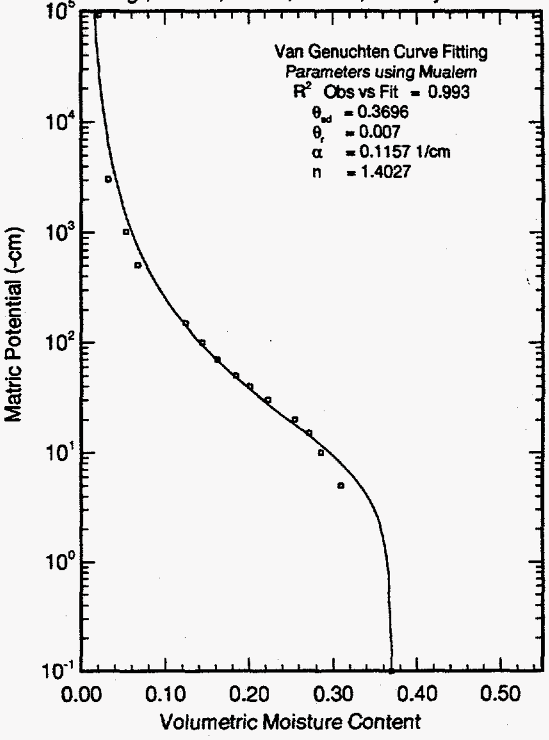

Grout, sample: 69A
3%gr, 71%cs, 19%fs, 5%silt, 2%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R^2 Obs vs Fit = 0.978
θ_{sd} = 0.3721
θ_r = 0.000
α = 0.3357 1/cm
n = 1.2658
Matric Potential (-cm)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content


Grout; sample: 69B
3%gr, 71%cs, 19%fs, 5%silt, 2%clay
Van Genuchten Curve Fitting
Parameters using Mualem
R^2 Obs vs Fit = 0.982
θ_{sd} = 0.4042
θ_r = 0.029
α = 0.2269 1/cm
n = 1.6572
Matric Potential (-cm)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.00
0.10
0.20
0.30
0.40
0.50
Volumetric Moisture Content

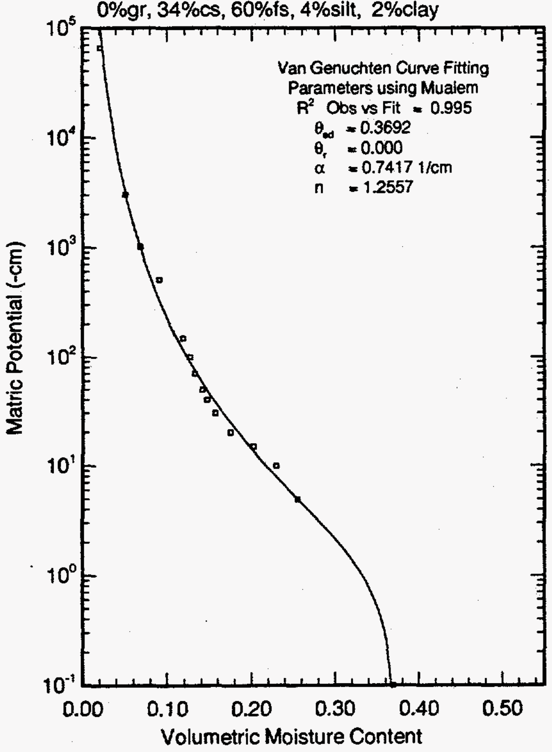
Grout; sample: 83A
4%gr, 70%cs, 19%fs, 5%silt, 2%clay



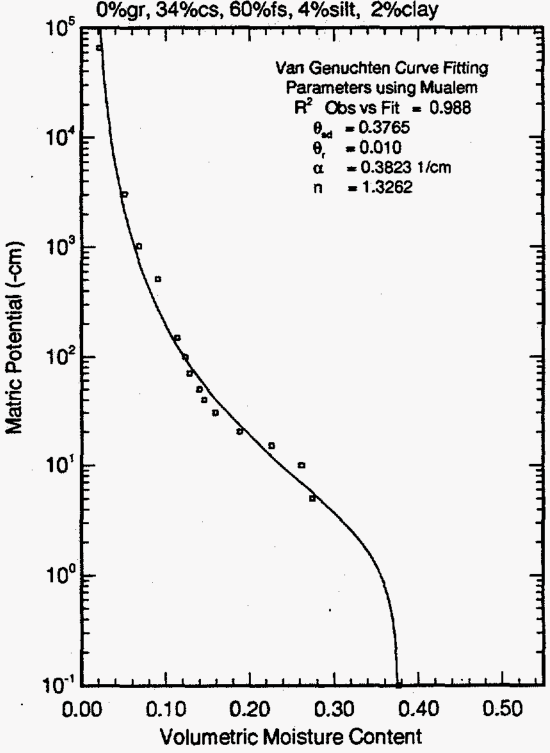
Grout; sample: 83B
4%gr, 70%cs, 19%fs, 5%silt, 2%clay

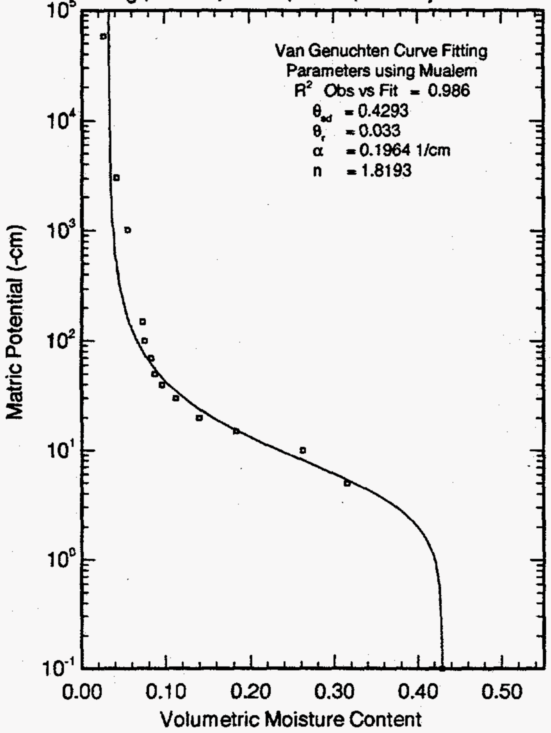


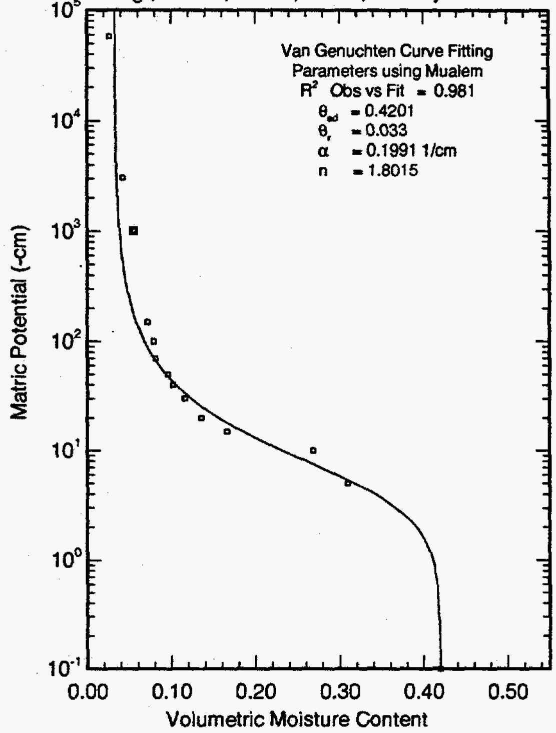
Grout; sample: 99A
0%gr, 34%cs, 60%fs, 4%silt, 2%clay

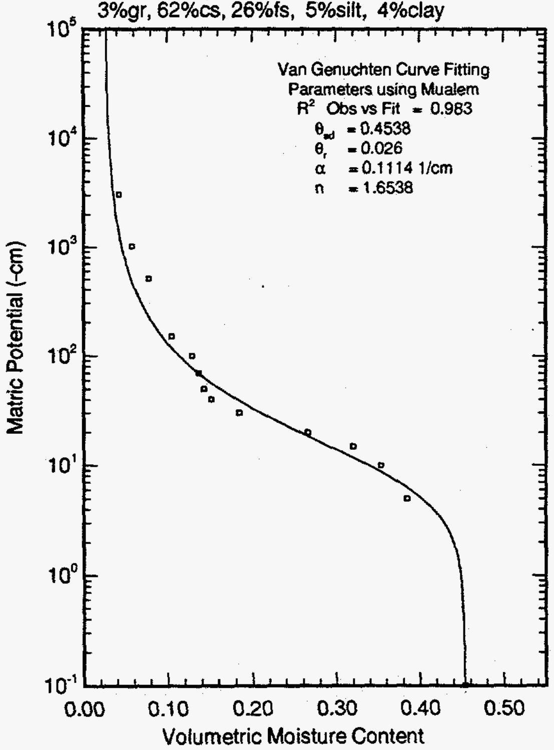


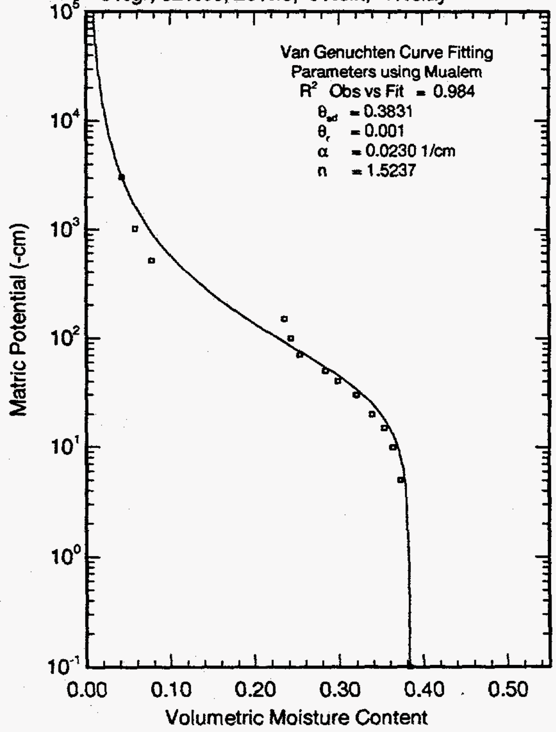
Grout; sample: 99B
0%gr, 34%cs, 60%fs, 4%silt, 2%clay

