**Exhibit 5Sb. Descriptions of all thematic units 1 through 10**

This exhibit includes the descriptions of the thematic units as they appear on the page of the open course (https://ocw.aoc.ntua.gr/courses/CIVIL115/). The purpose of the descriptions is triple: (a) to prepare students for the content of each unit using everyday language and avoiding technical terms as much as possible, (b) to highlight the connections among thematic units and (c) to stress the connections between specific content and educational material of the open course, i.e. presentations, notes, case studies and solved problems.

NOTE ON FILE CODES INCLUDED IN BRACKETS. P: PowerPoint presentation, N: notes, CS: case study, SP: solved problems.

**Unit 1: Introduction**

Environmental Geotechnics is an applied field [1-1P]. The course too has an applied emphasis and starts with a case study of contamination and site restoration in Greece [1CS]. Case studies guide the phrasing of the essential questions addressed in the course [1-2P], which will be answered by the course’s completion and are stated in everyday language, i.e. without the technical terms we will learn in the course, as follows:

What is the danger (from pollutants)?

Where will the pollutant go, how will it behave?

What can we do to reduce the danger?

When do things are relatively easy or difficult and why?

The introduction also includes a review of the legislation [1-3P] and of the contaminant sources and contaminant characteristics of interest for Environmental Geotechnics [1-4P].

**Unit 2: Risk Assessment**

This thematic unit deals with the impact from contamination caused by chemical substances to human health and, hence, concerns every active citizen. It addresses the essential question phrased in everyday language as “what is the danger?” and it rephrases it, in a way that the answer can be used for remedial decisions at contaminated sites, by introducing the concept of risk. The focal point of the unit is the distinction between hazard identification (identifying the adverse effects caused a substance, the “danger” in everyday language) and risk assessment (calculating the likelihood of a specific effect occurring within a specified period or in specified circumstances) [2P]. The case study of the unit is an example of calculating risk at a contaminated site [2CS].

**Unit 3: Mechanisms of pollution spreading (qualitative description)**

This thematic unit presents in a qualitative way how contaminants spread, as an introduction for later units and particularly for the quantitative-mathematical study of contaminant transport in Unit 7. It consists of two parts.

The first part does not require any technical background. It includes pictures from laboratory experiments of spills and subsequent movement in soil of organic contaminants that do not mix with water [3-1P, 3-2P, 3-3P, 3-4P] and uses knowledge and experiences from our everyday life in order to describe qualitatively the mechanisms contributing to the spreading of contaminants dissolved in water [3-5P]. In this way, Unit 3 helps us appreciate the usefulness the next units: in order to find out where will the contaminant go (Unit 7), we first need to know where does groundwater move to (Unit 4).

The second part requires the completion of Unit 6 and starts with describing the contribution of all the phenomena affecting pollution spreading in the subsurface [3-6P]. Using an experiment-game that can take place in class, and through an analogy of “temporary storage of contaminant mass”, the interaction between soil solids and contaminants is introduced qualitatively [3-7P]. The last presentation describes one last time qualitatively the influence of soil solids on the movement of contaminants [3-8P], this time with the help of measurements from a field experiment of contaminant release and transport.

**Unit 4: Subsurface flow**

This thematic unit consists of two parts of different scope. The first part deals exclusively with steady-state groundwater flow in saturated soil, in flow fields that are or can be simplified as one-dimensional. It introduces the background and tools necessary to answer the main questions of applied interest: where groundwater moves to [4-1P], how we calculate the quantity of groundwater moving in the subsurface using Darcy’s law [4-2P] and, how we estimate how quickly a contaminant moves with the movement of groundwater [4-3P]. Solved problems aim at familiarizing students with the calculations needed to answer these questions. It is noted that solved problems 4-3-2SP και 4-3-3SP incorporate elements from the methodology for the modelling of physical systems presented in the next thematic unit [5P]. Because the concepts studied in the 1st part are foundational for Environmental Geotechnics, the last presentation includes detailed learning outcomes for this subunit [4-4P].

