## THE PENNSYLVANIA STATE UNIVERSITY DEPARTMENT OF ENERGY AND GEO-ENVIRONMENTAL ENGINEERING ENVSE 408 CONTAMINANT HYDROLOGY

## $\label{eq:mid-term} \begin{array}{c} \mbox{Mid-term Examination} - \mbox{Tuesday March 1}^{st}, 2016 - 75 \mbox{ minutes} \\ \mbox{Answer all three questions.} \end{array}$

For water (in contact with air):  $\sigma = 7.3 \times 10^{-2} N/m$ ;  $\mu = 1.12 \times 10^{-3} Pa.s$ 

Name:	Question	Points	Score
	1	100	
Question 1	2	100	
	3	100	
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.	Total	300	
1. Leverett J-function.			
2. Pendular saturation.			
3. Estimating capillary behavior from field measured permeabili	ty.		

4. Darcy's Law,  $v = k / \mu \partial p / \partial x$ 

5. Relative permeability,  $k_{r}(S_{w})$ .

6. Van Genuchten relations.

7. Advection-Dispersion equation.

8. Hydrodynamic dispersion,  $D_L = D^* + \alpha_L v^a_{\phantom{a}L}$  .

9. Fick's first law,  $F = -D \frac{\partial c}{\partial x}$ 

10. Retardation coefficient,  $R = (1 + \frac{\rho_d K_d}{\theta})$ 

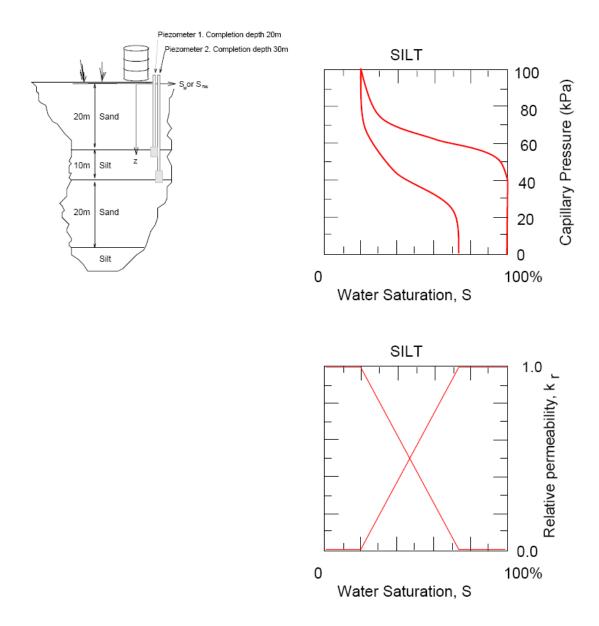
## **Question 2**

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  $1.12 \times 10^{-3} N.s \ / \ m^2$  and for TCE is  $0.96 \times 10^{-3} N.s \ / \ m^2$ .

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  $K_{sil} = 2.5 \times 10^{-5} cm/s$ . 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 in the vertical direction per plan area of flow?

## **Question 3**

A two-component DNAPL cocktail has been spilled through the vadose zone in a sand aquifer and has reached and penetrated the saturated zone. Soil samples are taken from the saturated zone within (an arbitrary) part of the aquifer where a dissolved plume is presumed to have developed. The sample is centrifuged to remove the pore fluids, and the fluid assayed to determine aqueous concentrations,  $c_a$ . Components are desorbed from the solid grains to define the presumed equilibrium sorbed concentrations,  $c_s$ . The porosity of the sand aquifer is n=25%, the bulk density is  $\rho_b=1200 \text{ kg/m}^3$ , and the mean volumetric moisture content in the vadose zone is  $\theta=5\%$ . The mean soil temperature is  $20^{\circ}C$ . Aqueous solubility of each of the components approximately triple with an increase in temperature from  $20^{\circ}$  to  $60^{\circ}C$ .

Component	$c_a$	$c_s$	Mole fraction, $X_i$	
	mg/l	mg/kg	%	
Trichloroethane (TCA)	$0.13 \times 10^3$	325	60	
Methyl Chloride	$0.6x10^4$	600	40	

Component	Aqueous Conc. $c_a$ (60°C) $mg/l$
Trichloroethane (TCA)	
Methyl Chloride	

1. Complete the missing entries in the table above.

2.	Approximately 10,000 l of the cocktail is to be removed from the system. Evaluate the
	time taken to remove this material from the aquifer if the system is flushed with water at
	$20^{\circ}C$ , at a rate of 40 $m^{3}/day$ . Assume that mole fraction approximates mass fraction, and
	that mean density of the NAPL is $1400 \text{ kg/m}^3$ .

3. What is the time taken to remove the material if warm water is used.