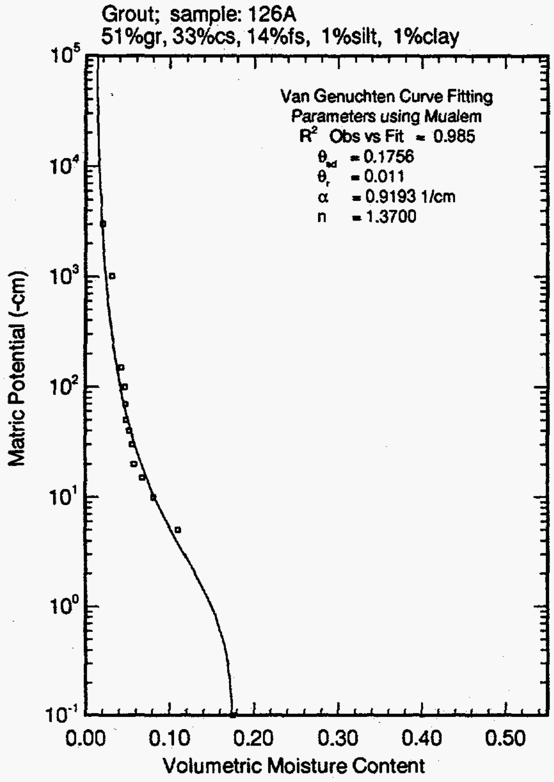


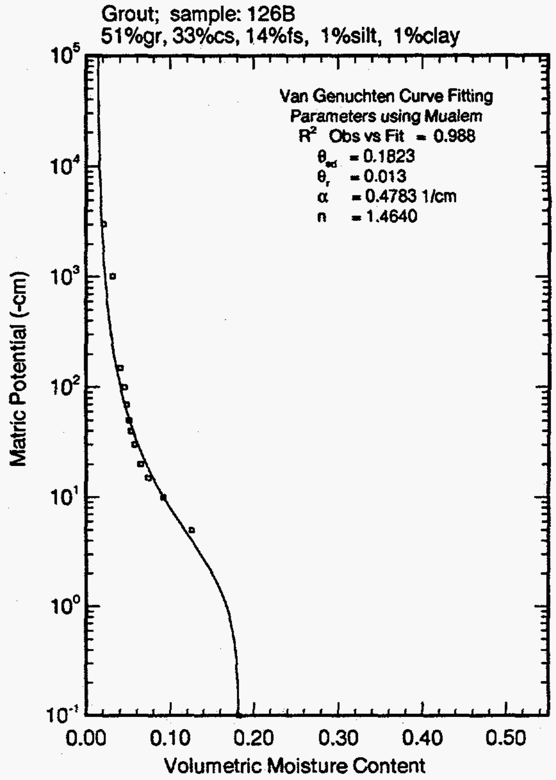

Grout; sample: 110A
6%gr, 64%cs, 23%fs, 5%silt, 2%clay

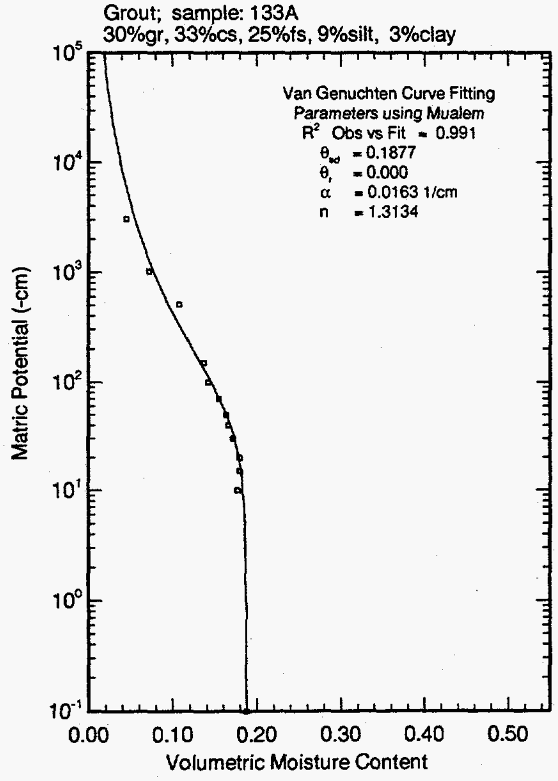

Grout; sample: 110B
6%gr, 64%cs, 23%fs, 5%silt, 2%clay

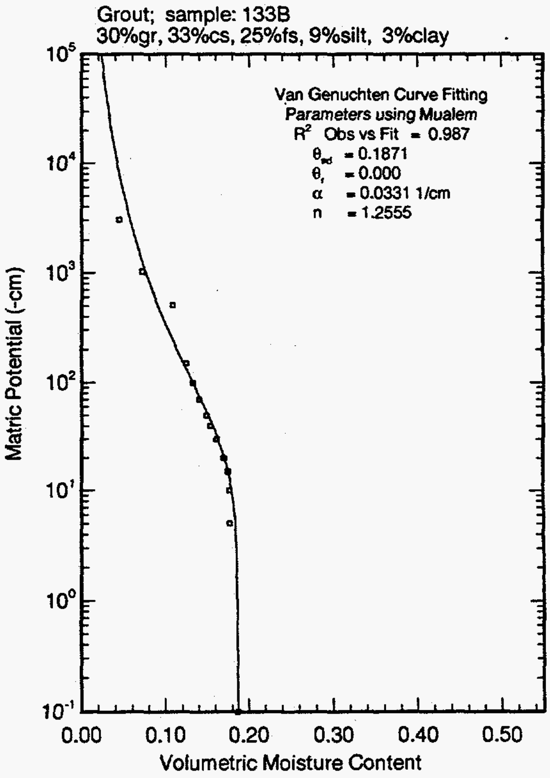

Grout; sample: 117A
3%gr, 62%cs, 26%fs, 5%silt, 4%clay

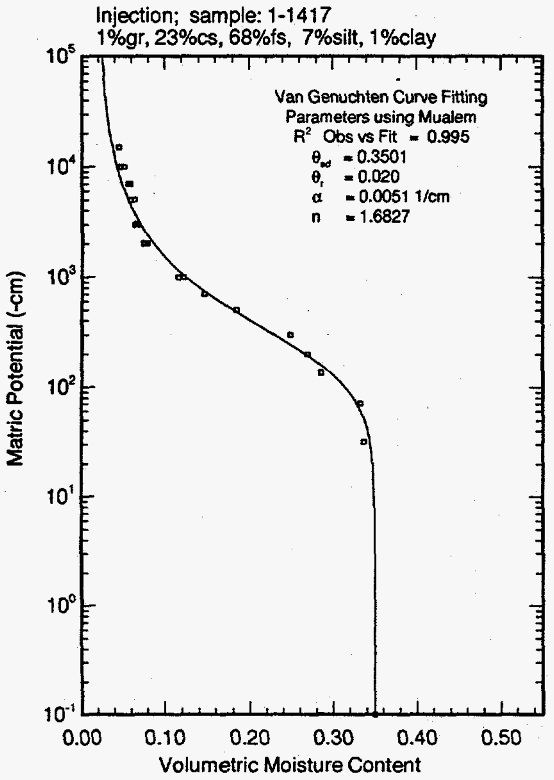

Grout; sample: 117B
3%gr, 62%cs, 26%fs, 5%silt, 4%clay

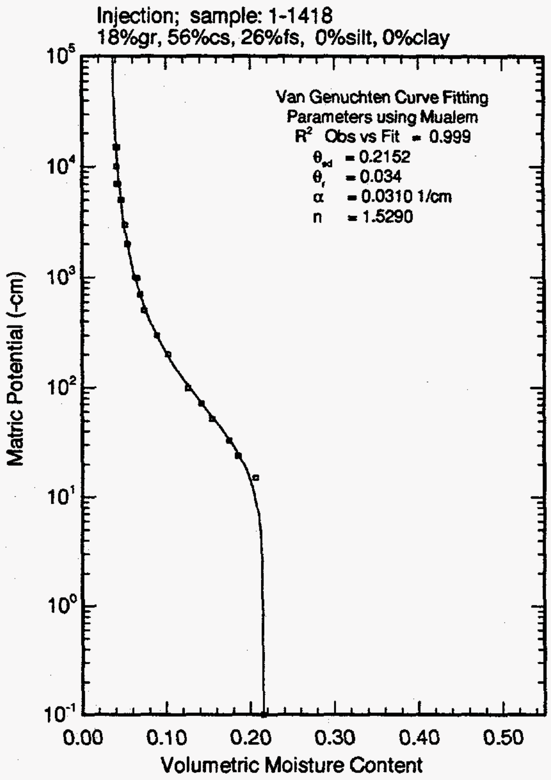

Grout; sample: 126A
51%gr, 33%cs, 14%fs, 1%silt, 1%clay

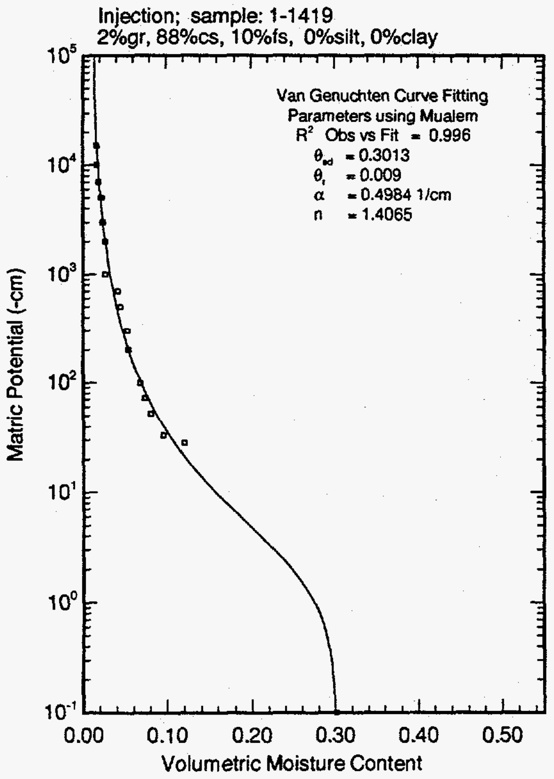

Grout; sample: 126B
51%gr, 33%cs, 14%fs, 1%silt, 1%clay

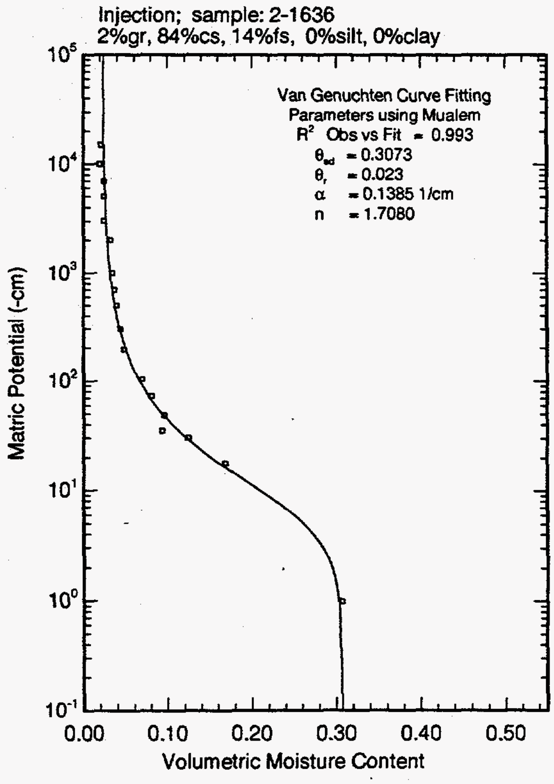

Grout; sample: 133A
30%gr, 33%cs, 25%fs, 9%silt, 3%clay


Grout; sample: 133B
30%gr, 33%cs, 25%fs, 9%silt, 3%clay

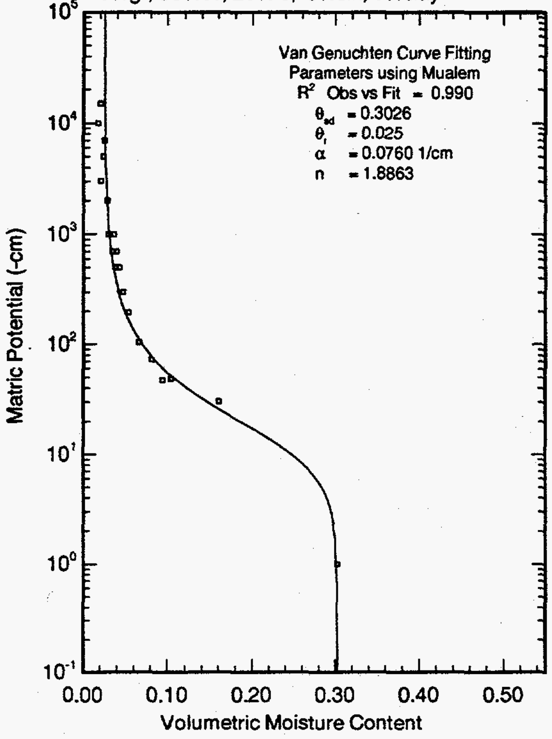

Injection; sample: 1-1417
1%gr, 23%cs, 68%fs, 7%silt, 1%clay


Injection; sample: 1-1418
18%gr, 56%cs, 26%fs, 0%silt, 0%clay

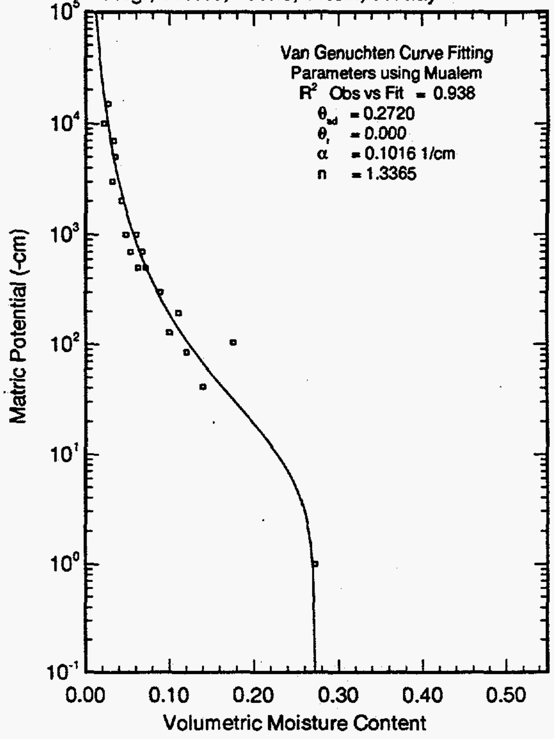

Injection; sample: 1-1419
2%gr, 88%cs, 10%fs, 0%silt, 0%clay


Injection; sample: 2-1636
2%gr, 84%cs, 14%fs, 0%silt, 0%clay

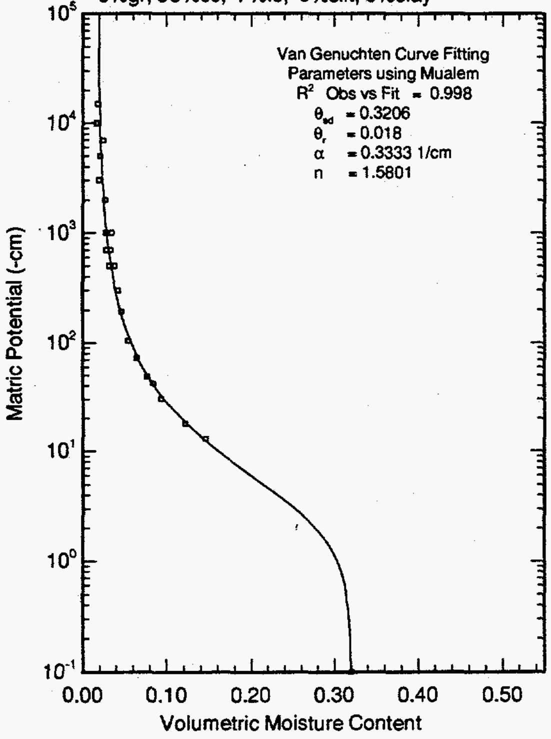
Injection; sample: 2-1637
0%gr, 80%cs, 20%fs, 0%silt, 0%clay



