THE UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE AND ENGINEERING
CIV 549 – GROUNDWATER FLOW AND CONTAMINATION

Final Examination, December 1999
Examiner: C.A. Kennedy

Instructions
1. This is an open-book examination.
2. Non-programmable, silent, self-powered, electronic calculators are permitted.
3. If doubt exists as to the interpretation of any question, a clear statement of any assumptions made should be included with the answer.

Question 1 (8 marks)

Explain the meaning of the following groundwater terms. Describe how you would measure or calculate each quantity in a field situation, and give an indication of the accuracy with which each can typically be established.

(a) hydraulic gradient
(b) hydraulic conductivity
(c) mean pore velocity
(d) storativity

Question 2 (6 marks)

A well in an infinite, confined aquifer was pumped for 16 hours at a rate of 3 l/s before the pump was shut off. The aquifer is 10 m thick with a hydraulic conductivity of 2×10^{-5} m/s, and a specific storage of 10^{-5} m^{-1}. Determine the drawdown in the aquifer at a point 150 m from the well 24 hours after the well started pumping.

Question 3 (12 marks)

A barrel of trichloroethylene (TCE) has been spilt over an unconfined, fine sand aquifer. Properties of TCE are as follows:

solubility: 1100 mg/l
density: 1.46 g/cm^3
K_{oc} = 126 ml/g
interfacial tension, $\sigma = 4.5 \times 10^{-2}$ N/m (water-TCE)

Properties of the sand are:

hydraulic conductivity = 10^{-6} m/s
pore size = 0.1 mm
density = 2.6 g/cm^3
organic carbon content, f_{oc} = 1%
porosity, n = 0.35

(a) The DNAPL initially flows downwards through the sand and collects above the water table. Estimate the head of DNAPL that accumulates before the DNAPL can penetrate the water table.

(b) As the DNAPL flows through the saturated zone it leaves behind a residual of trapped "pure phase" over an area of 1 m x 1 m (plan dimensions). The residual saturation in the DNAPL zone is initially 5%. Calculate the number of years it will take for all of the residual DNAPL to dissolve into groundwater flowing through the DNAPL zone. The hydraulic gradient is 0.01.

(c) A water sample is taken from the dissolved TCE plume a few meters downstream of the residual zone. If the aqueous phase concentration of TCE is 50 mg/l determine the concentration of TCE sorbed to the soil grains at this location. What is the total mass of TCE per unit volume of porous media at the sampling location?

Question 4 (12 marks)

Numerical modeling of groundwater flow and transport involves the following five steps:

(i) understanding the natural system
(ii) developing a conceptual model
(iii) formulating a mathematical model
(iv) solving the mathematical model
(v) model calibration

Explain what each of these steps involves. Identify key elements and indicate what choices may be made at each stage. Be as specific as possible and give examples to aid in your explanation.

Question 5 (12 marks)

The input of tritium in precipitation recharging a saturated, sandy-gravel aquifer (Fig. 1) may be approximated as follows:

From 1950 to 1963: $C_{3H} = 10 \exp \{0.2304\, t\}$
From 1963: $C_{3H} = 200 \exp \{-0.0658\, (t-13)\}$

where t is the number of years starting from 1950 and concentration, C_{3H}, is in tritium units (TU). The half-life of tritium is 12.43 years.

(a) Given that the aquifer has uniform groundwater flow with mean velocity, v= 50 m/year, determine the location of the peak tritium concentration in the aquifer in 1998. Using a plug-flow model, i.e., ignoring disperison, sketch the profile of tritium concentrations along the aquifer (x = 0 at the recharge zone). Assume that the aquifer is fully confined (except in the recharge zone) with tight aquitards above and below.

(b) An old mining lake is located 1 km from the recharge zone in the direction of flow. Water from the lake leaks through the narrow confining layer and mixes into the groundwater with a dilution of 1 part lake-water to 10 parts groundwater. The bottom of the lake holds a large volume of water that was deposited in 1963 with a tritium concentration of 400 TU, and is not readily mixed with shallower water in the lake.

Determine the 1998 tritium profile in the aquifer again, this time including the input from the mining lake. Again, use a one-dimensional plug flow model, neglecting dispersion.

Figure 1. Cross-sectional view of the aquifer in question 5.