Main understandings – main points

**Unit: SUBSURFACE FLOW**

**Presentation 1 of 4**

**Direction of movement of groundwater**

Contents

1) Introduction (motivation for studying groundwater)

2) Search for an answer to the question “where does groundwater move to?”

**Important terminology clarification**

• The potentiometric surface is also called piezometric surface because it is the surface connecting the points where water rises in piezometers (or wells).

**Main point**

**Q:** “where does groundwater move to?

**A:** groundwater moves from areas of high hydraulic head to areas of low hydraulic head

• If I have a map with equipotential lines in an isotropic soil, the path followed by a molecule of water (or a molecule of a contaminant) will dissect each one of the equipotential lines at a 90° angle

**Presentation 2 of 4**

**Darcy’ law**

**Main points**

• For groundwater flow, Darcy velocity is a function of:

(1) characteristics of the flow domain: hydraulic gradient

(2) the soil: hydraulic conductivity

• The hydraulic gradients of natural groundwater movement are low, e.g. common values range between 0.001 and 0.01

hydraulic gradient is written as decimal, not percentage, e.g. 0.001 (not ~~0.1%~~)

• The hydraulic conductivity of the soil varies within 10+ orders of magnitude

**Presentation 3 of 4**

**Velocity of groundwater movement & of contaminant spreading (advection velocity)**

**Main points – concepts**

• Attention! Depending on the thematic field, the term “groundwater velocity” may correspond to different concept

When we read in a text “groundwater velocity”, without clear explanation we cannot be 100% certain which quantity is meant by the authors

• In Environmental Geotechnics we should be careful not to use loosely the term “groundwater velocity”, which refers to the seepage velocity, vs (and not to Darcy velocity)

• The terms “average linear velocity” and “seepage velocity” refer to the same quantity

**Presentation 4 of 4**

**Until now, what did we learn/what can we do with what we learned?**

**Specifying detailed learning outcomes**

• From the first, introductory lesson: “The goal is achieved if at the end of the course the students are confident in applying principles of subsurface flow”

• How can I be more specific about what you should be able to do?

• Well, first I should list the particular cases of the general problem “groundwater flow” I learned how to handle

**Common features of groundwater flow problems we can handle**

• Flow can be approximated as one-dimensional (at least in parts)

• Hydraulic head does not change (significantly) with time

**Learning outcomes for “Groundwater flow”**

• For 1-D problems (or 1-D simplifications of 2-D flow fields), and constant hydraulic gradient (in time):

• I can calculate hydraulic head and piezometric head;

• I can read potentiometric maps (i.e. hydraulic head maps), i.e. I can tell the direction of groundwater flow and calculate hydraulic gradient;

• I can apply Darcy’s law to calculate velocity, discharge, or hydraulic head;

• I can perform calculations for advection-driven transport of contaminants (e.g. travel time).

**Unit: SOIL-CONTAMINANT INTERACTION**

**Presentation 1 of 4**

**1) Motivation for studying soil-contaminant interaction**

**2) Concepts and terms**

**3) Prerequisites from physics, chemistry and soil mechanics**

**How is the contaminant distributed in the soil phases: air, water, solids?**

Main questions (motivation for study):

- **Q:** Where will the contaminant go, how will it behave?

- **Q:** What can we do to reduce risk? **Α:** remove contaminant mass **Q:** what is the total contaminant mass in the subsurface? How much mass do we have to remove?

**Presentation 2 of 4**

**Interaction between pairs of liquid phase – gaseous phase**

1) Nonaqueous contaminant – gaseous phase

2) Contaminant in aqueous solution – gaseous phase

**Main Points**

• Interaction between phases of the system contaminant–soil

- A dynamic, two-way phenomenon, consisting of contaminant mass transfer from one phase to all the others

- Using physicochemical parameters (vapor pressure, Henry’s law constant), we describe equilibrium in a closed system

**Presentation 3 of 4**

**Interaction between phases in the saturated zone (also applicable to the unsaturated zone as well!)**

1) Nonaqueous phase – aqueous phase

2) Solid phase – aqueous phase

**Review Question**

• What is happening in water? How will I think/calculate which substance and how much of it exists in water?



olive oil

water

**Presentation 4 of 4**

**Summary & main points**

**Learning outcomes**

**Summary**

• The contaminant will partition (or distribute itself) to all phases, trying to achieve equilibrium for each pair of phases

• The concentrations we calculate with the aid of physicochemical parameters (=partition coefficients) describe equilibrium between phases and provide maximum possible values

• Partition coefficients either (i) are found in the literature (vapor pressure, Henry’s law constant, solubility, octanol-water partition coefficient, Κοw – for single contaminants), or are determined (ii) through correlations (Κp – for hydrophobic organic contaminants under certain conditions) or (iii) with experiments (parameters of models of equilibrium sorption isotherms, e.g. Κp for linear isotherm)

**What can I do with what I learned? (which are the learning outcomes of the soil-contaminant interaction unit?)**

• If I want to evaluate the behavior of a contaminant in the subsurface: I can find its mass transfer characteristics (vapor pressure, Henry’s constant, solubility, soil-water partition coefficient) from reliable sources.