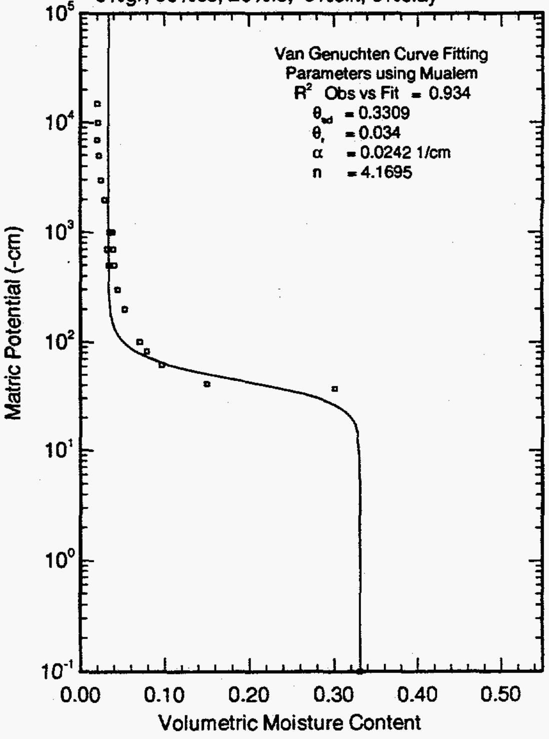
Injection; sample: 2-1638
0%gr, 81%cs, 19%fs, 0%silt, 0%clay

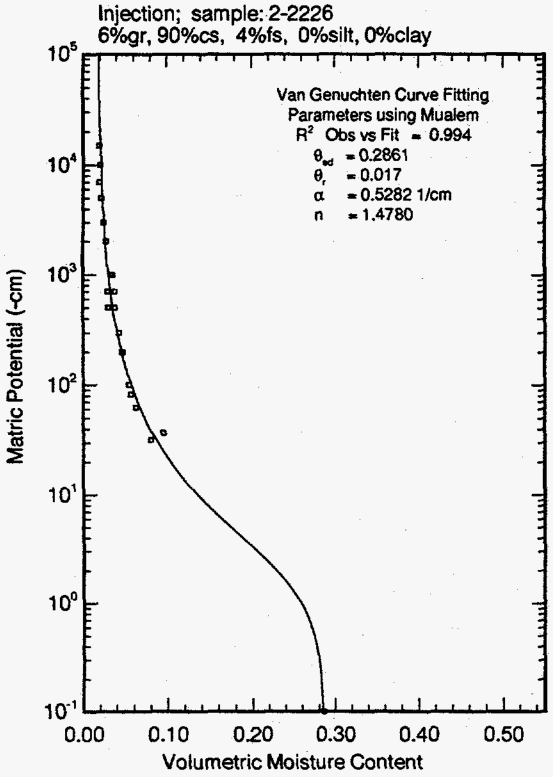


Injection; sample: 2-1639
0%gr, 93%cs, 7%fs, 0%silt, 0%clay

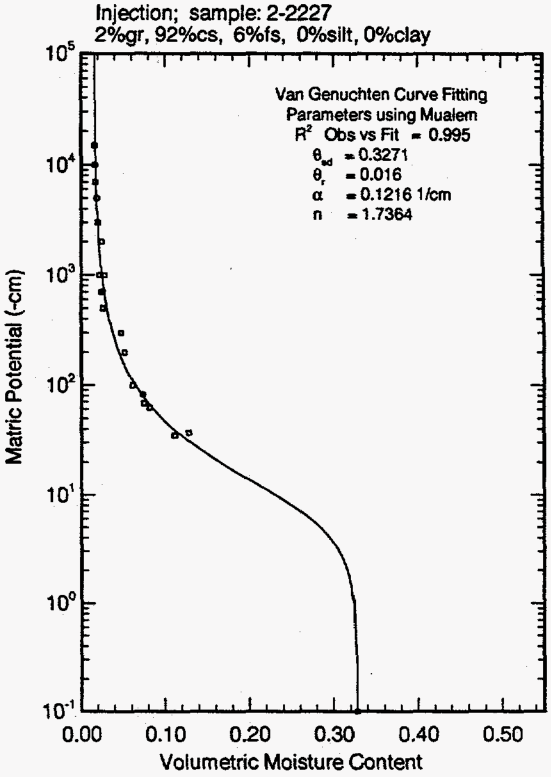


Injection; sample: 2-2225
0%gr, 80%cs, 20%fs, 0%silt, 0%clay

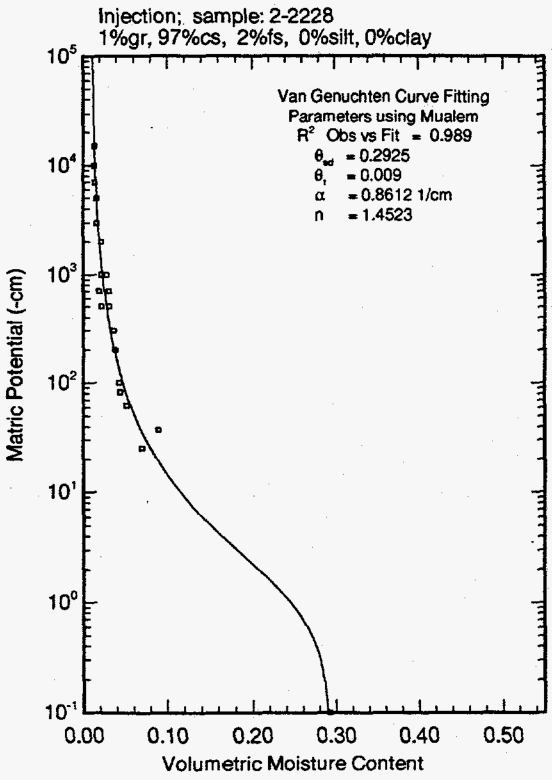




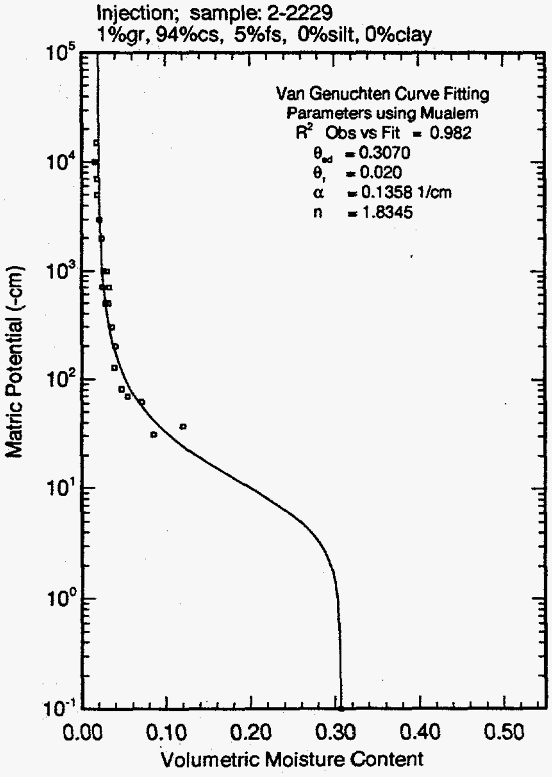
Injection; sample: 2-2226
6%gr, 90%cs, 4%fs, 0%silt, 0%clay



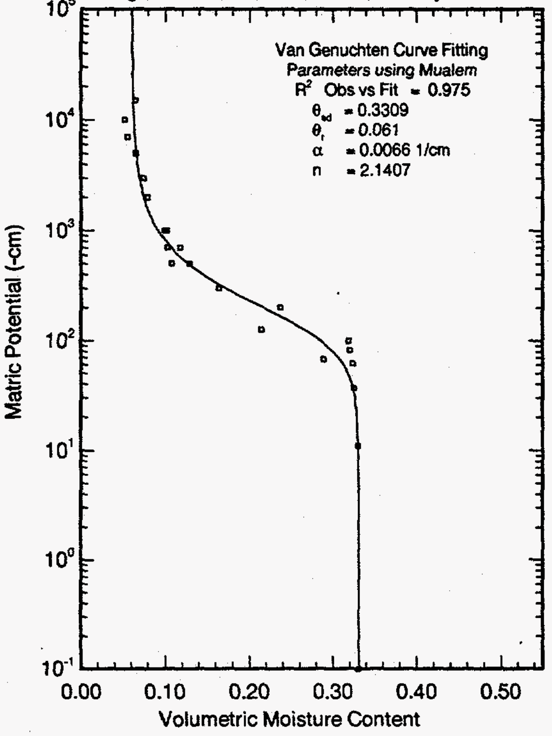
Injection; sample: 2-2227
2%gr, 92%cs, 6%fs, 0%silt, 0%clay

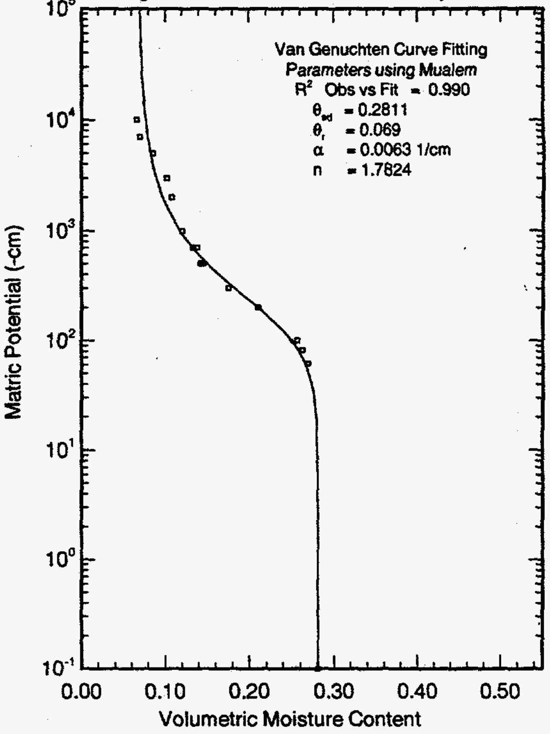


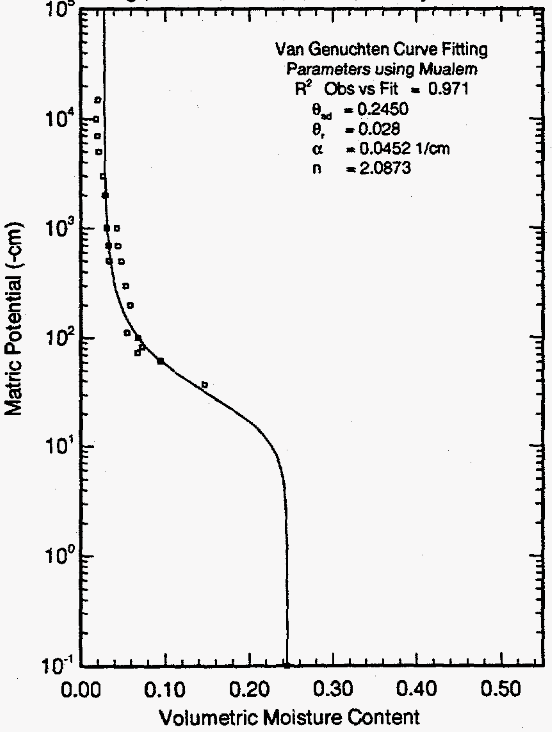
Injection; sample: 2-2228
1%gr, 97%cs, 2%fs, 0%silt, 0%clay

