THE PENNSYLVANIA STATE UNIVERSITY
DEPARTMENT OF MINERAL ENGINEERING
GEOEE 408 CHARACTERIZATION OF GROUNDWATER SYSTEMS

Mid-term Examination - Due: Thursday March 20th at 3.45 pm.

Name/Signature: _____

SSN: _____

The work presented in this examination is solely the result of my independent endeavors.
Include extra sheets, as needed, and return entire packet.

Question	Points	Score
1	40	
2	40	
3	60	
4	60	
Total	200	

Question 1

Define the following terms, and identify the units [MLT] of the quantity, where relevant. Be as specific in your definitions as possible.

1. Capillary pressure, p_c.

2. Permeability, k.

3. Relative permeability, k_r.

4. Saturation, S_α.

5. Irreducible saturation, S_{nw_0}, S_{w_0}.

6. Moisture content, θ.

7. Pendular zone.

8. Diffusion coefficient, D.

9. Longitudinal dispersivity, α_L.

10. Advective velocity, v_a.

11. Bubbling pressure, p_b.

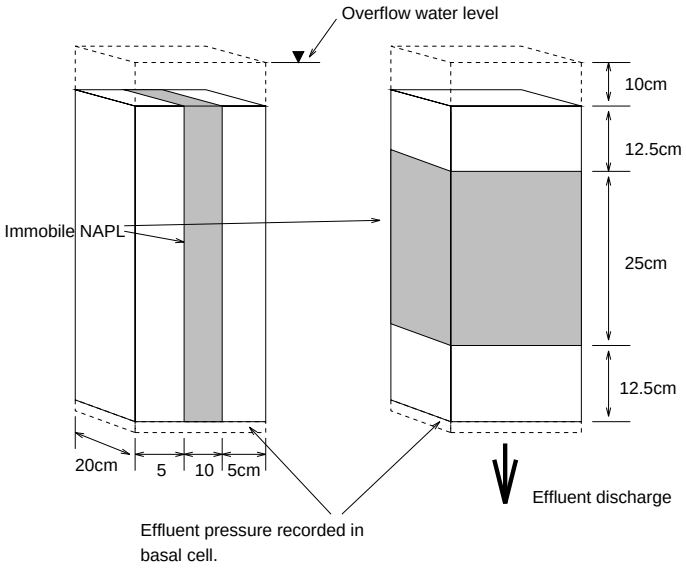
Question 2

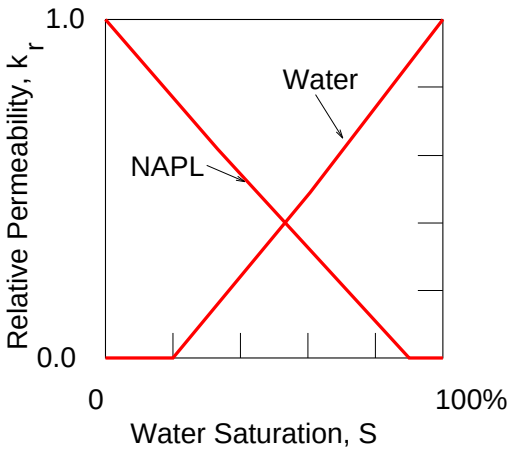
Two different column leaching tests are devised to evaluate the ability to remediate a site where NAPL contamination has been found. The columns, shown in the figure are flushed with water to remove TCE, in solubilized form, from the contaminated zone. In each test, the initial free phase NAPL saturation is 10%, and it is present as an immobile phase. The permeability of the sand is $k = 10^{-6}\ cm^2$. The dynamic viscosity of water is $\mu = 1.12 \times 10^{-3} N.s/m^2$ and for the NAPL, $\mu = 0.96 \times 10^{-3} N.s/m^2$. The upper water level is held constant by an overflow tank and the effluent pressure is retained at atmospheric. The samples remain fluid saturated throughout the test with $S_w + S_{nw} = 1$. Aqueous solubility of TCE is $1060\ mg/l$, density is $1500\ kg/m^3$ and the porosity, 30%.

1. Estimate effluent concentration from the cell with time following initiation of the leaching test for the parallel flow geometry. When will the effluent concentration drop below the drinking water standard of $5\ ppb$. Choose the simplest model you believe reasonable.

2. Estimate effluent concentration from the cell with time following initiation of the leaching test for the series flow geometry. When will the effluent concentration drop below the drinking water standard of $5\ ppb$.

