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

Mid-term Examination – Tuesday March 4th, 2008 – 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*

For TCE (in contact with water): $\sigma = 3.5 \times 10^{-2}\ N/m$; $\mu = 0.96 \times 10^{-3} N.s/m^2$; $\rho_{TCE} = 1540\ kg/m^3$

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. Advection-dispersion equation, $D_L \partial^2 c / \partial x^2 - v_x \partial c / \partial x = \partial c / \partial t$.

2. Minimum ganglion length for DNAPL migration in the subsurface, $h_{\min} = h_c / (1 - \rho_w / \rho_{nw})$.

3. Capillary pressure versus saturation relationship defined in terms of the Leverett J-function, J.

4. Brooks-Corey relationship, $S_e = (p / p_b)^{-\lambda}$.

5. Darcy’s law defined in terms of fluid pressures.

6. True floating product thickness versus well-measured thickness for LNAPL.

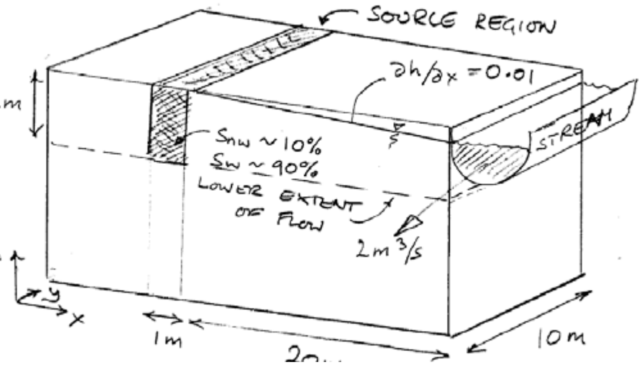
7. Laboratory apparatus to determine capillary pressure –*vs*- saturation relationships.