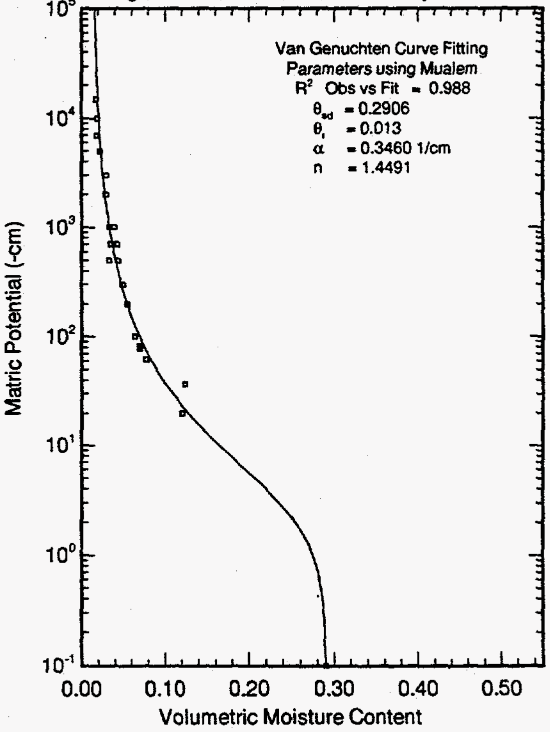


Injection; sample: 2-2229
1%gr, 94%cs, 5%fs, 0%silt, 0%clay

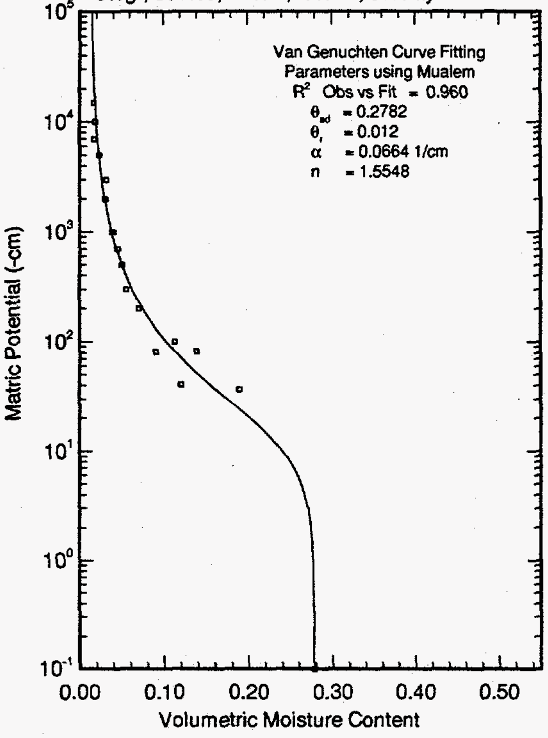

Injection; sample: 2-2230
2%gr, 32%cs, 52%fs, 11%silt, 3%clay


Injection; sample: 2-2231
12%gr, 52%cs, 36%fs, 0%silt, 0%clay

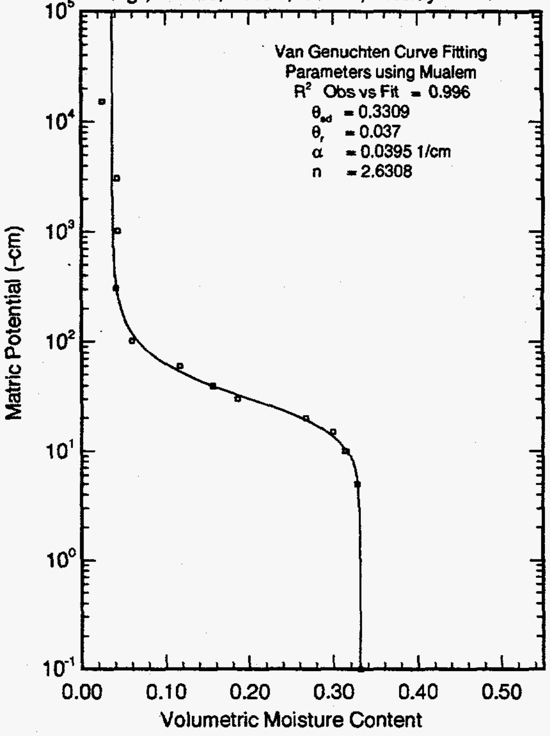

Injection; sample: 2-2232
4%gr, 88%cs, 8%fs, 0%silt, 0%clay


Injection; sample: 2-2233
2%gr, 90%cs, 8%fs, 0%silt, 0%clay

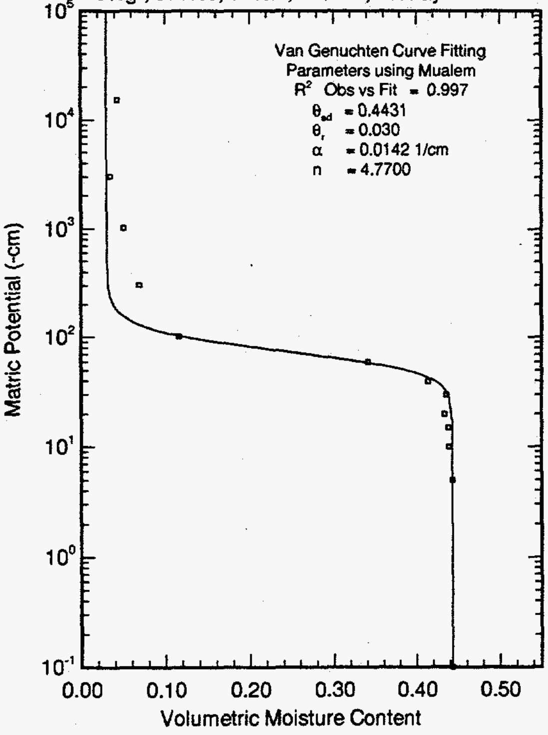
Injection; sample: 2-2234
0%gr, 86%cs, 14%fs, 0%silt, 0%clay



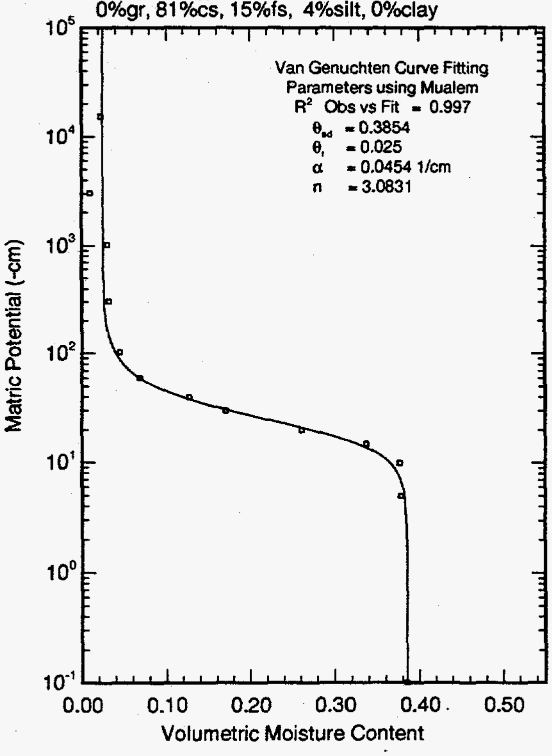
U.S. Ecology (MW5); sample: 50
1%gr, 75%cs, 18%fs, 6%silt, 0%clay



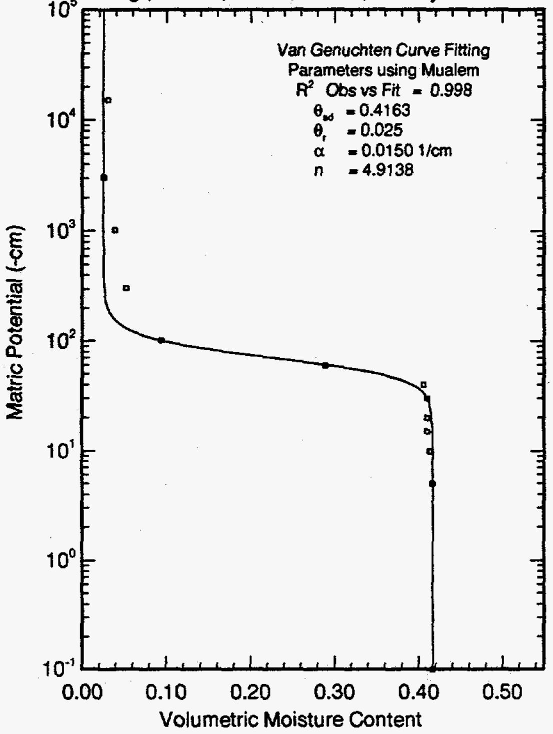
U.S. Ecology (MW5); sample: 70
0%gr, 38%cs, 51%fs, 11%silt, 0%clay



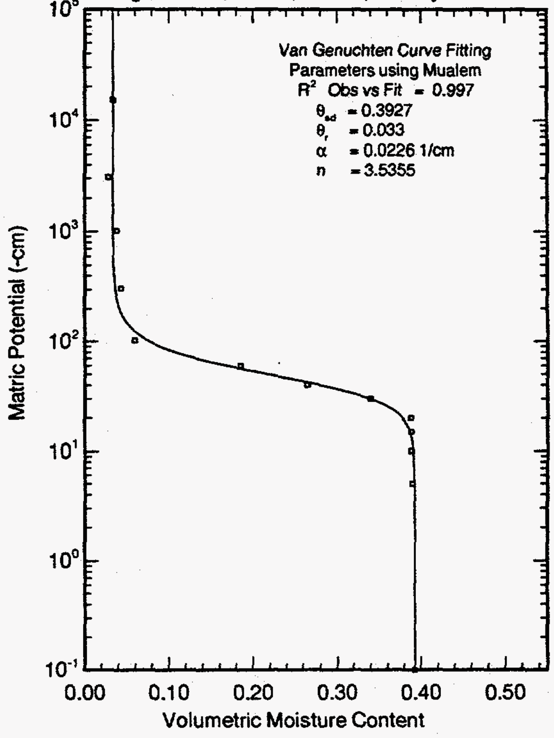
U.S. Ecology (MW5); sample: 90
0%gr, 81%cs, 15%fs, 4%silt, 0%clay



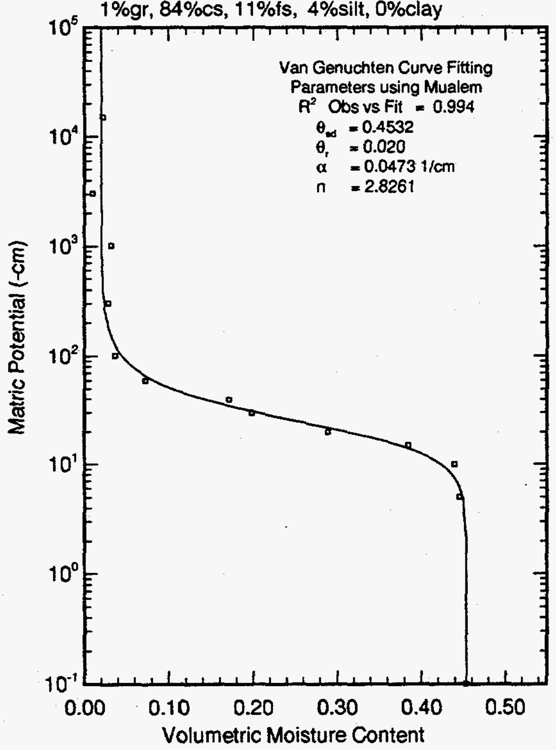
U.S. Ecology (MW5); sample: 130
0%gr, 28%cs, 68%fs, 4%silt, 0%clay



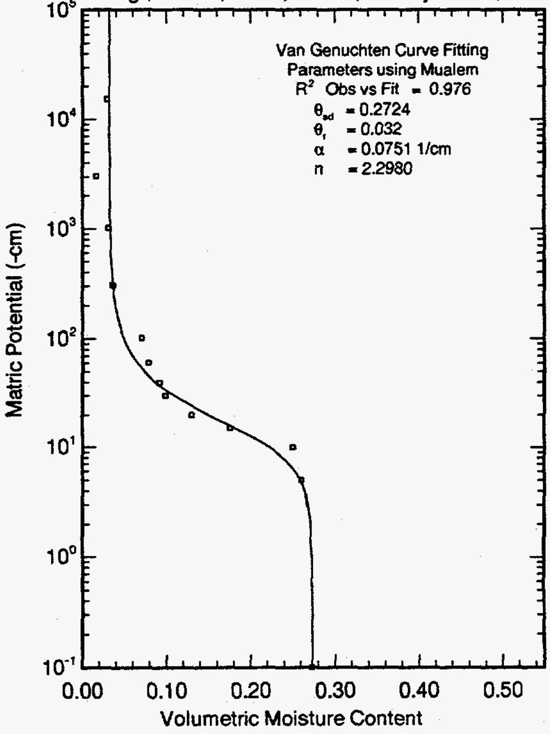
U.S. Ecology (MW5); sample: 170
0%gr, 52%cs, 42%fs, 6%silt, 0%clay

