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Pacific Northwest National Laboratory
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Summary

This report presents sampling and measurement procedures and measurement results for 60 samples from the S-1, S-2, and S-3 bore holes at the Vadose Zone Transport Field Study Leak Simulation Test Site, located at the Sisson and Lu (1984) injection site in the 200 East Area of the Hanford Site. Measured data include particle size distributions (19 points), bulk densities (and bulk density-derived porosity), water retention characteristics (16 static points), and saturated and unsaturated hydraulic conductivities.

The coring and sub-sampling procedures led to partially, and occasionally completely, disturbed samples. Textural analyses showed that most of the samples could be classified as sand, some as loamy sands, and two as sandy loams. The multi-step outflow method failed for seven samples, yielding 53 samples for which hydraulic parameters were available. Van Genuchten and Brooks-Corey water retention parameters were determined using static retention points (derived from multi-step outflow time series). Inverse analyses of the multi-step outflow data yielded additional unsaturated hydraulic conductivity parameters. Unfortunately, the inverse analyses had some problems in reaching stable solutions. Therefore, we sometimes fixed saturated and residual water contents and saturated hydraulic conductivities at initial values. Even then, it was not possible to reach a solution for two samples leaving the total number of samples for which inverse solutions were available at 51. We also noticed that Brooks-Corey inversions were of lesser quality than van Genuchten inversions. We suggest that Brooks-Corey inversions be treated carefully and that, where possible, the far more reliable direct fits of the Brooks-Corey curve to the static retention data be used.

The data gathered in this effort are for the most part reported in the appendix. Raw, outflow time series data from the multi-step outflow procedure are not included. An electronic version of the data is available from the first and third authors.

Acknowledgments

The samples discussed in this report were taken from cores provided by Glendon Gee, Andy Ward, and George Last of Pacific Northwest National Laboratory as part of the Vadose Zone Transport Field Study, Hanford Science and Technology Project funded by the U.S. Department of Energy Richland Operations Office. Mark Rockhold of Pacific Northwest National Laboratory provided valuable review of the data and this report. The work discussed in this report was supported by the U.S. Department of Energy Environmental Management Science Program.

Contents

Figures

Tables

1.0 Introduction

Assessing the environmental impact of past and future activities at the Hanford Site often makes use of models that simulate the hydrological processes in and around the disposal facilities. Presently, the appropriateness of the models is being tested using data obtained in past and recent on-site field experiments. Complicating factors are the depth of the unsaturated zone and the high degree of vertical variability in the sediments, resulting in a high degree of spatial variability in hydraulic properties. This report describes an effort to measure unsaturated hydraulic properties at the Vadose Zone Transport Field Study Leak Simulation Test Site, located at the Sisson and Lu (1984) injection site in the 200 East Area of the Hanford Site in Washington State. The information presented in this report partly complements a report by Last and Caldwell (2001) who described the core sampling done at this site during the summer of 2000. This report describes the sampling and measurement methodologies for determining water retention and hydraulic conductivity in the lab, and presents some analysis of the results. The appendices present the majority of the data collected, but do not include the raw multi-step outflow data. The data reported here are also available from the first or third authors in electronic format as a spreadsheet file.

2.0 Hydraulic Properties

Soil hydraulic properties are required to model transport of water and solutes in the vadose zone. A broad array of methods currently exists to determine soil hydraulic properties in the field or in the laboratory (Dane and Topp 2002). Field methods allow for *in-situ* determination of the hydraulic properties but have uncertainties about the actual sample volume. Laboratory measurements often require more sample preparation but do allow a larger number of measurements and a better control of the experimental conditions.

The hydraulic characteristics necessary to calculate flow and transport in porous media are water retention and saturated and unsaturated hydraulic conductivity. Water retention characteristics are commonly given as the water content (θ, with units of cm^3 of water per cm^3 of soil) versus a capillary pressure (h, usually defined in cm of water pressure). The notation followed in this report will assume that h is negative for unsaturated soils. The water content of nearly all porous media decreases with increasingly negative capillary pressures. For reference, plant life is generally possible for pressures between 0 and $-1.5\ 10^4$ cm, while extremely dry desert soils may have even lower pressures (and very low water contents). The shape of the water retention characteristic, however, is strongly dependent on soil texture, porosity, and other factors. The strongest changes in water content are generally present around the "air entry" value, which is generally the capillary pressure where the most common pore-size drains.

Saturated hydraulic conductivity, K_s, provides the water conductivity at zero or positive capillary pressure (i.e., when the soil is completely saturated with water). Unsaturated hydraulic conductivity provides the water conductivity in terms of capillary pressure, $K(h)$, or water content or relative saturation ($K(S_e)$, discussed below). Measurement of unsaturated conductivity is generally difficult, cumbersome, and expensive. Reasons for this are that unsaturated hydraulic conductivity can vary many orders of magnitude within a pressure range between 0 and -10^3 cm and substantial data analyses (e.g. inverse modeling) are often needed. Reduction in conductivity with decreasing pressure is especially strong for pressures smaller than the air entry value (or water contents smaller than the water content at the air-entry pressure).

For modeling and other numerical or graphical purposes, it is often convenient to provide the water retention and unsaturated hydraulic conductivity characteristics in functional form. For this purpose, the van Genuchten (1980) and Brooks-Corey (1964) equations are commonly used to describe the water retention characteristic with four adjustable parameters. Combining the van Genuchten and Brooks-Corey equations with the Mualem (1976) pore-size distribution model yields an unsaturated hydraulic conductivity expression for which two additional adjustable parameters are required. The van Genuchten (1980) equation for water retention is:

$$S_e(h) = \frac{\theta(h) - \theta_r}{\theta_s - \theta_r} = \frac{1}{\left(1 + |\alpha h|^n\right)^{1-1/n}} \qquad [1]$$

Substitution into the Mualem (1976) model yields a closed-form expression for the unsaturated hydraulic conductivity characteristic,

$$K(S_e) = K_0 S_e^L \left[1 - \left(1 - S_e^{1/m}\right)^m\right]^2 \qquad [2]$$

where m=1-1/n. To make an easy comparison with the van Genuchten equation possible, we use a modified notation for the Brooks-Corey (1964) equation in which we replaced the bubbling pressure h_b with $1/\alpha$

$$S_e(h) = \frac{\theta(h) - \theta_r}{\theta_s - \theta_r} = \begin{cases} \dfrac{1}{|\alpha h|^{\lambda}} & h < -1/\alpha \\ 1 & h \geq -1/\alpha \end{cases} \qquad [3]$$

The corresponding equation for the unsaturated hydraulic conductivity characteristic is given by

$$K(S_e) = \begin{cases} K_0 S_e^{2+L+2/\lambda} & h < -1/\alpha \\ K_0 & h \geq -1/\alpha \end{cases} \qquad [4]$$

In these equations S_e is the relative saturation, θ is the water content, h is the pressure head, $K(S_e)$ is the unsaturated hydraulic conductivity function, and θ_r and θ_s denote the residual and saturated water contents, respectively. K_0 is the matching point at saturation, and α, n, λ, and L are curve shape parameters. Generally, α is interpreted as the inverse of the air-entry pressure, n and λ are pore distribution parameters, and L is a pore connectivity or pore continuity parameter (Mualem 1976). The hydraulic characteristics defined by Eqs. (1) and (2), or Eqs. [3] and [4] contain 6 unknown parameters: θ_r, θ_s, α, n (or λ), L, and K_0. We did not a-priori assume that $K_0 = K_s$ as Schaap and Leij (2000) showed that K_0 is often much smaller than K_s because of the effects of macropore versus matrix flow.

3.0 Methods

3.1 Sampling and Sub-Sampling Procedure

The hydraulic data that are presented in this report were obtained from samples derived from three boreholes, S-1, S-2, and S-3, at the Sisson and Lu Site in the 200 East Area of the Hanford Site (officially, the 299-E24-111 Experimental Test Well Site). A site description, borehole logs, and related data are described in Last and Caldwell (2001). To give a comprehensive description of the way the samples were obtained we quote Last and Caldwell (2001) while adding some images to their description. Figure references were added and refer to figures in this report.

> Each borehole was drilled using a Mobile Drill 61 drill rig and 25 cm (10 in.) OD hollow-stem auger flights (Fig. 1a). The upper 4 m (13 ft) of each borehole was drilled with a pilot bit inside the hollow-stem auger to keep drill cuttings out. Once the borehole was advanced to the desired sampling interval, the pilot bit was removed, and a 7.6 cm (3 in) ID by 0.6 m (2 ft) long splitspoon sampler was lowered to the bottom of the borehole. The sampler was then driven into relatively undisturbed materials in front of (i.e., below) the auger flights using a drive hammer weighing up to 227 kg (500 lbs.). Once the sampler had been driven the length of the sampler, or to refusal, the sampler was withdrawn and taken to the breakdown table for disassembly and subsampling (Fig. 1b). However, at times, during difficult retrievals, the sampled materials were not retained by the sampler, and thus not recovered from that particular sampling interval. Once the sampler was retrieved from the borehole, the pilot bit was again lowered into the auger flights and the borehole advanced to the next sampling interval.
>
> Once the splitspoon sampler was taken to the breakdown table and disassembled, one half of the sample barrel was removed to expose the four 15 cm (6 in.) long Lexan core liners (Fig 1c) and a cursory inspection was made to evaluate the representativeness and the vertical heterogeneity of the various geologic strata. The most intact and representative core liners were selected for analysis and/or archiving, marked with an up arrow, and labeled in accordance with the Pacific Northwest National Laboratory's (PNNL) procedure PNL-MA-567, DO-2. The selected core liners were carefully removed from the sample barrel in a way that would minimize the loss of material out of the liner (Fig 1d). The liners were then capped and transferred to the field laboratory for archiving and further subsampling. Remaining sample was then recapped, sealed and refrigerated.
>
> Each splitspoon sampling run was identified by a unique number, and each sample liner was labeled relative to its position within the splitspoon sampler. For boreholes S-2 and S-3, the bottom most (deepest) liner was designated as "A" and the top most (shallowest) liner designated as "D", in accordance with procedure PNL-MA-567, DO-2. Note, however, that the liners for borehole S-1 were labeled just opposite to this with "D" being the deepest sample liner and "A" being the shallowest. Each sample was labeled not only with the unique sample and liner number, but also with the borehole number, the depth interval, and the date of sample collection. [Last and Caldwell, 2001, pp. 1-4]

The procedures for determining hydraulic properties at the GEBJ Salinity Laboratory require 6 cm high, 5.6 cm O.D. (5.3 cm I.D.) samples that are smaller than the 7.6 cm Lexan liners from the splitspoon sampling. The smaller cores were obtained by sub-sampling the continuous splitspoon samples. To this end, we taped a 1 cm spacer ring to the top and bottom of a brass sampling ring using duct tape. A 2-kg hammer was subsequently used to ram the spacer-sampling ring assembly into the Lexan core liners (Fig. 1e). At times, several blows were necessary to insert the core ring below the top surface of the liners. We carefully extracted the spacer-sampling ring assembly (Fig. 1f) and removed the spacer ring (Fig. 1g.).

Figure 1. Splitspoon core sampling (a-d) and brass ring subsampling (e-h). Pictures taken by P.D. Meyer and G.W. Gee.

The exposed material was then carefully removed with a knife such that the material in the ring had a level surface (Fig. 1h). Some loose samples were not obtained with this procedure. Instead we filled the brass core ring by hand from the loose material (mostly material from incompletely filled liners). A total of 60 samples were obtained, 33 for borehole S-1, 12 samples for S-2, and 15 for S-3. The brass rings were capped and stored for transport. The samples were taken as carry-on luggage for airplane transport to the GEBJ Salinity Lab (Riverside, CA). Additional material (about 200 g/sample) was put in Zip-Lock^{TM} bags and shipped by commercial courier. At the GEBJ Salinity Lab, the samples were stored in a dark, cold (5 C) storage room until the hydraulic measurements started.

The relative violence used in the coring process (drilling rig and sub-sampling) probably resulted in samples that did not completely preserve the natural structure of the parent material. We observed that finer material seemed to stick to the Lexan liner, whereas coarser material was located in the center of the cores. This may have been due to sorting caused by the hammer blows while retrieving the splitspoon samples (George Last, personal communication, May 31, 2000). Because we took the brass rings mainly from the center, there may thus be a bias towards coarser material. Sometimes the brass ring did not go in straight because a small pebble was blocking the insertion. During the sample insertion, we also observed that the material of several samples rose above the rim of the brass ring. We assume that the samples are semi-undisturbed at best. Because of confinement during the two coring processes we expect that the bulk density increased somewhat, though it is difficult to say by how much.

3.2 Laboratory Procedures

3.2.1 Saturated Hydraulic Conductivity

Saturated hydraulic conductivity (K_s) was determined with the constant head method (Reynolds et al. 2002), after the samples were used in the multi-step outflow method.

3.2.2 Water Retention and Multi-Step Outflow Measurements

At the GEBJ Salinity Lab the samples were stored in a cold storage room until the samples could be admitted to the multi-step outflow setup. This setup consists of 22 pressure cells (Dane and Hopmans 2002) with each sample enclosed between two sample holders (Figure 2). The bottom sample holder contains a porous plate (1 bar high flow ceramics, Soil Moisture, Santa Barbara, CA) and is connected to a graduated cylinder with a pressure transducer to measure the water level. The sample holder at the top is connected to a pressure regulator that allows air pressures between zero and 1 bar to be applied. Control hardware and software take care of data registration. Figure 3 is a schematic of a single pressure cell.

Figure 2. Overview of the pressure cell setup.

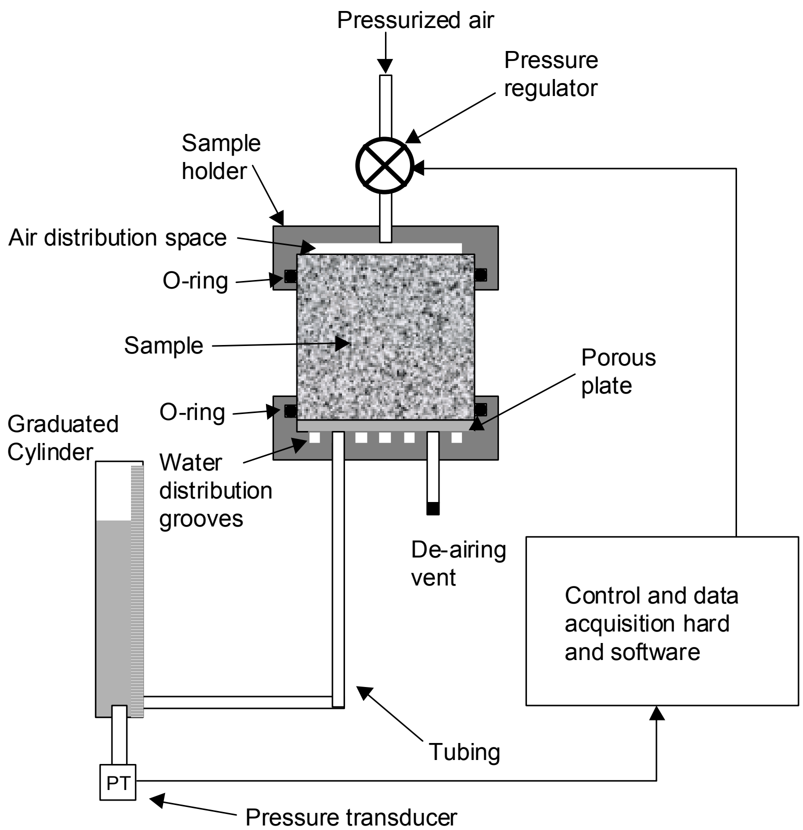

Figure 3. Schematic of the multi-step outflow measurement device.

The measurements start by saturating the sample, after which the air pressure is increased in periodic increments. Each pressure increase will drive water out of the sample, through the ceramic plate and into the burette where the time-series of the outflow volume is registered with a pressure transducer. Static equilibrium occurs when the outflow stops, leaving an opportunity to determine a water retention point. Subsequently, the air pressure is raised again until the maximum pressure is reached. We performed the measurements at -12, -20, -30, -50, -100, -150, -220, -300, -330, and -460 cm of capillary pressure (approximate values). A typical outflow pattern, showing seven clearly visible pressure steps, is shown in Figure 4. The multi-step outflow method failed for seven samples (numbers 7, 25, 28, 29, 30, 37, 58), mainly because the coarseness of the material caused air leakage between the brass ring and the O-ring. Final water content was determined by drying the samples at 105 C. This measurement also yielded the dry bulk density of the samples.

