January 7, 1999

Mr. Howard Nelson
Exacto Labs
1212 Hard Rock Rd.
Green Valley, WY 55555

SITE: Timbuctoo, USA

SUBJECT: CAPILLARY CENTRIFUGE DATA CURVE FITTING RESULTS

On January 6, 1999, **AQUI-VER, INC.** (AVI) received 2 sets of soil capillary data from the referenced site, as provided by Exacto Labs, Green Valley, Wyoming. This report presents the results of capillary curve fitting analyses of the 2 samples.

Before capillary testing, the soil samples are stripped of non-aquesous phase liquid (NAPL) impacts (if present or suspected) using the Dean-Stark extraction technique (API RP40), with capillary testing following immediately thereafter. A drainage curve is measured with water being displaced by air entering the pore space. Fourteen pairs of pressure head/moisture data were measured at pressure heads ranging from 0 to 4886 centimeters. A measurement is complete when the soil moisture content reaches equilibrium with a particular pressure head value.

An analytic function describing the parametric soil moisture/pressure relationship is fit to the capillary data provided by Exacto Labs. For these analyses, the van Genuchten (1980) equation (1) was used. Other functions are available (e.g., Brooks-Corey). The equation was modified for lab data given as saturation (S), a fraction of the pore space, by the relationship $S = \theta/\theta_s$.

$$\theta = \theta_r + \frac{(\theta_s - \theta_r)}{\left[1 + (\alpha h)^{\beta}\right]^{\gamma}} \qquad (1)$$

Where: θ *= Volumetric moisture,* θ_r *= residual moisture content,* θ_s *= saturated moisture content,* α *= van Genuchten parameter, h = capillary pressure head,* β *= van Genuchten parameter,* $\gamma = 1/(1-\beta)$*. The* α *parameter is roughly inversely proportional to the capillary fringe height, and* β *reflects pore throat uniformity (higher values indicate greater pore uniformity and grain sorting).*

An iterative solver is used to fit the van Genuchten function (1980) to the lab data, with visual assistance. The solver is programmed to produce the greatest statistical R^2 value, with values closer to 1.00 indicating a better fit; residual sum of errors are also minimized. No other interpretation is provided. The lab data and analytic curve fits are provided in the appendix. A summary table of parameters is also provided. Using the derived capillary parameters, the relative water and air permeability were estimated for a range of pressure heads and saturations using the Mualem functions (Mualem, 1976).

The enclosed diskette contains the same information in EXCEL[tm] format, version 5.0. To obtain the unsaturated hydraulic conductivity or permeability at any pressure or moisture, multiply the corresponding relative permeability scaler by the measured hydraulic conductivity or permeability, respectively.

If the referenced site has free product fuel or DNAPL, **AQUI-VER, INC.** also offers other unit cost services to calculate in situ hydrocarbon volume, estimate relative mobility and other factors affecting NAPL transport, recoverability, and environmental risk. The opportunity to be of service is appreciated. Please call if you have any questions.

Sincerely,
AQUI-VER, INC.

Jenna Lynch
Environmental Technician

G.D. Beckett, R.G., C.HG.
Hydrogeologist

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enclosure: 3.5" Diskette

APPENDIX A

CURVE FITS AND PARAMETER OUTPUT

SUMMARY TABLE OF CAPILLARY TEST RESULTS

Sample ID	alpha (cm^{-1})	beta	Residual Saturation	Curve Fit R^2
ABC-1	2.33E-03	1.49	0.19	0.999
ABC-2	1.14E-02	2.33	0.17	0.994

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ABC-1

alpha (1/cm)	2.330E-03		R^2
beta	1.494E+00		9.986E-01
residual water	1.900E-01		
total water	1.000E+00		
gamma	3.306E-01		

Capillary Head (cm)	Saturated Pore Volume	Predicted Moisture
1.000E-03	1.000E+00	1.000E+00
5.430E+00	1.000E+00	9.996E-01
2.171E+01	1.000E+00	9.969E-01
4.890E+01	9.840E-01	9.898E-01
8.690E+01	9.510E-01	9.768E-01
1.357E+02	9.510E-01	9.571E-01
1.954E+02	9.350E-01	9.311E-01
2.660E+02	8.950E-01	9.000E-01
3.470E+02	8.620E-01	8.660E-01
5.430E+02	7.890E-01	7.947E-01
1.221E+03	6.430E-01	6.438E-01
2.171E+03	5.300E-01	5.436E-01
3.393E+03	4.650E-01	4.775E-01
4.886E+03	4.330E-01	4.315E-01

Capillary Head (cm)	**ABC-1**	Curve Fit	RPD (%)
1.000E-03	1.000E+00	1.000E+00	-1.031E-09
5.430E+00	1.000E+00	9.996E-01	-3.911E-04
2.171E+01	1.000E+00	9.969E-01	-3.079E-03
4.890E+01	9.840E-01	9.898E-01	5.919E-03
8.690E+01	9.510E-01	9.768E-01	2.709E-02
1.357E+02	9.510E-01	9.571E-01	6.379E-03
1.954E+02	9.350E-01	9.311E-01	-4.215E-03
2.660E+02	8.950E-01	9.000E-01	5.628E-03
3.470E+02	8.620E-01	8.660E-01	4.637E-03
5.430E+02	7.890E-01	7.947E-01	7.176E-03
1.221E+03	6.430E-01	6.438E-01	1.233E-03
4.886E+03	4.330E-01	4.315E-01	-3.359E-03

