Groundwater and soil remediation
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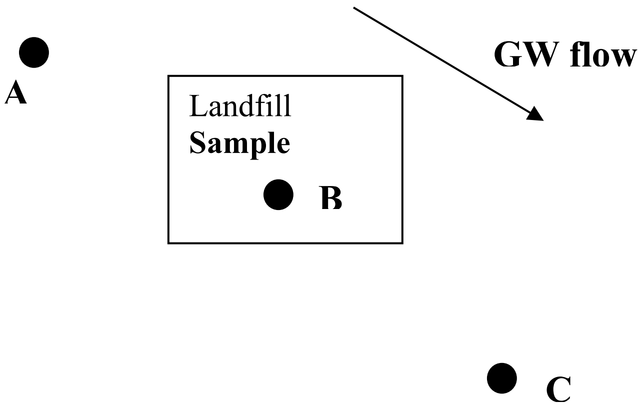
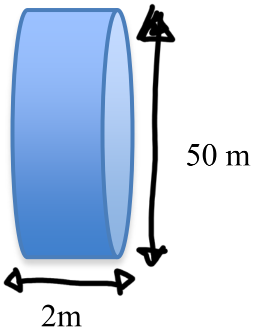
Problem set #7 solution: in situ bioremediation

Problem 1



Case	Parameter	Measured values	Bio?	Why?
A	Dissolved O_2 in GW	A=B>C	P	Bkg 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- <u>determine liquid- and solid-phases concentrations of diesel</u>

Mass balance (no gas phase in aquifer):

$$m_{total} = m_{aq} + m_s = C_{aq}V_L + C_s M_S = C_{aq}(V_L + K_D M_S)$$
$$= C_{aq}V_T(\epsilon + \rho_b K_D M_S) = C_{aq}V_T(\epsilon + (\rho_{wb} - \epsilon\rho_{water})K_D)$$

Aqueous concentration:

$$C_{aq} = \frac{m_{total}}{V_T(\epsilon + (\rho_{wb} - \epsilon\rho_{water})K_D M_S}$$
$$= \frac{4{,}000\ kg}{3{,}927\ m^3 * \left(0.4 + \left(1{,}700\frac{kg}{m^3} - 997\frac{kg}{m^3} * 0.4\right) * 10\frac{m^3}{kg}\right)}$$
$$= 78.3\frac{mg}{m^3}$$

Sorbed concentration:

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

b- <u>determine rate of diesel degradation and length of the remediation</u>

$Q = 111\ m^3/d$

$DO = 47\ g\ O_2/m^3$ 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:

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

c- comment

This amount of time would be acceptable for the remediation of this site but it is contingent on a fast 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.

Problem 3

1. Sorbed toluene concentration

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

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

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

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

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

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

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

2. Total mass of toluene

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

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

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

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

$$C_7H_8 + \mathbf{9}0_2 => 7CO_2 + 4\,H_2O$$

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

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.