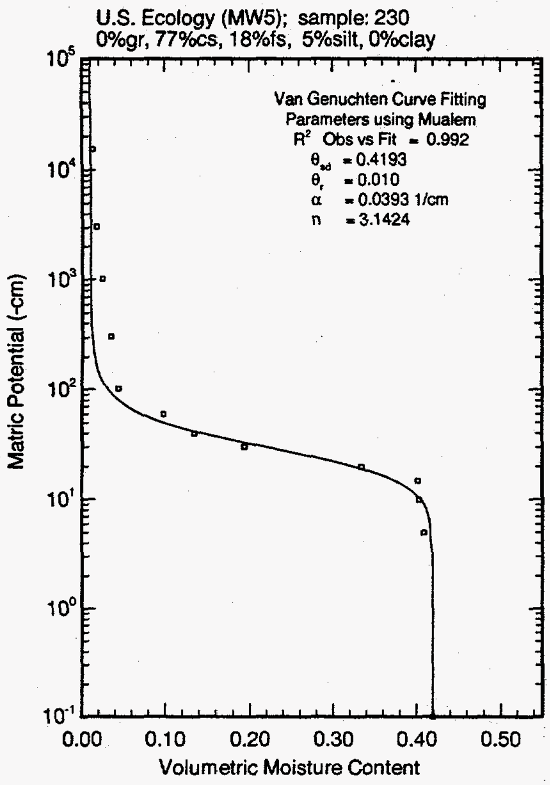


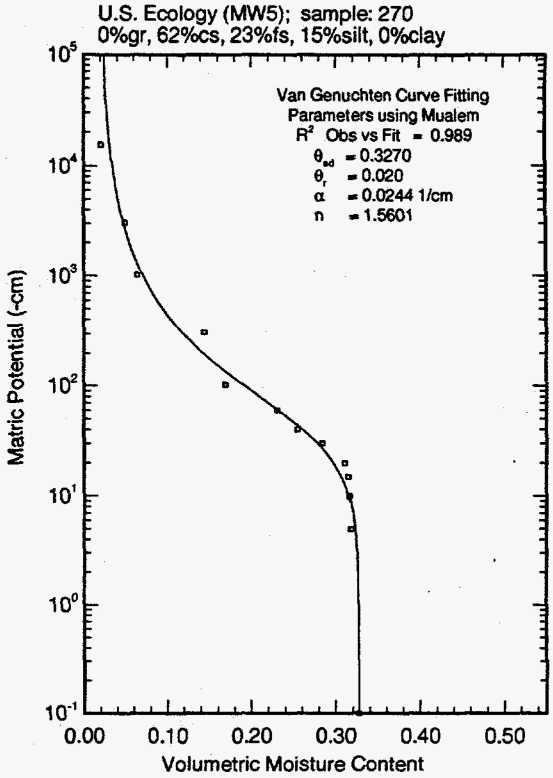
U.S. Ecology (MW5); sample: 190
1%gr, 84%cs, 11%fs, 4%silt, 0%clay

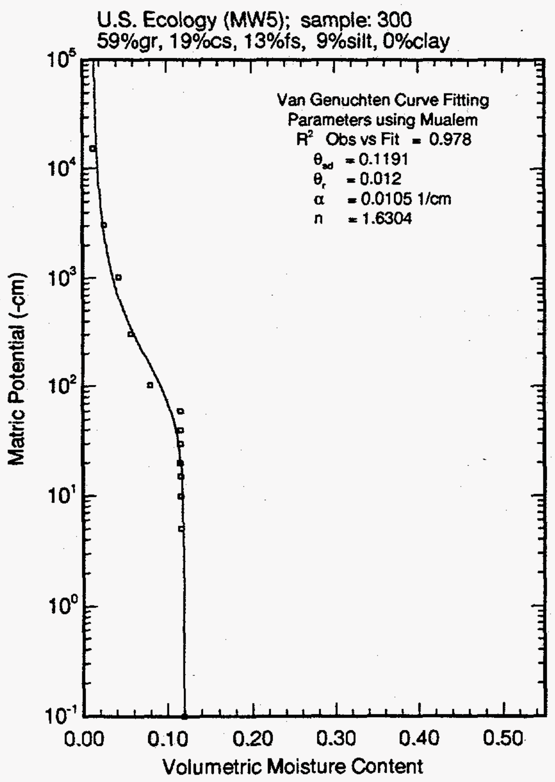


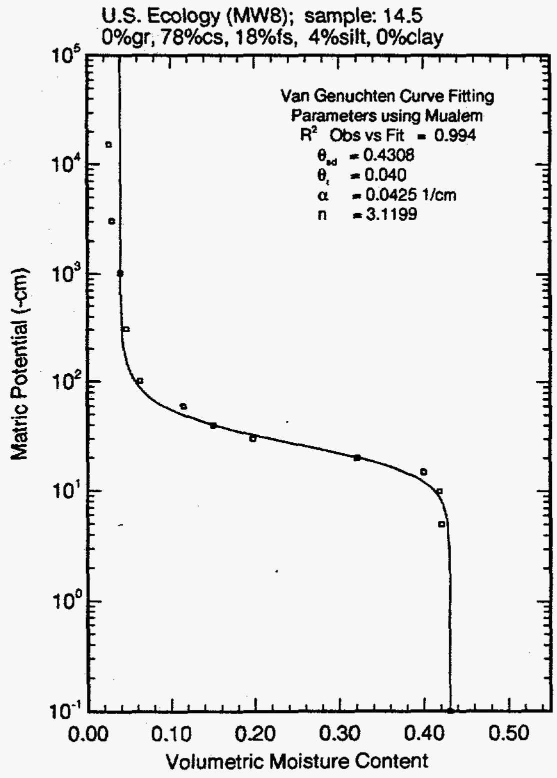
U.S. Ecology (MW5); sample: 210
3%gr, 85%cs, 8%fs, 4%silt, 0%clay

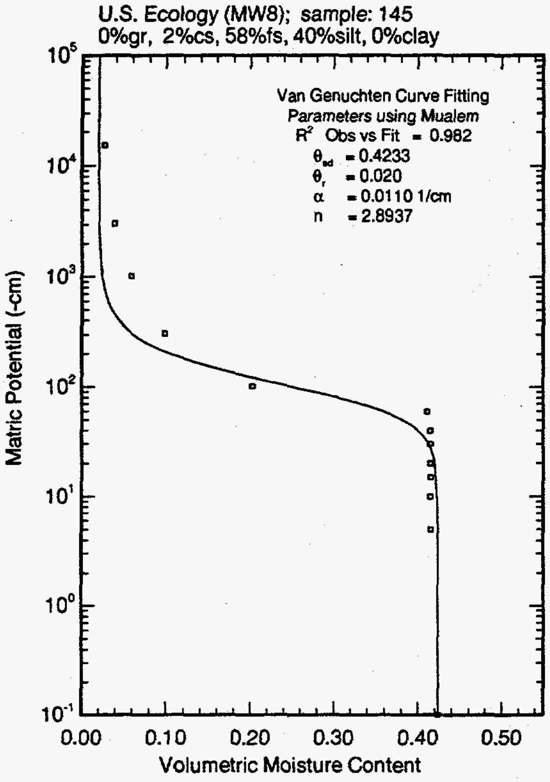



U.S. Ecology (MW5); sample: 230
0%gr, 77%cs, 18%fs, 5%silt, 0%clay

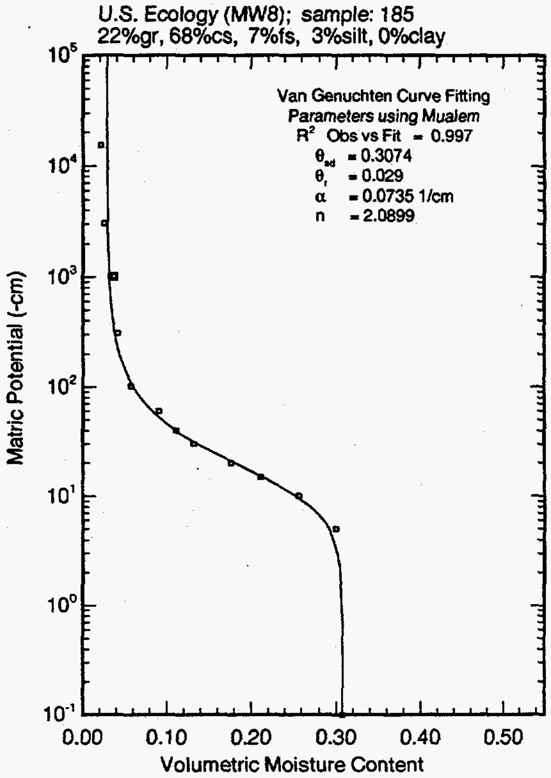

U.S. Ecology (MW5); sample: 270
0%gr, 62%cs, 23%fs, 15%silt, 0%clay


U.S. Ecology (MW5); sample: 300
59%gr, 19%cs, 13%fs, 9%silt, 0%clay

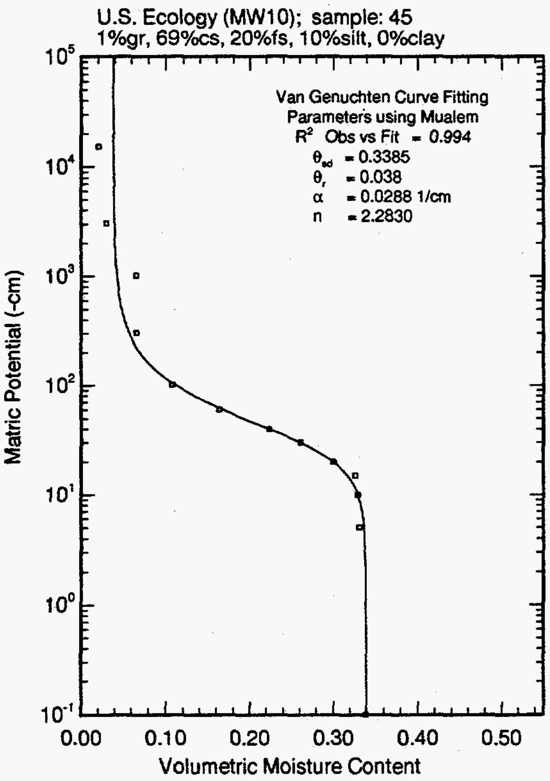

U.S. Ecology (MW8); sample: 14.5
0%gr, 78%cs, 18%fs, 4%silt, 0%clay



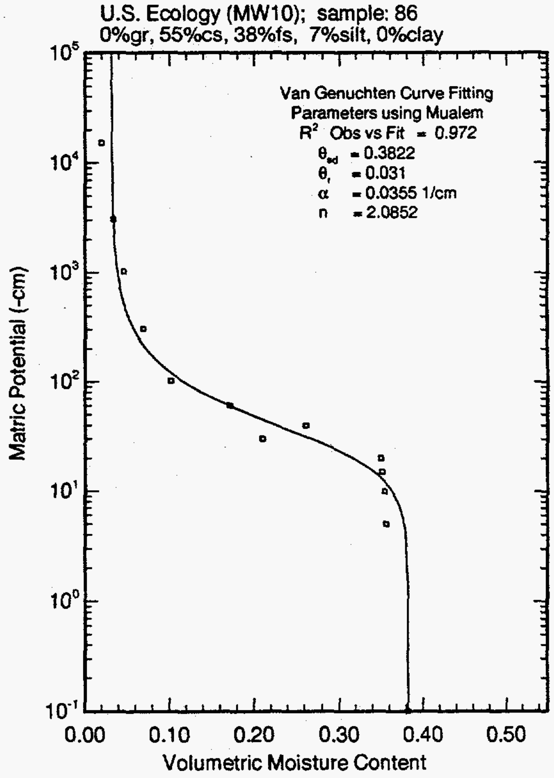
U.S. Ecology (MW8); sample: 145
0%gr, 2%cs, 58%fs, 40%silt, 0%clay