FUNCTIONAL RELATIONSHIPS BASED ON DERIVED CAPILLARY PARAMETERS

Capillary Head (cm)	(van Genuchten, 1980) Saturation	Effective Saturation	(Mualem, 1976) Relative Water Perm	(Mualem, 1976) Relative Air Perm
1.000E-03	1.000E+00	1.000E+00	9.967E-01	9.738E-11
2.000E-02	1.000E+00	1.000E+00	9.855E-01	1.760E-08
4.000E-02	1.000E+00	1.000E+00	9.797E-01	5.857E-08
5.000E-02	1.000E+00	1.000E+00	9.773E-01	8.625E-08
8.000E-02	1.000E+00	1.000E+00	9.714E-01	1.949E-07
9.000E-02	1.000E+00	1.000E+00	9.697E-01	2.391E-07

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ABC-1

1.000E+00	1.000E+00	1.000E+00	9.023E-01	1.558E-05
1.200E+00	1.000E+00	9.999E-01	8.934E-01	2.138E-05
1.300E+00	1.000E+00	9.999E-01	8.892E-01	2.457E-05
1.500E+00	9.999E-01	9.999E-01	8.813E-01	3.149E-05
2.000E+00	9.999E-01	9.999E-01	8.639E-01	5.186E-05
3.000E+00	9.998E-01	9.998E-01	8.350E-01	1.048E-04
5.000E+00	9.997E-01	9.996E-01	7.904E-01	2.539E-04
7.000E+00	9.994E-01	9.993E-01	7.551E-01	4.548E-04
9.000E+00	9.992E-01	9.990E-01	7.253E-01	7.027E-04
1.100E+01	9.989E-01	9.986E-01	6.993E-01	9.943E-04
1.500E+01	9.982E-01	9.978E-01	6.547E-01	1.699E-03
2.000E+01	9.973E-01	9.966E-01	6.086E-01	2.788E-03
2.500E+01	9.962E-01	9.953E-01	5.695E-01	4.090E-03
3.000E+01	9.950E-01	9.939E-01	5.355E-01	5.587E-03
3.500E+01	9.938E-01	9.923E-01	5.053E-01	7.265E-03
4.000E+01	9.924E-01	9.906E-01	4.782E-01	9.113E-03
4.500E+01	9.910E-01	9.889E-01	4.535E-01	1.112E-02
5.000E+01	9.895E-01	9.870E-01	4.310E-01	1.327E-02
6.000E+01	9.863E-01	9.831E-01	3.910E-01	1.799E-02
7.000E+01	9.829E-01	9.789E-01	3.565E-01	2.321E-02
7.500E+01	9.811E-01	9.767E-01	3.409E-01	2.599E-02
8.000E+01	9.793E-01	9.745E-01	3.263E-01	2.886E-02
8.500E+01	9.775E-01	9.722E-01	3.126E-01	3.184E-02
9.000E+01	9.756E-01	9.699E-01	2.996E-01	3.490E-02
9.500E+01	9.737E-01	9.675E-01	2.874E-01	3.805E-02
1.000E+02	9.717E-01	9.651E-01	2.759E-01	4.128E-02
1.200E+02	9.636E-01	9.551E-01	2.356E-01	5.489E-02
1.400E+02	9.552E-01	9.447E-01	2.027E-01	6.939E-02
1.600E+02	9.466E-01	9.341E-01	1.756E-01	8.453E-02
1.800E+02	9.379E-01	9.233E-01	1.529E-01	1.001E-01
2.000E+02	9.290E-01	9.124E-01	1.338E-01	1.159E-01
2.200E+02	9.202E-01	9.015E-01	1.176E-01	1.318E-01
2.400E+02	9.114E-01	8.906E-01	1.038E-01	1.478E-01
2.600E+02	9.026E-01	8.798E-01	9.194E-02	1.636E-01
2.800E+02	8.940E-01	8.691E-01	8.175E-02	1.792E-01
3.000E+02	8.855E-01	8.586E-01	7.293E-02	1.946E-01
3.200E+02	8.771E-01	8.483E-01	6.526E-02	2.098E-01
3.400E+02	8.688E-01	8.381E-01	5.858E-02	2.246E-01
3.600E+02	8.608E-01	8.281E-01	5.273E-02	2.390E-01
3.800E+02	8.528E-01	8.183E-01	4.759E-02	2.531E-01
4.000E+02	8.451E-01	8.088E-01	4.307E-02	2.669E-01
4.200E+02	8.375E-01	7.994E-01	3.907E-02	2.802E-01
4.400E+02	8.301E-01	7.903E-01	3.553E-02	2.932E-01
4.600E+02	8.229E-01	7.813E-01	3.238E-02	3.057E-01
4.800E+02	8.158E-01	7.726E-01	2.958E-02	3.180E-01
5.000E+02	8.089E-01	7.641E-01	2.707E-02	3.298E-01
5.500E+02	7.924E-01	7.437E-01	2.189E-02	3.578E-01
6.000E+02	7.769E-01	7.246E-01	1.790E-02	3.837E-01
6.500E+02	7.623E-01	7.066E-01	1.478E-02	4.075E-01
7.000E+02	7.486E-01	6.896E-01	1.233E-02	4.296E-01

