3D6 Environmental Geotechnics
Crib 2008

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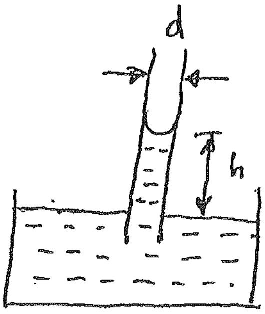
1.

a)



Let 'h' be height of capillary rise in a tube of diameter 'd'.

$$\text{weight of water column} = \frac{\pi d^2}{4} \times h \times \gamma_w$$

Let surface tension of water be 'T'.

$$T \pi d = \frac{\pi d^2}{4} h \gamma_w$$

$$h = \frac{4T}{\gamma_w d}$$

[20%]

b) From table 1, typical pore size of silt $= D_{10} = 0.01\,\text{mm}$

$$\therefore h = \frac{4 \times 7.3 \times 10^{-5}}{10 \times 0.01 \times 10^{-3}}$$

$$h = 2.92\ \text{m}$$

[10%]

c) Unit weight of soil

$$\gamma = \frac{(G + e S_r)}{(1+e)} \gamma_w$$

For dry case $S_r = 0$ $\quad \therefore \gamma = \dfrac{G \gamma_w}{1+e}$

$$\therefore \gamma_{silt} = \frac{2.63 \times 10}{1+0.73} = \underline{15.20}\ \text{kN/m}^3$$

$$\gamma_{sand} = \frac{2.65 \times 10}{1+0.62} = \underline{16.36}\ \text{kN/m}^3.$$

For saturated case $S_r = 1$

$$\therefore \gamma_{silt} = \frac{(G+e)\gamma_w}{1+e} = \frac{(2.63+0.73)\,10}{1+0.73} = \underline{19.42}\ \text{kN/m}^3$$

$$\gamma_{sand} = \frac{(2.65+0.62)}{(1+0.62)} \times 10 = \underline{20.19}\ \text{kN/m}^3.$$

[20%]

1 d/

Darcy's flow $V = 0.05\ cm/s = 5\times10^{-4}\ m/s$

$$V = K\frac{d\bar{h}}{ds}$$

$$5\times10^{-4} = 2.5\times10^{-2}\ \frac{d\bar{h}}{ds}$$

$$ds = 50\ m \rightarrow \quad d\bar{h} = \frac{5\times10^{-4}}{2.5\times10^{-2}}\times 50$$

$$= 1\ m$$

[10%]

$\therefore\ \bar{h}_A - \bar{h}_B = 1m$

Since A & B at same elevation, $h_A - h_B = 1m$

$\therefore\ h_A = 2.5 + 1.5 = 4m$

$h_B = 4-1 = 3m \rightarrow$ water level in B will be 1.5m below the top of silt layer. [10%]

e/ Assumptions

1/ Flow is laminar in sand (A→B)

2/ Pressure head drop is linear A to B

3/ Flow in sand is uniform & steady state.

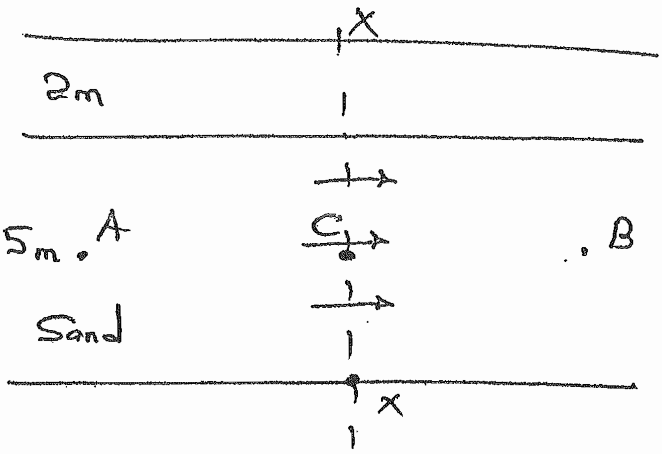
4/ Flow is parallel to A→B

1 e/ γ_{silt} saturated = 19.42 kN/m^3 } from
γ_{sand} saturated = 20.19 kN/m^3 } part (b)