Note that your result is dependent on the assumptions you make. State and justify all your assumptions.





Question 3

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 $\gamma = 15.6 kN/m^2$.

The capillary pressure relationship is defined for the sand units, as shown. Hydraulic conductivity magnitudes are available from pumping tests that yield, $K_{sand} = 10^{-2}\ cm/s$ and $K_{silt} = 2.5 \times 10^{-5}\ cm/s$. The porosity of the sand is 31% and and for the silt 31%.

Spills have occurred at two locations and TCE is known to have penetrated below the water table. In the first, water is drawn from the underlying sand aquifer for water supply, resulting in a slight depressurization of the lower sand unit.

1. Evaluate the capillary relationship for TCE penetration into the sand and silt.

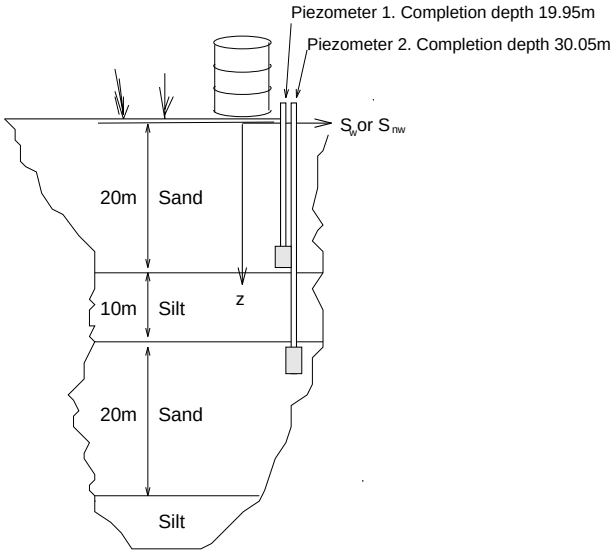
2. Assuming a large spill, evaluate the maximum potential saturation profile within the vertical section. The water levels in the piezometers are at $2\ m$ below the ground surface for piezometer 1, and $10\ m$ below the surface for piezometer 2.

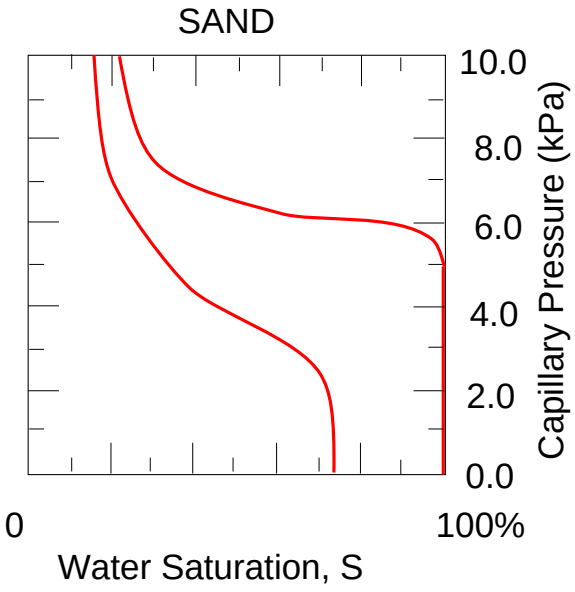
3. For a small spill, what is the corresponding anticipated maximum saturation profile.

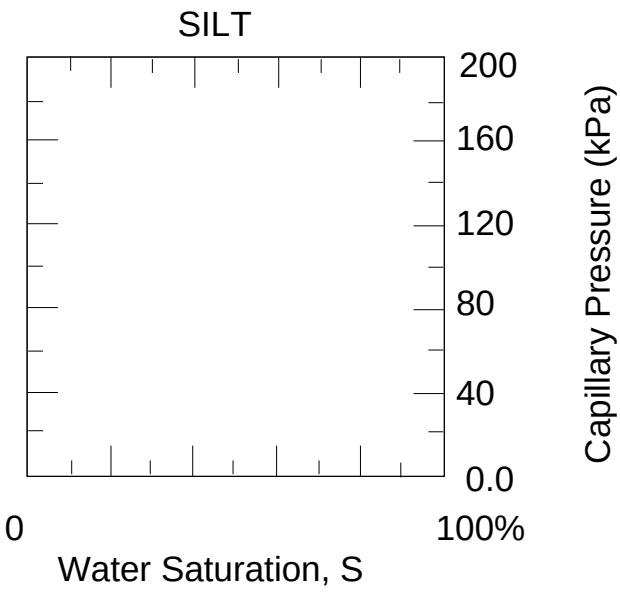
4. Estimate the recoverable volume of free product per unit area of the upper and lower aquifers (sand), and the intermediate (silt) aquitard.

