Mid-term 2004

1. Excavate and remove
   Low volatility means SVE will not work
   High $K_{oc}$ means P&T will not work

2. s/s
   Metals are generally not volatile — SVE will not work
   Metals generally do not biodegrade

3. Note gasoline contains butane, pentane, benzene, toluene, and xylene, so results are mixed:

   very likely success for lightest hydrocarbons (butane)
   somewhat likely for BTEX, pentane

   Somewhat likely overall

   3 points for somewhat likely answer
   2 points for recognizing nature of mixture

4. Values from Heath

Medium sand $\quad\quad K \approx 8 \text{ m/d}$ $\quad\quad\quad\quad\quad\quad i = 0.007$

$\quad\quad\quad\quad\quad\quad n = 0.25$

$$V = \frac{Ki}{n} = 0.2 \text{ m/d} = 0.7 \text{ ft/d}$$

From PRB chart: $\quad$ Want $5000 \to 5$ (1000-fold reduction)

$$W \approx 3 \text{ ft} \approx 1 \text{ m} \quad \text{for } t_{1/2} = 10$$

5. Anaerobic conditions favors biodegradation of chlorinated compounds: PCE, carbon tet and denitrification of $NO_3$
Benzene, toluene, and petroleum hydrocarbons need aerobic conditions to degrade, so will not be degraded


6. Methylene chloride is a common laboratory artifact — MeCl is probably not in actual ground water since it is not in site soils

7.    Soil vapor conc will look like this:



Ca = 0
c_vapor
4 m
□ sample
c_vapor in equilibrium with c_W
c_W = 10,000 μg/L
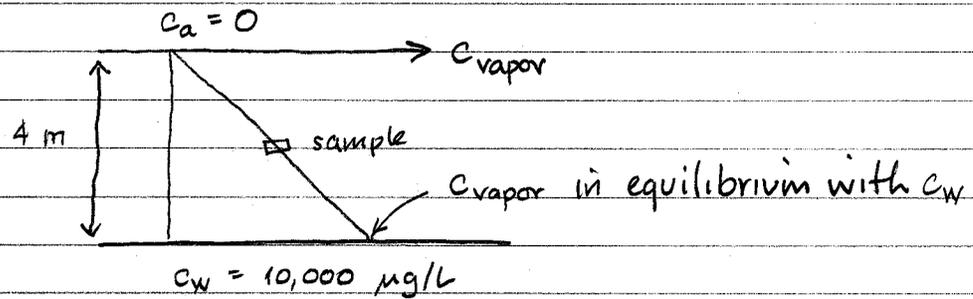
$c_{vapor}$ at g-w interface:    $\dfrac{C_v}{C_w} = H'$

$$H = 9.1 \times 10^{-3} \ \frac{atm \ m^3}{mol}$$

$$H' = \frac{H}{RT} = \frac{9.1 \times 10^{-3} \ \frac{atm \ m^3}{mol}}{8.2 \times 10^{-5} \ \frac{atm \ m^3}{mol \ °K} \ 293 \ °K}$$

$$= 0.38$$

5 pts
to get $C_G$

$$C_G = 3800 \ \mu g/L$$

Under steady-state, with zero advection, soil gas conc is given by:

5 pts to
get right
problem
structure

$$\frac{\partial C_G}{\partial t} = 0 = -\cancel{V} \frac{\partial C_G}{\partial z} + D \frac{\partial^2 C_G}{\partial z^2}$$
0

$$D \ \frac{\partial^2 C_G}{\partial z^2} = 0 \longrightarrow \frac{\partial C_G}{\partial z} = constant$$

Linear $C_G$ gradient as shown above

7.  con't

Since sample is halfway between w.t. and g.s.,

$$C_G = \frac{1}{2} \cdot 3800 = 1900 \ \mu g/L$$

Consider partitioning from gas to soil water:

$$C_W = C_G / H' \approx 5000 \ \mu g/L$$

Consider partitioning from soil water to soil

$$C_S = K_d \ C_W$$

$$K_d = f_{oc} K_{oc} = 0.001 \cdot 126 \ \frac{ml}{g} = 0.126 \ \frac{ml}{g}$$

5 pts →
to get $C_S$

$$C_S = 0.126 \ \frac{mL}{g} \cdot 5000 \ \frac{\mu g}{L} \cdot \frac{1}{1000} \frac{L}{mL}$$

