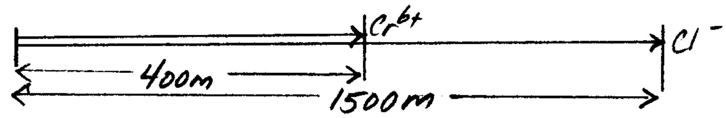
Problem #1

In a plan view of a contaminant plume you observe that a conservative constituent (e.g. chloride) has moved about 1500 meters while a reactive constituent (e.g. chromium) has moved only 400 meters. Assuming both species were released at the same time, estimate the distribution coefficient of the reactive species for the porosity is 0.35 and the solids density is 2.22 g/mL.



$n = 0.35$

$\rho_s = 2.22$

$x_{Cl} = V_{Cl} t \qquad x_{Cr} = V_{Cr} t$

$\frac{x_{Cl}}{x_{Cr}} = \frac{1500m}{400m} = 3.75 = R$ (retardation coefficient)

$* \; R = 1 + \frac{\rho_b K_d}{n};$ (Eq 5.6.6)

$* \; n = 1 - \frac{\rho_b}{\rho_s};$ (Eq 1.3.2)

$\frac{\rho_b}{\rho_s} = 1 - n \rightarrow \rho_b = \rho_s(1-n)$

$\therefore \; R = 1 + \frac{\rho_s(1-n)K_d}{n}$ Solve for K_d

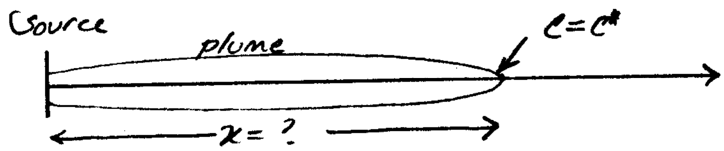
$n(R-1) = \rho_s(1-n)K_d$

$\frac{n(R-1)}{\rho_s(1-n)} = K_d$

$\frac{(0.35)(3.75-1)}{(2.22)(1-0.35)} = \frac{(0.35)(2.75)}{(2.22)(0.65)} = 0.667 \frac{mL}{g}$

Problem #2

Dissolution of constituents from a residual NAPL source results in a contaminant plume whose maximum length is determined by the balance between advection and decay. Develop an expression for the maximum plume length if the constituent source-term concentration is C_o. Apply the expression to estimate the maximum length of a benzene plume whose equilibrium concentration in water at the source is 2.4 mg/L and whose MCL is 0.005mg/L. Assume that the pore velocity is 0.35 m/d and the half-life of the benzene in a first order decay model is 60 days. Assume that the retardation coefficient for benzene in the aquifer is 2.



$$R\frac{\partial c}{\partial t} + v\frac{\partial c}{\partial x} - D\frac{\partial^2 c}{\partial x^2} + \lambda R c = 0$$

neglect dispersion (problem statement & no role at extinction boundary)

$=0$ steady state c profile at extinction boundary

$$v\frac{\partial c}{\partial x} + \lambda R c = 0$$

$$\frac{\partial c}{\partial x} = -\frac{\lambda R}{v}c \quad \text{(1st order, linear ODE (as written))}$$

$$\int \frac{\partial c}{c} = \int -\frac{\lambda R}{v}dx$$

$$\ln(c) = -\frac{\lambda R x}{v}$$

$$c = c_0 \exp\left(-\frac{\lambda R x}{v}\right)$$

$$\ln\frac{c}{c_0} = -\frac{\lambda R x}{v}$$

or

$$x = -\frac{v}{\lambda R}\ln\left(\frac{c}{c_0}\right)$$

$$\frac{c}{c_0} = \frac{2.4\,mg/L}{0.005\,mg/L}$$

$$\frac{1}{2} = \exp(-\lambda t_{1/2}) = \exp(-\lambda\, 60_d) \quad \text{1st order decay}$$

$$-\frac{\ln(\frac{1}{2})}{60\,d} = \lambda = -0.01155$$

$R = 2.$

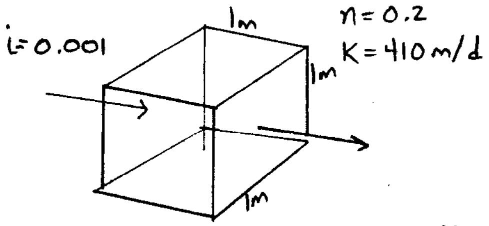
$v = 0.35\,m/d$

$$x = \frac{-(0.35)\ln\left(\frac{2.4}{0.005}\right)}{-0.01155\,(2)} = 93.5\,m$$

Problem #3

A cubic meter of sand-gravel aquifer is contaminated with 20 L of tetrachloroethylene (PCE). The aquifer has porosity of 20% and hydraulic conductivity of 410 m/d. You may assume that the air content is negligible.

a) What is the equilibrium concentration of PCE in the water phase?
b) What is the mass PCE in the water phase?
c) What is the mass PCE in the NAPL phase?
d) If the aquifer gradient is 0.001 estimate how long it would take to completely dissolve and flush the PCE from the cubic-meter source zone.



