THE PENNSYLVANIA STATE UNIVERSITY
DEPARTMENT OF ENERGY AND MINERAL ENGINEERING
GEOEE 408 CONTAMINANT HYDROLOGY

Mid-term Examination – Tuesday March 3rd, 2009 – 75 minutes
Answer all three questions.

Name: ______________________________________

Include extra sheets, as needed, and return entire packet

Question	Points	Score
1	100	
2	100	
3	100	
Total	300	

Question 1

Define the following terms, and identify the units [MLT] of the quantity, where relevant. Be as specific and as exhaustive in your definitions as possible.

1. Retardation factor, $R = (1 + \frac{\rho_b}{\theta} K_d)$.

2. Advective velocity, v_a.

3. Mechanisms contributing to mechanical dispersion.

4. Darcy's law defined in terms of heads.

5. Recoverable floating product volume of LNAPL.

6. Capillary pressure –*vs*- saturation relationships.

7. Air sparging.

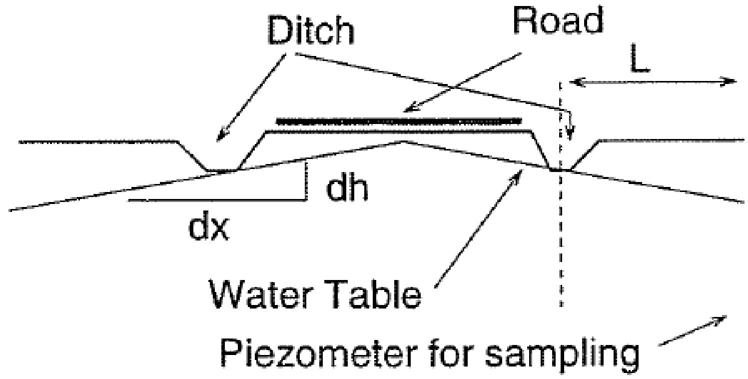
8. Capillary pressure, $p_c = p_{nw} - p_w$.

9. Irreducible saturations of the wetting and non-wetting phases.

10. Height of moving ganglion, $h_{\min} = h_c / (1 - \rho_w / \rho_{DNAPL})$.

Question 2

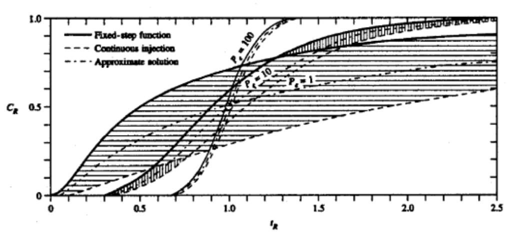
The effects of groundwater contamination by calcium chloride applied as road salt is a widespread problem. The salt is applied over the winter months and its transport can be approximated as an analog to 1-D transport for the geometry shown.

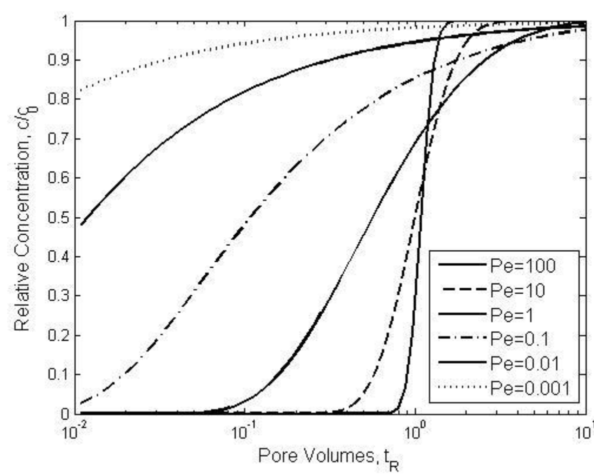


The salt rests in the ditches at either side of the road at concentration c_0 for the winter months of December, January, and February, and flushes through the groundwater system as shown in the figure. The groundwater gradient ($\partial h / \partial x$) is 1:100 and the hydraulic conductivity of the sand aquifer is $4 \times 10^{-4} cm / s$ and the porosity is 30%. The system flushes clean each year in time for the next winter.

The figures below show the solution for the advection-diffusion equation for a constant upstream concentration (fixed step concentration), c_0, with Peclet number, $Pe = v_x L / D$, and pore volumes of flow past a point downstream at coordinate $x = L$, of $t_R = v_x t / L$, i.e. the solution for:

$$c / c_0 = 1/2[erfc(Pe/4t_R)^{1/2}(1 - t_R) + \exp(Pe) erfc(Pe/4t_R)^{1/2}(1 + t_R)]$$





1. Determine the Darcy velocity of the flowfield.
2. Determine the advective velocity of the flowfield.
3. Estimate the dispersion coefficient, D_L, for the snady aquifer. The coefficient of molecular diffusion of slat in the saturated aquifer is $D^* = 2 \times 10^{-9} m^2 / s$.
4. Determine the Peclet number of the flow.
5. Determine how long it takes following the first application of salt for breakthrough to occur at the sampling location $L = 20m$ down-gradient from the ditch.
6. Sketch the breakthrough curve for a five year period annotating important features.