$$= 0.63 \ \mu g/g$$

$$= 630 \ \mu g/kg \approx 0.63 \ mg/kg$$

5 pts. → Total conc in soil sample (from Lecture 3)
to get $C_T$

$$C_T = \rho_b C_S + \Theta_w C_W + \Theta_G C_G$$

$$= 1.65 \ \frac{g}{cm^3} \cdot 0.63 \ \frac{mg}{kg} + 0.4 \cdot 0.25 \cdot 5000 \ \frac{\mu g}{L}$$

$$+ \ 0.4 \cdot 0.75 \cdot 1900 \ \frac{\mu g}{L}$$

Soil $= 1.65 \ \frac{g}{cm^3} \cdot 1000 \ \frac{cm^3}{L} \cdot 0.63 \ \frac{mg}{kg} \cdot \frac{1}{1000} \frac{kg}{g} \cdot 1000 \ \frac{\mu g}{mg}$

7.  con't

$$\text{Soil} \quad - \quad 1040 \quad \frac{\mu g}{L}$$

$$\text{Water} \quad 500 \quad \frac{\mu g}{L}$$

$$\text{Air} \quad 570 \quad \frac{\mu g}{L}$$

$$\text{Total} \quad 2,110 \quad \frac{\mu g}{L}$$

In terms of dry mass, $\quad 1 \; L = 1.65 \; Kg$

$$\frac{2110 \; \mu g/L}{1.65 \; Kg/L} = 1280 \; \frac{\mu g}{Kg}$$

$$= 1.3 \; \frac{mg}{Kg}$$

Yes   ground water could contaminate soil
        to 1 mg/Kg

8.



$\leftarrow 2\,m \rightarrow$   Area $= 3.1\,m^2$

3 m   sand

10 cm   clay
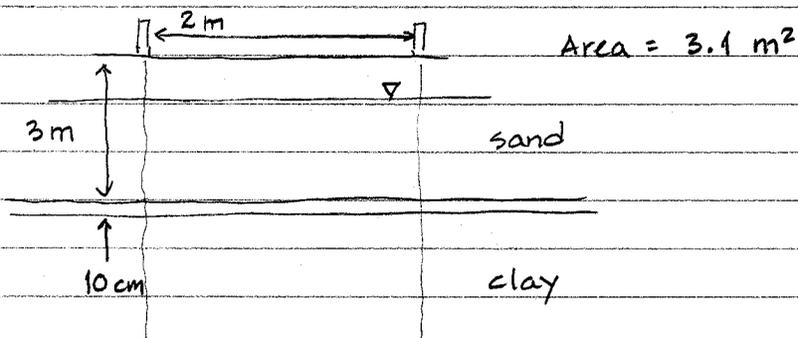
Volume in sand column beneath spill area

$= 3 \cdot 3.1 = 9.3\,m^3 = \forall$

Volume of voids $= 0.25 \cdot 9.3 = 2.3\,m^3 = n\forall$

Volume for TCE residual $= S_r\,n\,\forall$
$= 0.2 \cdot 2.3 = 0.47\,m^2$

TCE spill $= 1\,m^3 > S_r\,n\,\forall = 0.47\,m^3$

10 pts
for residual
calc

$\therefore$ TCE will reach clay layer as DNAPL

Compute ponding height on clay. Assume TCE
in excess of residual saturation will saturate
sand above clay. Saturation profile looks like
this

10 pts for
recognizing this
mass balance



$S_r$   100% $\leftarrow$ S  Ground surface
residual, $S = S_r = 0.2$
DNAPL pool $- S = 100\%$
clay
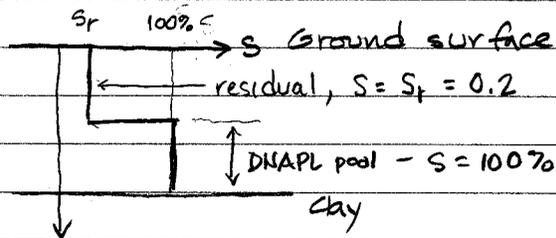
Mass accounting   $\forall_{total} = 1\,m^3 = \forall_{residual} + \forall_{pool}$