a) $C_{pce}^{aq} = S_{pce} X_{pce} = (150 mg/L)(1) = 150 mg/L$

b) Volume of water phase: $(0.2)(1m^3) = 0.2m^3$

Mass in water: $0.2m^3 \cdot \frac{150mg}{1L} \cdot \frac{1000L}{1m^3} = 30{,}000mg = \underline{30g}$

c) Mass PCE Napl

Total PCE $= 20L \cdot \frac{1.63g}{cm^3} \cdot \frac{1000cm^3}{1L} = 32{,}600g$

$PCE_{NAPL} = 32{,}600g - 30g = \underline{32{,}570g}$

d) pore velocity

$V = \frac{K}{n}\frac{dh}{dl} = \frac{410m/d}{0.2} \cdot 0.001 = 2.05m/d$

flushing rate

$2.05m/d * 1m^2 = 2.05m^3/d$

$\therefore$ $2.05m^3/d$ of aquifer is flushed

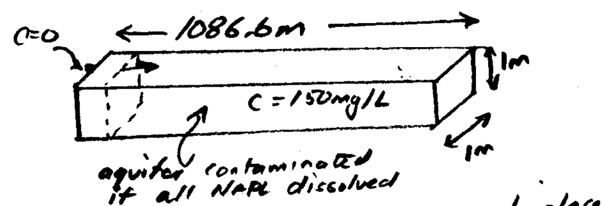
$(2.05m^3/d)(30g/m^3) = 60.1\ g/d$

Total mass, dissolve, then flush

$32{,}600g \frac{1d}{60.1g/d} = 530\ days$

d) explaination sketch

$32{,}600g \cdot \frac{1L}{0.15g} \cdot \frac{m^3}{1000L} \cdot \frac{1m^3 aquifer}{0.2m^3 water} = 1086.6 m^3$ aqu[ifer]



how fast does clean water displace

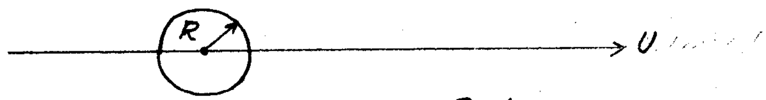
$V = 2.05m/d$

how long to displace contaminated water

$\frac{1086.6m}{2.05m/d} \approx 530\ days$

Problem #4

A circular lake with radius 600m is located in an alluvial valley in direct contact with an underlying unconfined aquifer. The mean regional aquifer flux is 0.1 m^2/d. The lake is sustained by a number of creeks and water is lost by evaporation. The net recharge rate is estimated to be $300m^3/d$. Is the lake recharged by groundwater or does it act solely as a source of groundwater recharge?



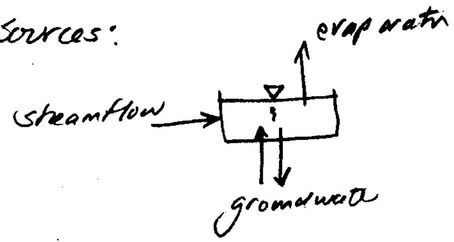
$R = 600m$

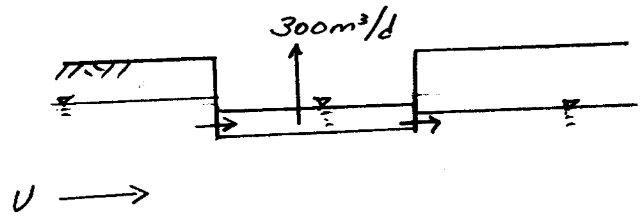
$U = 0.1 m^2/d$

$Q = 300 m^3/d$

Net "recharge" to lake is
$Q = 300 m^3/d$

Sources:





Solution: Use 6.3.14

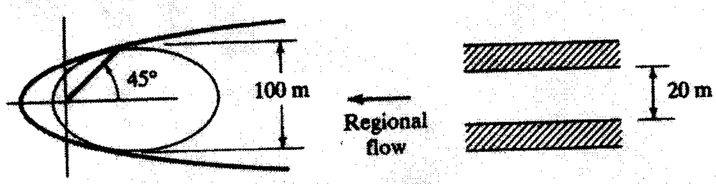
$$4\pi R U = 4\pi (600m)(0.1 m^2/d) = 754 m^3/d$$

$$754 m^3/d > Q = 300 m^3/d$$

∴ There is no net outflow from lake, thus lake recieves water from groundwater

Problem #5

A single well is to be used to remove a symmetrical oblong plume of contaminated groundwater in an aquifer 20.0 m thick, porosity 0.30, hydraulic conductivity 1.0 x 10^{-4} m/sec, and hydraulic gradient 0.0015. With the plume and well oriented as shown, the angle from the well to the edge of the plume at the widest part of the plume is 45°. The plume is 100 meters wide at this point. What pumping rate is required to achieve these conditions?



lecture notes

$$y = \frac{Q}{2U} - \frac{Q}{2\pi U}\tan^{-1}\left(\frac{y}{x}\right)$$

at 45° $y = x = 50$ m

$\tan^{-1}(1) = \frac{\pi}{4}$

$$* \; 50 = \frac{Q}{2U} - \frac{Q}{2\pi U}\cdot\frac{\pi}{4} = \frac{4Q}{8U} - \frac{Q}{8U} = \frac{3Q}{8U}$$

solve for Q

$$** \; U = nbv \qquad v = \frac{K}{n}\frac{dh}{dL}$$

$$\frac{8}{3}(50)\left(\frac{(0.30)(20)(1\cdot 10^{-4})(0.0015)}{0.30}\right) = Q = 0.0004 \, m^3/s$$

Direct use of 6.4.1 not strictly correct because still need to evaluate ψ_0.
(In 6.4.1 if $\psi = 0$, $\psi_0 \neq 0$)