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

Mid-term Examination – Tuesday March 22nd, 2011 – 75 minutes
Answer all three questions.

For water (in contact with air): $\sigma = 7.3 \times 10^{-2}$ *N/m*; γ=9.8 kN/m^3; $\mu = 1.12 \times 10^{-3}$ *N.s/m^2*
For TCE (in contact with water): $\sigma = 3.5 \times 10^{-2}$ *N/m*; γ=15.6 kN/m^3; $\mu = 0.96 \times 10^{-3}$ *N.s/m^2*

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. Capillary pressure –vs- saturation relation, $p_c - S_w$

2. Van Genuchten relations

3. Advection-dispersion equation, $\frac{\partial c}{\partial t} = D_L * \frac{\partial^2 c}{\partial x^2} + D_T * \frac{\partial^2 c}{\partial y^2} - v_a \frac{\partial c}{\partial x}$

4. Gaseous retardation coefficient, R_g

5. Rotary drilling.

6. Raoult's law, $S_{ei} = X_i S_i$

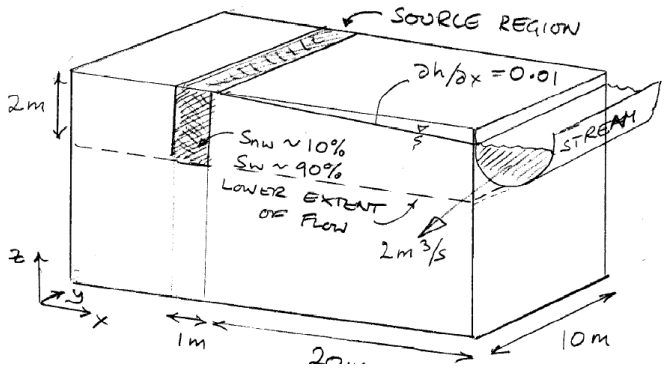
7. Non-conservative transport.

8. Geophysical site investigation methods.

9. Peclet number, $P_e = v_a l / D^*$

10. Bubbling pressure, $p_b = p_{c0}$

Question 2

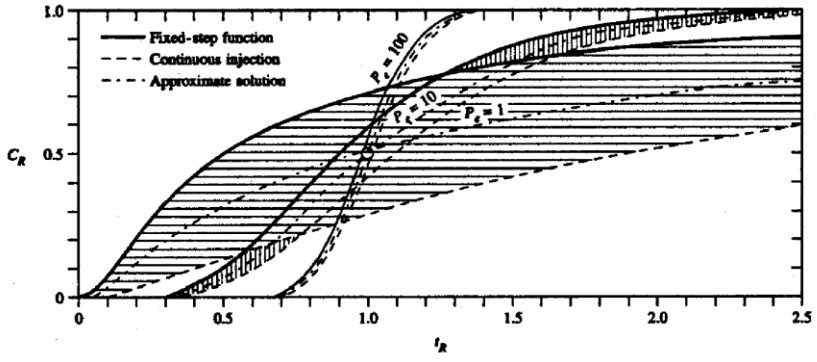


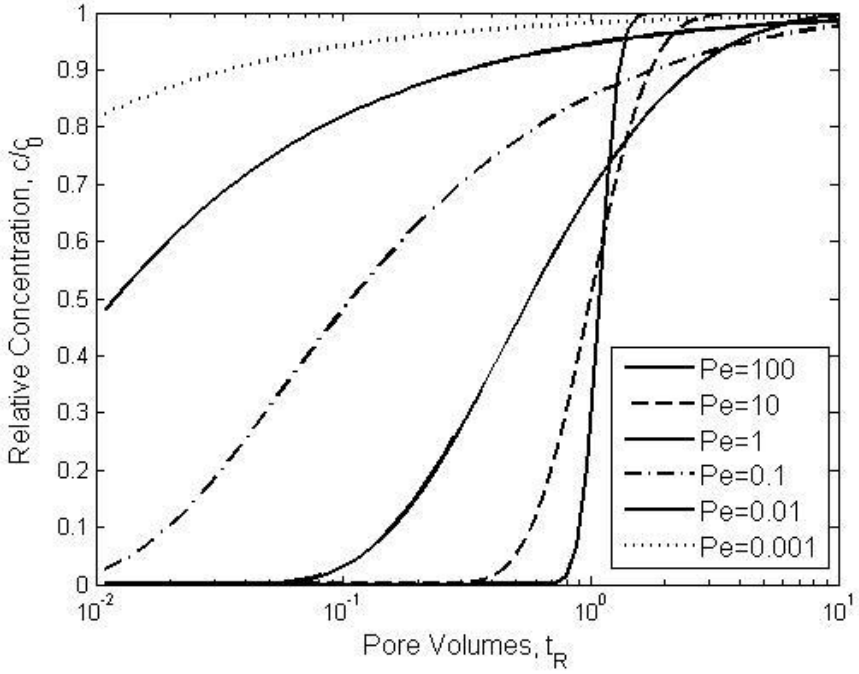
A surface spill of gasoline has penetrated into the subsurface. It previously rested on the groundwater table, which has fallen and subsequently risen, to smear it as shown. The floating free-product has been removed, and the smeared zone is below the water table and at a residual saturation of 90% water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

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 ρ_b=1200 kg/m^3, and the mean volumetric moisture content in the vadose zone is θ=5%. The mean soil temperature is 20^oC. Solubility of each of the components approximately triple with an increase in temperature from 20^o to 60^oC. The non-dimensional Henry's law coefficient, H, approximately doubles over the same temperature range.

Component	c_a *mg/l*	c_s *mg/kg*	Henry's Law Coef. $H(20^oC)$ *[dimensionless]*	Mole fraction, X_i *%*
Trichloroethane (TCA)	$0.13x10^3$	325	0.4	60
Methyl Chloride	$0.6x10^4$	600	0.6	40

Component	Gaseous Conc. c_g(20^oC) *mg/l*	Aqueous Conc. c_a (60^oC) *mg/l*	Gaseous Conc. c_g (60^oC) *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^oC, at a rate of 40 m^3/day. Assume that mole fraction approximates mass fraction, and that mean density of the NAPL is 1400 kg/m^3.

3. If air sparging is used (bubbling air through the saturated zone – remember the DNAPL penetration and remediation modeling video), at ambient temperature of 20^oC and throughput is also 40 m^3/day, estimate the time needed to remove all free product from the aquifer. State any assumptions.

4. To improve removal rates, steam is injected into air sparging wells. These rapidly raise temperatures of the recirculating fluids to 60^oC. This decreases viscosity of water, and together with the higher applied pressures, enables a larger throughput of fluid to flush the system. If the steam injection results in concurrent circulation of 60 m^3/day of 60^oC water and 60 m^3/day of 60^oC sparged air through the system, evaluate the rate of removal. How long will it take to clean the system for each of the components? Which method of removal, air sparging or water, is the most effective agent of removal?