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7.500E+02	7.357E-01	6.737E-01	1.037E-02	4.500E-01
8.000E+02	7.235E-01	6.587E-01	8.792E-03	4.689E-01
8.500E+02	7.120E-01	6.445E-01	7.509E-03	4.865E-01
9.000E+02	7.012E-01	6.311E-01	6.455E-03	5.028E-01
9.500E+02	6.909E-01	6.185E-01	5.584E-03	5.180E-01
1.000E+03	6.812E-01	6.065E-01	4.858E-03	5.321E-01
1.050E+03	6.720E-01	5.951E-01	4.249E-03	5.454E-01
1.100E+03	6.633E-01	5.843E-01	3.735E-03	5.578E-01
1.150E+03	6.549E-01	5.740E-01	3.298E-03	5.694E-01
1.200E+03	6.470E-01	5.642E-01	2.925E-03	5.803E-01
1.250E+03	6.395E-01	5.549E-01	2.605E-03	5.906E-01
1.300E+03	6.322E-01	5.460E-01	2.328E-03	6.003E-01
1.350E+03	6.253E-01	5.375E-01	2.089E-03	6.094E-01
1.400E+03	6.187E-01	5.293E-01	1.880E-03	6.181E-01
1.450E+03	6.124E-01	5.215E-01	1.697E-03	6.263E-01
1.500E+03	6.063E-01	5.140E-01	1.537E-03	6.341E-01
1.550E+03	6.005E-01	5.068E-01	1.396E-03	6.414E-01
1.600E+03	5.949E-01	4.999E-01	1.271E-03	6.485E-01
1.650E+03	5.896E-01	4.933E-01	1.160E-03	6.551E-01
1.700E+03	5.844E-01	4.869E-01	1.062E-03	6.615E-01
1.750E+03	5.794E-01	4.807E-01	9.739E-04	6.676E-01
1.800E+03	5.746E-01	4.748E-01	8.951E-04	6.734E-01
1.850E+03	5.700E-01	4.691E-01	8.245E-04	6.790E-01
1.900E+03	5.655E-01	4.635E-01	7.609E-04	6.843E-01
1.950E+03	5.611E-01	4.582E-01	7.035E-04	6.894E-01
2.000E+03	5.570E-01	4.530E-01	6.516E-04	6.943E-01
2.200E+03	5.415E-01	4.339E-01	4.876E-04	7.120E-01
2.400E+03	5.278E-01	4.170E-01	3.735E-04	7.272E-01
2.600E+03	5.156E-01	4.019E-01	2.918E-04	7.405E-01
2.800E+03	5.046E-01	3.883E-01	2.319E-04	7.522E-01
3.000E+03	4.946E-01	3.760E-01	1.871E-04	7.626E-01
3.200E+03	4.855E-01	3.648E-01	1.529E-04	7.718E-01
3.400E+03	4.772E-01	3.545E-01	1.265E-04	7.802E-01
3.600E+03	4.695E-01	3.451E-01	1.057E-04	7.877E-01
3.800E+03	4.624E-01	3.363E-01	8.915E-05	7.946E-01
4.000E+03	4.558E-01	3.282E-01	7.583E-05	8.009E-01
4.200E+03	4.497E-01	3.207E-01	6.500E-05	8.067E-01
4.400E+03	4.440E-01	3.136E-01	5.610E-05	8.120E-01
4.600E+03	4.387E-01	3.070E-01	4.873E-05	8.169E-01
4.800E+03	4.336E-01	3.008E-01	4.257E-05	8.215E-01
5.000E+03	4.289E-01	2.949E-01	3.739E-05	8.258E-01
5.200E+03	4.244E-01	2.894E-01	3.301E-05	8.298E-01
5.400E+03	4.202E-01	2.842E-01	2.927E-05	8.336E-01
5.600E+03	4.162E-01	2.792E-01	2.607E-05	8.371E-01
5.800E+03	4.124E-01	2.745E-01	2.331E-05	8.404E-01
6.000E+03	4.087E-01	2.700E-01	2.092E-05	8.436E-01
6.500E+03	4.004E-01	2.598E-01	1.620E-05	8.507E-01
7.000E+03	3.930E-01	2.506E-01	1.278E-05	8.570E-01
7.500E+03	3.863E-01	2.423E-01	1.025E-05	8.625E-01
8.000E+03	3.802E-01	2.348E-01	8.331E-06	8.675E-01

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ABC-1

8.500E+03	3.746E-01	2.280E-01	6.859E-06	8.720E-01
9.000E+03	3.696E-01	2.217E-01	5.709E-06	8.761E-01
9.500E+03	3.649E-01	2.159E-01	4.799E-06	8.798E-01
1.000E+04	3.605E-01	2.105E-01	4.069E-06	8.832E-01