• If I know or suspect the presence of a NAPL contaminant: I can estimate degree of NAPL saturation and calculate total contaminant mass.

• With known contaminant concentration in any of the three soil phases (air, water, solids), or in a water sample, or in a soil sample, I can calculate concentration in each of the three phases and total contaminant mass in a soil sample or in the contaminated area in the field.

• When I am asked to calculate total mass, given either NAPL saturation or contaminant concentration in one of the three soil phases, I don’t need to be reminded that the contaminant will partition to all soil phases!

**Unit: TRANSPORT OF SOLUTES (DISSOLVED CONTAMINANTS) IN SATURATED SOIL: ΜATHEMATICAL DESCRIPTION**

**Presentation 1 of 4**

**Transport due to diffusion**

**Main aim of presentation**

• Why do we study here only diffusion?

- for educational purposes mainly

• For the partial differential equations that describe the transport of a contaminant dissolved in the aqueous phase of saturated soil, the aim is to understand:

* how are they derived: contaminant mass balance
* what do they express? Which term, which parameter expresses each mechanism contributing to transport?

**Concluding remarks**

• Little (?) contaminant spreading due to diffusion alone

* Yes, little in general for a contaminated site
* Important for other problems, e.g. the low-permeability bottom liner of a landfill

• After showing qualitatively [with the in-class experiment of the transport of chocolates (Pantazidou, 2010) and the tracer test at the Borden site (Roberts et al., 1986)] that sorption delays the spreading of the contaminant, we now see this delay through the mathematical description of transport

**Broader remarks**

• Phenomena are presented one by one (diffusion only, diffusion first without sorption, then with sorption) for educational purposes exclusively

- we always “have” sorption (and, likewise, diffusion) – if we do not account for it, we should justify our decision

- the same justification requirements hold for every decision

e.g. the decision to ignore any phenomenon involved in contaminant transport – we should be able to estimate (a) the relative contribution of the phenomenon and (b) if the resulting solution gives a conservative estimate

**Presentation 2 of 4**

**Transport due to advection+diffusion+dispersion**

**Concluding remarks**

• The solution of the equation for 1-D transport due to advection and hydrodynamic dispersion gives, for a specific distance X from the source, the time it takes a specific concentration to reach X.

• Small concentrations arrive faster. That’s why, the calculation of the travel time for a contaminant due to advection (= travel time of concentration approximately equal to ½ of the concentration at the source) gives a non-conservative estimate (i.e. bigger time).

**Presentation 3 of 4**

**General equation for solute transport and analytical solutions for specific conditions**

**Concluding remarks**

• THE GOOD NEWS: There exists a variety of analytical solutions for the contaminant transport equation

• THE NOT SO GOOD NEWS: In order for the solutions to be valid, significant assumptions are necessary, e.g.

- Source of constant concentration and infinite duration

• realistic assumption only when NAPLs are present, if not, we can use superposition of solutions for sources starting at different times

- Instantaneous equilibrium for sorption

• accounting for mass transfer during sorption and desorption is mathematically complicated

- Constant parameter values in time

• often not valid assumption for half lives, e.g. if oxygen is depleted from an aquifer, then degradation slows down for contaminants that are biodegraded faster under aerobic conditions (e.g. benzene)

**Presentation 4 of 4**

**Three solved problems & learning outcomes**

**What can I do with what I learned? (which are the learning outcomes of the contaminant transport unit?)**

• I can estimate the relative contribution of transport phenomena for specific combinations of pollutants, soils and characteristics of the flow and transport fields

• I am familiar with searching in the literature for values of transport parameters

• I can back reasonable estimates for the values of the parameters involved in a problem of contaminant transport

• I am aware of a variety of analytical solutions of the equation for contaminant transport and I understand the limitations of each one

• I can select from a variety of analytical solutions of the transport equation the one that fits better the geometry of a contaminant release and the expected contribution of the transport phenomena

**References**

• Pantazidou, M. (2010). The Scholarship of Teaching: A case in Environmental Geotechnics, In: Inquiries into European Higher Education in Civil Engineering, 9th Vol., Erasmus Thematic Network: European University Civil Engineering Education and Training (EUCEET), I. Manoliu (Ed.), pp. 125-152.

• Roberts, P.V., Goltz, M.N. and Mackay, D.M. (1986). A natural gradient experiment on solute transport in a sand aquifer 3. Retardation estimates and mass balances of organic solutes, Water Resources Research, 22: 13: 2047-2058.