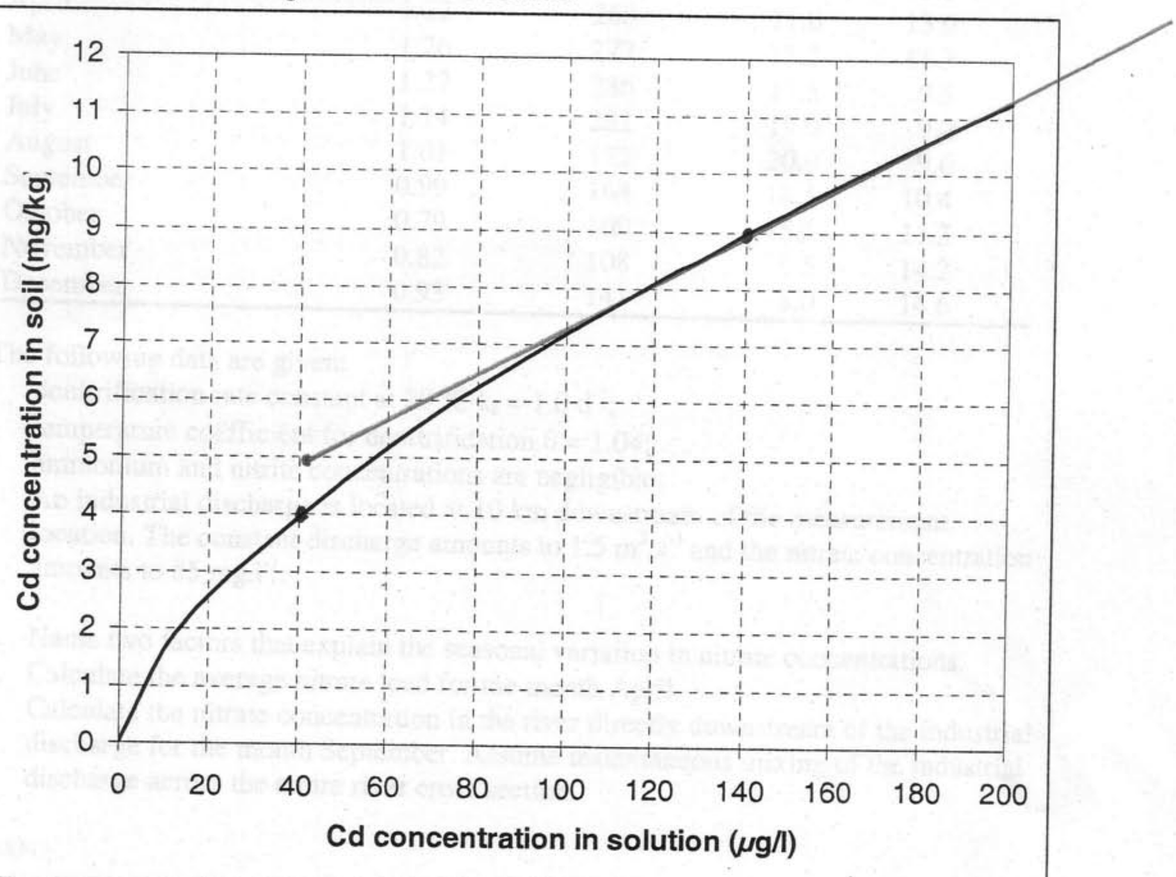
Final exam GEO3-4301 Soil and Water Pollution
3 February 2005 14:00 – 17:00 h

1. Explain in brief (max. 30 words per answer)
   a. why nitrate concentrations in groundwater underneath forest are generally greater near the forest edge than in the centre of the forest.
   b. why the alkalinity of groundwater increases sharply at a certain depth in a sandy aquifer.
   c. why heavy metal concentrations in soil correlate positively with soil clay content.
   d. why the Q-C relationship for total phosphorus in rivers exhibits positive clockwise hysteresis.
   e. why dissolved iron disappears in the sulphate reduction zone in groundwater.
   f. why the topsoil of floodplains along the river Rhine is more contaminated at locations with low sediment deposition rates than at locations with high deposition rates;
   g. why the chloride concentration in streams decreases during a storm event.
   h. why the ^{137}Cs inventory in soil is greater at concave parts than at convex parts of a slope
   i. why the peak concentration of an instantaneous contaminant release into a river decreases in downstream direction.
   j. why the K^+/Cl^- ratio in groundwater increases with time downgradient from a surface discharge of waste water.