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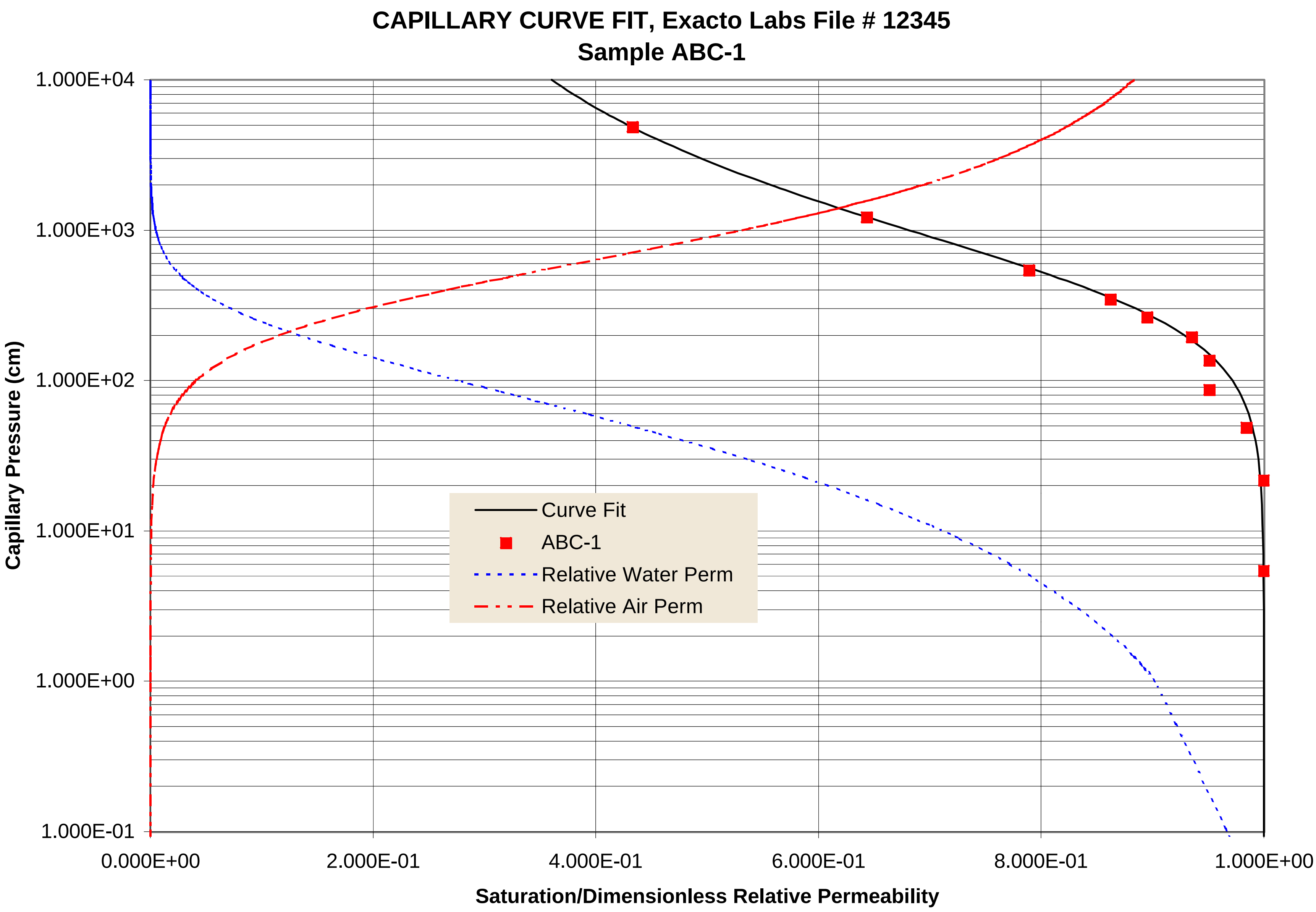
CAPILLARY CURVE FIT, Exacto Labs File # 12345
Sample ABC-1
1.000E+04
1.000E+03
1.000E+02
1.000E+01
1.000E+00
1.000E-01
Capillary Pressure (cm)
Curve Fit
ABC-1
Relative Water Perm
Relative Air Perm
0.000E+00
2.000E-01
4.000E-01
6.000E-01
8.000E-01
1.000E+00
Saturation/Dimensionless Relative Permeability

ABC-2

alpha (1/cm)	1.136E-02	R^2
beta	2.328E+00	9.935E-01
residual water	1.700E-01	
total water	1.000E+00	
gamma	5.704E-01	

Capillary Head (cm)	Saturated Pore Volume	Predicted Moisture
1.000E-03	1.000E+00	1.000E+00
5.740E+00	1.000E+00	9.992E-01
2.295E+01	9.410E-01	9.800E-01
5.160E+01	9.010E-01	8.884E-01
9.180E+01	7.430E-01	7.133E-01
1.434E+02	4.660E-01	5.405E-01
2.065E+02	4.070E-01	4.187E-01
2.811E+02	3.280E-01	3.413E-01
3.670E+02	2.890E-01	2.922E-01
4.650E+02	2.690E-01	2.600E-01
5.740E+02	2.490E-01	2.384E-01
1.291E+03	1.900E-01	1.935E-01
2.295E+03	1.600E-01	1.809E-01
3.585E+03	1.300E-01	1.760E-01

Capillary Head (cm)	**ABC-2**	Curve Fit	RPD (%)
1.000E-03	1.000E+00	1.000E+00	-1.462E-12
5.740E+00	1.000E+00	9.992E-01	-8.209E-04
2.295E+01	9.410E-01	9.800E-01	4.143E-02
5.160E+01	9.010E-01	8.884E-01	-1.403E-02
9.180E+01	7.430E-01	7.133E-01	-3.993E-02
1.434E+02	4.660E-01	5.405E-01	1.599E-01
2.065E+02	4.070E-01	4.187E-01	2.871E-02
2.811E+02	3.280E-01	3.413E-01	4.040E-02
3.670E+02	2.890E-01	2.922E-01	1.118E-02
4.650E+02	2.690E-01	2.600E-01	-3.335E-02
5.740E+02	2.490E-01	2.384E-01	-4.267E-02
1.291E+03	1.900E-01	1.935E-01	1.816E-02
2.295E+03	1.600E-01	1.809E-01	1.308E-01
3.585E+03	1.300E-01	1.760E-01	3.542E-01