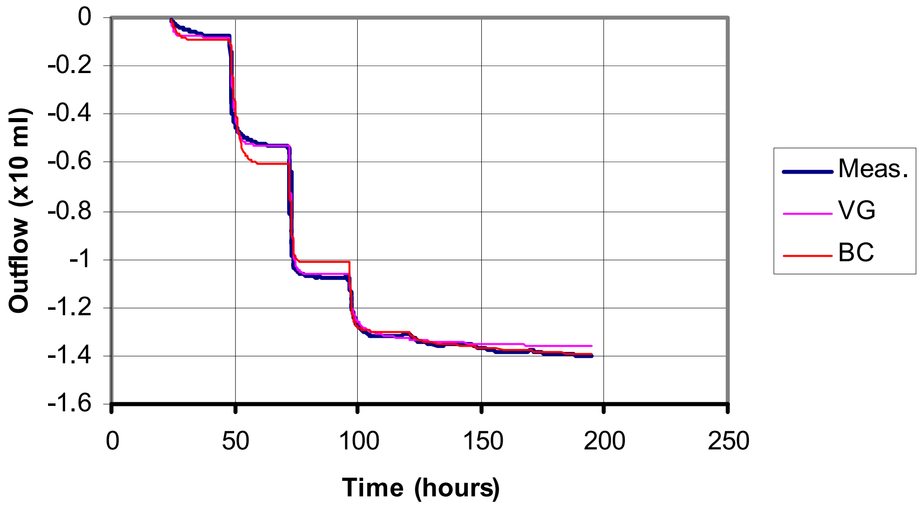

Figure 4. Typical time series example for the multi-step outflow method (blue line). The measurement starts at t=25 hours. Also shown are inverse simulations based on the Mualem-Brooks-Corey (BC, red) and Mualem-van Genuchten (VG, pink) models.

In addition to the multi-step outflow method, separate disturbed samples of about (30 g) were used to determine water retention points at -330, -550, -730, -1000, -3000, -8000, and -15000 cm with a pressure apparatus (Dane and Hopmans 2002). Results for the -330 cm pressure points of the pressure apparatus and the multi-step outflow were compared for consistency and the multi-step outflow determination was repeated if results diverged too much. For each sample, a total 15 or 16 static retention points were determined with the combined results of the multi-step outflow and the pressure apparatus. In addition, the time-series of outflow and the pressure apparatus data were used to inversely determine the unsaturated hydraulic conductivity and retention parameters.

3.2.3 Direct Fit of the Retention Parameters to Static Retention Data

The van Genuchten curve (VG, Eq.[1]) and the Brooks-Corey (BC, Eq. [3]) curve were fitted to the static water retention data using non-linear optimization software (MATLAB, Mathworks, Natick, MA). In order to arrive at realistic fitted parameters we applied the following constraints on the parameters: θ_r>0, θ_s <=porosity, 0<α<1, 1<n<20 (VG), and 0<λ<20 (BC). The objective function that was minimized was

$$\Phi\,(\mathbf{b}, \boldsymbol{\theta}) = \sum_{i=1}^{N_\theta} [\theta^*(h_i) - \theta(h_i, \mathbf{b})]^2 \qquad [5]$$

where N_θ is the number of static water retention measurements, $\theta^*(h_i)$ is the water content for measurement i at a pressure head of h_i, $\theta(h_i,\boldsymbol{b})$ is the water content estimate by the VG or the BC equation, and **b** is the parameter vector (consisting of θ_r, θ_s, α, and n or λ).

3.2.4 Inverse Determination of Unsaturated Hydraulic Parameters

We used the observed time series of outflow to inversely determine the unsaturated hydraulic parameters θ_r, θ_s, α, n, L, and K_0 using the HYDRUS-1D model (Šimůnek et al. 1998b). The governing equation for one-dimensional isothermal Darcian water flow in a variably saturated, rigid, isotropic porous medium is given by the Richards equation:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}[K(\frac{\partial h}{\partial z} + 1)] \qquad [6]$$

where z is the vertical coordinate positive upwards and t is time. Equation [6] was solved numerically using the finite element method for a given set of initial and boundary equations, and using Eqs. [1] and [2] for the Mualem-van Genuchten formulation and Eqs. [3] and [4] for the Mualem-Brooks-Corey variant.

The objective function Φ to be minimized during the parameter estimation is defined as:

$$\Phi(\mathbf{b}, \mathbf{q}) = \sum_{i=1}^{N_q} w_{q,i}\,[q^*(z,t_i) - q(z,t_i,\mathbf{b})]^2 + \sum_{j=1}^{N_\theta} w_{\theta,j}[\theta^*(h_j) - \theta(h_j,\mathbf{b})]^2 + w_k[K_s - K_0]^2 \qquad [7]$$

where N_q is the number of outflow measurements, $q^*(z,t_i)$ is a specific outflow measurement at time t_i at location z, $q(z,t_i,\boldsymbol{b})$ is the corresponding modeled outflow for the vector of optimized parameters $\boldsymbol{b}$ (e.g., θ_r, θ_s, α, n or λ, L, K_0), and $w_{q,i}$, $w_{\theta j}$, and w_k are weights associated with individual measurements of outflow, water content, and saturated hydraulic conductivity, respectively. Other terms in Equation 7 were defined previously. The measured static water retention points and the saturated hydraulic conductivity are taken into account with the second and third terms. The weights applied were $w_{q,i} = 4 \quad \forall i$, $w_{\theta,j} = 2 \ \forall j$, and $w_k = 1.5 \ \forall k$. The parameter optimization scheme in HYDRUS-1D is based on Marquardt's (1963) method, which has proven to be very effective in many applications involving nonlinear least squares fitting.

In some cases when all six hydraulic parameters are optimized, the inverse solution is ill-posed and yields no acceptable solution. In such cases, we fixed some parameters to initial values that remained constant during the optimization. This was sometimes necessary for θ_r and/or θ_s as only the difference of these parameters will affect the measured outflow. Occasionally it was also necessary to fix K_0 at a reasonable value because the multi-step outflow data contained no near-saturated data (the first point is at –12 cm pressure).

3.2.5 Particle size distribution

After determining the hydraulic properties we measured the particle-size distribution of the samples by wet-sieving (Gee and Or 2002) for weight fractions at sizes smaller than 2000, 1400, 1000, 700, 500, 355, 250, 180, 147, 105, and 90 µm, and by sedimentation in water (Gee and Or 2002) with size boundaries approximately at 53, 43, 31, 22, 10, 5, 3 and 1.5 µm. Due to low clay contents, the smallest particle sizes have a relatively high error (1.25 % weight fraction). The gravel content was determined as the fraction that did not pass the 2000 µm sieve. In most cases, the gravel size was just greater than 2000 µm but smaller than 5 mm. The fraction boundaries below 90 µm vary slightly from sample to sample as the time between readings determines the particle size. The 19 particle size fractions were summarized into sand, silt and clay fractions. The silt boundary (50 µm) was derived from the fractions at 53 and 43 µm boundaries by log-linear interpolation (i.e., the particle-size was log transformed before linear interpolation).

4.0 Results and Discussion

4.1 Field Data

Appendix A provides a listing of the data gathered in the field. Section A.1 includes the ring number to identify the samples as well as the corresponding field designation so that the samples can be cross-referenced with the information in Last and Caldwell (2001). Also listed is the top and bottom depth of the Lexan liners from which the sub samples were taken and the approximate position of the sub sample in each liner (top, middle, or bottom). Sample personnel and some subjective field remarks are also listed in Section A.1. Sixty samples were taken with samples 46, 57, 58, 59 and 60 having partially missing field designations. Samples 1, 2, 4, 28, 29 through 33, 39, and 41 should be considered to be partially or completely disturbed.

4.2 Particle Size Distributions, Bulk Density and Saturated Hydraulic Conductivity

Figure 5 illustrates the textural classification of the 60 samples. As was already apparent in the field, the samples are all coarse textured. Most samples fall into the "Sand" textural class, 13 have Loamy Sand textures, and just two can be classified as Sandy Loams. The sand percentage is always greater than 72.5%, clay percentages are always lower than 7.5%, and silt percentages range between 6 and 22%. Figure 6 shows the textural distributions of a Sand (sample 10, 98.5% sand and 1.25 % clay), Loamy Sand (sample 52, 85.2% sand and 5.0% clay), and a Sandy Loam (sample 41, 72.5% sand and 4.9 % clay). We note that the textural distribution of the Sand and Loamy Sand are similar for sizes greater than 500 μm, indicating that they have a similar content of coarse sand. The difference between the two classes becomes apparent at the sizes below 500 μm, with the Loamy Sand almost exhibiting a bi-modal particle-size distribution. The Sandy loam appears to have a more uniform particle-size distribution without a clearly dominating particle size. Gravel, sand, silt, and clay percentage data is listed in Appendix A, Section A.2. Detailed particle size distribution data is listed in Section A.3.

Section A.2 also shows that the bulk density ranges between 1.39 and 1.71 g/cm^3, with an arithmetic average value of 1.57 g/cm^3. Bulk density was not determined for seven of the 60 samples, mainly because the water retention curve was not determined because of repeated air-leakage in the Multi-Step outflow apparatus. Also shown in Appendix A.2 is the porosity, ϕ ,which is calculated as ϕ=1-BD/2.65, where BD is the dry bulk density and 2.65 is the assumed density of the solid phase. The porosity ranges between 0.35 and 0.47 cm^3/ cm^3/cm^3, with an average value of 0.41 cm^3/cm^3. The bulk density and porosity are most likely affected by the coring and sub sampling of the samples. It is possible that the bulk density is higher (porosity lower) in the samples as compared to the *in situ* material. With the data present it is impossible to say how great this effect might be.

Section A.2 shows that the saturated hydraulic conductivity of the samples ranges between 36 and 9100 cm/day. The saturated hydraulic conductivity clearly increases with the sand percentage, as shown in Figure 7. Likewise, K_s increases with porosity (Figure 8). Table 1 provides summary statistics (minimum, maximum, averages, and standard deviations) for the observed K_s values). A more elaborate statistical interpretation of the relations between textural, bulk density data, and hydraulic data is underway.

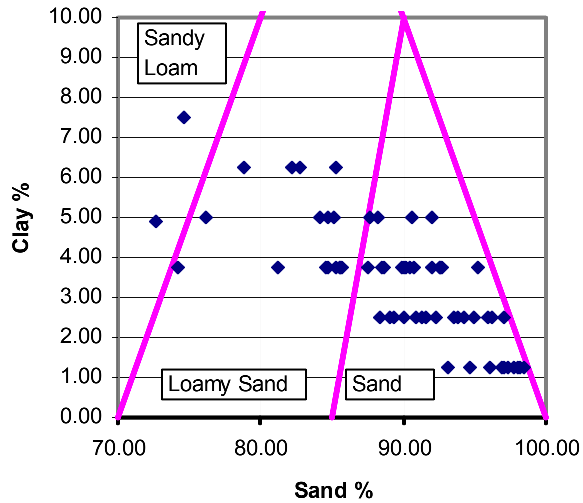

Figure 5. Textural classification of the samples. The lines indicate the boundaries between the sand, loamy sand, and sandy loam textural classes. For reasons of clarity, only a small part of the textural triangle is shown.

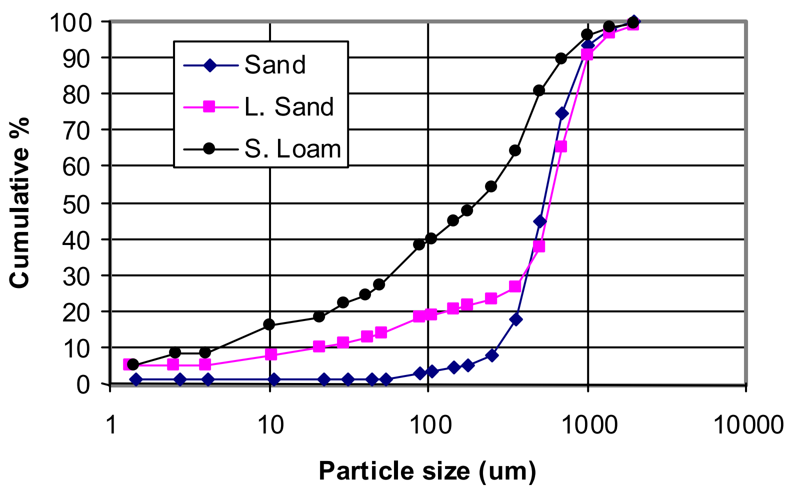

Figure 6. Textural distribution of a sand (sample 10), loamy sand (sample 52), and a sandy loam (Sample 41). The symbols indicate particle size class boundaries.

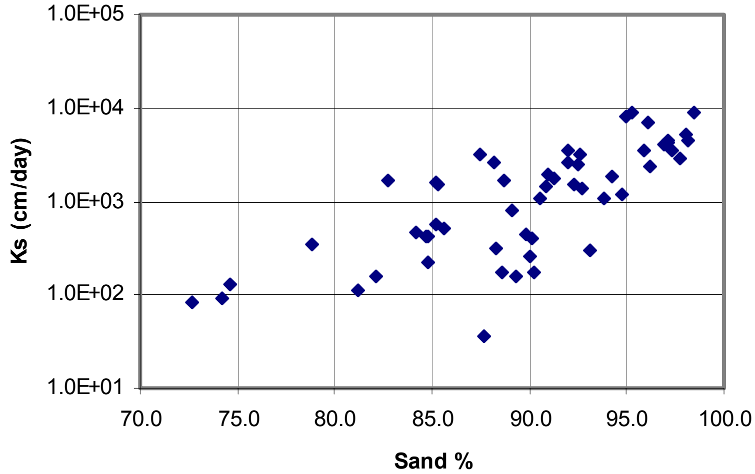

Figure 7. Saturated hydraulic conductivity versus sand percentage. Note the logarithmic vertical axis.

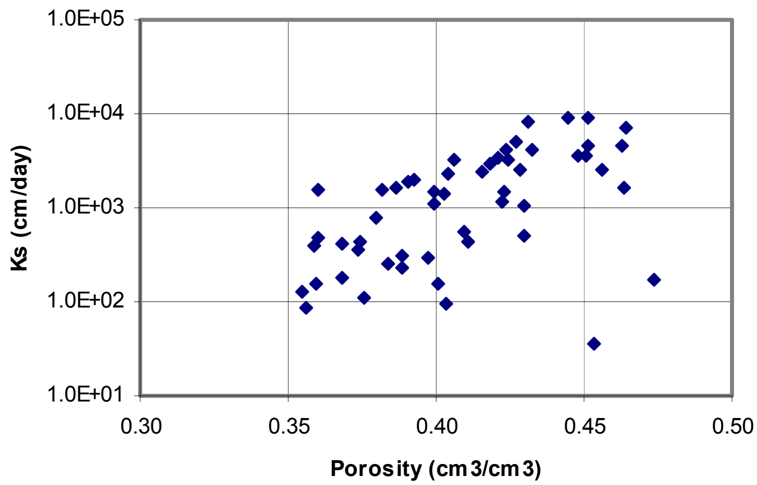

Figure 8. Saturated hydraulic conductivity versus porosity. Note the logarithmic vertical axis.

4.3 Unsaturated Hydraulic Parameters

The water retention data is listed in Appendix A, Section A.4. Results for direct fits of the van Genuchten and Brooks-Corey equations to these data are listed in Sections A.5 and A.6, with summary statistics appearing in Table 1. Figures 9a through 9d provide an overview in the ranges of individual parameters, as well as the similarity of equivalent VG and BC parameters. Figure 9e shows the range in root mean square errors (RMSE), defined here as:

$$RMSE = \sqrt{\frac{\sum_{i}^{N}[\theta^{*}(h_i) - \theta(h_i, \mathbf{b})]^2}{N - n_p}} \quad [8]$$

where θ^* and θ are the observed and fitted water content, respectively, h is the soil water pressure, and **b** is the parameter vector (consisting of θ_r, θ_s, α, and n or λ). The number of points (N) is corrected with the number of parameters (n_p, equal to four).

Figure 9 shows that while the Brooks-Corey and van Genuchten parameters are reasonably correlated for θ_r, α, n or λ, no clear correlation is present for the θ_s parameter. The lack of correlation is probably due to the fact that the first retention point is situated at approximately 12 cm suction, and further because of difficulties of fitting θ_s for the Brooks-Corey equation due to the discontinuity at $1/\alpha$ (see Eq. [3]). It also appears that the assumption $\lambda = n$-1 that is often made (e.g., Rawls and Brakensiek 1985; Carsel and Parrish 1988) appears valid for $\lambda < 1$ (i.e. $n<2$, see Figure 9d). For larger values of n, the value for λ is overestimated when this relation is used. The relationship between λ and n presented in Lenhard et al. (1989) is also shown in Figure 9d and appears to better represent the correlation between these parameters. Table 1 shows minimum, maximum, average value, and standard deviation of the estimated parameters and RMSE values. Alpha values for the Brooks-Corey Equation are, on average, lower than those of the van Genuchten fits, while the RMSE values for BC are also somewhat lower than the RMSE values for the VG equation.