Total stress – base of silt layer = 19.42×2 = 38.84 kPa

Total stress – base of sand layer = $38.84 + 20.19 \times 5$ = 139.8

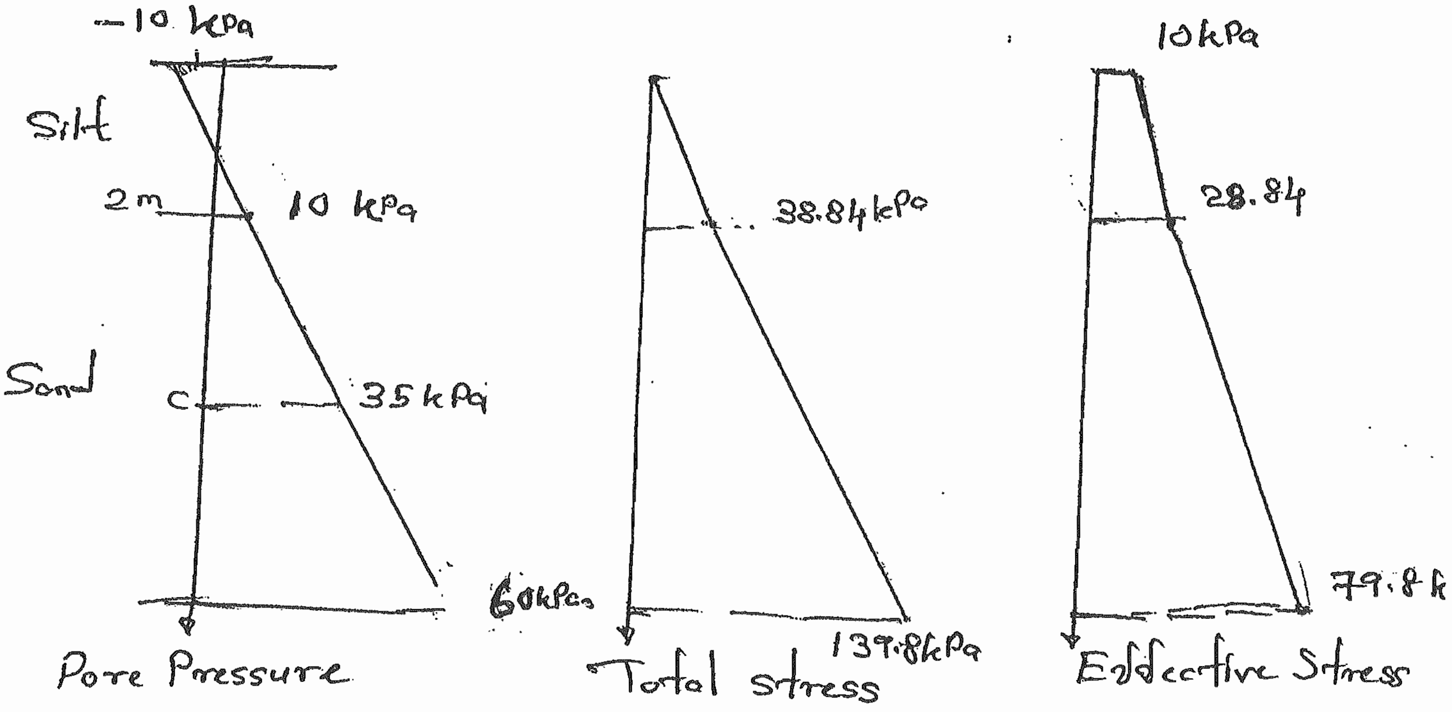
using AB as datum.



$h_A = 4m$, $h_B = 3m$

$\therefore h_c = 3.5m$

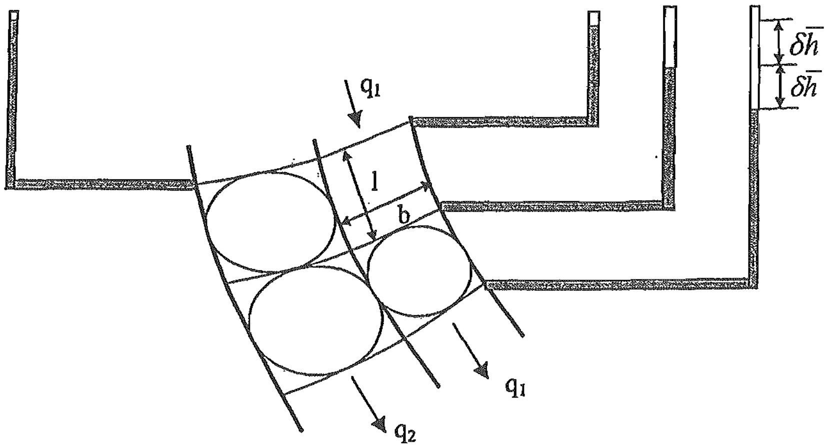
Since flow is parallel to AB, xx is sand is a equipotential.



