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

Mid-term Examination – Tuesday March 4th, 2014 – 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/m²*

Name: ______________________________________

Question	Points	Score
1	100	
2	100	
3	100	
Total	300	

Include extra sheets, as needed, and return entire packet

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.

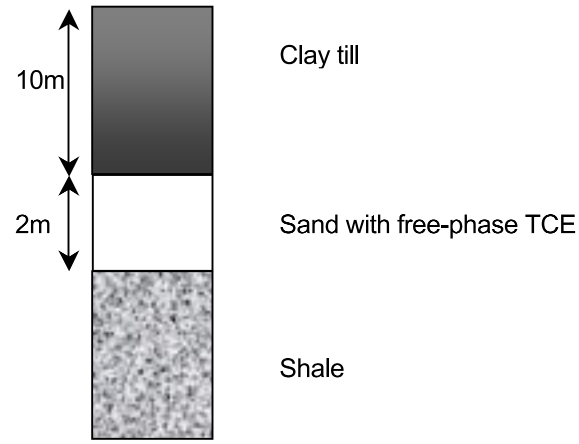
8. Pendular saturation.

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

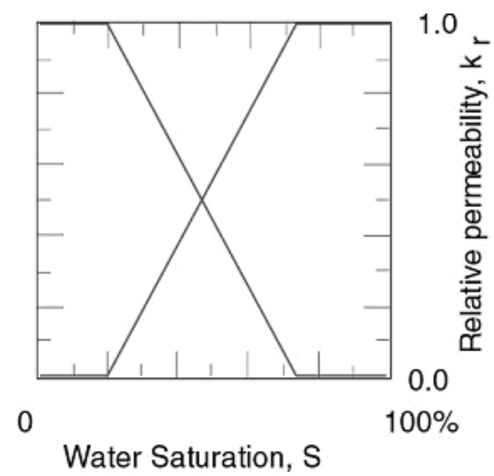
10. Fick's first law, $F = -D\frac{\partial c}{\partial x}$

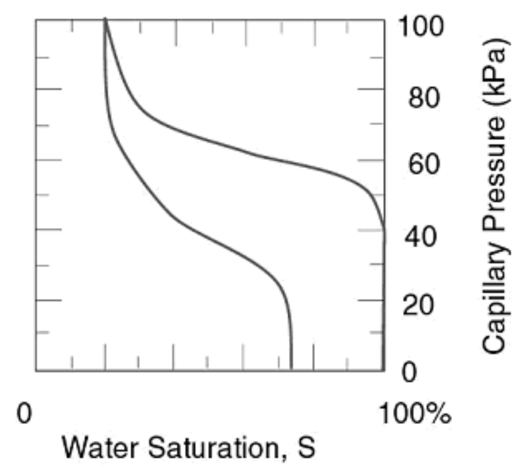
Question 2

Free-phase TCE has been detected in a sand aquifer that was thought to be protected by 10 meters of clay till, as illustrated. The water-table is at the ground surface. The sand aquifer is underlain by shale.



The capillary pressure versus saturation and relative permeability versus saturation curves are available for the underlying sand.





Determine the following:

1. If you assume the clay till to be unfractured, with a porosity of 20%, evaluate the minimum matrix permeability at its base if the free-phase TCE has managed to cross it. [Leverett curve gives $J=0.3$ at $S_w=99.999\%$]

2. How does this magnitude of permeability compare with values you expect for clay? Correspondingly, what does this say about the likely presence or absence of fractures in the clay?

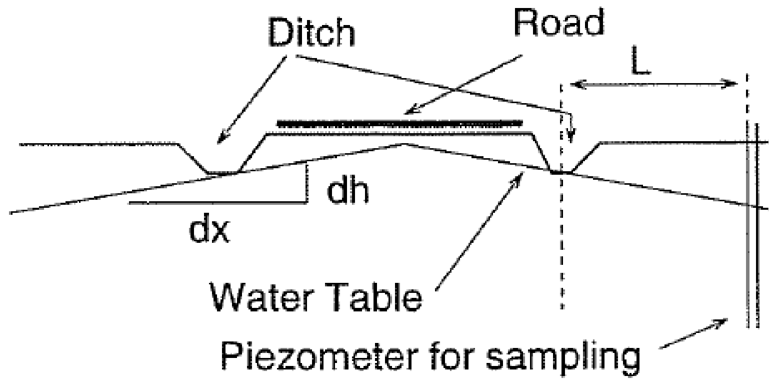
3. If TCE may be present only up to the ground surface, what is the range of maximum saturations that may be present in the sand? i.e. at the top and base of the aquifer.

4. If the horizontal hydraulic gradient is 1 in 100 in the sand aquifer, what is the average horizontal advective velocity, if the hydraulic conductivity of the sand is $K=10^{-5}$ m/d, and its porosity 30%.

5. How far will the plume travel in 10 years if transport is both near-conservative and you assume advection dominated (i.e. Pe>100)?

6. Based on your knowledge of the fidelity of plume length predictions for Peclet numbers less than 10, do you expect your prediction of the plume length to underestimate, closely estimate, or overestimate the true length? [In this do not assume that the main dispersive process is mechanical dispersion.] Explain your reasoning.

Question 3

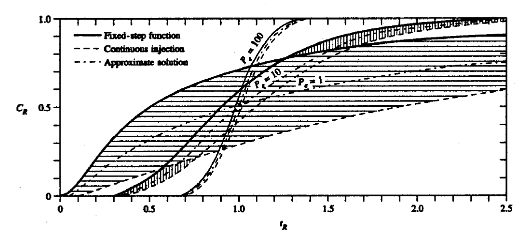


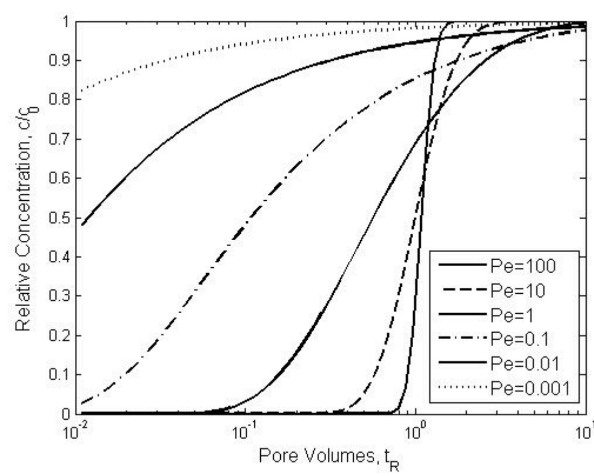
The effects of groundwater contamination by calcium chloride applied as road salt is a widespread problem. The salt is applied over the winter months and its transport can be approximated as an analog to 1-D transport for the geometry shown.

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 $D^{*} = 2¥10^{-9} m^2 / s$.
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.