Results of the inverse optimizations for the van Genuchten and Brooks-Corey parameters appear in Figures 10 and 11. Here, the inverse estimates of the parameters are plotted versus their counterparts from the direct fit to the static retention data. We note that parameter values were plotted even when they were not optimized (see Sections A.7 and A.8). For the van Genuchten parameters (Figure 10) there appears to be a reasonable correspondence between the inverse solution and the direct fit, although there is some scatter as well. However, the inverse solution for the α parameter appears to be generally lower than that of the direct fit as is also clear from Table 1 where the average value for α for the direct fit is 0.078 cm^{-1} versus 0.051 cm^{-1} for the inverse solution. Inverse solution n values appear to be somewhat higher than the direct fit values. RMSE values appear in Figure 10e and Table 1; the values are, on average, approximately twice as large as the values for the direct fits to the static retention data. We note that RMSE values for the inverse solutions were *not* corrected for the (four) degrees of freedom because the inverse parameters were mainly optimized on outflow data. Table 1 also shows that inversely optimized K_0 values are more than one order of magnitude lower than the measured K_s values. This seemingly confirms findings by Schaap and Leij (2000) who found that $K_0 << K_s$. However, we have to note that the inverse solutions were very insensitive to the actual value of K_0, mainly because the first reliable data point in the pressure cell outflow is at –12 cm pressure. Results for K_0, although lower than K_s, are probably not very reliable. Average values for L are 0.5, confirming Mualem (1976) but we also note that there is a wide range of variation (between –3.1 and 4.4).

Similar graphs for the Brooks-Corey data show considerably more scatter, as can be seen in Figure 11. Our experience was that many of the inversions of the Mualem-Brooks-Corey equations were ill-posed problems and yielded unstable parameter values (i.e., different initializations gave widely varying inverse solutions). Many unsatisfying solutions were found for Brooks-Corey parameters, such as shown in Figure 4 for sample 2. This figure shows that the van Genuchten solution adequately matches the observed outflow pattern. The Brooks-Corey solution, however, provides a poor fit (especially during the period between 50 and 100 hours). The problems are mainly caused by the discontinuous shape of Eqs. [3] and [4] allowing many combinations of the Brooks-Corey parameters to fit the outflow data. We suggest that users treat the inverse solutions of the Brooks-Corey parameters with considerable suspicion. When possible we suggest using the direct fits of the Brooks-Corey parameters to the static retention data.

Table 1. Minimum, maximum, average values and standard deviations of the hydraulic parameters or RMSE values. The first column lists the type of data being evaluated and the number of samples available. Abbreviations in the second column are min=minimum, max=maximum, avg=average, and s=standard deviation (corrected for one degree of freedom). RMSE values for the inverse VG and BC solutions were not corrected for the degrees of freedom. Results for K_s and K_0 are given for the appropriate data type (see text). For n or λ and K_s we also list results based on logarithmic (base 10) values of the parameters; the average and standard deviation of $\log(K_s)$ and $\log(K_0)$ are based on the entire dataset and not on the average of K_s or K_0 .

		θ_r cm^3/cm^3	θ_s cm^3/cm^3	α 1/cm	n or λ -	log(n) -	RMSE cm^3/cm^3	K_s or K_0 cm/day	Log(K_s)	L -
Ks	min							3.55E+01	1.550	
	max							9.12E+03	3.960	
N=54	avg							**2.07E+03**	**3.003**	
	σ							2.28E+03	0.599	
Fit VG	min	0.000	0.271	0.008	1.400	0.146	0.0021			
	max	0.059	0.474	0.349	12.038	1.081	0.0173			
N=53	avg	**0.033**	**0.364**	**0.078**	**2.693**	**0.371**	**0.0085**			
	σ	0.012	0.050	0.064	1.810	0.208	0.0032			
Fit BC	min	0.000	0.188	0.012	0.359	-0.445	0.0016			
	max	0.058	0.474	0.239	2.690	0.430	0.0255			
N=53	avg	**0.030**	**0.303**	**0.067**	**1.088**	**-0.035**	**0.0078**			
	σ	0.011	0.053	0.042	0.643	0.251	0.0040			
Inv VG	min	0.001	0.267	0.008	1.513	0.180	0.005	1.11E+00	0.190	-3.144
	max	0.077	0.435	0.127	8.776	0.943	0.133	4.06E+02	2.609	4.353
N=51	avg	**0.035**	**0.344**	**0.051**	**3.146**	**0.459**	**0.016**	**9.36E+01**	**1.709**	**0.535**
	σ	0.014	0.041	0.023	1.525	0.189	0.018	9.74E+01	0.562	1.112
Inv BC	min	0.001	0.250	0.010	0.125	-0.904	0.005	1.21E+00	0.083	-3.152
	max	0.050	0.400	0.252	3.494	0.543	0.093	3.80E+02	2.580	6.418
N=51	avg	**0.024**	**0.319**	**0.070**	**1.300**	**0.015**	**0.016**	**9.21E+01**	**1.648**	**1.006**
	σ	0.013	0.034	0.038	0.880	0.321	0.013	9.78E+01	0.641	1.799

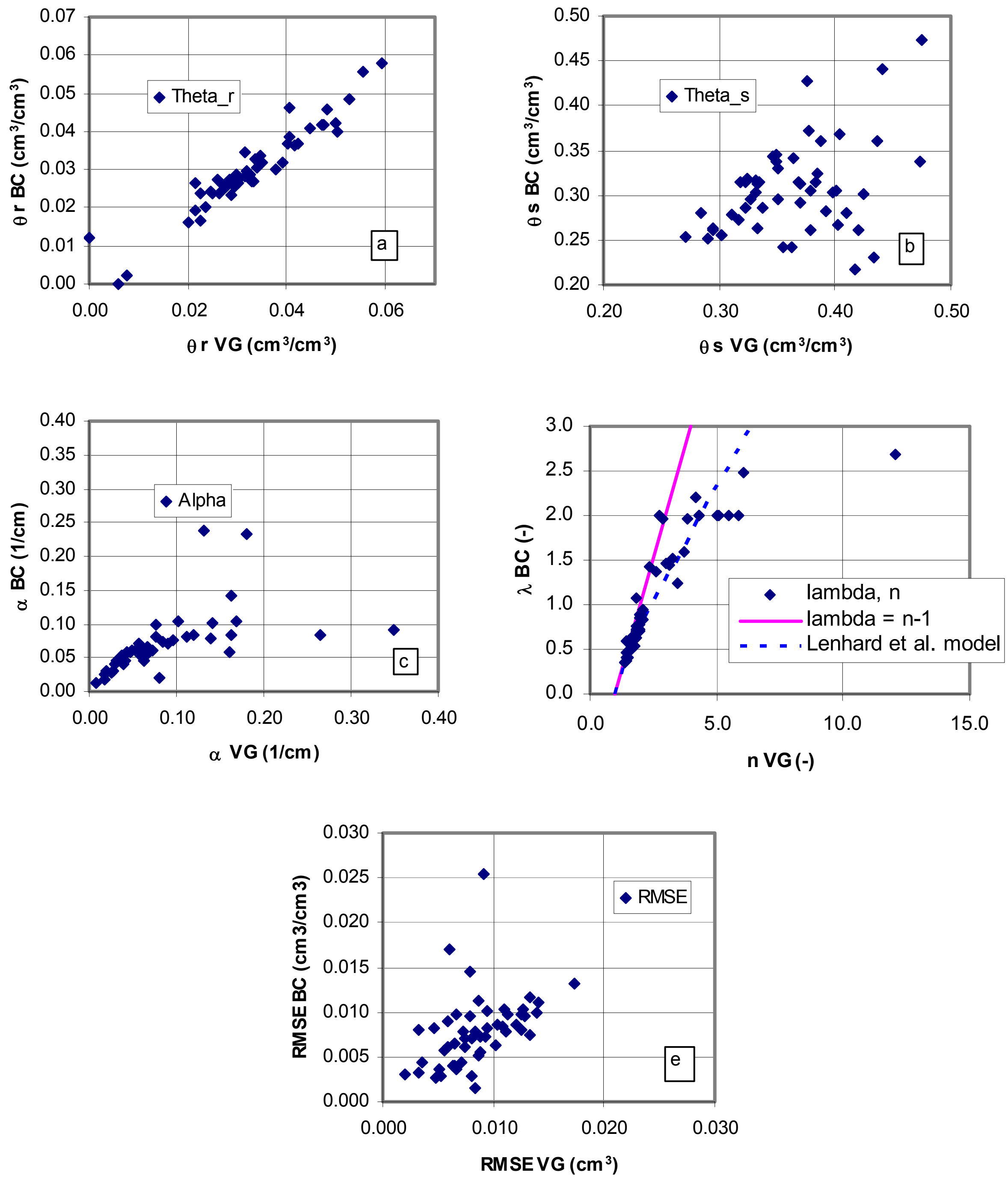

Figure 9. Distributions of the direct fits of Brooks-Corey parameters (vertical) to static retention data versus the distribution of the direct fits van Genuchten parameters (horizontal). Plot e shows root mean square residual errors (RMSE) of the BC fits versus RMSE of the VG fits. Plot d also contains the lines λ=n-1 and the λ(n) relationship from Lenhard et al. (1989) (see text).

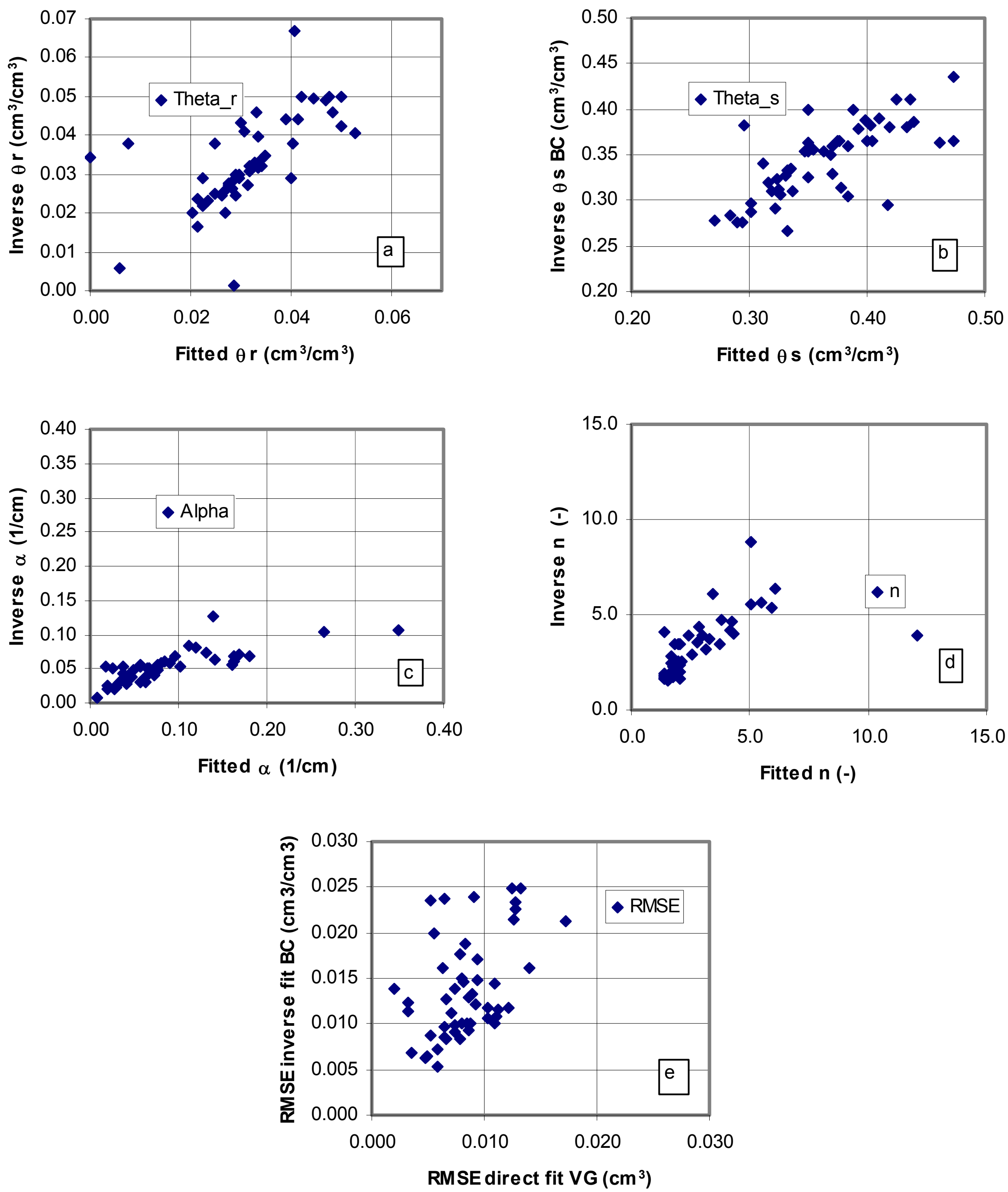

Figure 10. Distributions of the inverse optimizations of the van Genuchten parameters (vertical) versus direct fits to static retention data. (horizontal). Plot e shows root mean square residual errors (RMSE) of the inverse optimization versus RMSE of the direct fits

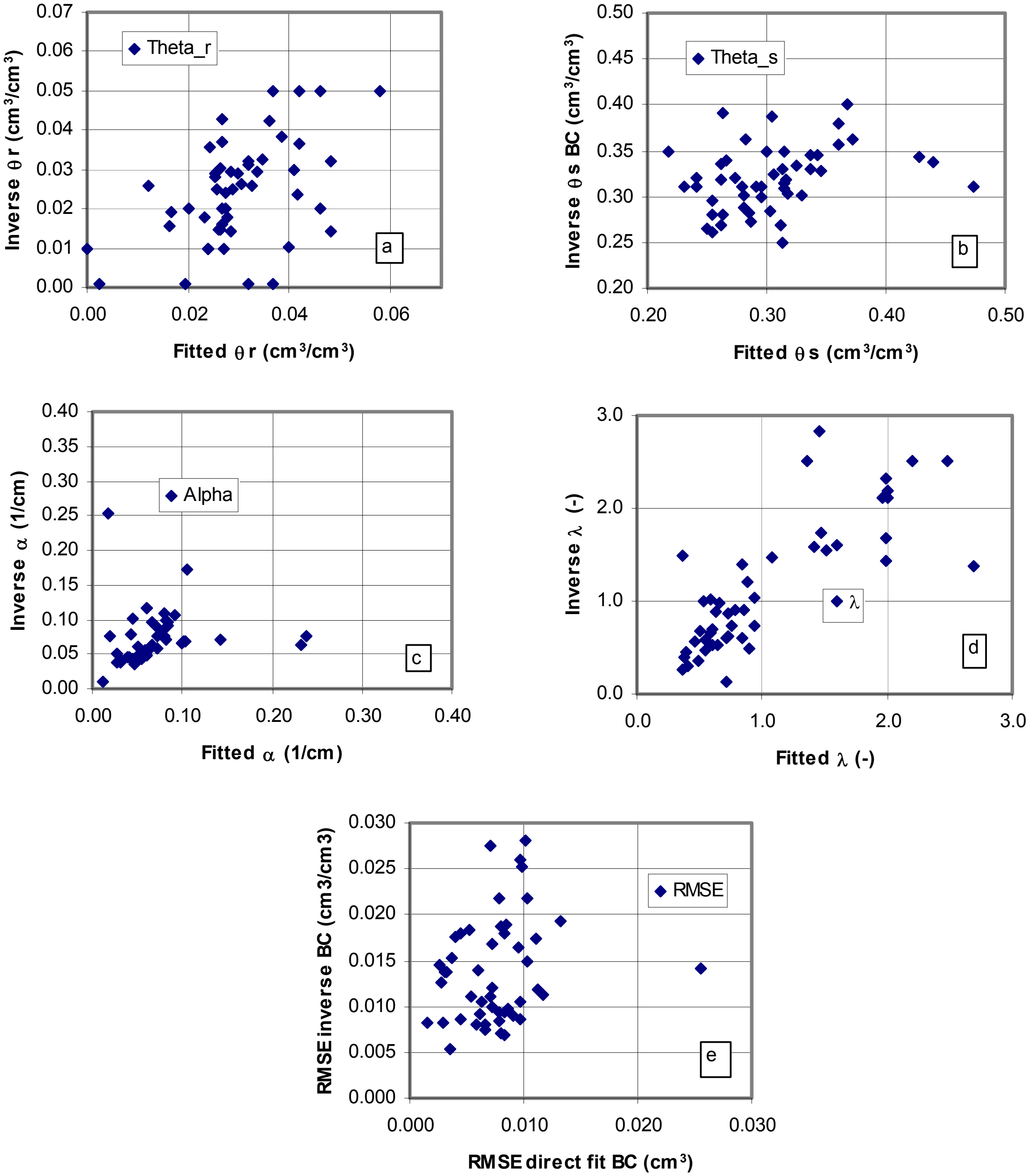

Figure 11. Distributions of the inverse optimizations of the Brooks-Corey parameters (vertical) versus direct fits to static retention data. (horizontal). Plot e shows root mean square residual errors (RMSE) of the inverse optimization versus RMSE of the direct fits.

5.0 Summary and Conclusions

This report presents sampling and measurement procedures and measurement results for 60 samples from the S-1, S-2, and S-3 bore holes at the Vadose Zone Transport Field Study Leak Simulation Test Site, located at the Sisson and Lu (1984) injection site in the 200 East Area of the Hanford Site. Measured data and estimated parameters appear in the appendices and include particle size distributions (19 points), bulk densities (and bulk density-derived porosity), water retention characteristics (16 static points), and saturated and unsaturated hydraulic conductivity.