U.S. Ecology (MW8); sample: 185
22%gr, 68%cs, 7%fs, 3%silt, 0%clay

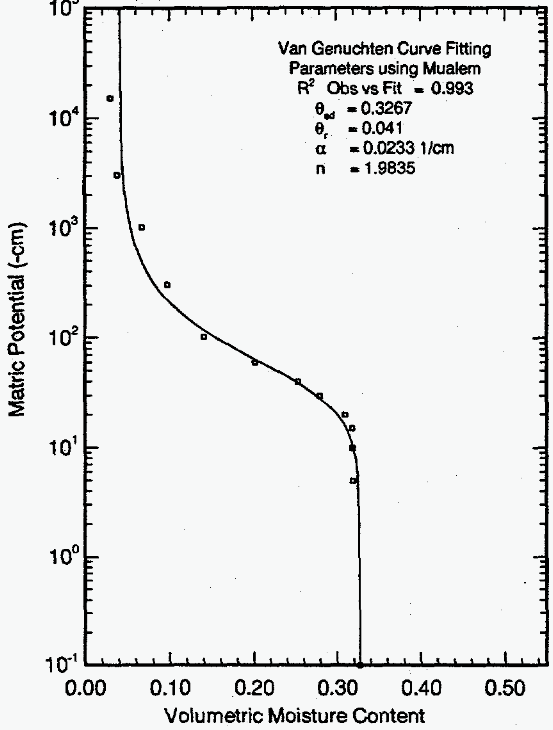


U.S. Ecology (MW10); sample: 45
1%gr, 69%cs, 20%fs, 10%silt, 0%clay

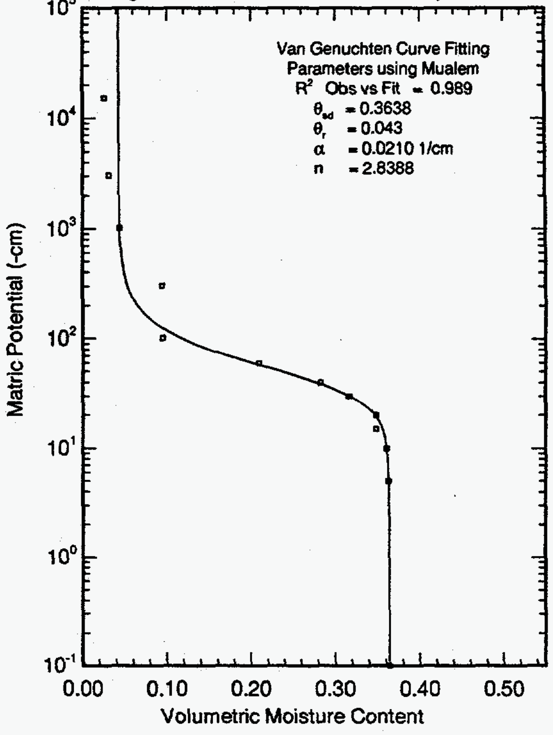


U.S. Ecology (MW10); sample: 86
0%gr, 55%cs, 38%fs, 7%silt, 0%clay

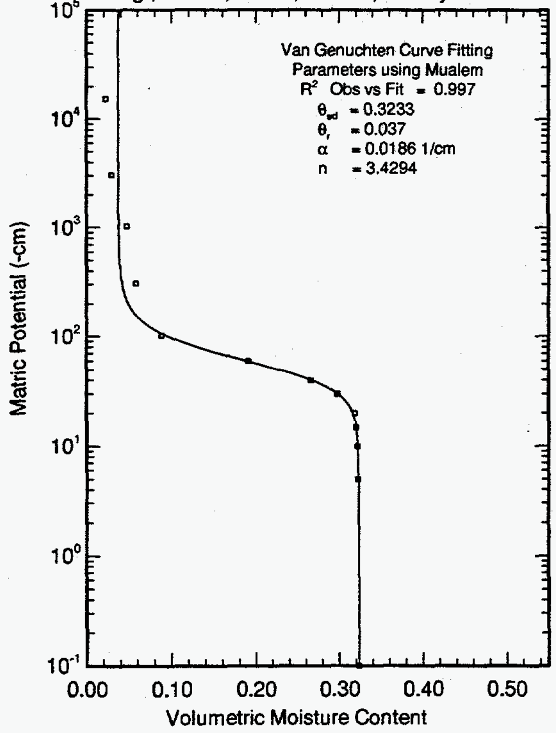
U.S. Ecology (MW10); sample: 105
1%gr, 62%cs, 24%fs, 13%silt, 0%clay



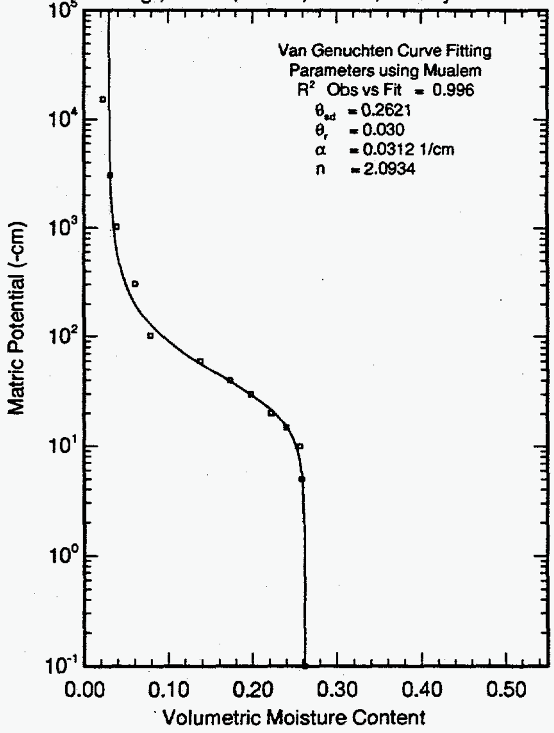
U.S. Ecology (MW10); sample: 125
1%gr, 59%cs, 30%fs, 10%silt, 0%clay



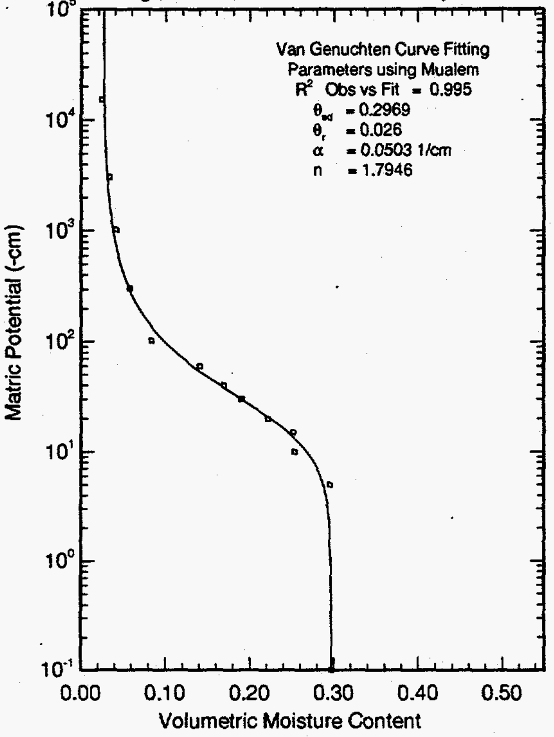
U.S. Ecology (MW10); sample: 165
1%gr, 59%cs, 30%fs, 10%silt, 0%clay



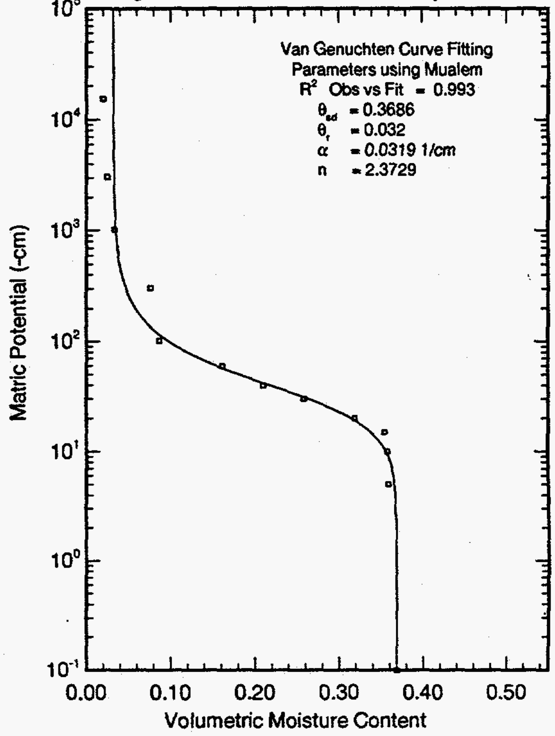
U.S. Ecology (MW10); sample: 195
24%gr, 57%cs, 13%fs, 6%silt, 0%clay



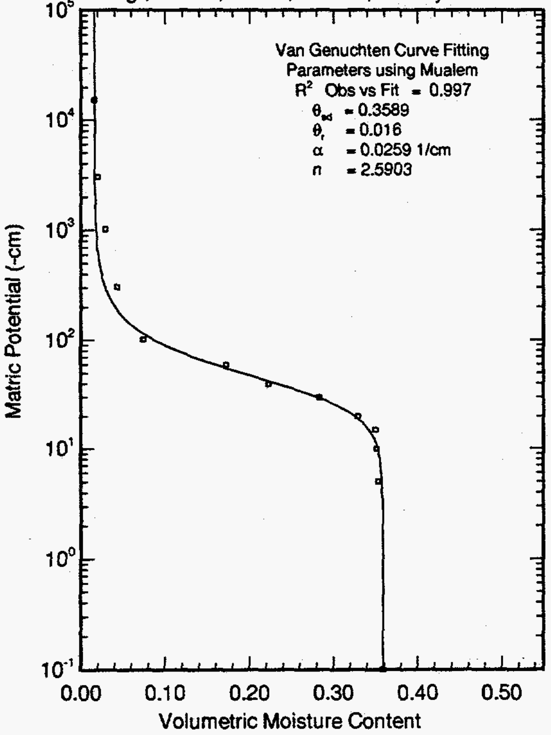
U.S. Ecology (MW10); sample: 205
10%gr, 71%cs, 12%fs, 7%silt, 0%clay



U.S. Ecology (MW10); sample: 245
0%gr, 71%cs, 20%fs, 9%silt, 0%clay



U.S. Ecology (MW10); sample: 265
0%gr, 64%cs, 25%fs, 11%silt, 0%clay



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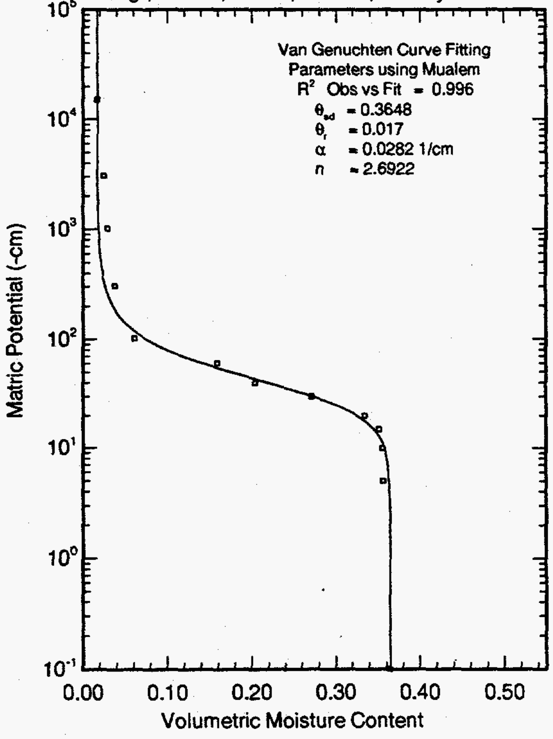