FUNCTIONAL RELATIONSHIPS BASED ON DERIVED CAPILLARY PARAMETERS

Capillary Head (cm)	(van Genuchten, 1980) Saturation	Effective Saturation	(Mualem, 1976) Relative Water Perm	(Mualem, 1976) Relative Air Perm
1.000E-03	1.000E+00	1.000E+00	1.000E+00	9.810E-20
2.000E-02	1.000E+00	1.000E+00	1.000E+00	9.140E-15
4.000E-02	1.000E+00	1.000E+00	9.999E-01	1.290E-13
5.000E-02	1.000E+00	1.000E+00	9.999E-01	3.026E-13
8.000E-02	1.000E+00	1.000E+00	9.998E-01	1.822E-12
9.000E-02	1.000E+00	1.000E+00	9.998E-01	2.857E-12

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ABC-2

1.000E+00	1.000E+00	1.000E+00	9.948E-01	2.819E-08
1.200E+00	1.000E+00	1.000E+00	9.933E-01	5.657E-08
1.300E+00	1.000E+00	1.000E+00	9.926E-01	7.679E-08
1.500E+00	1.000E+00	1.000E+00	9.910E-01	1.326E-07
2.000E+00	9.999E-01	9.999E-01	9.869E-01	3.980E-07
3.000E+00	9.998E-01	9.998E-01	9.775E-01	1.872E-06
5.000E+00	9.994E-01	9.993E-01	9.558E-01	1.315E-05
7.000E+00	9.987E-01	9.984E-01	9.312E-01	4.744E-05
9.000E+00	9.977E-01	9.972E-01	9.045E-01	1.235E-04
1.100E+01	9.963E-01	9.955E-01	8.762E-01	2.645E-04
1.500E+01	9.924E-01	9.909E-01	8.162E-01	8.541E-04
2.000E+01	9.853E-01	9.823E-01	7.377E-01	2.504E-03
2.500E+01	9.758E-01	9.708E-01	6.586E-01	5.688E-03
3.000E+01	9.637E-01	9.563E-01	5.814E-01	1.096E-02
3.500E+01	9.493E-01	9.390E-01	5.082E-01	1.880E-02
4.000E+01	9.329E-01	9.191E-01	4.402E-01	2.955E-02
4.500E+01	9.146E-01	8.971E-01	3.784E-01	4.341E-02
5.000E+01	8.949E-01	8.734E-01	3.231E-01	6.039E-02
6.000E+01	8.524E-01	8.222E-01	2.321E-01	1.029E-01
7.000E+01	8.080E-01	7.686E-01	1.646E-01	1.545E-01
7.500E+01	7.857E-01	7.418E-01	1.382E-01	1.826E-01
8.000E+01	7.636E-01	7.152E-01	1.160E-01	2.116E-01
8.500E+01	7.419E-01	6.891E-01	9.737E-02	2.411E-01
9.000E+01	7.208E-01	6.636E-01	8.178E-02	2.707E-01
9.500E+01	7.003E-01	6.389E-01	6.877E-02	3.001E-01
1.000E+02	6.805E-01	6.150E-01	5.793E-02	3.290E-01
1.200E+02	6.089E-01	5.288E-01	2.978E-02	4.367E-01
1.400E+02	5.495E-01	4.572E-01	1.597E-02	5.277E-01
1.600E+02	5.008E-01	3.986E-01	8.959E-03	6.018E-01
1.800E+02	4.609E-01	3.505E-01	5.249E-03	6.613E-01
2.000E+02	4.281E-01	3.110E-01	3.201E-03	7.091E-01
2.200E+02	4.008E-01	2.781E-01	2.024E-03	7.476E-01
2.400E+02	3.780E-01	2.505E-01	1.322E-03	7.790E-01
2.600E+02	3.586E-01	2.272E-01	8.882E-04	8.048E-01
2.800E+02	3.421E-01	2.073E-01	6.122E-04	8.262E-01
3.000E+02	3.279E-01	1.902E-01	4.317E-04	8.442E-01
3.200E+02	3.155E-01	1.754E-01	3.106E-04	8.593E-01
3.400E+02	3.048E-01	1.624E-01	2.276E-04	8.722E-01
3.600E+02	2.953E-01	1.509E-01	1.696E-04	8.833E-01
3.800E+02	2.869E-01	1.408E-01	1.282E-04	8.930E-01
4.000E+02	2.794E-01	1.318E-01	9.825E-05	9.014E-01
4.200E+02	2.727E-01	1.238E-01	7.623E-05	9.087E-01
4.400E+02	2.667E-01	1.165E-01	5.981E-05	9.152E-01
4.600E+02	2.613E-01	1.100E-01	4.742E-05	9.210E-01
4.800E+02	2.564E-01	1.041E-01	3.795E-05	9.261E-01
5.000E+02	2.519E-01	9.868E-02	3.064E-05	9.307E-01
5.500E+02	2.423E-01	8.712E-02	1.857E-05	9.403E-01
6.000E+02	2.345E-01	7.773E-02	1.175E-05	9.479E-01
6.500E+02	2.281E-01	6.997E-02	7.701E-06	9.540E-01
7.000E+02	2.227E-01	6.347E-02	5.206E-06	9.590E-01

