ENV 6002: Physical and Chemical Principles of Environmental Engineering

Fall 2008 — University of South Florida
Homework #11 — Civil & Environmental Eng.
Due date: Thursday, Dec. 4 — J. A. Cunningham

1. (15 pts)
   a. (7 pts) Starting with a mass balance for a solute in a representative elementary volume (REV), derive a differential equation that accounts for the following processes that can occur during groundwater transport: advection, dispersion, sorption, and reaction. Define all variables, and state your assumptions. Assume that the sorption equilibrium is linear, and that sorption equilibrium is reached instantaneously (i.e., Local Equilibrium Assumption). For the reaction kinetic expression, adopt the Monod kinetic model for substrate degradation.
   b. (3 pts) Identify the solute retardation factor, *R*, in the differential equation that you derived in part (a), and explain how *R* influences solute transport, dispersion, and reaction.
   c. (5 pts) Under what conditions is it justified to simplify the reaction term to a first order rate equation, i.e., k_1C? Explain briefly. If you think it would help, include a sketch of the Monod specific reaction rate, (r/X), vs. C.

2. (20 pts) Consider the fate and transport of the pesticide DDT in groundwater.
   Chemical properties for DDT are:
   Octanol-water partition coefficient, $\log_{10}(K_{OW}) = 6.36$
   Aqueous solubility, $C^{SL} = 5.6\ \mu g/L$
   For the aquifer (silty sand), assume the following parameters:
   Hydraulic conductivity, $K_H = 10^{-5}$ m/s
   Porosity, n = 0.30
   Hydraulic gradient, $J = 10^{-3}$
   Longitudinal dispersivity, $\alpha_x = 5$ m
   Solid density (not bulk density!), $\rho_s = 2500\ kg/m^3$
   Organic carbon content, $f_{OC} = 0.0010$ (i.e., 0.10%)
   Reaction is intentionally omitted, because DDT is very persistent in the subsurface.

   a. (5 pts) Calculate the value of the retardation factor, *R*, for DDT transport in the groundwater aquifer. Use the Karickhoff relationship to evaluate the sorption distribution coefficient, K_d. Discuss briefly the environmental significance of the value of *R* that you have calculated. (And think about that when you complete parts b and c, below!)

problem 2 continues →

2. continued

b. (5 pts) Estimate the travel time required for DDT to be transported a distance of 100 m under the conditions above.

c. (5 pts) Estimate the length of the DDT plume, $(\Delta x)_{plume}$, at the point in time calculated in part b. Assume that the plume boundary is given by $\bar{x} \pm 2\sigma_{x,DDT}$. Estimate the Peclet number, Pe.

d. (5 pts) Re-evaluate the assumption that degradation of DDT is negligible in this scenario, by estimating the fraction of DDT that is degraded during transport over 100 m. Assume that C_{DDT} = 0.005 mg/L (i.e., it is present almost at its solubility limit); $k = 0.5\times10^{-6}$ mg•(mg cells)$^{-1}$•d^{-1}; K_S = 0.5 mg/L; and X = 0.1 mg cells/L. What fraction of DDT is degraded during 100 m of transport? (Hint: you may treat the system as a plug-flow reactor for the purposes of estimating the fraction degraded, even though we know the system is not actually plug-flow.) Based on this, do you think it is acceptable to neglect degradation, or must we account for it?