(30 points)

4. A pipe leakage underneath an industrial facility has discharged cadmium contaminated wastewater in small volumes into groundwater. The cadmium concentration in the waste water was 170 $\mu g\ l^{-1}$. Ten years after the beginning of the leakage, the leakage is discovered and repaired. To assess the dispersal of cadmium in the shallow sandy aquifer, the local hydrologic situation and the adsorption characteristics of the aquifer material are determined. The porosity of the aquifer material amounts to 0.3 and the dry bulk density amounts to 1600 $kg\ m^{-3}$. The horizontal groundwater flow velocity was determined to be 30 m per year. To determine the cadmium distribution coefficient a batch-experiment with the aquifer material was carried out, from which the cadmium isotherm shown in the figure below was derived.



a. Derive the cadmium distribution coefficient expressed in $l\ kg^{-1}$ for the situation described above from the cadmium isotherm.
b. Estimate the maximum horizontal displacement of cadmium 10 years after the beginning of the leakage, given the retardation factor R_f (=1+ $K_d*\rho_b/n$) (neglect dispersion).

(10 points)

3. At two nearby locations samples A and B were collected from the shallow groundwater. At one location the groundwater originates exclusively from infiltrated rainwater, whereas the other location, another important source is iniltrated surface water, but here the groundwater is also mixed with rainwater infiltrated in an adjacent field.The chemical composition of both samples plus the composition of the rainwater and surface water are given in the table below.

	sample A	**sample B**	**rainwater**	**surface water**
pH	8.0	5.7	4.4	7.7
Ca	76.9	2.4	0.6	78
Mg	7.0	1.2	0.3	12
Fe	3.1	0.4	0.1	0.0
Mn	0.9	0.0	0.0	0.1
Na	55.3	8.8	2.2	83
K	12.6	0.8	0.2	6.2
Cl	71.8	15.6	3.9	151
HCO_3 (alk)	225.0	5.2	0.0	155
NO_3	0.0	12.4	3.1	16.8
NH_4	0.8	7.7	1.9	0.9
SO_4	90.2	25.6	6.4	71

a. Which of the samples (A or B) originates from rainwater? Explain your answer.
b. Explain the differences in chemical composition between rainwater and the groundwater sample originating from rainwater.
c. Estimate the contributions of surface water to the groundwater sample that has surface water as primary source.
d. Which chemical changes have occurred in this groundwater that has surface water as primary source since infiltration. Explain your answer in terms of the chemical processes responsible for these changes.