$= A\,(H_{residual} \cdot S_r \cdot n + H_{pool} \cdot n)$

$= A\,([3 - H_{pool}] \cdot S_r\,n + H_{pool} \cdot n)$

$$\forall_{total} = A \cdot H \left( 3 S_r + H_{pool} \left( 1 - S_r \right) \right)$$

$$1 \text{ m}^3 = 3.1 \text{ m}^2 \cdot 0.25 \left( 3m \cdot 0.2 + H_{pool} \, 0.8 \right)$$

Solve for height of pool:

$$H_{pool} = 0.86 \text{ m}$$

Check    $0.86 \cdot 3.1 \cdot 0.25 = 0.67 \text{ m}^3 = \forall_{pool}$

$$\left( 3 - 0.86 \right) 3.1 \cdot 0.25 \cdot 0.2 = 0.33 \text{ m}^3 = \forall_{res}$$

$$\Sigma = 1 \text{ m}^3 \checkmark$$

Height of DNAPL above linear fracture

From Homework 2, height of DNAPL to achieve
entry pressure is:

$$H_c = \frac{2\sigma}{\Delta \rho \, g \, D}$$

10 pts for
fracture
calc.

$$\sigma = 34.5 \text{ dyn/cm} = 34.5 \text{ g/cm}^2 \cdot s$$

$$\Delta \rho = 1.46 - 1.00 = 0.46 \text{ g/cm}^3$$

$$D = 20 \text{ } \mu m = 2 \times 10^{-3} \text{ cm}$$

$$H_c = \frac{2 \cdot 34.5 \text{ g/cm}^2 \cdot s}{0.46 \text{ g/cm}^3 \cdot 980 \text{ cm/s}^2 \cdot 2 \times 10^{-3} \text{ cm}}$$

$$= 76 \text{ cm} = 0.76 \text{ m}$$

The DNAPL will barely penetrate the clay

9.  G-w velocity $\qquad v = \dfrac{Ki}{n} = \dfrac{0.1 \text{ cm/s} \quad 0.0025}{0.25}$

2 pts $\qquad\qquad\qquad\qquad\qquad = 0.001$ cm/s

$\qquad\qquad\qquad\qquad\qquad\quad = 0.86$ m/d

Use 1-D transport equation from Lecture 3:

$$c(x,t) = \frac{c_0}{2} \, erfc\left(\frac{R_d x - ut}{\sqrt{4 R_d D_H t}}\right)$$

5 pts for
correct
$C_0$

Assume $C_0 =$ solubility $= 1100$ mg/L

From chart by Gelhar et al in Lecture 3, for
length scale of 200 m, $\alpha_L \approx 10$ m

4 pts $\qquad D_H = \alpha_L V = 10 \text{ m} \cdot 0.86 \text{ m/d} = 8.6 \text{ m}^2/d$

2 pts $\qquad K_d = K_{oc} f_{oc} = 126 \frac{ml}{g} \cdot 0.005 = 0.63 \frac{ml}{g}$

2 pts $\qquad R_d = 1 + \dfrac{\rho_b K_d}{n} = 1 + \dfrac{1.6 \text{ g/ml} \cdot 0.63 \text{ m/g}}{0.25}$

$\qquad\qquad\qquad = 5.0$

5pts
for correct
eqn and
solution

See attached spreadsheet for solution: concentration
will exceed MCL within one year — Need to work faster!

| | | |
|---|---|---|
| $n$ | 0.25 | |
| $i$ | 0.0025 | |
| $K$ | 0.1 cm/s | |
| $V$ | 0.0010 cm/s | $= K\,i\,/\,n$ |
| $V$ | 0.864 m/d | |
| $\alpha_L$ | 10 m | |
| $D_H$ | 8.64 m$^2$/d | $= \alpha_L\,V$ |
| $f_{oc}$ | 0.005 | |
| $K_{oc}$ | 126 ml/g | |
| $K_d$ | 0.63 ml/g | $= f_{oc}\,K_{oc}$ |
| $\rho_b$ | 1.6 g/ml | |
| $R_d$ | 5.032 | $= 1 + K_d\,\rho_b\,/\,n$ |
| $x$ | 200 m | |
| $t$ | 365 d | |
| $C_0$ | 1100000 ug/L | |
| $C(x,t)$ | 58 ug/L | $= C_0\,/\,2\ \mathrm{erfc}\left(\,(\,R_d\,x - V\,t\,)\,/\,\mathrm{sqrt}\,(\,4\,R_d\,D_H\,t\,)\,\right)$ |