5. It is feared that NAPL has penetrated the lower aquifer. One possible safeguard to prevent further incursion is to overpressure the lower aquifer to prevent further migration. If sufficient pressure is applied to achieve this, what water level would be recorded in piezometer 2, relative to the ground surface.

6. If the upper aquifer is depressured during this remedial action, what would be the net effect on NAPL saturations and penetration in the system.


Piezometer 1. Completion depth 19.95m
Piezometer 2. Completion depth 30.05m
S_w or S_{nw}
20m
Sand
10m
Silt
z
20m
Sand
Silt


SAND
10.0
8.0
6.0
4.0
2.0
0.0
Capillary Pressure (kPa)
0
100%
Water Saturation, S


SILT
200
160
120
80
40
0.0
Capillary Pressure (kPa)
0
100%
Water Saturation, S

Question 4

Inventory of brine filling a disused underground storage tank is known to have been lost. The tank is located below the phreatic surface within an unconfined sandy aquifer. The regularly recorded inventory of the tank remained unchanged until December 1993 but had dropped significantly by May 1994, with no recorded withdrawals. On discovery of this, in May 1994, the remaining inventory was removed, and the tank interior grouted to surface.

Piezometers were installed downgradient of the tank in July 1994, and monitored for chloride concentrations. Chloride is a conservative tracer. The results from a single multi-point piezometer array, recording the maximum change in concentration, and believed to intercept the plume center, are shown. The aquifer is laterally extensive and of a recorded saturated thickness greater than $100\ m$. The mean porosity of the aquifer is 27%.

Litigation between the tank owner and an adjacent landowner holds up remediation of the site until September 1996.

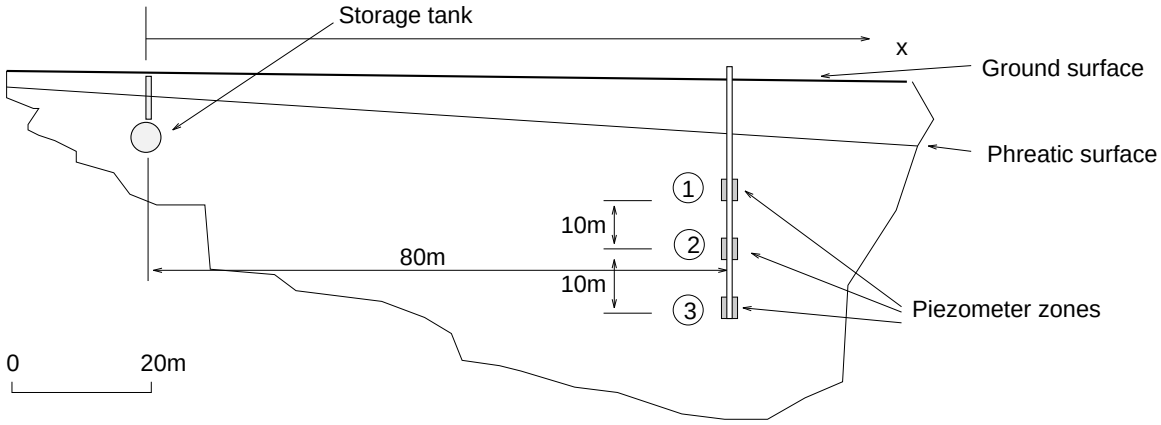
1. Evaluate the advective velocity, coefficients of hydrodynamic dispersion, D_L, D_T, and dispersion coefficients, α_L, α_T, for the aquifer.

2. Determine the optimal location for the placement of a monitoring cluster of piezometers to detect the evolving plume? Define downgradient location and desired depth range below surface, if the earliest possible installation is September 1996.

3. If the plume is located in September 1996, and the remediation standards for chloride are a maximum of 20 ppm, determine the maximum concentration of the plume and the minimum fluid volume that must be removed from the aquifer to reach this remedial standard?

4. If the remediation is delayed by a further year (September 1997), will the volume required to be recovered (at the new plume location) be increased or decreased? What volume must be recovered?

5. Is there any elapsed time when the plume will attenuate naturally to the remediation standard? If so, when will this be?



Vertical and horizontal scales are equivalent