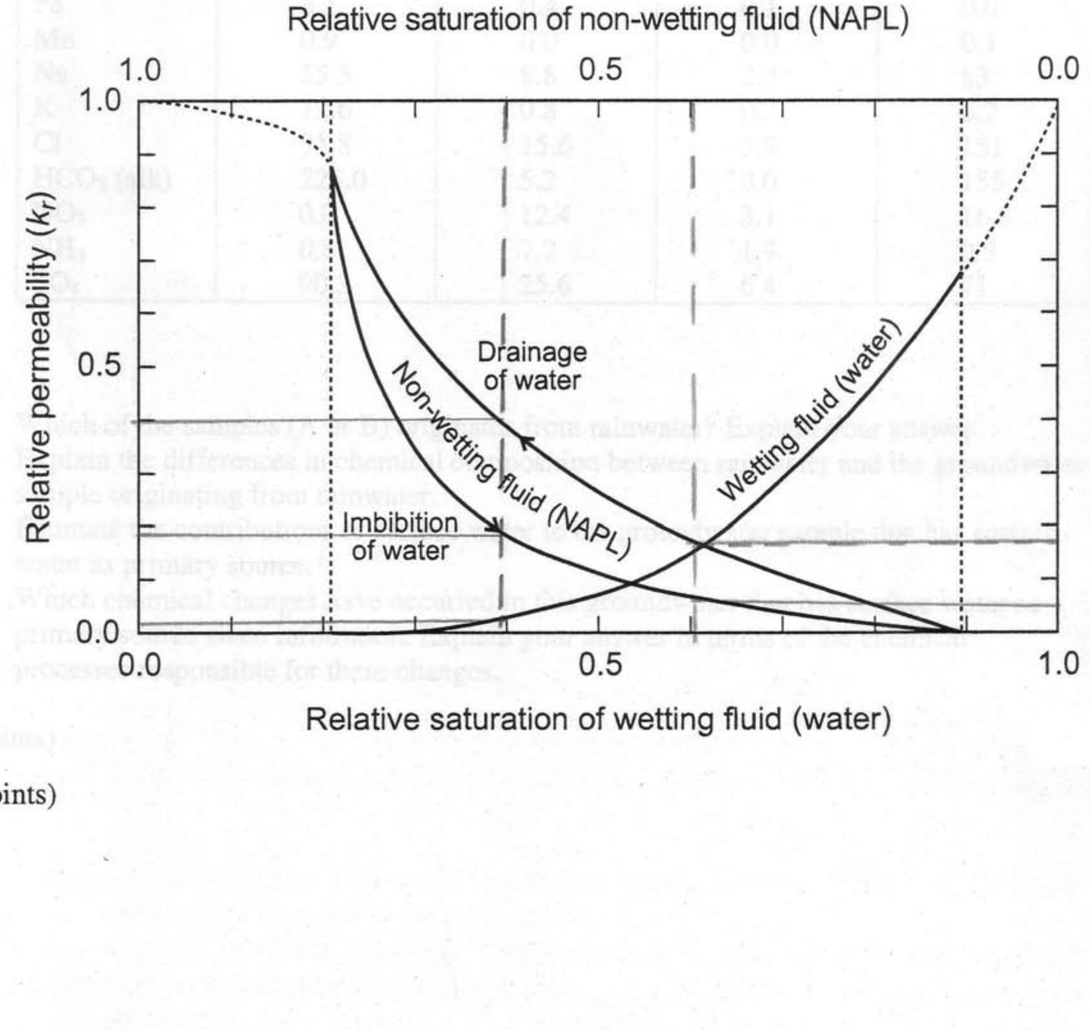
(20 points)

2. After a spill of 50 litres of a NAPL into a water-saturated soil with a porosity of 30 %, the maximum relative saturation of the NAPL in the soil reaches 60 %. Determine from the figure below:

a. The relative permeability of the soil with respect to water.
b. The relative permeability of the soil with respect to the NAPL.
c. Why do the relative permeabilities of the soil with respect to water and the NAPL not sum to one?

The NAPL is slowly replaced by water.

d. Determine the residual saturation of the NAPL.
e. Explain why the NAPL will not be completely replaced by water in the contaminated and a NAPL residue will remain.
f. Calculate the volume of soil contaminated by the NAPL at residual saturation.



(15 points)

5. At a fixed location in a river, weekly measurements are performed to determine mean flow velocity (U), discharge (Q), and a number water quality parameters, amongst which temperature (T) and nitrate concentration (NO_3). For one year the following monthly averages have been determined:

Month	U ($m\ s^{-1}$)	Q ($m^3\ s^{-1}$)	T (^0C)	NO_3 ($mg\ l^{-1}$)
January	1.04	183	3.0	12.2
February	1.28	289	3.5	11.3
March	1.08	200	8.0	13.5
April	1.22	260	11.0	13.0
May	1.26	277	13.5	11.3
June	1.27	286	17.5	9.5
July	1.14	222	19.0	9.2
August	1.01	172	20.0	9.6
September	0.99	164	18.5	10.4
October	0.79	100	15.5	11.3
November	0.82	108	9.5	14.2
December	0.93	141	8.0	14.6

The following data are given:

- denitrification rate constant at 20 ºC $k_d = 1.0\ d^{-1}$;
- temperature coëfficiënt for denitrification $\theta = 1.04$;
- ammonium and nitrite concentrations are negligible;
- An industrial discharge is located at 10 km downstream of the measurement location. The constant discharge amounts to $1.5\ m^3.s^{-1}$ and the nitrate concentration amounts to $85\ mg.l^{-1}$.

a. Name two factors that explain the seasonal variation in nitrate concentrations.
b. Calculate the average nitrate load for the month April.
c. Calculate the nitrate concentration in the river directly downstream of the industrial discharge for the month September. Assume instantaneous mixing of the industrial discharge across the entire river cross section.

(15 points)