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ABC-2				
7.500E+02	2.181E-01	5.795E-02	3.615E-06	9.631E-01
8.000E+02	2.142E-01	5.322E-02	2.569E-06	9.665E-01
8.500E+02	2.108E-01	4.912E-02	1.863E-06	9.695E-01
9.000E+02	2.078E-01	4.555E-02	1.377E-06	9.720E-01
9.500E+02	2.052E-01	4.241E-02	1.033E-06	9.742E-01
1.000E+03	2.029E-01	3.963E-02	7.873E-07	9.761E-01
1.050E+03	2.008E-01	3.715E-02	6.078E-07	9.778E-01
1.100E+03	1.990E-01	3.493E-02	4.748E-07	9.793E-01
1.150E+03	1.973E-01	3.293E-02	3.750E-07	9.806E-01
1.200E+03	1.958E-01	3.113E-02	2.992E-07	9.818E-01
1.250E+03	1.945E-01	2.949E-02	2.409E-07	9.828E-01
1.300E+03	1.932E-01	2.799E-02	1.956E-07	9.838E-01
1.350E+03	1.921E-01	2.663E-02	1.601E-07	9.846E-01
1.400E+03	1.911E-01	2.538E-02	1.319E-07	9.854E-01
1.450E+03	1.901E-01	2.422E-02	1.095E-07	9.862E-01
1.500E+03	1.892E-01	2.316E-02	9.144E-08	9.868E-01
1.550E+03	1.884E-01	2.217E-02	7.682E-08	9.874E-01
1.600E+03	1.876E-01	2.126E-02	6.489E-08	9.880E-01
1.650E+03	1.869E-01	2.041E-02	5.510E-08	9.885E-01
1.700E+03	1.863E-01	1.962E-02	4.702E-08	9.890E-01
1.750E+03	1.857E-01	1.888E-02	4.031E-08	9.894E-01
1.800E+03	1.851E-01	1.818E-02	3.470E-08	9.899E-01
1.850E+03	1.846E-01	1.753E-02	3.000E-08	9.903E-01
1.900E+03	1.840E-01	1.692E-02	2.603E-08	9.906E-01
1.950E+03	1.836E-01	1.635E-02	2.267E-08	9.910E-01
2.000E+03	1.831E-01	1.581E-02	1.982E-08	9.913E-01
2.200E+03	1.816E-01	1.393E-02	1.194E-08	9.924E-01
2.400E+03	1.803E-01	1.241E-02	7.517E-09	9.933E-01
2.600E+03	1.793E-01	1.116E-02	4.912E-09	9.940E-01
2.800E+03	1.784E-01	1.012E-02	3.312E-09	9.946E-01
3.000E+03	1.777E-01	9.231E-03	2.295E-09	9.951E-01
3.200E+03	1.770E-01	8.473E-03	1.628E-09	9.955E-01
3.400E+03	1.765E-01	7.818E-03	1.179E-09	9.959E-01
3.600E+03	1.760E-01	7.247E-03	8.701E-10	9.962E-01
3.800E+03	1.756E-01	6.745E-03	6.527E-10	9.964E-01
4.000E+03	1.752E-01	6.301E-03	4.968E-10	9.967E-01
4.200E+03	1.749E-01	5.906E-03	3.833E-10	9.969E-01
4.400E+03	1.746E-01	5.552E-03	2.993E-10	9.971E-01
4.600E+03	1.743E-01	5.234E-03	2.362E-10	9.973E-01
4.800E+03	1.741E-01	4.946E-03	1.884E-10	9.974E-01
5.000E+03	1.739E-01	4.685E-03	1.516E-10	9.976E-01
5.200E+03	1.737E-01	4.447E-03	1.231E-10	9.977E-01
5.400E+03	1.735E-01	4.230E-03	1.007E-10	9.978E-01
5.600E+03	1.733E-01	4.031E-03	8.297E-11	9.979E-01
5.800E+03	1.732E-01	3.847E-03	6.884E-11	9.980E-01
6.000E+03	1.731E-01	3.678E-03	5.749E-11	9.981E-01
6.500E+03	1.727E-01	3.307E-03	3.755E-11	9.983E-01
7.000E+03	1.725E-01	2.997E-03	2.532E-11	9.985E-01
7.500E+03	1.723E-01	2.735E-03	1.754E-11	9.986E-01
8.000E+03	1.721E-01	2.510E-03	1.244E-11	9.987E-01

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ABC-2				
8.500E+03	1.719E-01	2.316E-03	9.014E-12	9.988E-01
9.000E+03	1.718E-01	2.147E-03	6.651E-12	9.989E-01
9.500E+03	1.717E-01	1.998E-03	4.988E-12	9.990E-01
1.000E+04	1.715E-01	1.867E-03	3.797E-12	9.990E-01