Question 3

A spill of TCE occurs at the surface for the stratigraphy given in the figure. The profile includes laterally extensive and horizontally bedded sands and silts. An approximate capillary pressure curve is available for TCE penetration into the sand. Unit weight of TCE is $15.6\ KN/m^3$ and for water $9.8\ KN/m^3$. The dynamic viscosity of water is $1.12\times10^{-3} N.s/m^2$ and for TCE is $0.96\times10^{-3} N.s/m^2$.

The capillary pressure relationship is defined for the silt units, as shown, and the piezometers measure pressures in the silt. Hydraulic conductivity magnitudes are available from pumping tests that yield $K_{silt} = 2.5\times10^{-5} cm/s$. The porosity of the sand and the silt are both 31%.

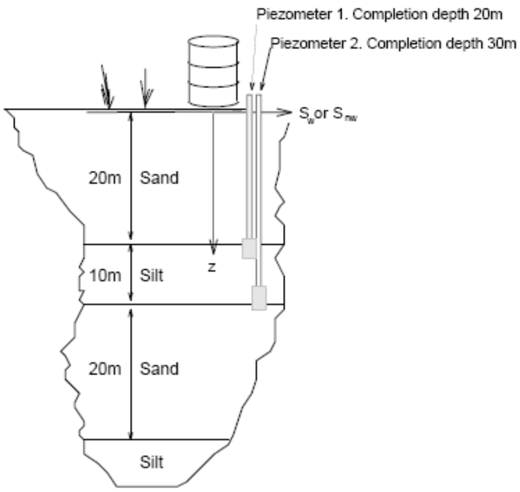
1. Water pressures are hydrostatic, with the water-table at the ground surface. Evaluate water pressures at the piezometer locations.

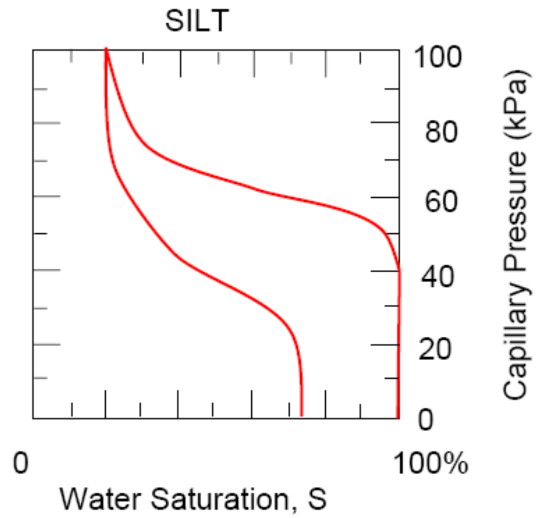
2. The piezometers measure TCE pressures in the silt layer. The TCE pressure in the upper piezometer is 280 kPa, and 436 kPa in the lower piezometer. Determine the capillary pressures at the upper and lower piezometer locations. Are these positive or negative.

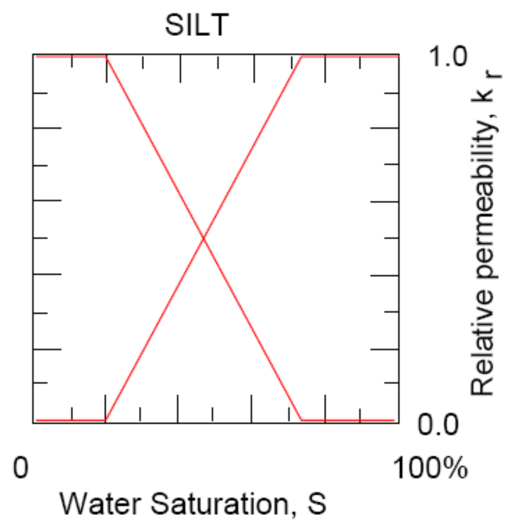
3. Evaluate the effective water and TCE saturations at the locations of each of the piezometers. Explain your rationale for choice of drainage or imbibition curves.

4. What is the permeability of the silt to TCE? State your assumptions.

5. What is the volumetric flow rate per plan area of flow?


Piezometer 1. Completion depth 20m
Piezometer 2. Completion depth 30m
S_w or S_{nw}
20m Sand
10m Silt
z
20m Sand
Silt


SILT
100
80
60
40
20
0
Capillary Pressure (kPa)
0
100%
Water Saturation, S


SILT
1.0
0.0
Relative permeability, k_r
0
100%
Water Saturation, S