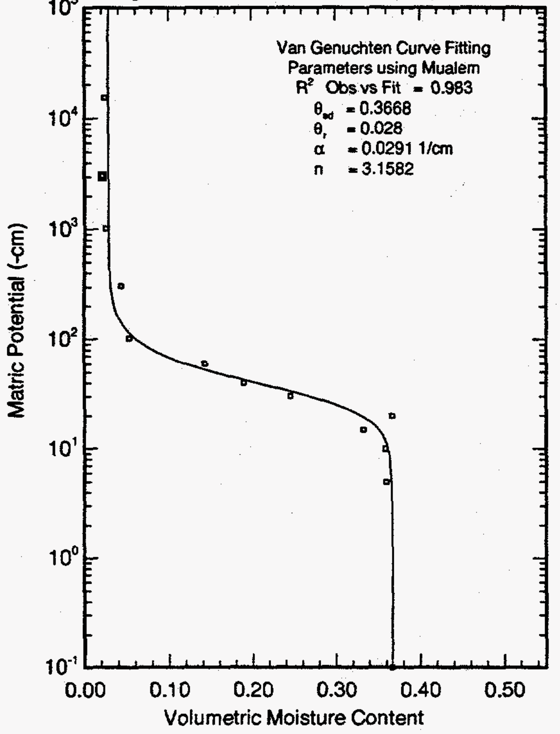
U.S. Ecology (MW10); sample: 300
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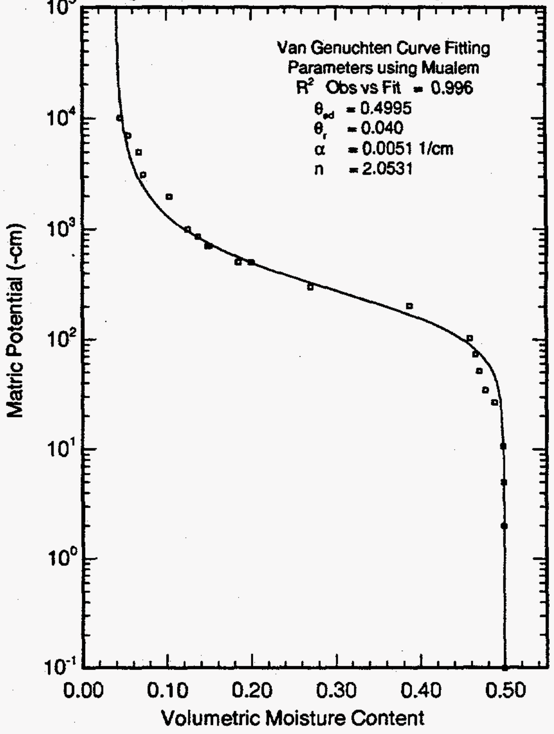
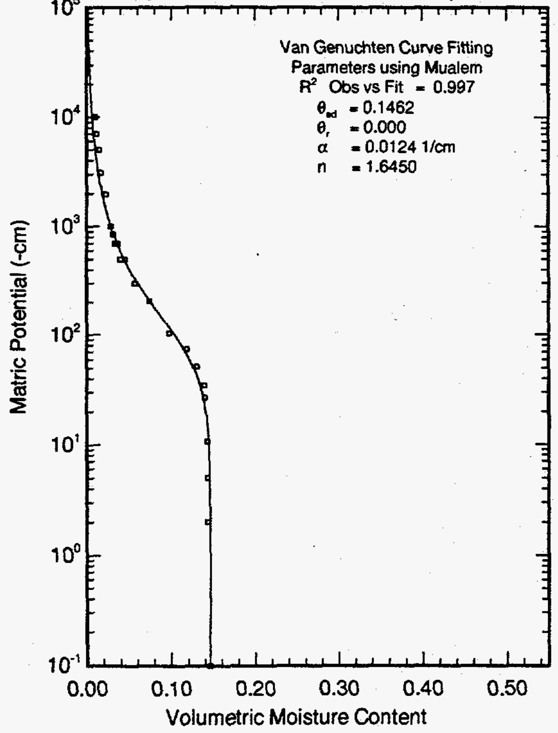
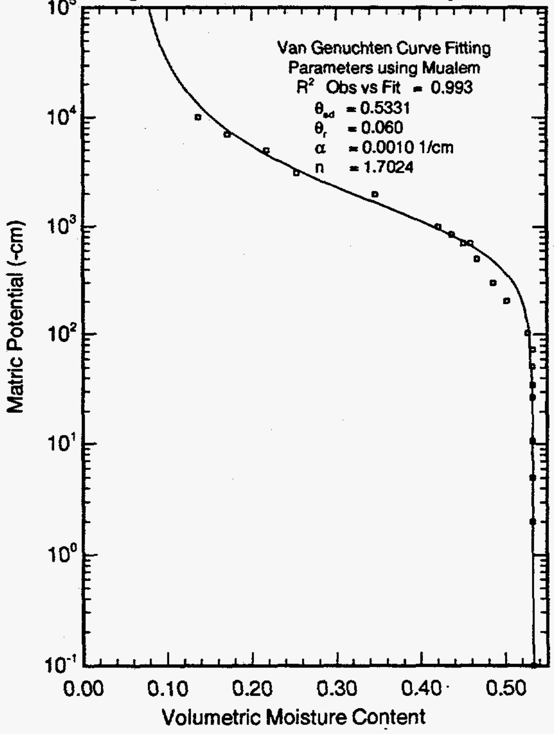

VOC; sample: 3-0647
0%gr, 2%cs, 78%fs, 14%silt, 6%clay


VOC; sample: 3-0648
62%gr, 18%cs, 20%fs, 0%silt, 0%clay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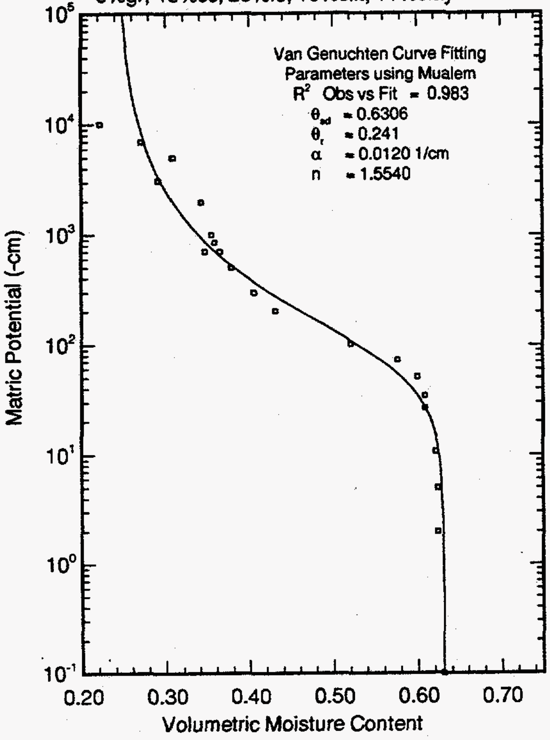
0%gr, 10%cs, 38%fs, 40%silt, 12%clay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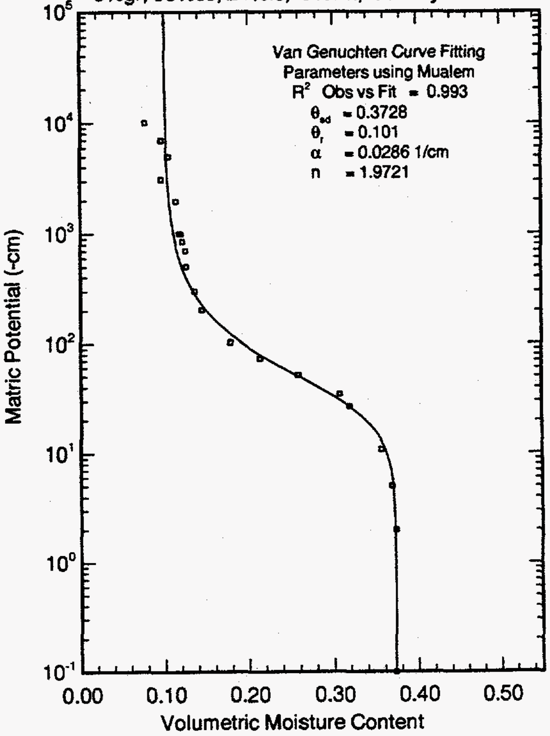
0%gr, 46%cs, 28%fs, 15%silt, 11%clay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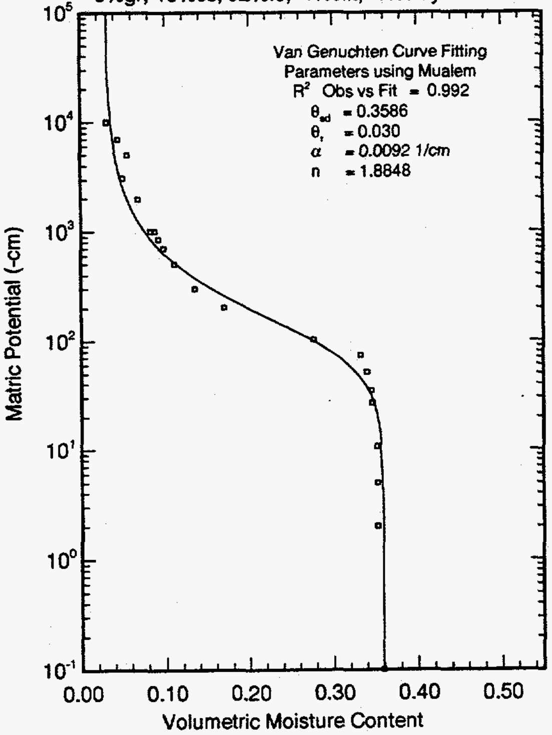
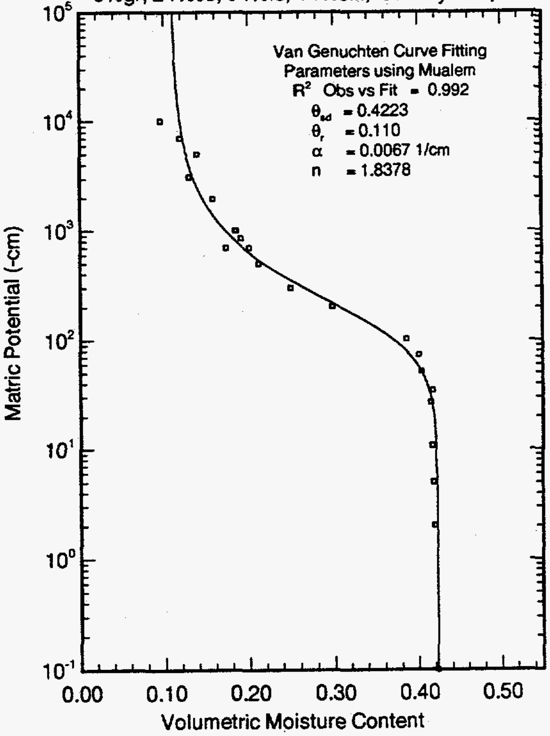
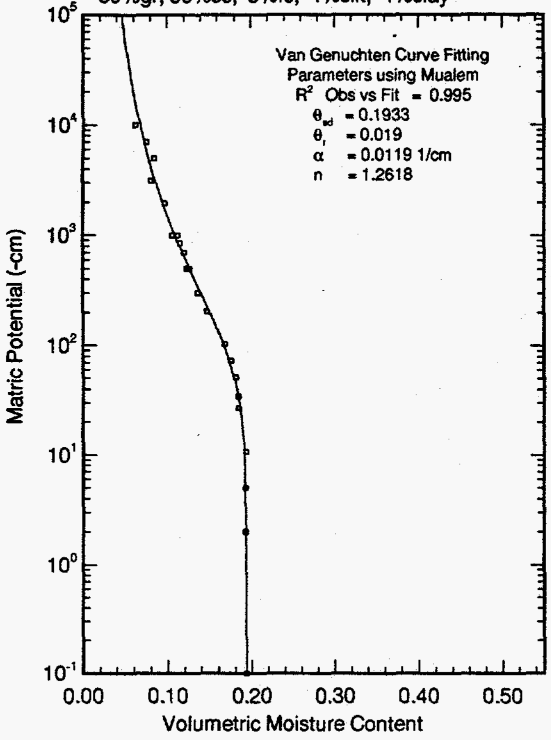
0%gr, 58%cs, 24%fs, 9%silt, 9%clay

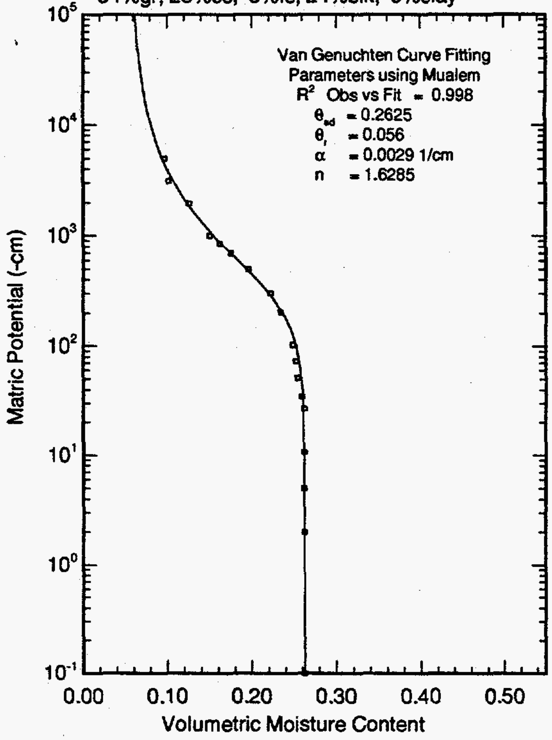

VOC; sample: 3-0652
0%gr, 40%cs, 52%fs, 4%silt, 4%clay


VOC; sample: 3-0653
0%gr, 24%cs, 54%fs, 14%silt, 8%clay

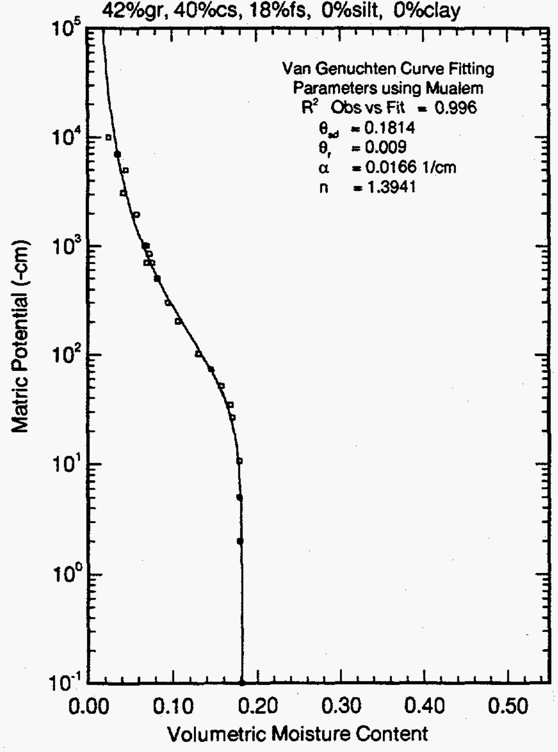
VOC; sample: 3-0654
59%gr, 30%cs, 3%fs, 4%silt, 4%clay