Assume pore pressure variation linear in Silt layer.

[30%]

2.a) Consider a set of flow lines and equi-potentials in the soil. From continuity, the volume flow rate within each flow tube must be constant.



Applying Darcy's law to the element of breadth b and length l:

$$v = K.i_1 = K\frac{\delta\bar{h}}{l}$$

$$q_1 = A_1.v_1 = b \times 1 \times K \times \frac{\delta\bar{h}}{l}$$

$$= K \times \delta\bar{h}$$

For convenience a flow net of curvilinear squares is usually drawn with $b=l$, by adopting simple trail and error solutions. If the equi-potentials are drawn with equal drops in potential heads then $\delta\bar{h} = \Delta\bar{h}/N_h$, where $\Delta\bar{h}$ is the total drop in the potential head along the flow tube from a source of water to a sink and N_h is the number of drops in potential. The flow rate per flow tube is:

$$q = K\delta\bar{h} = K \times \frac{\delta\bar{h}}{N_h} \qquad \text{per tube.}$$

So a flow net of curvilinear squares will have constant potential differences and the same flow rate in each tube. Curvilinear squares have edges crossing at right angles, and an inscribing circle would just touch all four sides.

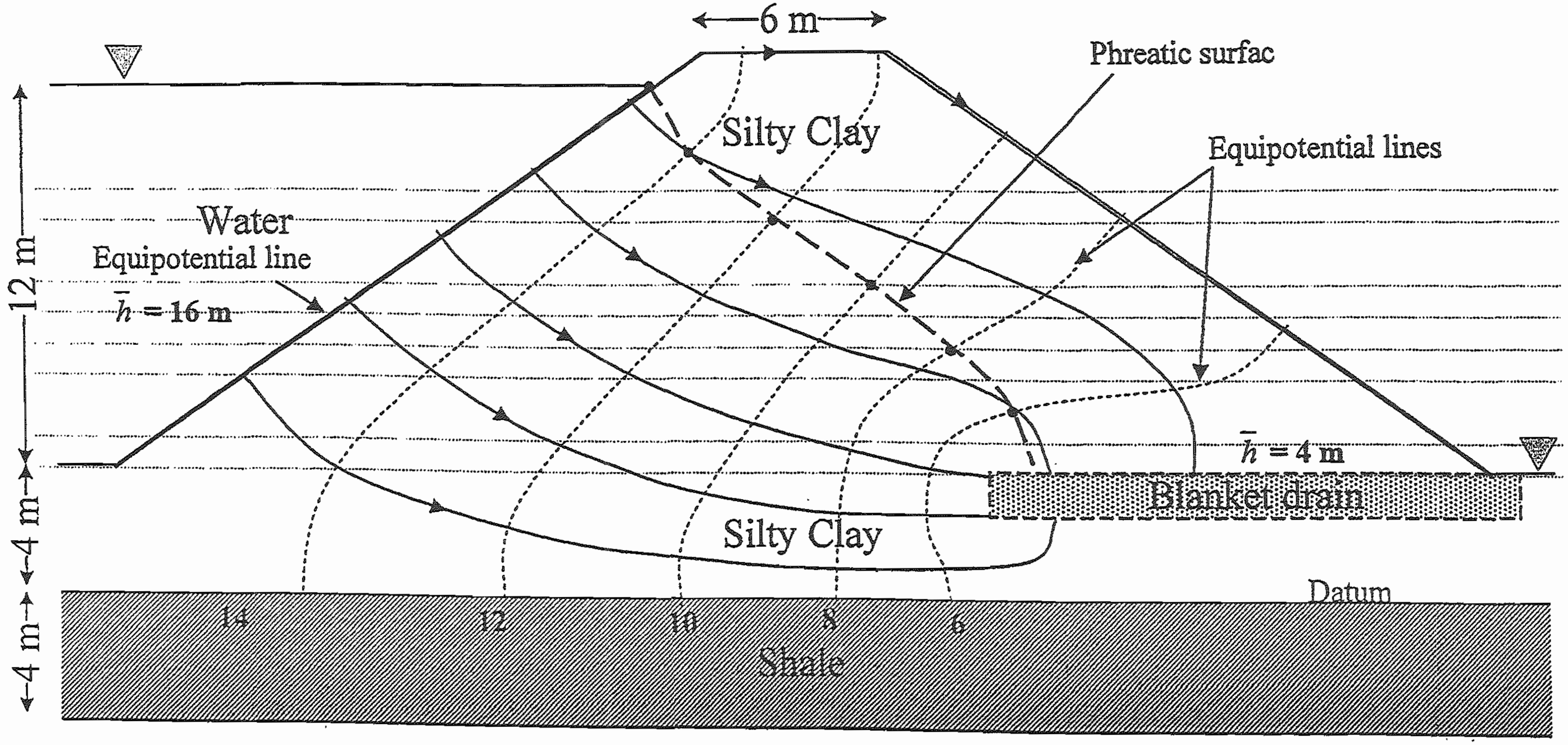
$$q = q_1 = q_2$$

If there are N_f flow tubes then the total flow quantity will be:

$$q = K\Delta\bar{h}\frac{N_f}{N_h} \qquad \text{m}^3\text{/s/m length}$$

[20%]

2) b. i)



6 m
Phreatic surfac
Silty Clay
Equipotential lines
Water
Equipotential line
$\bar{h}$ = 16 m
12 m
4 m
4 m
$\bar{h}$ = 4 m
Blanket drain
Silty Clay
Datum
14
12
10
8
6
Shale

2 b) ii) $q = K \Delta h \dfrac{N_f}{N_h}$

$N_f = 6 \qquad N_h = 6$ from flownet.

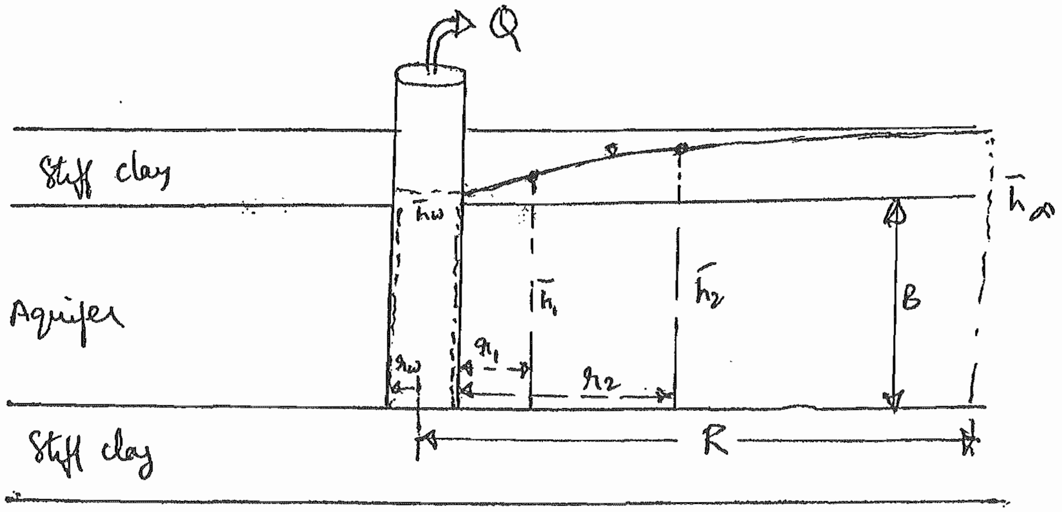
$\therefore q = 6.8 \times 10^{-6} \times 12 \times \frac{6}{6} = 8.16 \times 10^{-5}\ m^3/s/m$

$\simeq 8.16\ m^3/s/m$. [2

2c) If the blanket drain is too long then the leakag rate through the dam increases, decreasing its perfor as an earth dam.