The coring and sub sampling procedures led to partially, and occasionally completely, disturbed samples. Textural analyses showed that most of the samples could be classified as sand, some as loamy sands, and two as sandy loams. The multi-step outflow method failed for seven samples, yielding 53 samples for which hydraulic parameters were available. Van Genuchten and Brooks-Corey water retention parameters were determined using static retention points (derived from multi-step outflow time series). Inverse analyses of the multi-step outflow data yielded additional unsaturated hydraulic conductivity parameters. Unfortunately, the inverse analyses had some problems in reaching stable solutions. Therefore, we sometimes fixed saturated and residual water contents and saturated hydraulic conductivities at initial values. Even then, it was not possible to reach a solution for two samples leaving the total number of samples for which inverse solutions were available at 51. We also noticed that Brooks-Corey-type inversions were of lesser quality than van Genuchten inversions. We suggest that Brooks-Corey inversions be treated carefully and that, where possible, the far more reliable direct fits of the Brooks-Corey curve to the static retention data be used.

6.0 References

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Appendix A

Data Tables

Appendix A

Data Tables

A.1 Field Data

Sheet:	**Field data**	**Project:**	EMSP
Version:	**1**		
Date:	**12-Apr-01**		
Purpose:	Contains observations in the field, depth.		
Data:	Depth information, other more qualitative observations about the samples		
Model:	NA		
Software:	NA		
Analyses:	Phil Meyer, Marcel Schaap, Jack Jobes		
Contact:	Marcel G. Schaap, GEBJ Salinity Lab, 450 W. Big Springs Road, Riverside, CA 92507		
E-mail:	mschaap@ussl.ars.usda.gov		

Column	**Explanation**	**Methodology**
Ring ID	Identifier (Ring number)	
Ring Tare	Empty weight of ring in g	
Core	Field designation of the core	Split Spoon, the ring was subsampled in the 6 inch liner
Depth Upper	Upper depth of the 6 inch liner	Provided by the drilling crew
Depth Lower	Lower depth of the 6 inch liner	Provided by the drilling crew
Position in liner	Position in liner	Qualitative observation whether the ring was obtained from top middle or bottom of 6 inch liner
Sampled by	Persons performing subsampling	
USSL Log entries	Very qualitative observations about the sample	

Comments	Some core field designations are missing for S3
	Subsampling involved forcing (hitting) a ring into the material in the liner. This procedure may have led to partially disturbed samples

(continues on next page)

Ring ID	Ring Tare (g)	liner field designation	liner top	liner bottom	Position in liner t=top b=bottom m=middle d=disturbed	Sampled by PM: Phil Meyer MS: Marcel Schaap JJ: Jack Jobes	USSL log entries (texture indication is a subjective estimate)
1	146.6	S-1/24	18	19	d	PM&MS	Disturbed (ring filled by hand) contains plant roots, medium coarse
2	147.08	S-1/25	19	19.5	d	PM&MS	Disturbed (ring filled by hand) contains plant roots, medium coarse/coarse
3	142.71	S-1/26B	19.5	20	t	PM&MS	undisturbed, wet, coarse sand
4	147.38	S-1/26C	20	20.5	t	PM&MS	undisturbed/disturbed , wet, coarse sand, subsample rose in the ring
5	142.71	S-1/26D	20.5	21	b	PM&MS	undisturbed, wet, coarse sand
6	147.18	S-1/27B	21	21.5	t	PM&MS	undisturbed, wet, coarse sand
7	142.61	S-1/27C	21.5	22	t	PM&MS	undisturbed, wet, (medium) coarse sand
8	142.97	S-1/27D	22	22.5	b	PM&MS	undisturbed, coarse sand/almost gravel
9	142.72	S-1/29	23.5	25.5	d	PM&MS	Disturbed (ring filled by hand). Obtained only a small amount of grab sample
10	144.65	S-1/32B	25.5	26	t	PM&MS	undisturbed, coarse sand/almost gravel, dry
11	146.43	S-1/32C	26	26.5	t	PM&MS	undisturbed, coarse sand
12	146.87	S-1/34B	27.5	28	t	PM&MS	undisturbed, coarse sand
13	146.32	S-1/34C	28	28.5	t	PM&MS	undisturbed, medium coarse/coarse sand
14	146.59	S-1/34D	28.5	29	m	PM&MS	undisturbed, medium coarse/coarse sand
15	146.32	S-1/36B	29.5	30	t	PM&MS	undisturbed, medium coarse sand
16	147.2	S-1/36C	30	30.5	t	PM&MS	undisturbed, medium coarse sand
17	144.99	S-1/36D	30.5	31	m	PM&MS	undisturbed, medium coarse sand
18	145.35	S-1/38B	31.5	32	t	PM&MS	undisturbed, medium coarse sand
19	142.2	S-1/38C	32	32.5	t	PM&MS	undisturbed, medium coarse sand
20	146.92	S-1/38D	32.5	33	m	PM&MS	undisturbed, fine/medium coarse sand/coarse sand (middle?, not on the outside of the liner)
21	147.1	S-1/40B	33	33.5	b	PM&MS	undisturbed, coarse sand/almost gravel, fine at bottom
22	146.6	S-1/40C	33.5	34	t	PM&MS	undisturbed, coarse sand(almost gravel)
23	146.06	S-1/40D	34	34.5	m	PM&MS	undisturbed, coarse sand(almost gravel)
24	143.15	S-1/42B	35.5	36	t	PM&MS	undisturbed, coarse sand
25	147.25	S-1/42C	36	36.5	t	PM&MS	undisturbed, coarse sand at top, fine at bottom
26	146.91	S-1/42D	36.5	37	t	PM&MS	undisturbed, fine sand
27	146.32	S-1/43C	37	37.5	t	PM&MS	undisturbed, fine sand at top, coarse at bottom, wet
28	142.97	S-1/42D	36.5	37.5	b	PM&MS	extra subsample of 26 (S-1/42D), probably pretty disturbed. This is at the bottom of the liner. NO GRAB SAMPLES
29	147.45	S-1/43C	36	36.5	b	PM&MS	extra subsample of 25 (S-1/42C), probably pretty disturbed. This is at the bottom of the liner. No real fine material. NO GRAB SAMPLES
30	147.01	S-1/43D	37.5	38	b	PM&MS	(un)disturbed, coarse sand
31	142.23	S-1/45B	38.5	39	t	PM&MS	(un)disturbed, fine sand at top, coarse at

							bottom, wet
32	145.39	S-1/45C	39	39.5	t	PM&MS	(un)disturbed, coarse sand dry
33	146.99	S-1/45D	39.5	40	b	PM&MS	(un)disturbed, coarse sand dry
34	147.23	S-2/1B	13.5	14	t	PM&JJ	undisturbed 0.9 cm high damp, loose
35	146.82	S-2/5C	17	17.5	t	PM&JJ	undisturbed 0.9 cm high damp
36	146.71	S-2/9B	21.5	22	t	PM&JJ	undisturbed 1.2 cm high wet semi solid
37	146.98	S-2/11B	23.5	24	t	PM&JJ	undisturbed 1.5 cm high damp
38	146.08	S-2/13C	22	22.5	t	PM&JJ	undisturbed 1.4 cm high damp
39	146.98	S-2/15B	27.5	28	t	PM&JJ	disturbed finer cemented
40	146.22	S-2/19B	31.5	32	t	PM&JJ	undisturbed 1.2 cm high
41	141.23	S-2/21B	33.5	34	t	PM&JJ	semi undisturbed fine, cemented
42	147.25	S-2/23B	35.5	36	t	PM&JJ	0.6 cm high coarse dry
43	147.35	S-2/25C	37	37.5	t	PM&JJ	level coarse loose damp
44	146.93	S-2/24B	37.5	38	t	PM&JJ	level coarse damp
45	147.18	S-2/30C	52	52.5	t	PM&JJ	0.3 cm very dry loose
46	147.57	S-3/NOID*	16	16.5	t	PM&JJ	0.8 cm damp loose
47	146.7	S-3/3'C	18	18.5	t	PM&JJ	0.9 cm damp loose
48	146.97	S-3/8C	19.5	20	t	PM&JJ	0.4 cm fines & sand damp
49	147.25	S-3/8B	20	20.5	t	PM&JJ	0.6 cm damp coarse
50	145.45	S-3/10B	22	22.5	t	PM&JJ	damp coarse
51	146.95	S-3/12C	24	24.5	t	PM&JJ	1.1 cm damp fine cemented
52	147.09	S-3/14C	26	26.5	t	PM&JJ	damp medium fine sand
53	146.94	S-3/16B	28.5	29	t	PM&JJ	1.3 cm high damp loose
54	146.85	S-3/20C	32.5	33	t	PM&JJ	0.5 cm high some silt, damp loose
55	147.07	S-3/20B	33	33.5	t	PM&JJ	1.1 cm high damp loose some silt
56	141.78	S-3/22C	34.5	35	t	PM&JJ	0.9 cm wet silt, compacted
57	148.5	S-3/??C*	36.5	37	t	PM&JJ	0.7 cm damp silt sand
58	147.28	S-3/??B*	44	44.5	t	PM&JJ	0.6 cm dry loose average sand
59	146.93	S-3/??C*	47.5	48	t	PM&JJ	level very dry loose
60	147.38	S-3/??C*	55	55.5	t	PM&JJ	level damp loose sand

*= No Core ID

A.2 Basic Sample Data

Sheet:	**Basic_Data**	**Project:**	**ESMP**
Version:	3		
Date:	**8-Apr-03**		
Purpose:	Contains physical soil properties and saturated hydraulic conductivity		
Data:	Texture, bulk density, saturated hydraulic conductivity		
Model:	NA		
Software:	NA		
Analyses:	Pete Shouse, Jack Jobes, Joan Fagerlund		
Contact:	Marcel G. Schaap, US Salinity Lab, 450 W. Big Springs Road, Riverside, CA 92507		
E-mail:	mschaap@ussl.ars.usda.gov		

Column	**Explanation**	**Methodology**
ID	Identifier (Ring number)	
Gravel	Gravel percentage	
Sand	Sand content (weight %)	Wet sieving until 90 microns, sedimentation for sizes smaller than 90 microns
Silt	Silt content (weight %)	
Clay	Clay content (weight %)	
BD	Bulk density (g/cm3)	Based on core, weighing and drying.
Porosity	Calculated pore volume (cm3/cm3)	Based on BD; porosity =1-BD/2.65
Ks	Saturated conductivity (cm/day)	Constant Head
Log Ks	Logarithm (base 10) of Ks	
Comments	Missing data are left blank	

(continued on next page)

ID	Gravel Weight %	Sand Weight %	Silt Weight %	Clay Weight %	BD Weight %	Porosity cm3/cm3	Ks cm/day	Log Ks
1	4.36	81.24	10.66	3.75	1.654	0.376	1.125E+02	2.051
2	1.95	94.74	2.06	1.25	1.532	0.422	1.187E+03	3.074
3	1.47	88.33	7.70	2.50	1.620	0.389	3.067E+02	2.487
4	0.33	93.83	3.34	2.50	1.590	0.400	1.084E+03	3.035
5	0.25	97.71	0.79	1.25	1.540	0.418	2.880E+03	3.459
6	0.18	92.32	5.00	2.50	1.590	0.399	1.512E+03	3.180
7	0.32	91.30	5.88	2.50			1.757E+03	3.245
8	0.14	84.76	11.35	3.75	1.621	0.388	2.254E+02	2.353
9	0.77	88.67	6.81	3.75	1.420	0.464	1.670E+03	3.223
10	0.27	98.48	0.00	1.25	1.454	0.452	9.122E+03	3.960
11	0.63	98.12	0.00	1.25	1.420	0.463	4.514E+03	3.655
12	1.37	96.13	1.25	1.25	1.420	0.464	7.006E+03	3.845
13	0.74	98.01	0.00	1.25	1.520	0.427	5.105E+03	3.708
14	0.40	97.10	1.25	1.25	1.450	0.452	4.565E+03	3.659
15	0.38	89.07	8.06	2.50	1.645	0.379	7.942E+02	2.900
16	0.59	96.91	1.25	1.25	1.500	0.433	4.140E+03	3.617
17	0.17	97.33	1.25	1.25	1.456	0.451	3.557E+03	3.551
18	0.54	88.55	7.16	3.75	1.674	0.369	1.757E+02	2.245
19	0.21	93.16	5.38	1.25	1.597	0.397	3.000E+02	2.477
20	0.00	90.21	6.04	3.75	1.394	0.474	1.699E+02	2.230
21	3.80	90.10	3.60	2.50	1.700	0.359	3.924E+02	2.594
22	0.94	94.27	2.30	2.50	1.615	0.391	1.886E+03	3.276
23	1.28	96.22	0.00	2.50	1.580	0.404	2.354E+03	3.372
24	0.43	89.85	5.97	3.75	1.658	0.374	4.385E+02	2.642
25	0.43	93.54	3.53	2.50				
26	0.28	74.23	21.75	3.75	1.581	0.403	9.360E+01	1.971
27	0.15	90.02	6.08	3.75	1.633	0.384	2.556E+02	2.408
28	3.22	76.11	15.67	5.00				
29	1.72	85.77	8.76	3.75				
30	2.00	85.49	8.76	3.75				
31	0.14	82.15	11.46	6.25	1.700	0.360	1.591E+02	2.202
32	0.41	97.09	0.00	2.50	1.527	0.424	4.212E+03	3.624
33	0.00	95.24	1.01	3.75	1.472	0.445	8.971E+03	3.953
34	0.00	92.67	3.58	3.75	1.582	0.403	1.395E+03	3.144
35	1.69	90.81	3.75	3.75	1.529	0.423	1.445E+03	3.160
36	1.21	85.29	7.25	6.25	1.638	0.382	1.519E+03	3.182
37	4.46	90.54	1.25	3.75				
38	1.18	82.70	9.87	6.25	1.630	0.386	1.670E+03	3.223
39	2.46	78.89	12.41	6.25	1.660	0.374	3.528E+02	2.548
40	0.07	88.17	6.76	5.00	1.440	0.456	2.599E+03	3.415
41	0.54	72.65	21.93	4.88	1.710	0.356	8.448E+01	1.927
42	0.73	87.51	8.01	3.75	1.570	0.406	3.233E+03	3.510
43	0.31	85.25	10.69	3.75	1.564	0.410	5.609E+02	2.749
44	1.14	89.36	7.00	2.50	1.590	0.401	1.584E+02	2.200
45	0.84	85.61	9.80	3.75	1.520	0.430	5.076E+02	2.706
46	0.78	91.96	2.26	5.00	1.534	0.421	3.485E+03	3.542

47	1.92	90.58	2.50	5.00	1.512	0.430	1.061E+03	3.026
48	2.99	92.01	1.25	3.75	1.514	0.429	2.570E+03	3.410
49	1.79	90.95	4.76	2.50	1.610	0.392	1.966E+03	3.293
50	0.08	94.93	2.50	2.50	1.510	0.431	8.179E+03	3.913
51	0.96	84.19	9.86	5.00	1.696	0.360	4.709E+02	2.673
52	1.23	85.19	8.59	5.00	1.695	0.360	1.563E+03	3.194
53	0.35	95.90	1.25	2.50	1.464	0.448	3.514E+03	3.546
54	0.37	84.78	9.86	5.00	1.561	0.411	4.291E+02	2.633
55	0.00	87.68	7.32	5.00	1.450	0.453	3.552E+01	1.550
56	0.61	84.65	11.00	3.75	1.674	0.368	4.234E+02	2.627
57	0.56	74.64	17.31	7.50	1.711	0.354	1.282E+02	2.108
58	2.23	91.52	3.75	2.50				
59	0.19	92.62	3.43	3.75	1.526	0.424	3.254E+03	3.512
60	0.00	92.50	3.75	3.75	1.550	0.415	2.441E+03	3.388
Min	0.00	72.65	0.00	1.25	1.394	0.354	3.552E+01	1.550
Max	4.46	98.48	21.93	7.50	1.711	0.474	9.122E+03	3.960
Average	0.98	89.49	6.10	3.44	1.566	0.409	2.074E+03	3.003
Stddev	1.07	6.23	5.04	1.50	0.088	0.033	2.276E+03	0.599

A.3 Particle Size Distribution Data

Sheet:	**Detailed_Particle_Size**	**Project:**	ES MP
Version:	**2**		
Date:	**8-Apr-03**		
Purpose:	Complete particle size distribution		
Data:	Particle size data		
Model:	NA		
Software:	NA		
Analyses:	Pete Shouse, Jack Jobes, Joan Fagerlund		
Contact:	Marcel G. Schaap, US Salinity Lab, 450 W. Big Springs Road, Riverside, CA 92507		
E-mail:	mschaap@ussl.ars.usda.gov		

Column	**Explanation**	**Methodology**
ID	Identifier (Ring number)	
Npoints	Number of particle points	
Psize	19 columns with particle size points	Wet sieving for sizes larger than 90 microns, sedimentation for the smaller fractions
Frac	19 columns with percentages scaled to 100%-Gravel% Percentage indicates relative amount smaller than the indicated size	
Comments	Note: gravel content represents the large 'sand' particles that didn't pass through the 2000 micron sieve Most gravel particles seemed smaller than 3000 micron. Small particle sizes have relatively large measurement uncertainty because of low clay content	