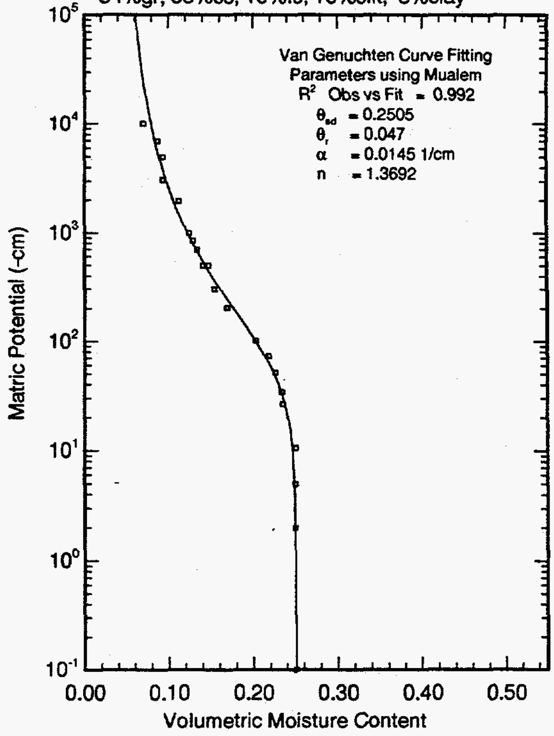
VOC; sample: 3-0655
34%gr, 28%cs, 8%fs, 24%silt, 6%clay



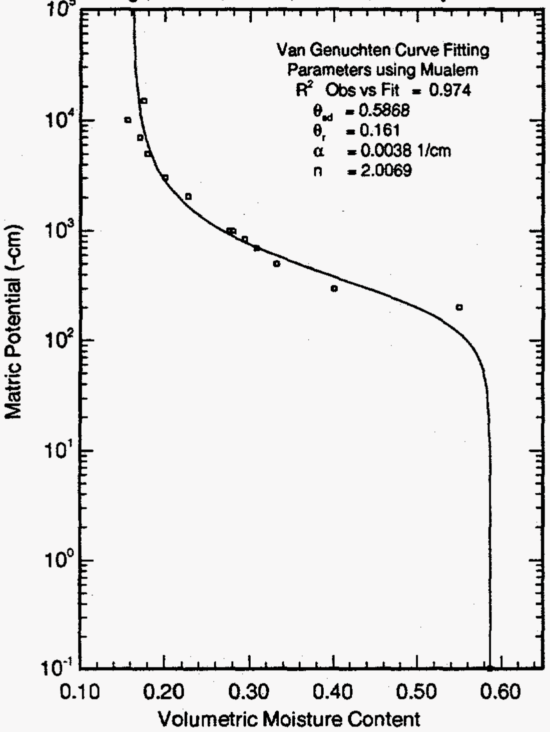
VOC; sample: 3-0656
42%gr, 40%cs, 18%fs, 0%silt, 0%clay



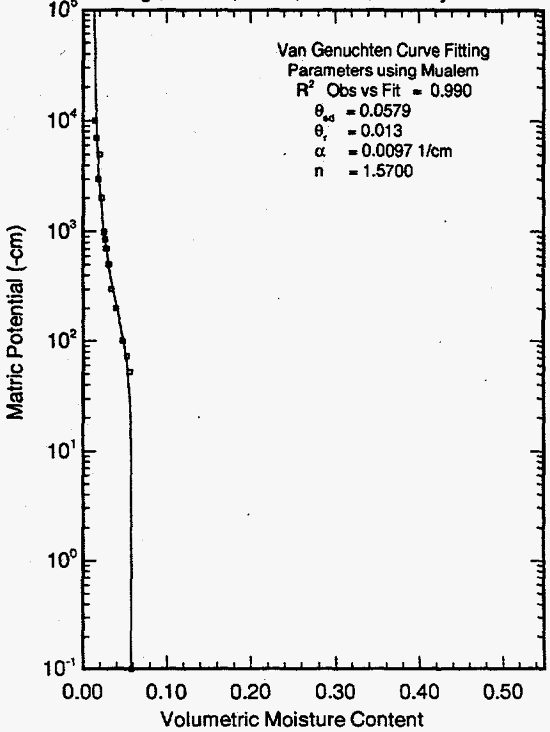
VOC; sample: 3-0657
34%gr, 38%cs, 10%fs, 10%silt, 8%clay



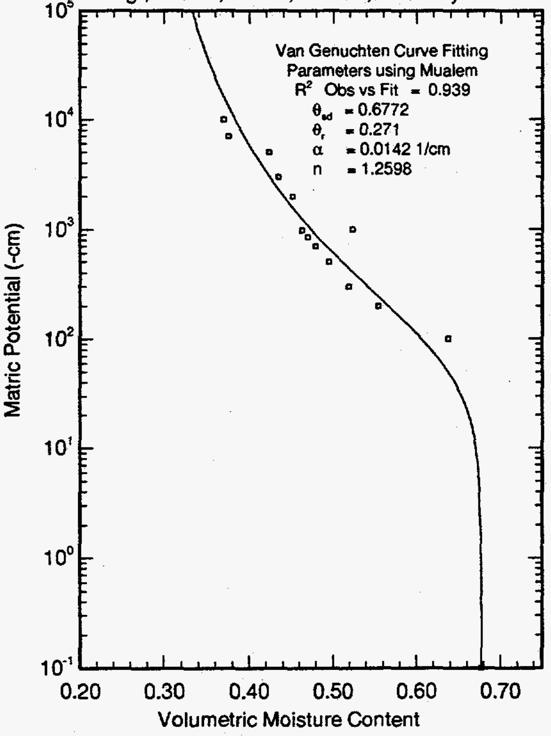
W-049-H; sample: 2-2865
0%gr, 22%cs, 58%fs, 14%silt, 6%clay



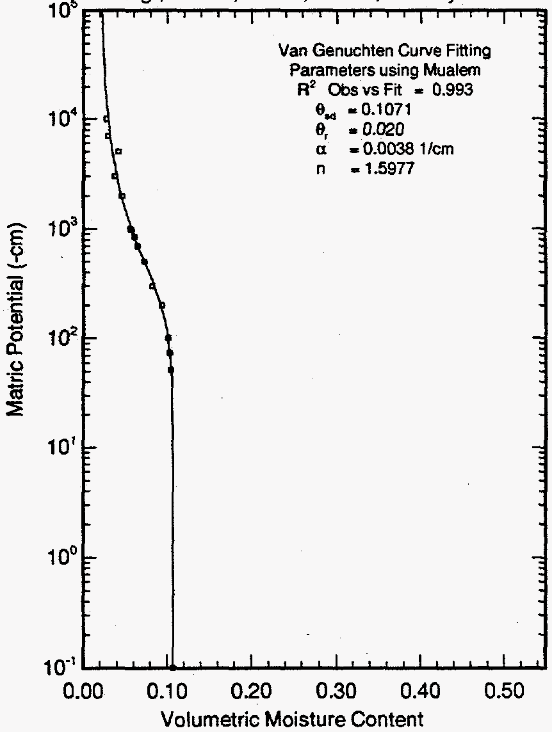
W-049-H; sample: 2-3084
82%gr, 14%cs, 4%fs, 0%silt, 0%clay



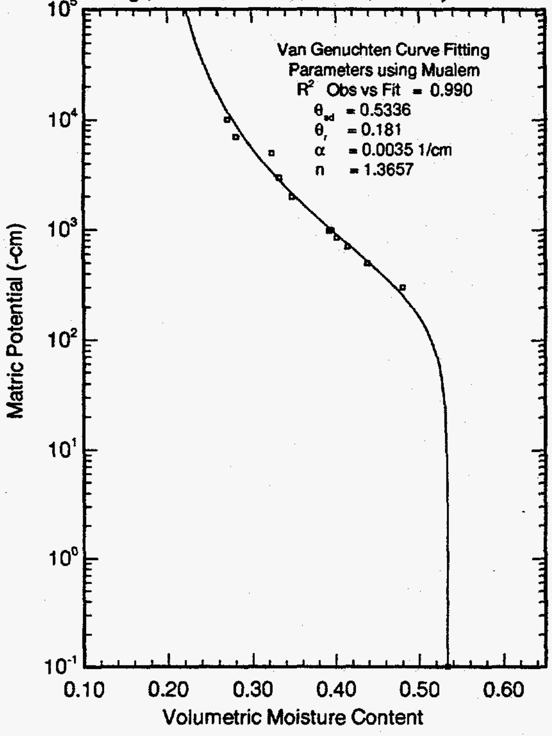
W-049-H; sample: 2-3085
0%gr, 55%cs, 25%fs, 10%silt, 10%clay



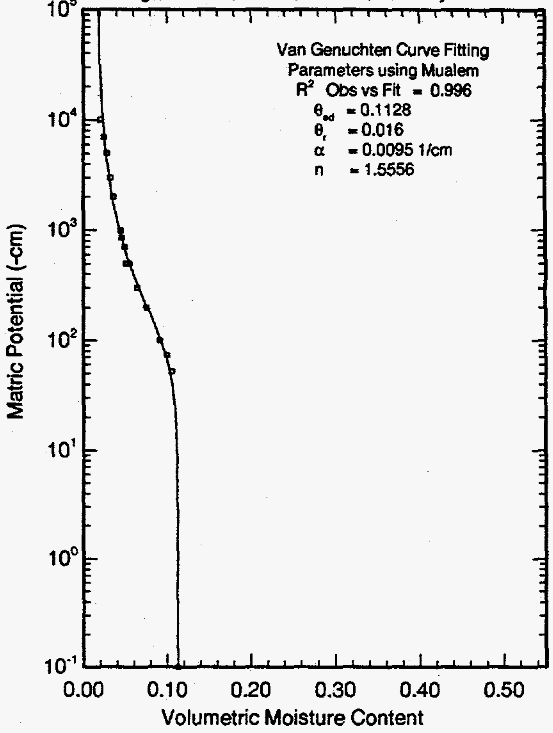
W-049-H; sample: 2-3088
65%gr, 20%cs, 12%fs, 3%silt, 0%clay



W-049-H; sample: 2-3089
0%gr, 35%cs, 30%fs, 27%silt, 8%clay



W-049-H; sample: 3-0001
68%gr, 19%cs, 6%fs, 7%silt, 0%clay



W-049-H; sample: 3-0003
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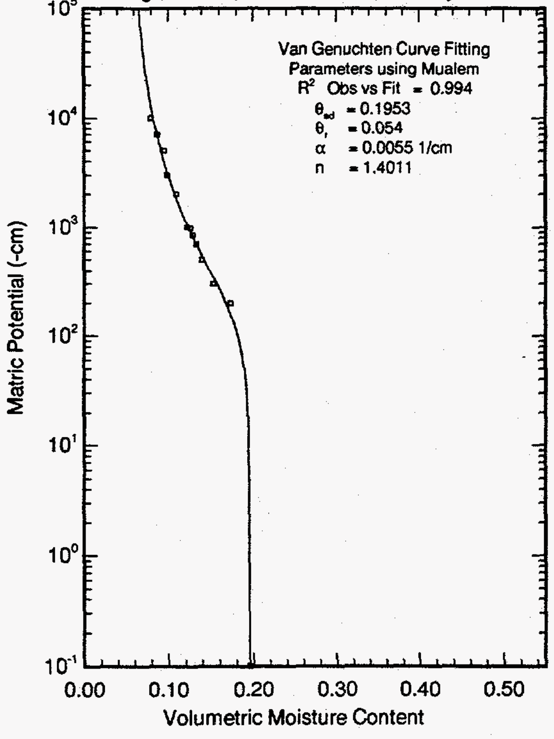

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