If the blanket drain is too short then the phreatic line exit through the downstream slope. If this happens then erosi of the downstream face can happen, eventually this may l to a catastrophic failure of the earth dam. [2

3 a)



$$Q = q \times A = K\, i\, A = 2\pi r\, b\, K \frac{d\bar{h}}{dr}$$

Rearranging. $\quad d\bar{h} = \dfrac{Q}{2\pi b K} \dfrac{dr}{r}$

Integrating $\quad \displaystyle\int_{\bar{h}_1}^{\bar{h}_2} d\bar{h} = \frac{Q}{2\pi b K} \int_{r_1}^{r_2} \frac{dr}{r} = \frac{Q}{2\pi b K} \ln\left(\frac{r_2}{r_1}\right)$

$$\therefore \quad \bar{h}_2 - \bar{h}_1 = \frac{Q}{2\pi b K} \ln\left(\frac{r_2}{r_1}\right)$$

we have $K = 5\times10^{-3}$ m/s $\quad r_1 = 20$m $\quad \bar{h}_1 = 7$m $\quad b = 6$m

$r_2 = 30$m $\quad \bar{h}_2 = 7.1$m

$$\therefore \quad 7.1 - 7.0 = \frac{Q}{2\pi\, 6 \times 5\times10^{-3}} \ln\left[\frac{30}{20}\right]$$

$$Q = 0.046488 \text{ m}^3/\text{s} \simeq 46.5 \text{ litres/sec}$$ [30%]

b) Total draw down $= \bar{h}_\infty - \bar{h}_{well}$

Potential head in the well $\bar{h}_{well}$: $\quad Q = 0.0464$ m³/s $\quad r_w = 0.1$m

at $r_1 = 20$ m $\quad \bar{h}_1 = 7$m. $\quad b = 6$m.

$$7 - \bar{h}_{well} = \frac{0.0464}{2\pi\, 6 \times 5\times10^{-3}} \times \ln\left[\frac{20}{0.1}\right] = 1.304 \text{ m}$$

$$\therefore \bar{h}_{well} = 7 - 1.304 = 5.696 \text{ m}$$

$$\simeq 5.7\text{m}$$

Radius of influence $R = 200\,m$.

$\bar{h}_\infty$ is the potential head at R.

$Q = 0.0464\ m^3/s \qquad R = 200\,m$

at $r_1 = 20\,m \qquad \bar{h}_1 = 7\,m \qquad b = 6\,m$.

$$\bar{h}_\infty - 7 = \frac{0.0464}{2\pi\, 6 \times 5 \times 10^{-3}} \times \ln\left[\frac{200}{20}\right] = 0.568\ m$$

$$\bar{h}_\infty = 7 + 0.568 = 7.568\ m$$

$\therefore$ Total draw down in the water table $= 7.568 - 5.7$

$\Delta\bar{h} = 1.868\ m$ [20%]

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3 c) Before the sheet pile wall is driven, the potential head at a distance of 10 m from the centre of the well.

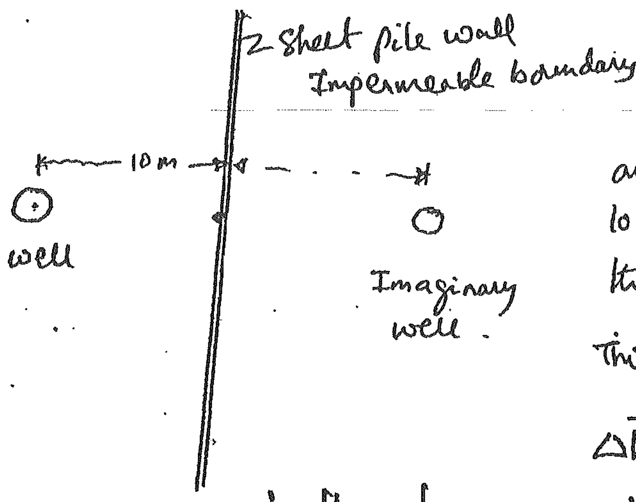
$$\bar{h}_{20} - \bar{h}_{10} = \frac{Q}{2\pi\, 6 \times 5 \times 10^{-3}} \ln\left[\frac{20}{10}\right] = \frac{0.0464}{2\pi\, 6 \times 5 \times 10^{-3}} \ln 2$$

$$7 - \bar{h}_{10} = 0.171$$

$$\bar{h}_{10} = 6.83\ m$$

$\therefore$ Draw down at this point will

$$\bar{h}_\infty - \bar{h}_{10} = 7.568 - 6.83$$
$$= 0.738\,m$$



From Image theory for wells, an imaginary abstraction well present 10m from the sheet pile wall will model the impermeable boundary condition. This will lead to doubling of the drawd

$$\Delta\bar{h} = 2 \times 0.738 = \underline{1.476}\ m$$

$\therefore$ the change in drawdown

$= 0.738\,m$ [20%]