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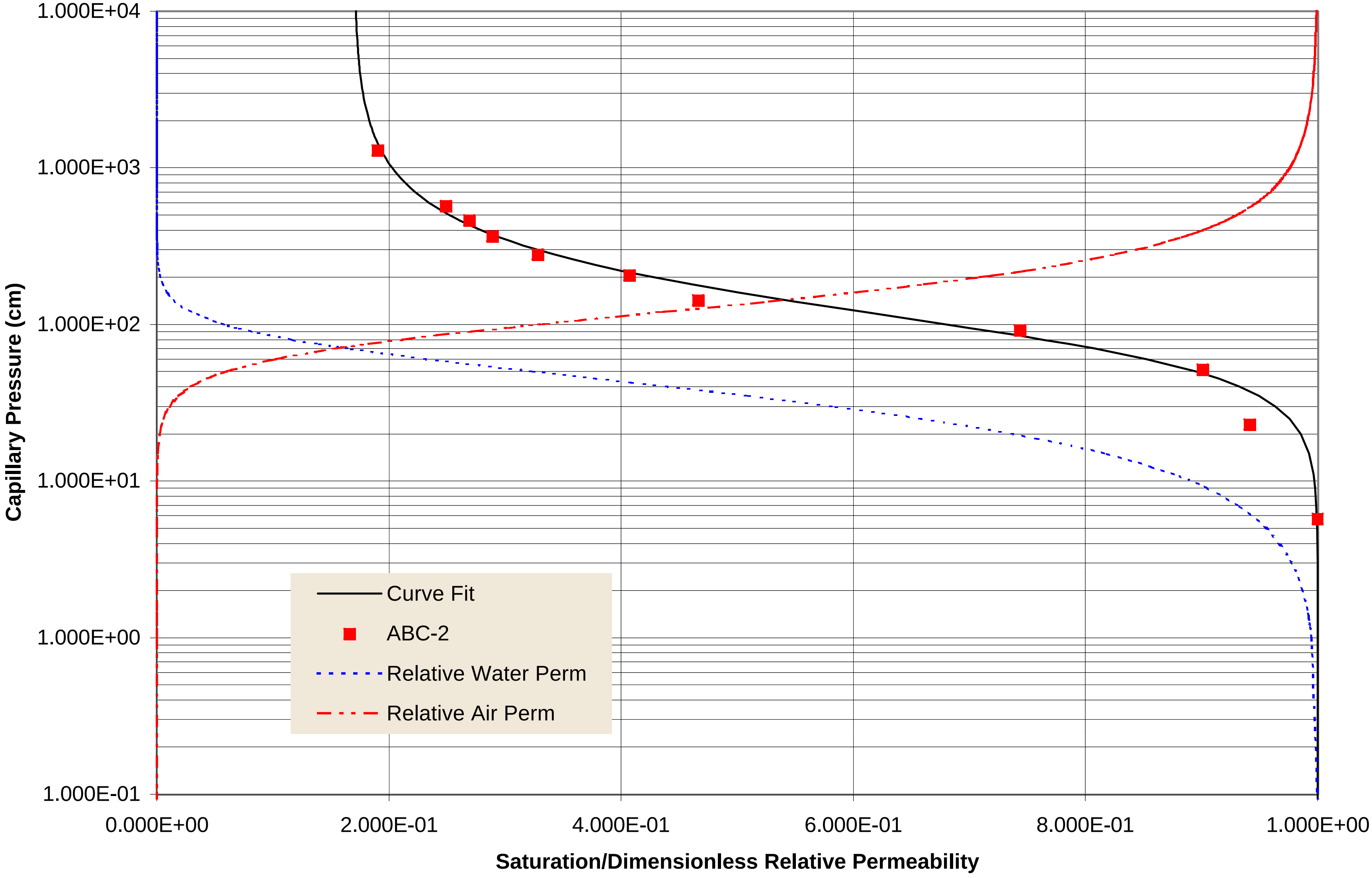
CAPILLARY CURVE FIT, Exacto Labs File # 12345
Sample ABC-2



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APPENDIX B

SUMMARY OF CAPILLARY DATA USES

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OVERVIEW OF CAPILLARITY

Following is a limited explanation of capillarity and its importance to flow and contaminant transport. The explanation is followed by examples of analyses and interpretations that depend primarily on soil capillary properties. Readers familiar with capillary properties or uninterested in a mathematical explanation are recommended to proceed directly to the examples section of this appendix. The examples are perhaps more informative and intuitively helpful than the explanations.

PHYSICAL DEVELOPMENT

Capillarity can be defined as the "action or condition by which a fluid, such as water, is drawn up in small interstices or tubes as a result of surface tension." (Dictionary of Geologic Terms, 1984). Surface tension results from the core chemical and physical interactions between the "pore" wall and the fluids present. Capillarity is the most sensitive parameter influencing water flow, multiphase non-aqueous phase liquid (NAPL) migration, and the associated chemical transport and other interactions. The primary reason for capillary sensitivity is that these properties exponentially control fluid saturation. In turn, the effective hydraulic conductivity of each fluid phase (water, air, NAPL) depends on saturation. As fluid saturation (with respect to any phase) approaches zero, the effective hydraulic conductivity also approaches zero in an exponential fashion. When effective conductivity is very small, movement in the associated fluid phase stops. This process occurs in all soils regardless of whether the soil has a large or small intrinsic permeability. These physical relationships are more clearly defined by the controlling equations, as provided below. All equations provided are scalable to a three-phase system of NAPL, air, and water coexisting in soil pores. They are the basis of all multiphase and unsaturated flow calculations.