8. Scanning curves in capillary pressure –*vs*- saturation relationships.

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

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

Question 2

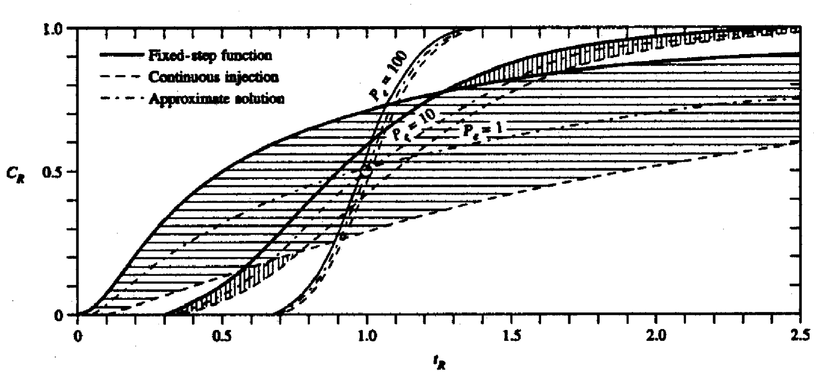


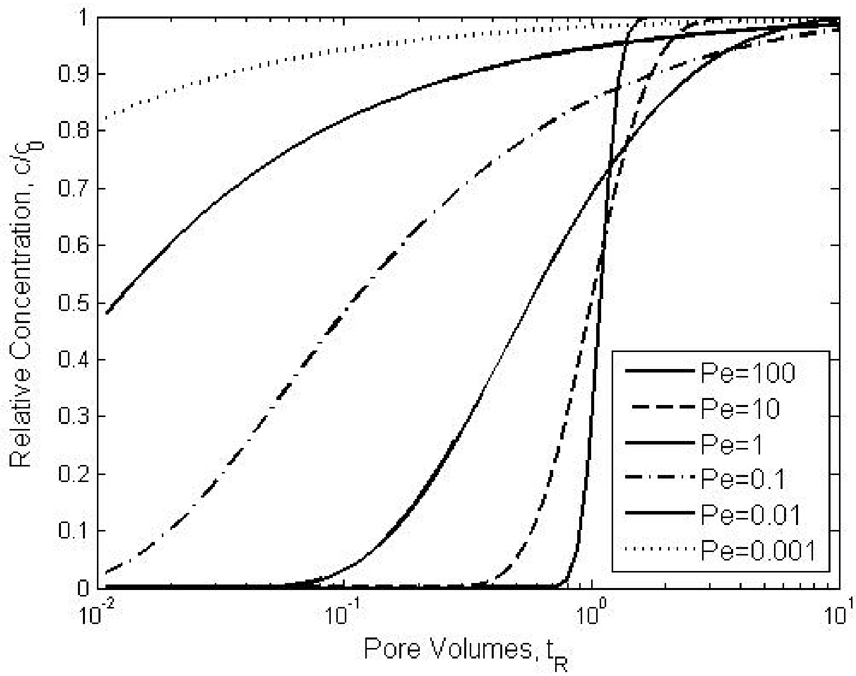
A surface spill of gasoline has penetrated into the subsurface. It previously rested on the groundwater table, which has fallen and subsequently risen, to smear it as shown. The floating free-product has been removed, and the smeared zone is below the water table and at a residual saturation of 90% water 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 both components 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 in the aquifer, immediately <u>before</u> discharging into the stream (i.e. the equilibrium concentration)?

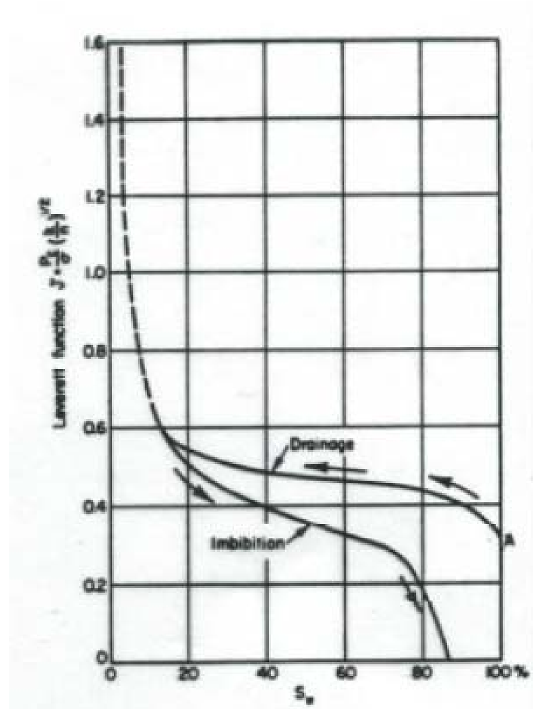
3. At this rate of transport from the source, approximately how long will it take to deplete the source by dissolution?

4. The dissolved flux enters the stream, flowing at $2\,m^3/s$. To what 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 permeability 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?

Question 3



The Leverett curve defines the relationship between water saturation, S_w , and a non-dimensional capillary pressure, J , where $J = \frac{p_c}{\sigma}\sqrt{\frac{k}{n}}$. For a site where the water table is $3\ m$ below the ground surface, with a porosity of 30%, and a permeability of $10^{-12}\ m^2$, compute the following:

1. The height of the capillary rise above the water table.
2. The water saturation at the ground surface. How close is this to the irreducible saturation of water?
3. At a nearby site, the water table is at the ground surface. Evaluate the height of TCE required to penetrate the aquifer. All parameters of permeability and porosity are the same.
4. If an overpressure is supplied at the ground surface, which is just sufficient to force TCE into the soil, at what depth will it be possible for the NAPL saturation to reach 40%?
5. If it is observed that the permeability is due to the presence of fractures, what impact do you expect this to have on the above results? Will the entry pressures be lower or higher? And will the saturations at any given depth be lower or higher? State your rationale.