(continued on next page)

ID	1	2	3	4	5	6	7	8
Npoints	19	19	19	19	19	19	19	19
Psize	2000	2000	2000	2000	2000	2000	2000	2000
Psize	1400	1400	1400	1400	1400	1400	1400	1400
Psize	1000	1000	1000	1000	1000	1000	1000	1000
Psize	700	700	700	700	700	700	700	700
Psize	500	500	500	500	500	500	500	500
Psize	355	355	355	355	355	355	355	355
Psize	250	250	250	250	250	250	250	250
Psize	180	180	180	180	180	180	180	180
Psize	147	147	147	147	147	147	147	147
Psize	105	105	105	105	105	105	105	105
Psize	90	90	90	90	90	90	90	90
Psize	52.40	53.64	52.82	53.37	53.78	53.23	53.09	52.26
Psize	43.01	43.91	43.46	43.69	44.02	43.46	43.46	43.12
Psize	30.57	31.05	30.97	31.05	31.13	30.81	30.81	30.81
Psize	21.73	21.96	21.96	21.96	22.01	21.84	21.79	21.84
Psize	10.30	10.57	10.76	10.76	10.64	9.88	10.70	10.70
Psize	4.26	4.19	3.91	4.06	4.24	4.42	3.99	4.01
Psize	2.66	2.66	2.76	2.80	2.86	2.66	2.63	2.67
Psize	1.41	1.43	1.42	1.43	1.43	1.43	1.43	1.43
Frac	95.64	98.05	98.53	99.67	99.75	99.82	99.68	99.86
Frac	92.46	96.40	90.76	94.61	98.96	94.63	97.45	98.42
Frac	88.96	92.62	75.00	82.34	96.81	79.80	91.24	92.56
Frac	78.95	80.71	48.07	45.43	88.52	44.73	67.57	65.66
Frac	64.38	61.98	33.07	25.33	69.45	29.45	41.48	41.74
Frac	47.98	36.61	27.96	18.08	38.33	22.63	28.97	33.90
Frac	38.01	21.83	26.33	15.68	20.41	19.53	23.94	32.30
Frac	33.36	15.75	25.45	14.42	12.27	17.61	21.33	31.45
Frac	31.03	13.93	24.90	13.87	9.66	16.69	20.01	31.06
Frac	26.99	11.85	23.72	12.79	6.64	14.94	17.69	30.21
Frac	25.55	11.33	23.13	12.45	6.07	14.42	16.92	29.70
Frac	15	3.75	11.25	6.25	2.5	7.5	8.75	16.25
Frac	12.5	2.5	7.5	5	1.25	7.5	7.5	11.25
Frac	10	2.5	3.75	2.5	1.25	6.25	6.25	6.25
Frac	7.5	2.5	2.5	2.5	1.25	5	6.25	5
Frac	5	1.25	2.5	2.5	1.25	2.5	5	5
Frac	5	1.25	2.5	2.5	1.25	2.5	3.75	5
Frac	3.75	1.25	2.5	2.5	1.25	2.5	2.5	3.75
Frac	3.75	1.25	2.5	2.5	1.25	2.5	2.5	3.75

9	10	11	12	13	14	15	16	17
19	19	19	19	19	19	19	19	19
2000	2000	2000	2000	2000	2000	2000	2000	2000
1400	1400	1400	1400	1400	1400	1400	1400	1400
1000	1000	1000	1000	1000	1000	1000	1000	1000
700	700	700	700	700	700	700	700	700
500	500	500	500	500	500	500	500	500
355	355	355	355	355	355	355	355	355
250	250	250	250	250	250	250	250	250
180	180	180	180	180	180	180	180	180
147	147	147	147	147	147	147	147	147
105	105	105	105	105	105	105	105	105
90	90	90	90	90	90	90	90	90
52.82	53.92	53.92	52.83	53.59	53.78	52.82	53.78	53.78
43.35	44.02	44.02	43.13	43.76	43.91	43.35	43.91	43.91
30.73	31.13	31.13	30.50	30.94	31.13	30.73	31.05	31.05
21.79	22.01	22.01	21.57	21.88	22.01	21.73	21.96	21.96
10.70	10.78	10.78	10.57	10.72	10.78	10.47	10.76	10.82
4.12	4.10	3.99	3.94	4.14	4.32	4.47	3.94	4.08
2.71	2.77	2.70	2.53	2.74	2.79	2.82	2.77	2.82
1.44	1.46	1.46	1.40	1.47	1.47	1.48	1.49	1.50
99.23	99.73	99.37	98.63	99.26	99.60	99.62	99.41	99.83
95.42	98.04	97.98	97.28	97.91	98.68	98.73	98.96	99.39
85.50	93.30	93.93	94.42	94.53	95.99	97.24	97.45	98.54
58.84	74.48	66.74	79.21	81.52	83.53	90.51	90.93	95.19
39.71	44.52	43.36	53.87	61.31	56.43	76.24	74.66	89.46
30.15	17.74	21.76	24.17	30.23	25.90	47.28	43.25	69.90
26.30	7.92	11.32	10.62	13.07	9.19	32.39	19.92	35.79
23.99	5.11	7.33	6.57	7.71	3.34	25.17	11.35	17.17
22.95	4.19	6.05	5.27	6.30	3.49	22.12	8.64	11.44
20.85	3.21	4.25	3.79	4.56	3.38	17.64	5.39	6.86
20.23	2.95	3.90	3.44	4.22	2.90	16.39	4.81	5.66
11.25	1.25	1.25	2.5	1.25	2.5	11.25	2.5	2.5
8.75	1.25	1.25	2.5	1.25	2.5	8.75	2.5	2.5
7.5	1.25	1.25	2.5	1.25	1.25	7.5	2.5	2.5
6.25	1.25	1.25	2.5	1.25	1.25	7.5	2.5	2.5
5	1.25	1.25	2.5	1.25	1.25	6.25	2.5	2.5
3.75	1.25	1.25	2.5	1.25	1.25	5	1.25	1.25
3.75	1.25	1.25	2.5	1.25	1.25	3.75	1.25	1.25
3.75	1.25	1.25	1.25	1.25	1.25	2.5	1.25	1.25

18	19	20	21	22	23	24	25	26
19	19	19	19	19	19	19	19	19
2000	2000	2000	2000	2000	2000	2000	2000	2000
1400	1400	1400	1400	1400	1400	1400	1400	1400
1000	1000	1000	1000	1000	1000	1000	1000	1000
700	700	700	700	700	700	700	700	700
500	500	500	500	500	500	500	500	500
355	355	355	355	355	355	355	355	355
250	250	250	250	250	250	250	250	250
180	180	180	180	180	180	180	180	180
147	147	147	147	147	147	147	147	147
105	105	105	105	105	105	105	105	105
90	90	90	90	90	90	90	90	90
52.82	53.55	50.82	51.22	51.65	51.91	51.11	51.81	49.48
43.24	43.95	41.71	41.93	42.28	42.38	41.95	42.41	41.18
30.73	31.24	29.57	29.72	29.97	29.97	29.82	29.99	29.66
21.73	22.09	20.96	21.02	21.19	21.19	21.08	21.21	21.03
10.74	10.82	10.33	10.42	10.05	10.01	10.33	10.39	10.39
4.22	4.46	3.82	4.00	4.09	3.69	3.79	3.93	3.88
2.86	2.93	2.59	2.52	2.66	2.57	2.61	2.48	2.51
1.50	1.52	1.39	1.40	1.41	1.42	1.40	1.41	1.42
99.46	99.79	100.00	96.20	99.06	98.72	99.57	99.57	99.72
97.89	98.19	99.81	82.97	93.16	92.38	97.22	96.32	97.70
95.79	92.07	99.34	65.37	78.22	77.70	88.89	85.60	92.46
85.77	60.04	97.75	36.02	41.66	40.01	49.00	52.27	81.33
69.75	29.70	94.26	23.37	22.79	17.62	30.23	30.79	74.35
47.44	17.11	85.93	19.15	16.76	11.23	22.68	24.11	71.81
31.78	14.76	73.89	17.71	14.90	9.62	20.04	22.50	70.93
24.79	13.51	63.86	16.91	13.78	8.83	18.48	21.61	70.29
22.29	13.01	56.65	16.53	13.22	8.42	17.73	21.20	69.84
18.29	12.06	38.14	15.83	12.42	7.85	16.43	20.08	68.27
17.21	11.74	33.24	15.54	11.99	7.61	15.88	19.59	67.17
11.25	7.5	10	6.25	5	2.5	10	6.25	25
10	5	7.5	5	3.75	2.5	7.5	5	16.25
7.5	2.5	6.25	3.75	2.5	2.5	5	5	7.5
7.5	2.5	5	3.75	2.5	2.5	5	5	6.25
6.25	2.5	5	3.75	2.5	2.5	5	5	5
5	2.5	5	2.5	2.5	2.5	5	5	3.75
3.75	1.25	3.75	2.5	2.5	2.5	3.75	2.5	3.75
3.75	1.25	3.75	2.5	2.5	2.5	3.75	2.5	3.75

27	28	29	30	31	32	33	34	35
19	19	19	19	19	19	19	19	19
2000	2000	2000	2000	2000	2000	2000	2000	2000
1400	1400	1400	1400	1400	1400	1400	1400	1400
1000	1000	1000	1000	1000	1000	1000	1000	1000
700	700	700	700	700	700	700	700	700
500	500	500	500	500	500	500	500	500
355	355	355	355	355	355	355	355	355
250	250	250	250	250	250	250	250	250
180	180	180	180	180	180	180	180	180
147	147	147	147	147	147	147	147	147
105	105	105	105	105	105	105	105	105
90	90	90	90	90	90	90	90	90
51.41	49.18	49.98	49.98	49.17	50.74	51.95	51.38	51.68
42.09	40.81	41.02	41.02	40.36	41.43	42.52	42.06	42.20
29.91	29.24	29.24	29.24	28.69	29.30	30.07	29.74	29.91
21.15	20.73	20.73	20.73	20.34	20.71	21.26	21.03	21.15
10.19	10.15	10.15	10.15	9.99	11.64	10.27	10.36	10.16
4.03	3.64	3.78	3.78	3.92	4.13	3.76	3.89	3.82
2.55	2.58	2.62	2.62	2.65	2.72	2.62	2.59	2.64
1.42	1.42	1.41	1.41	1.41	1.43	1.40	1.40	1.41
99.85	96.78	98.28	98.00	99.86	99.59	100.00	100.00	98.31
98.69	94.26	97.89	88.39	97.75	98.54	99.37	99.37	97.11
93.49	90.85	99.17	73.92	92.17	94.28	95.67	95.67	94.89
65.27	77.98	90.16	44.45	69.69	68.69	64.15	64.15	86.63
39.68	62.58	74.65	28.94	48.87	37.26	31.80	31.80	69.82
30.41	52.64	68.22	24.72	39.42	17.21	13.43	13.43	42.21
28.71	49.73	60.25	23.88	35.34	10.72	8.01	8.01	21.38
27.66	48.80	54.24	23.44	32.96	8.23	6.12	6.12	13.89
27.13	48.41	51.16	23.25	31.88	7.25	5.43	5.43	11.32
25.99	47.17	52.86	22.80	29.97	6.16	4.61	4.61	8.52
25.42	46.37	51.36	22.53	29.35	5.83	4.39	4.39	7.84
10	20	12.5	12.5	17.5	2.5	5	7.5	7.5
8.75	12.5	10	10	15	2.5	3.75	6.25	7.5
6.25	6.25	6.25	6.25	12.5	2.5	3.75	6.25	6.25
6.25	5	5	5	11.25	2.5	3.75	6.25	6.25
5	5	5	5	10	2.5	3.75	6.25	6.25
5	5	3.75	3.75	6.25	2.5	3.75	5	5
3.75	5	3.75	3.75	6.25	2.5	3.75	5	5
3.75	5	3.75	3.75	6.25	2.5	3.75	3.75	3.75

36	37	38	39	40	41	42	43	44
19	19	19	19	19	19	19	19	19
2000	2000	2000	2000	2000	2000	2000	2000	2000
1400	1400	1400	1400	1400	1400	1400	1400	1400
1000	1000	1000	1000	1000	1000	1000	1000	1000
700	700	700	700	700	700	700	700	700
500	500	500	500	500	500	500	500	500
355	355	355	355	355	355	355	355	355
250	250	250	250	250	250	250	250	250
180	180	180	180	180	180	180	180	180
147	147	147	147	147	147	147	147	147
105	105	105	105	105	105	105	105	105
90	90	90	90	90	90	90	90	90
51.00	52.25	51.03	50.75	51.44	50.07	51.44	51.47	52.02
41.87	42.66	41.78	41.55	42.44	41.11	42.44	42.36	42.69
29.76	30.17	29.62	29.54	30.09	29.23	30.17	30.19	30.34
21.10	21.33	21.00	20.94	21.33	20.84	21.33	21.40	21.51
10.19	10.06	10.32	10.11	10.45	10.27	10.45	10.51	10.54
3.95	4.02	4.05	4.22	3.89	4.02	4.04	3.88	3.89
2.57	2.54	2.56	2.60	2.66	2.60	2.56	2.62	2.57
1.39	1.41	1.39	1.42	1.41	1.41	1.41	1.42	1.43
98.79	95.54	98.82	97.54	99.93	99.46	99.27	99.69	98.86
92.09	91.42	96.50	94.72	99.45	98.35	95.44	98.00	92.83
74.62	83.88	92.23	89.58	97.63	96.29	85.18	92.67	80.65
43.66	44.68	74.56	68.27	85.80	89.59	47.28	69.73	49.13
32.90	22.37	53.03	55.67	71.11	80.46	25.51	45.55	28.86
28.12	12.72	35.22	45.34	43.61	63.87	19.07	36.09	22.37
26.30	9.49	28.78	39.13	21.96	53.97	17.29	32.92	20.89
25.07	7.76	25.09	35.65	14.06	47.74	16.36	31.16	20.20
24.28	6.89	23.39	33.84	11.44	44.79	15.97	30.30	19.86
22.66	5.87	20.59	30.43	8.30	39.61	15.24	28.92	19.15
22.01	5.55	19.67	29.28	7.69	38.37	14.97	28.31	18.67
13.75	5	16.25	18.75	12.5	26.83	12.5	15	10
11.25	5	15	17.5	7.5	24.39	7.5	11.25	7.5
8.75	5	13.75	15	6.25	21.95	5	7.5	5
7.5	5	12.5	13.75	5	18.29	5	6.25	3.75
7.5	5	11.25	11.25	5	15.85	5	5	3.75
7.5	3.75	7.5	8.75	5	8.54	5	3.75	2.5
6.25	3.75	6.25	7.5	5	8.54	3.75	3.75	2.5
6.25	3.75	6.25	6.25	5	4.88	3.75	3.75	2.5

45	46	47	48	49	50	51	52	53
19	19	19	19	19	19	19	19	19
2000	2000	2000	2000	2000	2000	2000	2000	2000
1400	1400	1400	1400	1400	1400	1400	1400	1400
1000	1000	1000	1000	1000	1000	1000	1000	1000
700	700	700	700	700	700	700	700	700
500	500	500	500	500	500	500	500	500
355	355	355	355	355	355	355	355	355
250	250	250	250	250	250	250	250	250
180	180	180	180	180	180	180	180	180
147	147	147	147	147	147	147	147	147
105	105	105	105	105	105	105	105	105
90	90	90	90	90	90	90	90	90
51.61	51.98	51.98	52.25	51.98	52.25	51.17	51.30	52.69
42.25	42.55	42.44	42.66	42.55	42.66	41.89	42.00	43.02
29.95	30.09	30.01	30.17	30.17	30.17	29.70	29.78	30.42
21.24	21.28	21.22	21.33	21.33	21.33	21.06	21.11	21.51
10.43	10.03	10.40	10.45	10.45	10.48	10.34	10.40	10.36
3.95	3.93	4.08	4.15	3.92	3.93	4.04	4.00	4.14
2.60	2.59	2.63	2.68	2.57	2.62	2.66	2.55	2.66
1.43	1.42	1.42	1.43	1.34	1.35	1.35	1.35	1.44
99.16	99.22	98.08	97.01	98.21	99.93	99.04	98.77	99.65
96.33	97.67	95.86	92.92	93.21	98.59	93.38	96.44	98.46
92.44	95.31	91.92	86.26	76.01	93.06	81.95	90.88	94.65
80.49	81.63	79.91	70.38	42.58	49.85	57.29	65.13	72.22
66.55	62.48	62.29	52.71	25.81	21.38	41.61	37.73	45.47
48.58	33.91	38.21	29.85	11.86	10.96	33.57	26.64	21.27
36.07	18.03	22.31	14.27	9.83	8.77	29.51	23.26	10.26
29.63	12.62	15.58	8.33	8.65	7.78	27.03	21.52	6.53
26.91	10.98	13.44	6.72	7.98	7.36	25.77	20.64	5.54
22.83	8.91	10.59	5.15	6.75	6.72	23.54	18.86	4.17
21.55	8.50	9.91	4.83	6.16	6.50	22.81	18.31	3.90
13.75	7.5	7.5	5	7.5	5	15	13.75	3.75
12.5	6.25	7.5	5	6.25	5	13.75	12.5	3.75
11.25	6.25	7.5	5	5	5	12.5	11.25	3.75
10	6.25	7.5	5	5	5	11.25	10	3.75
8.75	6.25	7.5	5	5	3.75	10	7.5	2.5
5	6.25	7.5	5	3.75	2.5	6.25	5	2.5
5	6.25	6.25	5	2.5	2.5	6.25	5	2.5
3.75	5	5	3.75	2.5	2.5	5	5	2.5

