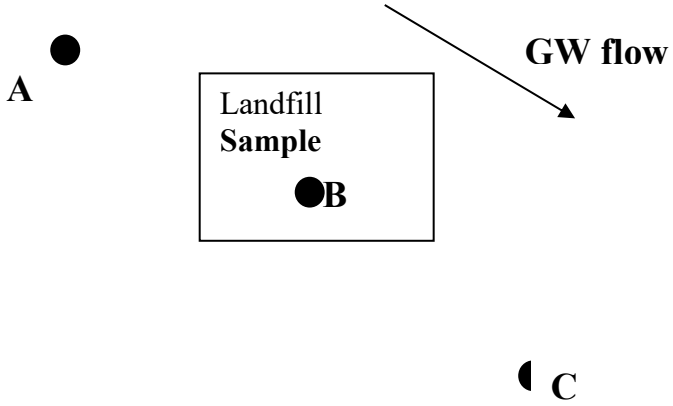
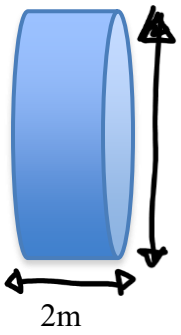
Groundwater and soil remediation
Rizlan Bernier-Latmani
Problem set #7 solution: in situ bioremediation

Problem 1



Case	Parameter	Measured values	Bio?	Why?
A	Dissolved O_2 in GW	A=B>C	P	Background O_2 at A, no consumption at B from toxicity, biodeg. at C
B	Dissolved O_2 in GW	A>B>C	S	Biodegradation at B and C
C	Chloride in GW	A>B>C	N	If dechlorination activity from biodegradation would expect higher Cl at B and/or C
D	PCE	B>C>A=0	P	A is bkg, high conc at B from landfill source, could be abiotic processes, dilution, sorption at C
E	Vinyl Chloride	C>B=A=0	S	No VC in original spill but an anaerobic transformation product of TCE and PCE
F	% BTEX degraders	B<A<C	P	Toxicity from high conc. under landfill, increase biomass downgradient
G	Oxygenase activity	A<C<B	S	Oxygenase activity corresponds to bioactivity
H	H_2S in soil gas	B>A=C	P	H_2S is produced by sulfate-reducing bacteria under the landfill

Problem 2



$V_T = 3{,}927\ m^3$

4,000 kg diesel
$\varepsilon = 0.4$
$\rho_{wb} = 1.700\ kg/m^3$
$K_D = 0.01\ L/mg = 10\ m^3/kg$

a- determine liquid- and solid-phases concentrations of diesel

Mass balance (no gas phase in aquifer):

$$m_{total} = m_{aq} + m_s = C_{aq}V_L + C_sM_S = C_{aq}(V_L + K_DM_S)$$
$$= C_{aq}V_T(\epsilon + \rho_bK_D) = C_{aq}V_T(\epsilon + (\rho_{wb} - \epsilon\rho_{water})K_D)$$

Aqueous concentration:

$$C_{aq} = \frac{M_{total}}{V_T(\epsilon + (\rho_{wb} - \epsilon\rho_{water})K_D)}$$

$$= \frac{4{,}000\ kg}{3{,}927\ m^3 * \left(0.4 + \left(1{,}700\frac{kg}{m^3} - 997\frac{kg}{m^3} * 0.4\right) * 10\frac{m^3}{kg}\right)}$$
$$= 78.3\frac{mg}{m^3}$$

Sorbed concentration:

$$C_s = K_DC_{aq} = 78.3\frac{mg}{m^3} * \frac{10\ m^3}{kg} = 783\frac{mg}{kg}$$

b- determine rate of diesel degradation and length of the remediation

$Q = 111\ m^3/d$
$DO = 47\ g\ O_2/m^3$ water
10 mg NH_4Cl/L water
Biodegradation oxygen need: 2.5 g O_2/g diesel

$$r_{diesel} = ratio_{diesel/O_2} * Q * DO = \frac{1}{2.5}\frac{g_{diesel}}{g_{O_2}} * 111\frac{m^3}{d} * 47\frac{g_{O2}}{m^3} = 2{,}086\frac{g_{diesel}}{d}$$

