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

Mid-term Examination – Tuesday February 28th, 2023 – 75 minutes
Answer all three questions.
For water (in contact with air): $\sigma = 7.3 \times 10^{-2}$ *N/m*; $\mu = 1.12 \times 10^{-3}$ *N.s/m*^{2}

Name: ______________________________

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. Advective velocity, v_a.

2. Irreducible saturation of the wetting phase, S_{w_0}.

3. Leverett J-function.

4. Van Genuchten relations.

5. Laboratory measurement of $p_c - vs - S_w$.

6. Relative permeability, $k_r(S_w)$.

7. Estimating capillary behavior from field measured permeability.

8. Pendular saturation.

9. Hydrodynamic dispersion, $D_L = D* + \alpha_L v^{a}{}_{L}$.

10. Fick’s first law, $F = -D \dfrac{\partial c}{\partial x}$

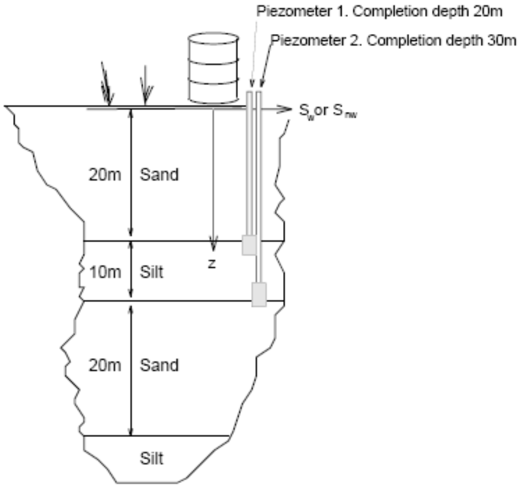
Question 2

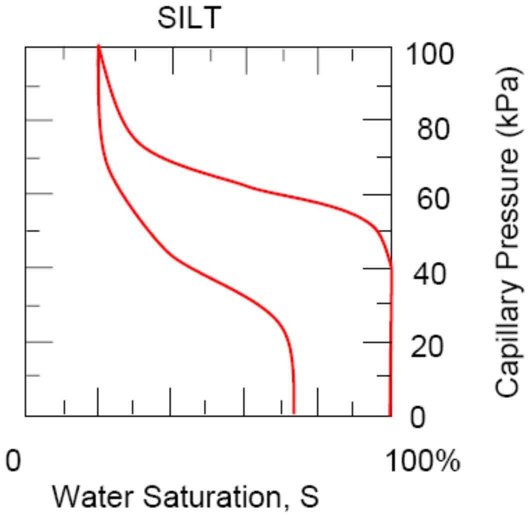
A spill of TCE occurs at the surface for the stratigraphy given in the figure. The profile includes laterally extensive and horizontally bedded sands and silts. An approximate capillary pressure curve is available for TCE penetration into the sand. Unit weight of TCE is $15.6\,KN/m^3$ and for water $9.8\,KN/m^3$.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

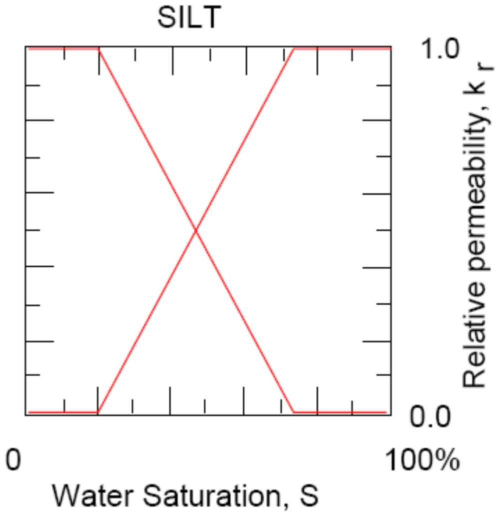
The capillary pressure relationship is defined for the silt units, as shown, and the piezometers measure pressures in the silt. Hydraulic conductivity magnitudes are available from pumping tests that yield $K_{silt}=2.5\times10^{-5}cm/s$. The porosity of the sand and the silt are both 31%.

1. Water pressures are hydrostatic, with the water-table at the ground surface. Evaluate water pressures at the piezometer locations in the figure at 20m and 30m depth.

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.





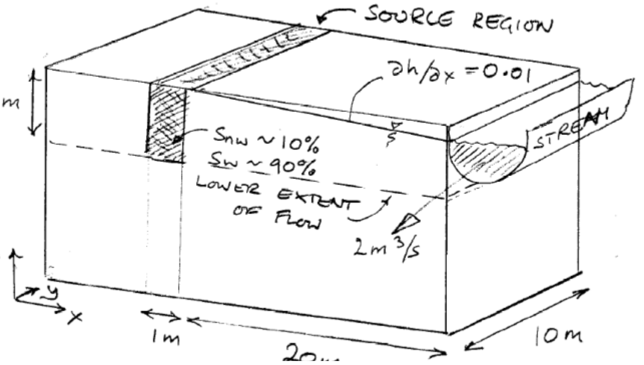


3. Evaluate the effective water and TCE saturations at the locations of each of the piezometers. Explain your rationale for choice of drainage or imbibition curves.