54	55	56	57	58	59	60
19	19	19	19	19	19	19
2000	2000	2000	2000	2000	2000	2000
1400	1400	1400	1400	1400	1400	1400
1000	1000	1000	1000	1000	1000	1000
700	700	700	700	700	700	700
500	500	500	500	500	500	500
355	355	355	355	355	355	355
250	250	250	250	250	250	250
180	180	180	180	180	180	180
147	147	147	147	147	147	147
105	105	105	105	105	105	105
90	90	90	90	90	90	90
51.17	51.44	52.08	50.77	52.73	52.60	52.60
41.89	42.11	42.64	41.69	43.06	43.06	42.95
29.70	29.93	30.31	29.64	30.45	30.45	30.45
21.06	21.22	21.49	21.07	21.53	21.53	18.64
10.32	10.40	10.49	10.15	10.37	10.55	10.57
3.78	3.93	3.84	3.92	3.82	3.95	4.12
2.58	2.63	2.57	2.59	2.54	2.58	2.62
1.36	1.36	1.40	1.40	1.42	1.42	1.43
99.63	100.00	99.39	99.44	97.77	99.81	100.00
98.91	99.94	96.57	97.19	90.78	97.21	99.44
97.41	99.67	90.70	93.68	78.66	89.44	95.87
93.32	96.58	75.50	85.13	51.66	58.56	66.27
87.08	89.98	64.56	75.72	31.72	32.34	43.53
71.04	83.73	53.66	65.30	17.67	16.71	29.87
49.17	77.13	41.50	54.94	11.76	11.23	23.37
35.86	68.27	33.44	48.65	9.04	8.81	19.72
30.77	59.51	29.47	45.65	7.84	8.00	17.89
24.36	36.84	21.68	37.79	6.50	6.57	14.57
22.79	31.30	19.72	35.09	5.99	6.22	13.16
15	12.5	15	25	6.25	7.5	7.5
13.75	11.25	13.75	22.5	6.25	6.25	7.5
12.5	8.75	11.25	20	6.25	6.25	6.25
11.25	7.5	10	17.5	6.25	6.25	6.25
11.25	7.5	10	15	5	6.25	5
6.25	6.25	5	11.25	3.75	3.75	5
6.25	6.25	5	8.75	3.75	3.75	3.75
5	5	3.75	7.5	2.5	3.75	3.75

A.4 Water Retention Data

Sheet:	**Retention_Data**	**Project:**	ESMP
Version:	1		
Date:	**12-Apr-01**		
Purpose:	Contains water retention data		
Data:	Pressures and water contents based on equilibrium outflow data (data just before a new pressure step)		
Model:	NA		
Software:	NA		
Analyses:	Pete Shouse, Jack Jobes		
Contact:	Marcel G. Schaap, US Salinity Lab, 450 W. Big Springs Road, Riverside, CA 92507		
E-mail:	mschaap@ussl.ars.usda.gov		

Row	**Explanation**	**Methodology**
ID	Identifier (Ring number)	
Npoints	Number of valid retention points (0,15 or 16)	
Pressure	16 rows with pressure data (cm)	Multistep outflow for pressures < 500 cm, pressure cookers for higher pressures
Theta	16 rows with water contents (cm3/cm3)	
Comments	Missing data are denoted with '-9.9' No data for samples 7, 25,28,29,30,37,58 : (Multi step outflow repeatedly failed)	

(continued on next page)

ID		1	2	3	4	5	6	7
Npoints		16	16	16	15	15	16	0
pressure	**cm**	12.4	12.4	12.4	10	10	12.4	-9.9
pressure	**cm**	20.2	20.2	20.2	20.2	20.2	20.2	-9.9
pressure	**cm**	29.4	29.4	29.4	29.4	29.4	29.4	-9.9
pressure	**cm**	47.77	47.77	47.77	48	48	47.77	-9.9
pressure	**cm**	102.89	102.89	102.89	103	103	102.89	-9.9
pressure	**cm**	149.04	149.04	149.04	213	213	149.04	-9.9
pressure	**cm**	213.44	213.44	213.44	310.5	310.5	213.44	-9.9
pressure	**cm**	307	307	307	333	333	307	-9.9
pressure	**cm**	333	333	333	459.4	459.4	333	-9.9
pressure	**cm**	460	460	460	551.2	551.2	460	-9.9
pressure	**cm**	552	552	552	735	735	552	-9.9
pressure	**cm**	736	736	736	1000	1000	736	-9.9
pressure	**cm**	1000	1000	1000	3000	3000	1000	-9.9
pressure	**cm**	3000	3000	3000	8000	8000	3000	-9.9
pressure	**cm**	8000	8000	8000	15000	15000	8000	-9.9
pressure	**cm**	15000	15000	15000			15000	-9.9
theta	**cm3/cm3**	0.2624	0.2853	0.2959	0.282	0.2664	0.2817	-9.9
theta	**cm3/cm3**	0.2587	0.2707	0.2558	0.1783	0.179	0.2198	-9.9
theta	**cm3/cm3**	0.2405	0.1965	0.234	0.1437	0.1536	0.1761	-9.9
theta	**cm3/cm3**	0.2078	0.1012	0.2034	0.1219	0.1354	0.1361	-9.9
theta	**cm3/cm3**	0.1634	0.0648	0.1361	0.0801	0.0881	0.0852	-9.9
theta	**cm3/cm3**	0.1488	0.056	0.0983	0.0509	0.0553	0.067	-9.9
theta	**cm3/cm3**	0.1215	0.0488	0.0691	0.0466	0.0335	0.0553	-9.9
theta	**cm3/cm3**	0.1033	0.0466	0.0546	0.0462	0.0333	0.0499	-9.9
theta	**cm3/cm3**	0.101	0.0459	0.0543	0.0415	0.026	0.0496	-9.9
theta	**cm3/cm3**	0.0888	0.0437	0.0459	0.0375	0.0223	0.0462	-9.9
theta	**cm3/cm3**	0.0844	0.0422	0.0437	0.0338	0.0204	0.0437	-9.9
theta	**cm3/cm3**	0.0742	0.0408	0.0422	0.0292	0.0187	0.0382	-9.9
theta	**cm3/cm3**	0.0655	0.0394	0.0416	0.0218	0.0175	0.0371	-9.9
theta	**cm3/cm3**	0.0579	0.0349	0.0364	0.0193	0.0162	0.0325	-9.9
theta	**cm3/cm3**	0.0575	0.0313	0.0319	0.0191	0.016	0.0306	-9.9
theta	**cm3/cm3**	0.0571	0.0306	0.0313			0.0298	-9.9

8	9	10	11	12	13	14	15	16
15	15	16	15	16	15	15	16	15
10	10	12.4	10	12.4	10	10	12.4	10
20.2	20.2	20.2	20.2	20.2	20.2	20.2	20.2	20.2
29.4	29.4	29.4	29.4	29.4	29.4	29.4	29.4	29.4
48	48	47.77	48	47.77	48	48	47.77	48
103	103	102.89	103	102.89	103	103	102.89	103
213	213	149.04	213	149.04	213	213	149.04	213
310.5	310.5	213.44	310.5	213.44	310.5	310.5	213.44	310.5
333	333	307	333	307	333	333	307	333
459.4	459.4	333	459.4	333	459.4	459.4	333	459.4
551.2	551.2	460	551.2	460	551.2	551.2	460	551.2
735	735	552	735	552	735	735	552	735
1000	1000	736	1000	736	1000	1000	736	1000
3000	3000	1000	3000	1000	3000	3000	1000	3000
8000	8000	3000	8000	3000	8000	8000	3000	8000
15000	15000	8000	15000	8000	15000	15000	8000	15000
		15000		15000			15000	
0.3108	0.3001	0.1697	0.3372	0.337	0.3429	0.3454	0.2962	0.3179
0.2072	0.2072	0.1042	0.23	0.2678	0.2929	0.3026	0.2758	0.2893
0.1929	0.1643	0.0751	0.1086	0.1368	0.1286	0.1597	0.2394	0.1607
0.1786	0.1357	0.0606	0.0604	0.0932	0.0572	0.0597	0.1594	0.0679
0.1465	0.0929	0.046	0.0389	0.064	0.0429	0.0454	0.103	0.0536
0.0964	0.07	0.0445	0.0318	0.0495	0.0321	0.0382	0.0866	0.0429
0.0786	0.0643	0.0358	0.0282	0.04	0.0286	0.0347	0.0757	0.0357
0.0765	0.06	0.0322	0.0275	0.0349	0.0276	0.0345	0.0655	0.0354
0.07	0.0579	0.032	0.0264	0.0343	0.0271	0.0329	0.0626	0.0336
0.0672	0.0557	0.0313	0.0257	0.0262	0.0268	0.0307	0.0546	0.0316
0.0664	0.0543	0.0291	0.025	0.0226	0.0264	0.0286	0.0473	0.0271
0.0657	0.0446	0.0269	0.0243	0.0204	0.0261	0.0271	0.04	0.0243
0.0321	0.0307	0.0244	0.0229	0.0189	0.0214	0.0243	0.0364	0.0214
0.0243	0.0293	0.0233	0.0221	0.0175	0.02	0.0229	0.0328	0.0207
0.024	0.0286	0.0233	0.0216	0.0167	0.0191	0.0221	0.0306	0.0204
		0.0233		0.016			0.0284	

17	18	19	20	21	22	23	24	25
15	16	15	15	16	15	15	15	0
10	12.4	10	10	12.4	10	10	10	-9.9
20.2	20.2	20.2	20.2	20.2	20.2	20.2	20.2	-9.9
29.4	29.4	29.4	29.4	29.4	29.4	29.4	29.4	-9.9
48	47.77	48	48	47.77	48	48	48	-9.9
103	102.89	103	103	102.89	103	103	103	-9.9
213	149.04	213	213	149.04	213	213	213	-9.9
310.5	213.44	310.5	310.5	213.44	310.5	310.5	310.5	-9.9
333	307	333	333	307	333	333	333	-9.9
459.4	333	459.4	459.4	333	459.4	459.4	459.4	-9.9
551.2	460	551.2	551.2	460	551.2	551.2	551.2	-9.9
735	552	735	735	552	735	735	735	-9.9
1000	736	1000	1000	736	1000	1000	1000	-9.9
3000	1000	3000	3000	1000	3000	3000	3000	-9.9
8000	3000	8000	8000	3000	8000	8000	8000	-9.9
15000	8000	15000	15000	8000	15000	15000	15000	-9.9
	15000			15000				-9.9
0.3215	0.298	0.3144	0.3765	0.3148	0.3051	0.2808	0.3251	-9.9
0.3019	0.2929	0.2679	0.3694	0.2566	0.1622	0.2793	0.2411	-9.9
0.2322	0.2697	0.1465	0.3336	0.2129	0.1265	0.1007	0.1947	-9.9
0.1072	0.194	0.0607	0.2979	0.1765	0.1086	0.0793	0.1625	-9.9
0.075	0.1212	0.05	0.1765	0.1255	0.0729	0.0579	0.109	-9.9
0.0536	0.1004	0.0429	0.1015	0.0935	0.0479	0.0364	0.0643	-9.9
0.0393	0.0815	0.0411	0.0943	0.0717	0.0443	0.0329	0.0579	-9.9
0.0386	0.0706	0.0407	0.0936	0.0546	0.0441	0.0321	0.0572	-9.9
0.0336	0.067	0.0393	0.0836	0.0528	0.0405	0.0293	0.0464	-9.9
0.0314	0.0633	0.0375	0.08	0.0473	0.0357	0.0279	0.0429	-9.9
0.0293	0.0597	0.0357	0.0764	0.0455	0.0343	0.0243	0.0393	-9.9
0.0271	0.0524	0.0343	0.0607	0.0437	0.0314	0.0233	0.035	-9.9
0.025	0.0473	0.02	0.0464	0.0429	0.0221	0.0226	0.0279	-9.9
0.0229	0.0364	0.0171	0.0429	0.04	0.02	0.0223	0.0271	-9.9
0.0222	0.0286	0.0158	0.0411	0.0364	0.0186	0.0222	0.0268	-9.9
	0.0255			0.0331				-9.9

26	27	28	29	30	31	32	33	34
15	15	0	0	0	16	15	15	15
10	10	-9.9	-9.9	-9.9	12.4	10	10	12.4
20.2	20.2	-9.9	-9.9	-9.9	20.2	20.2	20.2	20.2
29.4	29.4	-9.9	-9.9	-9.9	29.4	29.4	29.4	29.4
48	48	-9.9	-9.9	-9.9	47.77	48	48	47.77
103	103	-9.9	-9.9	-9.9	102.89	103	103	102.89
213	213	-9.9	-9.9	-9.9	149.04	213	213	184
310.5	310.5	-9.9	-9.9	-9.9	213.44	310.5	310.5	306
333	333	-9.9	-9.9	-9.9	307	333	333	333
459.4	459.4	-9.9	-9.9	-9.9	333	459.4	459.4	459.4
551.2	551.2	-9.9	-9.9	-9.9	460	551.2	551.2	551.2
735	735	-9.9	-9.9	-9.9	552	735	735	735
1000	1000	-9.9	-9.9	-9.9	736	1000	1000	1000
3000	3000	-9.9	-9.9	-9.9	1000	3000	3000	3000
8000	8000	-9.9	-9.9	-9.9	3000	8000	8000	8000
15000	15000	-9.9	-9.9	-9.9	8000	15000	15000	15000
		-9.9	-9.9	-9.9	15000			
0.3772	0.3072	-9.9	-9.9	-9.9	0.2802	0.2951	0.3301	0.2868
0.3737	0.2443	-9.9	-9.9	-9.9	0.2656	0.1808	0.1765	0.2413
0.3701	0.2186	-9.9	-9.9	-9.9	0.2438	0.095	0.0693	0.1467
0.3665	0.1958	-9.9	-9.9	-9.9	0.2074	0.0664	0.0479	0.0921
0.2951	0.1557	-9.9	-9.9	-9.9	0.1419	0.0414	0.0336	0.063
0.1093	0.1143	-9.9	-9.9	-9.9	0.1128	0.0379	0.0264	0.0539
0.095	0.0929	-9.9	-9.9	-9.9	0.091	0.0343	0.0229	0.0466
0.0929	0.0886	-9.9	-9.9	-9.9	0.0837	0.0332	0.0226	0.0464
0.0772	0.075	-9.9	-9.9	-9.9	0.082	0.0307	0.0214	0.0437
0.07	0.0607	-9.9	-9.9	-9.9	0.0764	0.0271	0.02	0.0415
0.0629	0.0536	-9.9	-9.9	-9.9	0.0728	0.0236	0.0186	0.0378
0.0572	0.0429	-9.9	-9.9	-9.9	0.0655	0.0207	0.0181	0.0367
0.0429	0.0304	-9.9	-9.9	-9.9	0.0582	0.0193	0.0157	0.0349
0.0343	0.0246	-9.9	-9.9	-9.9	0.0497	0.0179	0.015	0.0318
0.0336	0.0232	-9.9	-9.9	-9.9	0.0444	0.0179	0.015	0.0317
		-9.9	-9.9	-9.9	0.0437			

35	36	37	38	39	40	41	42	43
15	16	0	16	16	16	16	16	16
12.4	12.4	-9.9	12.4	12.4	12.4	12.4	12.4	12.4
20.2	20.2	-9.9	20.2	20.2	20.2	20.2	20.2	20.2
29.4	29.4	-9.9	29.4	29.4	29.4	29.4	29.4	29.4
47.77	47.77	-9.9	47.77	47.77	47.77	47.77	47.77	47.77
102.89	102.89	-9.9	102.89	102.89	102.89	102.89	102.89	102.89
184	149.04	-9.9	149.04	149.04	149.04	149.04	149.04	149.04
306	213.44	-9.9	213.44	213.44	213.44	213.44	213.44	213.44
333	307	-9.9	307	307	307	307	307	307
459.4	333	-9.9	333	333	333	333	333	333
551.2	460	-9.9	460	460	460	460	460	460
735	552	-9.9	552	552	552	552	552	552
1000	736	-9.9	736	736	736	736	736	736
3000	1000	-9.9	1000	1000	1000	1000	1000	1000
8000	3000	-9.9	3000	3000	3000	3000	3000	3000
15000	8000	-9.9	8000	8000	8000	8000	8000	8000
	15000	-9.9	15000	15000	15000	15000	15000	15000
0.317	0.2409	-9.9	0.3137	0.2729	0.2653	0.2933	0.2176	0.2693
0.3133	0.1856	-9.9	0.2882	0.2438	0.2362	0.2642	0.1303	0.2169
0.2151	0.1623	-9.9	0.2263	0.2147	0.1779	0.2496	0.1041	0.1747
0.115	0.1317	-9.9	0.1463	0.1856	0.0979	0.2256	0.0859	0.1543
0.0568	0.1026	-9.9	0.0953	0.1274	0.056	0.171	0.064	0.1252
0.0422	0.0852	-9.9	0.0855	0.1092	0.0524	0.1565	0.0531	0.1092
0.0378	0.0648	-9.9	0.0819	0.0961	0.0451	0.1419	0.0422	0.1019
0.0375	0.0531	-9.9	0.0775	0.0859	0.0386	0.1328	0.0328	0.0946
0.0364	0.0503	-9.9	0.0753	0.083	0.0382	0.1274	0.0315	0.0918
0.0342	0.0473	-9.9	0.0735	0.0786	0.0371	0.1092	0.0291	0.0873
0.0328	0.0444	-9.9	0.0691	0.0771	0.0342	0.1019	0.0277	0.0801
0.0316	0.0422	-9.9	0.0655	0.0713	0.0306	0.0892	0.0266	0.0728
0.0306	0.0378	-9.9	0.0582	0.0663	0.0287	0.0815	0.0255	0.0655
0.0304	0.0328	-9.9	0.0397	0.0509	0.0255	0.0721	0.0247	0.0437
0.0303	0.0315	-9.9	0.0364	0.0437	0.0247	0.067	0.024	0.0364
	0.0314	-9.9	0.0364	0.04	0.0247	0.064	0.0233	0.0353