Time needed for the remediation:

$$t = \frac{m_{total}}{r_{diesel}} = \frac{4{,}000{,}000\ g_{diesel}}{2{,}086 \frac{g_{diesel}}{d}} = 1918\ days$$

Therefore, if only the rate of delivery of O_2 is considered (rather than the degradation rate), it will take a long time (> 5 years) to remediate.

This is a best case scenario because it assumes a rapid rate of desorption (to make diesel bioavailable). Otherwise, it may be worth exploring enhanced desorption using surfactants that would pull diesel components off of the organic surfaces in the sediment and consequently enhance the rate of degradation. And, the rate of O_2 delivery could be increased to no longer be the rate limiting step.

Problem 3

1. Sorbed toluene concentration

$K_D\left(\frac{m^3}{g}\right) = 0.63 * 10^{-6} * 10^{2.73} * 0.02$ (Karickhoff expression)

$$\boxed{= 6.76 * 10^{-6} \frac{\mathrm{m^3}}{\mathrm{g}}}$$

$$K_D = \frac{Ci,s}{Ci,aq} \quad \Rightarrow \quad Ci,s = K_D * Ci,aq$$

$$= 6.76 * 10^{-6} \frac{m^3}{g} * 20 \frac{mg}{L} toluene$$

$$= 6.76 * 10^{-6} \frac{m^3}{g} * \frac{20\ mg\ toluene}{L} * \frac{1000\ L}{1\ m^3}$$

$$= 1.35 * 10^{-1} \frac{mg\ toluence}{g\ solid} * \frac{1000 g\ solid}{1\ kg\ solid}$$

$$\boxed{\mathrm{Ci,_s} = 135 \frac{\mathrm{mg\ toluence}}{\mathrm{kg\ solid}}}$$

2. Total mass of toluene

No information of the volume, we consider $V_T = 1\ \mathrm{m^3}$ of aquifer:

$$m_{total} = m_{aq} + m_s = C_{aq} V_L + C_s M_s = C_{aq} \epsilon V_T + C_s \rho_b V_T = \epsilon C_{aq} + C_s \rho_b$$

$$= 223 \frac{g}{m^3_{aquifer}}$$

3. Amount of DO in groundwater

$$DO = 4\ mg/L$$

$$m_{O_2} = DO * V_L = DO * \epsilon = 1.4 \frac{g_{O_2}}{m^3_{aquifer}}$$

4. ratio of mass of DO needed to degrade toluene

$$C_7H_8 + 9O_2 => 7CO_2 + 4\,H_2O$$

$$r_{O_2/toluene} = \frac{m_{O_2}}{m_{toluene}} = \frac{n_{O_2}}{n_{toluene}}\frac{M_{O_2}}{M_{toluene}} = 9 * \frac{32}{7 * 12 + 8} = 3.1\frac{g_{O_2}}{g_{toluene}}$$

5. Oxygenation

$$m_{O_2,sat} = 9\frac{mg}{L} * \epsilon = 3.15\frac{g_{O_2}}{m^3_{aquifer}}$$

$$m_{O_2,needed} = m_{toluene} r_{\frac{O_2}{toluene}} = 223\frac{g}{m^3_{aquifer}}3.1\frac{g_{O2}}{g_{toluene}} = 691\frac{g_{O_2}}{m^3}$$

$m_{O_2,needed} > m_{O_2,sat}$ so one oxygenation is not enough

Number of oxidations needed:

$$N = \frac{m_{O_2,needed}}{m_{O_2,sat}} = 220$$

6. Possible issues

Volatilization of toluene could be an issue if we are bubbling air into the groundwater.