For a perfect capillary tube, the capillary rise is proportional to the interfacial fluid tension and inversely proportional to the pore radius (1). For soil, the bulk capillarity can be defined by the van Genuchten (1980) equation provided on page 1 of the report. The equation accounts for the capillary attributes of the aggregate of pore distributions in a given soil.

$$h_c = \frac{2\sigma_{aw}}{r\ \gamma_w} \qquad (1)$$

Where h_c is capillary head, σ_{aw} is the interfacial tension between water and air (~75 dynes/cm^2), r is the capillary pore radius in consistent units, and γ_w is the unit weight of water.

Capillary head (or similarly pressure) is also defined (2) as the difference between pressure in the non-wetting phase minus pressure in the wetting phase (usually water).

$$h_c = h_{nw} - h_w \qquad P_c = P_{nw} - P_w \qquad (2)$$

The difference between head at two different locations and the distance between the points determines the hydraulic gradient (3). And total head at a point depends on elevation and pressure head, as defined by the Bernoulli equation for groundwater flow (4).

$$i = \frac{h_1 - h_2}{\overline{L_1 L_2}} \qquad ALSO \qquad \frac{\delta h}{\delta L} \tag{3}$$

$$h = Z + P/\gamma_w \tag{4}$$

Darcy's Law states that flow in porous material is proportional to the driving head and the hydraulic conductivity (5).

$$q = -Ki \tag{5}$$

As discussed previously, the effective hydraulic conductivity to a particular phase in the soil depends on the saturation of that phase and the intrinsic soil permeability. Several functions exist in industry literature exhibiting the exponential relationship between relative permeability and pore saturation (e.g., Stone; Mualem; Gardner; Brooks-Corey; etc.). The Mualem (1976) expression is provided below for reference (6). This equation shows that the relative permeability function is an exponential function acting on the saturation defined by the exponential capillary relationship (see equation on page 1).

$$k_{rw} = S_w^{1/2}\,[1-(1-S_w^{1/\gamma})^{\gamma}]^2 \tag{6}$$

Where k_{rw} is the relative permeability scaler with respect to water, S_w is the effective water phase saturation, and γ is a soil capillary parameter (van Genuchten, 1980; see page 1).

Because unsaturated hydraulic conductivity depends on relative permeability, which itself depends on the capillarity controlled fluid saturation, Darcy's Law is expanded for unsaturated flow and three-dimensional space by equation (7)[Aziz & Settari, 1976].

$$q_{pi} = -\frac{k_{rp}k_{ij}}{\mu}\left|\frac{\partial P_p}{\partial \gamma_.} + \rho_p g \frac{\partial z}{\partial \gamma_.}\right| \tag{7}$$

Where i and j are direction indices with repeated values indicating tensor notation, p is an index indicating fluid phase, q_{pi} is the Darcy velocity, k_{rp} is the relative permeability scalar, k_{ij} is the intrinsic permeability tensor of the soil, μ_p is viscosity, P_p is the pressure, ρ_p is the density, g is gravitational acceleration, z is elevation.

When solving general flow problems with transient effects such as pumping or temporally dependent releases, Darcy's Law must be coupled with the hydraulic continuity equation (8). The continuity equation, also known as the diffusion equation, is the mathematical representation of the statement that mass is neither created nor destroyed during groundwater flow and chemical interactions. The conservation of mass requires that the net rate of fluid flow into or out of an elemental volume be equal to the rate of change of fluid mass stored in the elemental volume (Freeze & Cherry, 1979). Mass in = Mass out, if you will.

$$\frac{\delta\theta}{\delta t} + \lambda = \frac{\delta}{\delta x}\left[K(\psi)\frac{\delta h}{\delta x}\right] + \frac{\delta}{\delta y}\left[K(\psi)\frac{\delta h}{\delta y}\right] + \frac{\delta}{\delta z}\left[K(\psi)\frac{\delta h}{\delta z}\right] \qquad (8)$$

Where θ is volumetric fluid content; t is time; $K(\psi)$ is hydraulic conductivity as a function of capillary pressure and saturation (recall prior equations); and x, y, z are Cartesian coordinate directions aligned with the primary flow vectors; and λ is a source/sink term.

Well finally, after all this gibberish we can again summarize, in English, the importance of capillarity. The rate of flow with respect to any fluid phase is proportional to the effective conductivity and inversely proportional to gradient. Capillarity is the most significant control over effective hydraulic conductivity and therefore the most significant factor affecting mulitphase flow. Where natural soil permeability may range over 10 orders of magnitude, capillarity may cause effective conductivity ranges over several 10's of orders.

Capillarity, as the control over saturation, also determines the true formation volume with respect to a contaminant NAPL phase (gasoline, for instance). The capillary properties of most soils limit the total fluid displacement by NAPL. For instance, a monitoring well in a silty soil exhibiting 3 feet of observed gasoline thickness might reflect a maximum NAPL formation saturation of 10 to 15% and a specific volume of 0.25 gallons per square foot (gal/ft^2). With the same 3-ft thickness in a clean medium to coarse sand, the peak formation saturation might be as high as 85% with the formation volume estimated at 8 gal/ft^2. Again, these widely varying conditions would have the same observed LNAPL thickness in an equilibrated monitoring well.