44	45	46	47	48	49	50	51	52
16	16	15	15	15	15	15	16	15
12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
20.2	20.2	20.2	20.2	20.2	20.2	20.2	20.2	20.2
29.4	29.4	29.4	29.4	29.4	29.4	29.4	29.4	29.4
47.77	47.77	47.77	47.77	47.77	47.77	47.77	47.77	47.77
102.89	102.89	102.89	102.89	102.89	102.89	102.89	102.89	102.89
149.04	149.04	184	184	184	184	184	149.04	184
213.44	213.44	306	306	306	306	306	213.44	306
307	307	333	333	333	333	333	307	333
333	333	459.4	459.4	459.4	459.4	459.4	333	459.4
460	460	551.2	551.2	551.2	551.2	551.2	460	551.2
552	552	735	735	735	735	735	552	735
736	736	1000	1000	1000	1000	1000	736	1000
1000	1000	3000	3000	3000	3000	3000	1000	3000
3000	3000	8000	8000	8000	8000	8000	3000	8000
8000	8000	15000	15000	15000	15000	15000	8000	15000
15000	15000						15000	
0.3443	0.3603	0.3141	0.2627	0.3159	0.27	0.3051	0.291	0.2413
0.3421	0.3166	0.2905	0.2227	0.2838	0.1754	0.1159	0.2474	0.183
0.3384	0.2529	0.1413	0.1608	0.1587	0.1463	0.0831	0.2092	0.1467
0.313	0.1983	0.0667	0.1099	0.0802	0.1226	0.0613	0.1509	0.1212
0.171	0.1365	0.0485	0.0735	0.0552	0.0862	0.046	0.1201	0.0993
0.1528	0.1201	0.0394	0.0553	0.048	0.06	0.0351	0.1128	0.0939
0.131	0.1074	0.0339	0.0466	0.04	0.0491	0.0278	0.1026	0.0902
0.1092	0.0946	0.0338	0.0453	0.0394	0.0473	0.0277	0.0946	0.0866
0.1021	0.0882	0.032	0.0386	0.0364	0.04	0.0242	0.0926	0.0801
0.0946	0.0837	0.0301	0.0349	0.0329	0.0364	0.0231	0.0837	0.0764
0.0837	0.0801	0.0291	0.032	0.0293	0.0328	0.0218	0.0801	0.0728
0.0655	0.0691	0.027	0.0313	0.0257	0.032	0.0211	0.0728	0.0691
0.0582	0.0619	0.0247	0.0298	0.0251	0.029	0.0207	0.0673	0.0582
0.0437	0.0473	0.024	0.0291	0.0251	0.0287	0.0204	0.0473	0.0509
0.0364	0.0422	0.0233	0.0284	0.025	0.0287	0.0204	0.0426	0.0508
0.0317	0.04						0.0424	

53	54	55	56	57	58	59	60
16	15	15	15	16	0	15	15
12.4	12.4	12.4	12.4	12.4	-9.9	12.4	12.4
20.2	20.2	20.2	20.2	20.2	-9.9	20.2	20.2
29.4	29.4	29.4	29.4	29.4	-9.9	29.4	29.4
47.77	47.77	47.77	47.77	47.77	-9.9	47.77	47.77
102.89	102.89	102.89	102.89	102.89	-9.9	102.89	102.89
149.04	184	184	184	149.04	-9.9	184	184
213.44	306	306	306	213.44	-9.9	306	306
307	333	333	333	307	-9.9	333	333
333	459.4	459.4	459.4	333	-9.9	459.4	459.4
460	551.2	551.2	551.2	460	-9.9	551.2	551.2
552	735	735	735	552	-9.9	735	735
736	1000	1000	1000	736	-9.9	1000	1000
1000	3000	3000	3000	1000	-9.9	3000	3000
3000	8000	8000	8000	3000	-9.9	8000	8000
8000	15000	15000	15000	8000	-9.9	15000	15000
15000				15000	-9.9		
0.3035	0.3042	0.389	0.2613	0.263	-9.9	0.2365	0.3006
0.2489	0.3035	0.3839	0.2576	0.247	-9.9	0.1164	0.2169
0.1543	0.2489	0.3785	0.2103	0.2339	-9.9	0.091	0.1587
0.0815	0.1798	0.3202	0.163	0.2121	-9.9	0.0764	0.1186
0.0415	0.1274	0.2475	0.1303	0.1568	-9.9	0.0564	0.0677
0.0342	0.1146	0.1747	0.1179	0.1422	-9.9	0.0455	0.0473
0.0324	0.1074	0.131	0.1092	0.1357	-9.9	0.0418	0.0382
0.0309	0.1057	0.1266	0.1071	0.1295	-9.9	0.0413	0.0371
0.0306	0.1001	0.1092	0.1004	0.129	-9.9	0.0346	0.0346
0.0291	0.0946	0.1019	0.0946	0.1208	-9.9	0.0328	0.0328
0.0262	0.0873	0.0946	0.0873	0.1179	-9.9	0.0291	0.0298
0.024	0.0764	0.0764	0.0837	0.1121	-9.9	0.0275	0.0296
0.0226	0.0582	0.0509	0.0619	0.1042	-9.9	0.0255	0.0295
0.0218	0.0531	0.0473	0.0517	0.0801	-9.9	0.0247	0.0295
0.0218	0.0525	0.0437	0.0509	0.0684	-9.9	0.0247	0.0295
0.0218				0.068	-9.9		

A.5 Directly Fitted "van Genuchten" Parameters

Sheet: **Retention Parameters VG** **Project:** ESMP
Version: **1**
Date: **12-Apr-01**
Purpose: Contains van Genuchten parameters fitted to water retention
Data: Equilibrium outflow data from multistep outflow experiment (Sheet: retention)
Model: van Genuchten (1980)
Software: MATLAB with dedicated optimization software
Analyses: Marcel G. Schaap
Contact: Marcel G. Schaap, US Salinity Lab, 450 W. Big Springs Road, Riverside, CA 92507
E-mail: mschaap@ussl.ars.usda.gov

Column	**Explanation**	**Methodology**
ID	Identifier (Ring number)	
θ_r	Residual water content in cm^3/cm^3	θ_r constrained to be greater or equal than 0
θ_s	Saturated water content in cm^3/cm^3	θ_s constrained to be smaller or equal to porosity
α	INVERSE of air entry pressure in 1/cm	α constrained between 0 and 1
n	Exponent in the van Genuchten Equation	*n* constrained to be greater that 1 and smaller than 20
RMSE_c	*Unbiassed* Root Mean Square Error, corrected for 4 parameters: sqrt(sum((measured-predicted)^2)/(npoints-4))	

Comments No data available for sample 7, 25, 28, 29, 30, 37, 58

(continued on next page)

ID	θ_r cm³/cm³	θ_s cm³/cm³	α 1/cm	*n* -	RMSE_c cm³/cm³
1	0.0500	0.2711	0.0203	1.7645	0.0047
2	0.0526	0.3022	0.0635	1.4002	0.0065
3	0.0285	0.2949	0.0248	2.0282	0.0078
4	0.0203	0.4100	0.1410	1.7346	0.0064
5	0.0058	0.3757	0.1305	1.6357	0.0094
6	0.0288	0.3922	0.0899	1.8455	0.0021
7					
8	0.0077	0.3983	0.1678	1.4118	0.0132
9	0.0301	0.4742	0.1813	1.6625	0.0052
10	0.0215	0.4613	0.3487	1.8065	0.0071
11	0.0270	0.3499	0.0483	4.1472	0.0064
12	0.0226	0.4740	0.0734	2.3788	0.0140
13	0.0283	0.3469	0.0401	6.0454	0.0086
14	0.0315	0.3495	0.0383	5.4675	0.0074
15	0.0306	0.3373	0.0415	1.9304	0.0074
16	0.0319	0.3248	0.0372	5.0635	0.0109
17	0.0334	0.3326	0.0321	3.4677	0.0127
18	0.0330	0.3270	0.0298	1.9577	0.0081
19	0.0342	0.3184	0.0392	5.0478	0.0110
20	0.0470	0.3878	0.0204	2.0813	0.0086
21	0.0288	0.3685	0.0577	1.7991	0.0079
22	0.0296	0.4006	0.1021	2.0696	0.0125
23	0.0341	0.2836	0.0374	12.0378	0.0173
24	0.0225	0.3843	0.0760	1.7405	0.0056
25					
26	0.0474	0.3767	0.0083	3.1346	0.0121
27	0.0000	0.3547	0.0811	1.4266	0.0091
28					
29					
30					
31	0.0446	0.2946	0.0266	1.8822	0.0033
32	0.0261	0.3506	0.0675	2.8508	0.0084
33	0.0214	0.3506	0.0564	4.2854	0.0073
34	0.0404	0.3225	0.0467	3.0300	0.0088
35	0.0349	0.3346	0.0327	3.6952	0.0084
36	0.0235	0.3630	0.1384	1.6070	0.0059
37					
38	0.0483	0.3835	0.0566	1.9860	0.0126
39	0.0391	0.3161	0.0561	1.6150	0.0036
40	0.0316	0.2901	0.0393	2.7473	0.0067
41	0.0502	0.3115	0.0373	1.5159	0.0059
42	0.0247	0.4176	0.1629	1.9448	0.0080
43	0.0248	0.4198	0.2645	1.4123	0.0081
44	0.0377	0.3645	0.0176	1.9474	0.0134

45	0.0415	0.4364	0.0672	1.6966	0.0067
46	0.0327	0.3234	0.0381	5.8945	0.0103
47	0.0297	0.3335	0.0641	2.0642	0.0053
48	0.0347	0.3319	0.0388	4.2772	0.0111
49	0.0274	0.4025	0.1202	1.8196	0.0093
50	0.0281	0.4402	0.0757	3.8406	0.0128
51	0.0422	0.3700	0.0960	1.5836	0.0089
52	0.0594	0.3704	0.1626	1.7096	0.0094
53	0.0264	0.3315	0.0435	3.2791	0.0049
54	0.0556	0.3787	0.0644	1.6662	0.0140
55	0.0401	0.4039	0.0167	1.8130	0.0060
56	0.0407	0.3783	0.1601	1.4268	0.0104
57	0.0526	0.3022	0.0635	1.4002	0.0065
58					
59	0.0336	0.4342	0.1112	2.5891	0.0113
60	0.0277	0.4251	0.0846	2.0899	0.0033
Min	0.0000	0.2711	0.0083	1.4002	0.0021
Max	0.0594	0.4742	0.3487	12.0378	0.0173
Average	0.0330	0.3637	0.0781	2.6935	0.0085
σ	0.0119	0.0496	0.0642	1.8103	0.0032

A.6 Directly Fitted "Brooks-Corey" Parameters

Sheet: **Retention Parameters BC** **Project:** ESMP
Version: **1**
Date: **12-Apr-01**
Purpose: Contains Brooks-Corey parameters fitted to water retention
Data: Equilibrium outflow data from multistep outflow experiment (Sheet: retention)
Model: Brooks-Corey (1964)
Software: MATLAB with dedicated optimization software
Analyses: Marcel G. Schaap
Contact: Marcel G. Schaap, US Salinity Lab, 450 W. Big Springs Road, Riverside, CA 92507
E-mail: mschaap@ussl.ars.usda.gov

Column	**Explanation**	**Methodology**
ID	Identifier (Ring number)	
θ_r	Residual water content in cm^3/cm^3	θ_r constrained to be greater or equal than 0
θ_s	Saturated water content in cm^3/cm^3	θ_s constrained to be smaller or equal to porosity
α	INVERSE of air entry pressure in 1/cm	α constrained between 0 and 1
λ	Exponent in the Brooks-Corey Equation	λ constrained to be greater that 1 and smaller than 20
RMSE_c	*Unbiased* Root Mean Square Error, corrected for 4 parameters: sqrt(sum((measured-predicted)^2)/(npoints-4))	

Comments No data available for sample 7, 25, 28, 29, 30, 37, 58

(continued on next page)

ID	θ_r cm^3/cm^3	θ_s cm^3/cm^3	α 1/cm	λ -	RMSE_c cm^3/cm^3
1	0.0420	0.2539	0.0303	0.5440	0.0083
2	0.0482	0.2550	0.0459	0.3593	0.0066
3	0.0273	0.2619	0.0279	0.8906	0.0145
4	0.0162	0.2806	0.1011	0.6311	0.0041
5	0.0000	0.4279	0.2388	0.5323	0.0101
6	0.0266	0.2817	0.0701	0.7519	0.0030
7					
8	0.0023	0.3038	0.1048	0.3719	0.0117
9	0.0265	0.4740	0.2323	0.5907	0.0037
10	0.0266	0.1876	0.0920	1.0817	0.0045
11	0.0260	0.3372	0.0602	2.2036	0.0041
12	0.0239	0.3369	0.0610	1.4195	0.0111
13	0.0264	0.3429	0.0531	2.4842	0.0052
14	0.0284	0.3455	0.0534	1.9992	0.0071
15	0.0279	0.2860	0.0452	0.7865	0.0060
16	0.0297	0.3179	0.0519	1.9974	0.0084
17	0.0268	0.3120	0.0463	1.2426	0.0103
18	0.0270	0.2954	0.0395	0.7281	0.0029
19	0.0319	0.3144	0.0542	1.9961	0.0104
20	0.0417	0.3598	0.0271	0.8411	0.0112
21	0.0233	0.3147	0.0664	0.6387	0.0096
22	0.0254	0.3056	0.1033	0.8401	0.0080
23	0.0307	0.2807	0.0499	2.6897	0.0132
24	0.0166	0.3250	0.0813	0.6091	0.0058
25					
26	0.0419	0.3719	0.0118	1.4521	0.0085
27	0.0122	0.2415	0.0201	0.6014	0.0255
28					
29					
30					
31	0.0410	0.2630	0.0312	0.7205	0.0080
32	0.0273	0.2951	0.0657	1.9653	0.0079
33	0.0193	0.3299	0.0718	1.9992	0.0078
34	0.0385	0.2869	0.0575	1.4688	0.0055
35	0.0319	0.3151	0.0447	1.5957	0.0016
36	0.0202	0.2412	0.0792	0.5420	0.0062
37					
38	0.0460	0.3137	0.0563	0.8544	0.0097
39	0.0318	0.2730	0.0612	0.4916	0.0045
40	0.0346	0.2507	0.0412	1.9960	0.0097
41	0.0399	0.2787	0.0433	0.4006	0.0090
42	0.0241	0.2179	0.0847	0.8873	0.0070
43	0.0237	0.2617	0.0831	0.3982	0.0073
44	0.0299	0.3416	0.0248	0.7084	0.0074

45	0.0361	0.3604	0.0651	0.5927	0.0036
46	0.0289	0.3141	0.0522	2.0022	0.0062
47	0.0285	0.2626	0.0612	0.9395	0.0028
48	0.0335	0.3161	0.0523	1.9956	0.0078
49	0.0253	0.2659	0.0826	0.7299	0.0073
50	0.0263	0.4398	0.0993	1.9586	0.0096
51	0.0368	0.2914	0.0771	0.5005	0.0072
52	0.0578	0.3126	0.1430	0.6539	0.0082
53	0.0240	0.3036	0.0570	1.5208	0.0026
54	0.0558	0.3044	0.0519	0.6328	0.0100
55	0.0369	0.3679	0.0185	0.7126	0.0170
56	0.0460	0.2616	0.0586	0.4617	0.0087
57	0.0482	0.2550	0.0459	0.3593	0.0066
58					
59	0.0326	0.2303	0.0808	1.3613	0.0098
60	0.0256	0.3004	0.0726	0.9365	0.0032
Min	0.0000	0.1876	0.0118	0.3593	0.0016
Max	0.0578	0.4740	0.2388	2.6897	0.0255
Average	0.0303	0.3032	0.0666	1.0881	0.0078
σ	0.0111	0.0529	0.0419	0.6427	0.0040