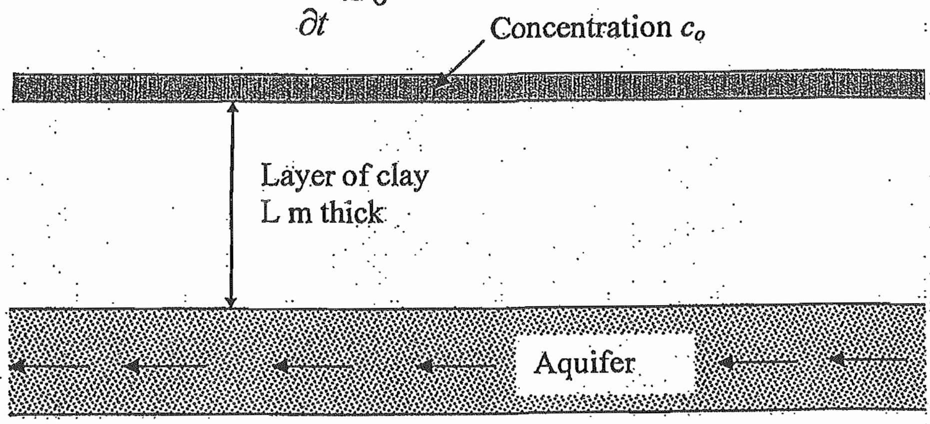
3d/

3b) The governing equation is, as before:

$$\frac{\partial c}{\partial t} = D_l \frac{\partial^2 c}{\partial z^2} - v_f \frac{\partial c}{\partial z}$$

Consider an old landfill, leaking aqueous pollutant into the underlying clay layer. Pollutant has been leaking for a number of years an is assumed to have reached the steady state distribution $t \to \infty$, for which:

$$\frac{\partial c}{\partial t} = 0$$



The advection-dispersion equation becomes:

$$D_l \frac{\partial^2 c}{\partial z^2} = v_f \frac{\partial c}{\partial z}$$

and integrating once with respect z gives:

$$\frac{D_l}{v_f} \frac{\partial c}{\partial z} = c - P$$

where P is a constant, while integrating again gives:

$$\ln(c - P) = \frac{v_f z}{D_l} + \ln Q$$

where Q is also a constant. Rearranging gives:

$$c = P + Q \exp\left(\frac{v_f z}{D_l}\right)$$

which must satisfy the boundary conditions:

for $z = 0$ $\qquad c = P + Q = c_o$

for $z = L$ $$c = P + Q\exp\left(\frac{v_l L}{D_l}\right) = 0$$ [c at z = L can be non zero as well]

the solution of which gives:

$$P = \frac{-c_o \exp\left(\frac{v_f L}{D_l}\right)}{1-\exp\left(\frac{v_f L}{D_l}\right)} \quad \text{and} \quad Q = \frac{c_o}{1-\exp\left(\frac{v_f L}{D_l}\right)}$$

and therefore the steady state distribution is:

$$\frac{c}{c_o} = \frac{\exp\left(\frac{v_f z}{D_l}\right) - \exp\left(\frac{v_f L}{D_l}\right)}{1-\exp\left(\frac{v_f L}{D_l}\right)}$$

If the mean linear water velocity is very small, then the exponentials can be approximated by power series:

$$\frac{c}{c_o} = \frac{\left(1+\frac{v_f z}{D_l}\right) - \left(1+\frac{v_f L}{D_l}\right)}{1-\left(1+\frac{v_f L}{D_l}\right)} = \frac{L-z}{L}$$

i.e. if advection is negligible and diffusion therefore dominates then the steady state distribution is linear from source to sink. This result could have also been reached by integrating the diffusion equation directly.