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

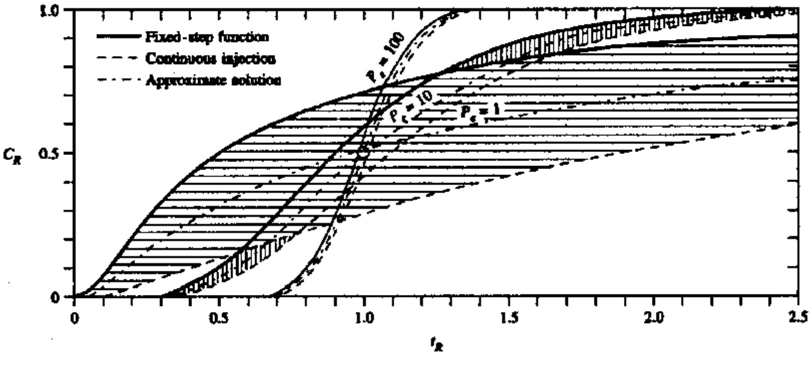


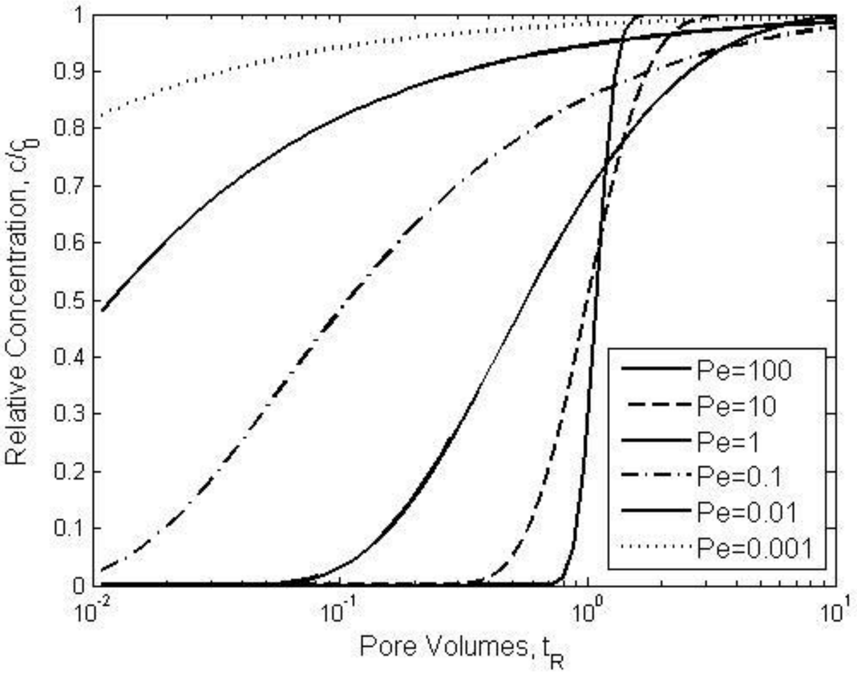
A surface spill of gasoline has penetrated into the subsurface. It previously rested on the groundwater table, which has fallen and subsequently risen, to smear it as shown. The floating free-product has been removed, and the smeared zone is below the water table and at a residual saturation of 90% water and 10% LNAPL.

The hydraulic conductivity of the aquifer is $K = 10^{-4} m/s$, and is at a relative permeability of $k_r = 1$ for water. The aquifer has a porosity of $n = 20\%$, and retardation is insignificant. The LNAPL is immobile, and comprises a single principal component of ethyl-benzene with a solubility of 140 mg/l and a density of 867 g/L. Assume an effective diffusion coefficient of the dissolved component to be $D^* = 10^{-9} m^2/s$. And a longitudinal dispersivity of α_L of one tenth of plume length.

The figures 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. Evaluate the arrival time of the mean concentration to the stream of ethyl-benzene. What are the approximate times of the 0.1 (10%) and 0.9 (90%) c/c_0 arrivals?

2. What is the concentration of ethyl-benzene when the plume arrives at the downstream extent of the aquifer, immediately <u>before</u> discharging into the stream (i.e. the equilibrium concentration)?

3. At this rate of transport from the source, approximately how long will it take to deplete the source by dissolution?

4. The dissolved flux enters the stream, with the stream flowing at a rate of $2\,m^3/s$. To what average dissolved concentration of ethyl-benzene is aquatic life exposed? The plume is 10 m wide and ~2 m deep.

5. If grouting the material between the source and the stream is used to slow the spread of the components, and the mean conductivity is reduced to $K = 10^{-10} m/s$, and the porosity to 2%, what is the new reduced mass loading to the stream, and the resulting concentration in the stream?

6. At this loading, how long-lived would the plume be?