A.7 Inversely Modeled "van Genuchten" Parameters

Sheet: **Inverse Parameters_VG** **Project:** ESMP
Version: **2**
Date: **11-Mar-03**
Purpose: Contains inversely optimized Brooks-Corey parameters for retention and saturated hydraulic conductivity
Data: Dynamic outflow data from multistep outflow experiment
Model: van Genuchten-Mualem
Software: Hydrus1D
Analyses: Pete Shouse, Jirka Simunek
Contact: Marcel G. Schaap, US Salinity Lab, 450 W. Big Springs Road, Riverside, CA 92507
E-mail: mschaap@ussl.ars.usda.gov

Column	**Explanation**
ID	Identifier (Ring number)
θ_r	Residual water content in cm3/cm3
θ_s	Saturated water content in cm3/cm3
α	INVERSE of air entry pressure in 1/cm
n	Exponent in van Genuchten Equation
K_s	Matching point in cm/day
L	Pore interaction term
RMSE	Biased Root Mean Square Error for STATIC WATER RETENTION ONLY, sqrt(sum((measured-predicted)^2)/(npoints))
1,2,3,4,5,6	Refer to the parameters Theta_r through L. A "0" indicates that this parameter was optimized, a "1" indicates that this parameter was *not* optimized. In the latter case the initial parameter value is given. This value did not change during the optimization.
Comments	Inverse method failed for samples 44 and 54. No hydraulic data were available for samples 7, 25, 28, 29, 30, 37, and 58

(continued on next page)

ID	θ_r cm³/cm³	θ_s cm³/cm³	α 1/cm	*n* -	K_s cm/day	*L* -	RMSE cm³/cm³	1	2	3	4	5	6
1	0.0426	0.2784	0.0196	1.7455	1.11E+00	0.0022	0.0063	0	0	0	0	0	0
2	0.0405	0.2880	0.0301	4.0787	4.94E+01	1.3787	0.0086	0	0	0	0	0	0
3	0.0012	0.3832	0.0501	1.6489	1.98E+01	0.9795	0.0176	0	0	0	0	0	0
4	0.0200	0.3900	0.0641	2.3970	4.72E+01	-0.0716	0.0237	1	1	0	0	0	0
5	0.0060	0.3650	0.0736	1.9250	1.43E+02	-3.1441	0.0171	1	1	0	1	0	0
6	0.0245	0.3777	0.0579	2.0375	7.01E+01	0.3258	0.0138	0	0	0	0	0	0
7													
8	0.0380	0.3880	0.0703	1.9290	1.10E+01	0.1053	0.0249	0	1	0	0	0	0
9	0.0430	0.4350	0.0688	2.4528	7.25E+01	-0.0002	0.0235	0	1	0	0	0	0
10	0.0236	0.3627	0.1058	2.5173	4.06E+02	0.0215	0.0112	0	0	0	0	0	0
11	0.0200	0.4000	0.0488	4.1650	1.88E+02	0.4623	0.0161	1	1	0	0	0	0
12	0.0292	0.3660	0.0411	3.9461	2.92E+02	4.3529	0.0162	0	1	0	0	0	0
13	0.0262	0.3540	0.0373	6.3455	2.13E+02	0.6000	0.0129	0	0	0	0	0	0
14	0.0272	0.3260	0.0335	5.6385	1.90E+02	1.6514	0.0138	0	0	0	0	0	0
15	0.0410	0.3100	0.0289	2.3656	2.09E+01	0.3031	0.0092	1	1	0	0	0	0
16	0.0320	0.3123	0.0354	5.5826	1.73E+02	0.8469	0.0101	0	0	0	0	0	0
17	0.0395	0.2671	0.0286	6.1136	1.48E+02	0.2067	0.0233	0	0	0	0	0	0
18	0.0460	0.3071	0.0228	2.4396	7.38E+00	0.0707	0.0101	0	0	0	0	0	0
19	0.0322	0.3100	0.0352	8.7755	1.25E+01	0.0240	0.0144	0	0	0	0	0	1
20	0.0491	0.3989	0.0248	2.0125	7.43E+00	0.1241	0.0093	0	0	0	0	0	0
21	0.0297	0.3500	0.0557	1.8084	2.01E+01	0.0312	0.0084	0	0	0	0	0	0
22	0.0290	0.3650	0.0528	3.4499	7.87E+01	0.0065	0.0248	1	1	0	0	0	0
23	0.0340	0.2840	0.0427	3.9120	9.81E+01	2.0305	0.0213	1	1	0	0	0	0
24	0.0220	0.3600	0.0492	2.2546	1.91E+01	0.0358	0.0199	1	1	0	0	0	0
25													
26	0.0500	0.3660	0.0082	3.2203	3.95E+00	0.8915	0.0118	0	0	0	0	0	0
27	0.0344	0.3550	0.0592	1.8415	1.29E+01	0.0010	0.0240	0	1	0	0	0	0
28													
29													
30													
31	0.0497	0.2761	0.0213	2.3262	1.55E+00	0.0035	0.0113	0	0	0	0	0	0
32	0.0247	0.3636	0.0515	4.3353	1.76E+02	0.0939	0.0187	0	0	0	0	0	0
33	0.0165	0.3529	0.0534	4.0275	3.74E+02	0.1234	0.0098	0	0	0	0	0	0
34	0.0379	0.2920	0.0372	3.9131	5.81E+01	-2.0336	0.0101	0	0	0	0	0	0
35	0.0350	0.3350	0.0305	3.5000	6.01E+01	0.6846	0.0100	1	1	0	1	0	0
36	0.0230	0.3530	0.1269	1.6070	1.23E+02	0.3192	0.0052	1	1	0	1	0	0
37													
38	0.0460	0.3040	0.0292	3.4991	2.12E+01	2.2133	0.0215	1	1	0	0	0	0
39	0.0440	0.3200	0.0523	1.6265	2.07E+01	1.2043	0.0068	0	1	0	0	0	0
40	0.0305	0.2765	0.0325	3.5786	1.08E+02	1.3272	0.0084	0	0	0	0	0	0
41	0.0500	0.3410	0.0534	1.5129	5.80E+00	-0.2413	0.0073	0	0	0	0	0	0
42	0.0250	0.2950	0.0614	2.5541	1.38E+02	0.0364	0.0150	1	1	0	0	0	0
43	0.0380	0.3800	0.1043	1.6555	3.94E+01	1.2713	0.0146	1	1	0	0	0	0
44													

45	0.0439	0.4100	0.0496	1.9129	2.42E+01	0.0041	0.0128	0	0	0	0	0	0
46	0.0330	0.3230	0.0364	5.4064	1.45E+02	0.6817	0.0107	1	1	0	0	0	0
47	0.0300	0.3330	0.0517	2.3195	4.61E+01	0.5928	0.0087	1	1	0	0	0	0
48	0.0350	0.3320	0.0367	4.6074	1.07E+02	0.4959	0.0108	1	1	0	0	0	0
49	0.0275	0.3829	0.0812	2.0900	9.32E+01	-0.2282	0.0122	0	0	0	0	0	0
50	0.0280	0.3870	0.0562	4.7400	3.41E+02	0.0021	0.0226	1	1	0	1	0	0
51	0.0500	0.3600	0.0682	1.8458	2.45E+01	0.7420	0.0133	0	1	0	0	0	0
52	0.0705	0.3290	0.0684	2.7798	6.63E+01	0.8473	0.0148	0	1	0	0	0	0
53	0.0254	0.3274	0.0397	3.6825	1.46E+02	0.0696	0.0064	0	0	0	0	0	0
54													
55	0.0290	0.3650	0.0528	3.4499	7.87E+01	0.0065	0.1333	1	1	0	0	0	0
56	0.0670	0.3144	0.0545	1.7610	2.23E+01	3.0042	0.0117	0	0	0	0	0	0
57	0.0768	0.2971	0.0368	1.6751	6.62E+00	2.2825	0.0097	0	0	0	0	0	0
58													
59	0.0317	0.3800	0.0843	2.9227	1.38E+02	2.0074	0.0115	0	1	0	0	0	0
60	0.0271	0.4100	0.0606	2.5339	1.05E+02	0.5608	0.0123	0	0	0	0	0	0
Min	0.0012	0.2671	0.0082	1.5129	1.11E+00	-3.1441	0.0052						
Max	0.0768	0.4350	0.1269	8.7755	4.06E+02	4.3529	0.1333						
Avg	0.0348	0.3439	0.0505	3.1464	9.36E+01	0.5354	0.0161						
σ	0.0141	0.0406	0.0228	1.5248	9.74E+01	1.1115	0.0176						

A.8 Inversely Modeled "Brooks-Corey" Parameters

Sheet: **Inverse_Parameters_BC** **Project:** ESMP
Version: **2**
Date: **11-Mar-03**
Purpose: Contains inversely optimized Brooks-Corey parameters for retention and saturated hydraulic conductivity
Data: Dynamic outflow data from multistep outflow experiment
Model: Brooks-Corey-Mualem
Software: Hydrus1D
Analyses: Pete Shouse, Jirka Simunek
Contact: Marcel G. Schaap, US Salinity Lab, 450 W. Big Springs Road, Riverside, CA 92507
E-mail: mschaap@ussl.ars.usda.gov

Column	Explanation
ID	Identifier (Ring number)
θ_r	Residual water content in cm3/cm3
θ_s	Saturated water content in cm3/cm3
α	INVERSE of air entry pressure in 1/cm
λ	Exponent in Brooks-Corey Equation
K_s	Matching point in cm/day
L	Pore interaction term
RMSE	Biased Root Mean Square Error for STATIC WATER RETENTION ONLY, sqrt(sum((measured-predicted)^2)/(npoints))
1,2,3,4,5,6	Refer to the parameters θ_r through *L*. A "0" indicates that this parameter was optimized, a "1" indicates that this parameter was *not* optimized. In the latter case the initial parameter value is given. This value did not change during the optimization.
Comments	Inverse method failed for samples 44 and 54. No hydraulic data were available for samples 7, 25, 28, 29, 30, 37, and 58

(continued on next page)

ID	θ_r cm³/cm³	θ_s cm³/cm³	α 1/cm	λ -	K_s cm/day	L -	RMSE cm³/cm³	1	2	3	4	5	6
1	0.0367	0.2606	0.0383	0.4747	4.68E+00	0.9623	0.0069	0	0	0	0	1	0
2	0.0323	0.2801	0.0442	1.4994	4.94E+01	1.0664	0.0074	0	0	0	0	0	0
3	0.0200	0.3350	0.0513	0.4896	1.21E+00	0.0050	0.0376	1	1	0	0	0	0
4	0.0158	0.3005	0.0685	0.8849	4.52E+01	1.2321	0.0175	0	0	0	0	0	0
5	0.0100	0.3439	0.0755	1.0017	6.96E+01	2.9763	0.0282	1	0	0	0	0	0
6	0.0200	0.3615	0.0917	0.7417	6.30E+01	0.2042	0.0137	1	0	0	0	0	0
7													
8	0.0010	0.3880	0.1727	0.3893	9.42E+00	0.8146	0.0113	1	1	0	0	1	0
9	0.0370	0.3106	0.0642	1.0192	6.96E+01	1.5532	0.0153	0	0	0	0	0	0
10	0.0160	0.3187	0.1060	1.4650	3.80E+02	1.6092	0.0180	1	0	0	0	0	0
11	0.0149	0.3458	0.0483	2.5060	2.13E+02	0.4243	0.0336	0	0	0	0	0	0
12	0.0100	0.3294	0.0553	1.5808	2.92E+02	6.1799	0.0174	1	0	0	0	0	0
13	0.0149	0.3458	0.0483	2.5060	2.13E+02	0.4243	0.0184	0	0	0	0	0	0
14	0.0294	0.3283	0.0425	3.0272	1.90E+02	1.5601	0.0111	0	0	0	0	0	0
15	0.0180	0.2814	0.0419	0.8994	3.74E+01	-0.3659	0.0140	1	0	0	0	0	0
16	0.0288	0.3031	0.0453	2.3142	1.73E+02	0.5824	0.0094	0	0	0	0	0	0
17	0.0426	0.2686	0.0351	3.0534	1.48E+02	0.3253	0.0219	0	0	0	0	0	0
18	0.0100	0.2993	0.0449	0.6194	7.32E+00	0.8356	0.0082	1	0	0	0	0	0
19	0.0311	0.3098	0.0423	3.4937	1.25E+01	-0.5012	0.0149	0	0	0	0	1	0
20	0.0234	0.3792	0.0388	0.6093	7.08E+00	1.7687	0.0119	0	0	0	0	0	0
21	0.0180	0.3500	0.0957	0.5325	1.64E+01	0.0030	0.0105	1	0	0	0	0	0
22	0.0290	0.3240	0.0688	1.3920	7.86E+01	0.3893	0.0188	0	0	0	0	1	0
23	0.0262	0.2884	0.0620	1.3714	9.81E+01	4.0536	0.0193	0	0	0	0	1	0
24	0.0191	0.3333	0.0717	0.7008	1.83E+01	0.4420	0.0080	0	0	0	0	0	0
25													
26	0.0500	0.3627	0.0103	2.8219	3.93E+00	0.1734	0.0189	0	0	0	0	1	0
27	0.0258	0.3195	0.0764	0.5224	1.06E+01	0.1032	0.0142	0	0	0	0	0	0
28													
29													
30													
31	0.0300	0.2800	0.0423	0.6056	1.76E+02	0.0012	0.0071	1	1	0	0	0	0
32	0.0240	0.3104	0.0634	2.1102	1.76E+02	0.0546	0.0093	0	0	0	0	1	0
33	0.0010	0.3020	0.0585	2.1046	3.74E+02	0.1637	0.0218	0	0	0	0	0	0
34	0.0383	0.2723	0.0492	1.7414	5.81E+01	0.6111	0.0110	0	0	0	0	0	0
35	0.0319	0.3151	0.0409	1.5957	4.47E+00	0.0531	0.0082	0	0	0	0	0	0
36	0.0200	0.3100	0.1080	0.5795	6.30E+01	0.4277	0.0091	1	1	0	0	0	0
37													
38	0.0201	0.3300	0.0452	0.8967	1.20E+02	6.4180	0.0259	0	1	0	0	0	0
39	0.0010	0.3200	0.1173	0.3561	1.47E+01	0.0934	0.0086	0	1	0	0	1	0
40	0.0323	0.2641	0.0455	1.4319	1.08E+02	1.7715	0.0087	0	0	0	0	0	0
41	0.0104	0.3100	0.0777	0.2945	3.52E+00	-1.2747	0.0091	0	1	0	0	0	0
42	0.0355	0.3500	0.0921	1.2014	1.35E+02	2.2013	0.0276	0	1	0	0	1	0
43	0.0100	0.3180	0.0963	0.4494	2.34E+01	4.9566	0.0169	1	0	0	0	0	0
44													

45	0.0422	0.3567	0.0579	0.6652	2.12E+01	1.9321	0.0054	0	0	0	0	0	0
46	0.0250	0.3153	0.0479	2.1864	1.45E+02	1.0750	0.0106	1	0	0	0	0	0
47	0.0141	0.3905	0.1160	0.7283	4.42E+01	0.0259	0.0126	0	0	0	0	0	0
48	0.0295	0.3193	0.0517	1.6809	1.07E+02	1.8002	0.0084	0	0	0	0	0	0
49	0.0279	0.3390	0.0989	0.8689	8.18E+01	-3.1517	0.0099	0	0	0	0	0	0
50	0.0303	0.3383	0.0660	3.2003	3.41E+02	0.0596	0.0164	0	0	0	0	0	0
51	0.0500	0.3100	0.0844	0.6728	1.97E+01	0.0872	0.0121	0	1	0	0	0	0
52	0.0500	0.2501	0.0701	0.9881	6.51E+01	3.2812	0.0180	0	0	0	0	0	0
53	0.0100	0.2842	0.0507	1.5461	1.46E+02	0.1082	0.0144	1	0	0	0	0	0
54													
55	0.0010	0.4000	0.2520	0.1247	1.47E+00	-1.4597	0.0927	1	0	0	0	0	0
56	0.0500	0.2691	0.0548	0.5600	1.76E+01	5.0836	0.0097	0	0	0	0	0	0
57	0.0144	0.2959	0.1000	0.2625	5.26E+00	0.0976	0.0081	0	0	0	0	0	0
58													
59	0.0260	0.3100	0.0763	2.5084	1.36E+02	0.0370	0.0252	1	1	0	0	1	0
60	0.0250	0.3500	0.0768	1.0312	1.02E+02	0.0173	0.0138	1	1	0	0	0	0
Min	0.0010	0.2501	0.0103	0.1247	1.21E+00	-3.1517	0.0054						
Max	0.0500	0.4000	0.2520	3.4937	3.80E+02	6.4180	0.0927						
Avg	0.0241	0.3192	0.0702	1.3001	9.21E+01	1.0057	0.0162						
σ	0.0130	0.0344	0.0382	0.8798	9.78E+01	1.7990	0.0130						

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