[30%]

4/ (a) DNAPLS and LNAPLS are acronym for Dense Non-aqueous phase liquids and Light Non-aqueous phase liquids, respectively. They are liquid contaminants which were immiscible with water. Typical DNAPL contaminants are chlorinated solvents such as PCE and TCE. Typical LNAPL contaminants are petroleum products such as Benzene and Toluene. DNAPLs are denser than water, whereas LNAPLs are lighter than water. Due to their density differences, when they are spilled from the ground, LNAPL tends to float on top of the water table and DNAPL tends to penetrate deeper than the water table. Within DNAPLs, chlorinated solvents are less viscous than water. Therefore, the penetration front is unstable under gravity dominated flow and move inside the subsurface in a complex manner. Hence, it is very difficult to find them in the subsurface. The solubility values are low and they remain as a continuous contaminant source for very long time. Although small amount of solvents can only dissolve into water, the toxicity is high.

[20%]

(b) One person in one million people will get a cancer if one million people are exposed to this daily dose value of a chemical throughout their life time, which is usually 70 years. The maximum allowable concentration of this contaminant in water can be estimated by applying this daily dose to an amount of 2L of water, which is consumed daily.

[15%]

(c)

(i) From Data sheet, the properties of benzene are

Henry's constant H = 5.55 atm/M

Molecular weight = 78.1

Gas concentration P = 2000 ppmV = 2000 x 10^{-6} atm = 2 x 10^{-3} atm.

Using Henry's law, the concentration in the soil moisture

C = P/H = 2 x 10^{-3}/5.55 = 3.6 x 10^{-4} M.

Convert this to mg/L.

3.6 x 10^{-4} (M)= 3.6 x 10^{-4} (mol/L) x 78.1 (g/mol) x 10^{3} (mg/g) = 28.2 mg/L.

[15%]

(ii) The octanol-water partition coefficient of toluene is $\log K_{ow}$=2.13 from Data sheet.

For aromatic compounds (see Data sheet), $\log K_{oc}$ = 0.544 (logKow) + 1.377 = 0.544 x 2.13 + 1.377 = 2.54

Hence, K_{oc} = 347 (L/kg)

The partitioning coefficient K_p is then estimated $K_p = f_{oc}K_{oc}$ = 0.01 x 347 = 3.47

(L/kg)

Using the linear isotherm model, $X = K_pC = 3.47 \times 28.2 = 97.9$ mg/kg.

[15%]

(iii) Gas concentration P = 2000 ppmV = 2000 x 78.1/24.05 (mg/m^3) x 10^{-3} (m^3/L) = 6.49 mg/L.

Mass of benzene inhaled = 6.49 (mg/L) x 2 (m^3) x 10^3 (L/m^3) = 12980 mg.

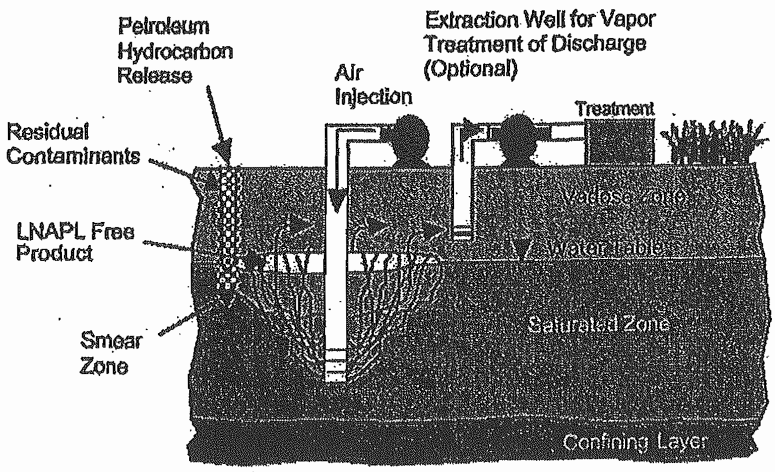
Mass of benzene ingested = 97.9 (mg/kg) x 1800 (kg/m^3) x 10 (cm^3) x 10^{-6} (m^3/cm^3) = 1.76 mg.

[15%]

Hence, Inhalation >> Ingestion.

(iv) Soil vapour extraction and air sparging.

Air or oxygen is injected through a contaminated aquifer. Injected air traverses horizontally and vertically in channels through the soil, creating an underground stripper that removes volatile and semi-volatile organic contaminants by volatilization. The injected air helps to flush the contaminants into the unsaturated zone. Soil vapor extraction (SVE) usually is implemented in conjunction with air sparging to remove the generated vapor-phase contamination from the vadose zone. Oxygen present in the air added to the contaminated groundwater and vadose-zone soils also can enhance biodegradation of contaminants below and above the water table.



[20%]