Yhd-12.3110 Transport of Harmful Substances 5 cr (P)

Final exam 24 May 2014

1. Explain briefly the following terms.

a)	Thermal dispersion
d)	REV (representative elementary volume) -assumption
c)	Darcy velocity, mean seepage velocity
d)	Freezing curve
e)	Yield coefficient

2. A solute is transported in soil saturated with water starting from a source area where the concentration is constantly at the level C_0 = 100 (μg/l). After the time of 4 and 5 days the one-dimensional concentration profile to the direction of constant seepage velocity looks the following:

Distance m	C (t=4 days)	C (t=5 days)
0	100.000	100.000
20	10.962	13.428
40	0.483	0.782
60	0.010	0.023
80	0.000	0.000
100	0.000	0.000

The first column shows the distance (m) from the source area. The next two columns present the solute concentration (μg/l) at different distances at the time instants of 4 and 5 days after the solute injection. The solute is concervative and its transport is affected by advection and dispersion along the distance.

Estimate the coefficient of hydrodynamic dispersion using the above concentration data. List the assumptions that you made in the estimation. The Darcy velocity along the distance is constant 0.1 m/d, the effective porosity is 0.3 m^3/m^3, and the bulk soil density is 1400 kg/m^3.

3. The Freudlich isotherm is defined as:

$$\overline{C} = K_f C^a$$

where $\overline{C}$ is the sorbed concentration, C is the solute concentration, and K_f and a are empirical coefficients. Write one-dimensional advection-dispersion equation for a non-conservative solute (seepage velocity is constant). Embed the Freundlich isotherm into the advection-dispersion equation and define the retardation factor. Show consistent units for variables and parameters.

Hint: The temporal change of concentration for the sorption only (without advection and dispersion) is:

$$\frac{\partial C}{\partial t} = -\frac{\rho_b}{\theta}\frac{\partial \overline{C}}{\partial t}$$

where ρ_b is the bulk soil density, θ is the effective porosity and t is the time.

4. A waste disposal site is protected against leaching of benzene by using material with a very low permeability. The thickness of the material is 1 m, its effective porosity is 0.4 m^3/m^3, and the molecular dispersion coefficient is $3.5X10^{-6}$ m^2/d.

Assume that the protective material is homogeneous and the solute transport can be described using one-dimensional advection-dispersion equation (note that the seepage velocity is zero). The biodegradation of benzene follows the first order (radioactive decay) process. After a long period the solute transport into the material has reached a steady-state condition, which means that the transport caused by dispersion is equal to the loss through biodegradation, and solute concentration no longer changes with time in the material.

The table below presents the steady-state concentration profile in the material for a distance of 10 cm. Produce an estimate of the coefficient of biodegradation (the first order decay coefficient). List your assumptions.

Distance [m]	Concentration [μg/l]
0	100
0.02	83.120
0.04	69.089
0.06	57.427
0.08	47.734
0.1	39.677

5. Consider non-concervative solute transport with water in saturated soil in

- till (bulk density 1400 kg/m^3, hydraulic conductivity $1X10^{-3}$ cm/s, effective porosity 0.25 m^3/m^3)
- peat (bulk density 350 kg/m^3, hydraulic conductivity $2X10^{-3}$ cm/s, effective porosity 0.85 m^3/m^3).

How are the differences in soil properties reflected to advection, dispersion and sorption (based on linear isotherm) according to the solute transport equation? What kind of differences in solute transport would you anticipate between the two soil domains, if there was a similar pollutant plume injected into saturated soil of these types?

In linear isotherm

$$\overline{C} = K_d C$$

where $\overline{C}$ is the sorbed concentration, C is the solute concentration, and K_d is the distribution coefficient.

GENERAL FORM OF SOLUTE TRANSPORT EQUATION

$$\frac{\partial(\theta C)}{\partial t} = \nabla \cdot (\theta \mathbf{D} \cdot \nabla C) - \nabla \cdot (\mathbf{q} C) + q_s C_s - \lambda_1 \theta C - \lambda_2 \rho_b \bar{C} - \rho_b \frac{\partial \bar{C}}{\partial t}$$

C is the solute concentration, $\bar{C}$ is the sorbed concentration, θ is the porosity, ρ_b is the bulk soil density, $\mathbf{D}$ is the dispersion tensor, $\mathbf{q}$ is the Darcy velocity vector, q_s is the flow rate due to sink/source, λ_i is the rate constant for the first-order decay (i=1 for solute, i=2 for sorbed substance).