The second part offers an overview of flow equations in 3 dimensions for saturated and unsaturated flow, as well as for multiphase flow [4-5P], which is relevant in cases of spills of nonaqueous organic liquids, which do not mix with water. This 2nd part aims at (a) stressing the subset of flow problems students can address with confidence using the knowledge from the course, (b) preparing them for the additional knowledge needed to enlarge this subset, (c) highlighting links between classical geotechnics and environmental geotechnics and (d) supporting further the qualitative study of spills of nonaqueous liquid contaminants that started in Unit 3.

**Unit 5: Modelling of physical systems**

This thematic unit deals with the horizontal skill of modelling of a physical system, i.e. the process necessary to translate an open question to a problem-to-be-solved, in thematic areas such as mechanics, geotechnics, hydraulics, etc. [5P]. This process cannot be unique, since it requires making a number of modelling decisions, often in the absence of one “correct” decision. Hence, the particular problem-to-be-solved is not unique, nor its solution. To this end, students are given an extensive check list with questions guiding them to choose among alternative decisions [5N], and examples of alternative solutions in the Thematic Units of Subsurface Flow [4-3-2SP, 4-3-3SP] and Contaminant Transport [7-2-1SP, 7-2-2SP, 7-2-3SP]. The message of this thematic unit is that modelling requires from the engineer to consider more than one acceptable approaches. Practice with open-ended problems admitting more than one solutions helps the engineer to estimate a priori, at least crudely, how the results of these alternative approaches may differ.

**Unit 6: Soil-contaminant interaction**

In Unit 3 we saw that in order to know where will the contaminant go (Unit 7), we need to first know where does the water go [3-5P]. But, apart from water (aqueous phase), in saturated soil we also have the soil grains or, to use a more general term, the solid phase. Moreover, in the unsaturated zone we also have air (the gas phase). Finally, as we saw in Units 3 and 4, it is possible to have organic contaminants that do not mix with water (aqueous phase) released in the subsurface. To answer the basic question “how will the contaminant behave?” we need to study how the contaminants interact with the soil phases, i.e. water, air and the soil solids. This unit requires a refresher of a few concepts from chemistry and soil mechanics, which is provided in the introductory presentation [6-1P] and notes [6N]. The detailed study of the interaction between phases starts from pairs of aqueous-gas phases [6-2P], which are familiar to us from everyday life (e.g. the phenomenon of volatilization), and continues with the interactions between liquid-liquid phases and liquid phase – solid phase [6-3P]. The descriptions of the interactions in pairs of phases are accompanied by short solved problems meant for practice [6-2SP]. The learning outcomes of this unit are given in the form of typical questions of applied interest [6-4P], the answers to which are supported by the solutions of problems that are inspired from problems that arise in practice [6-SP1, 6-SP2]. The presentation of an emblematic case of a spill from a crude oil pipeline in Bemidji, Minnesota, [6CS] gives an example of the applied usefulness of knowing how contaminants interact with the soil phases.

The big message of this unit is that when a contaminant finds its way into the subsurface, it will not remain contained in the phase of the original release (e.g. water = aqueous solution), but it will contaminate the other soil phases as well (e.g. the soil solids and air). The second big message is that when we decide how much to worry about a contaminant, we are not concerned only with contaminant concentration (does it exceed an allowable limit? by how much?) but also with total contaminant mass, especially at the stage of site remediation (how much contaminant mass we need to remove?).

**Unit 7: Contaminant transport in groundwater (quantitative-mathematical description)**

This is the third important technical thematic unit of the course. Following the qualitative description of the movement of contaminants (Thematic Unit 3), it gives the quantitative-mathematical description of contaminant transport in groundwater with the help of the transport equations, combining elements from the other two important technical thematic units of the course, subsurface flow (Thematic Unit 4) and soil-contaminant interaction (Thematic Unit 6). With this unit, we finally have all the necessary background to answer the question “where will the pollutant go, how will it behave?”, for the case of dissolved contaminants in saturated soil.

For educational purposes, the unit first presents the case of one-dimensional transport due to diffusion alone [7-1P] and then adds the phenomena of advection and dispersion [7-2P]. Then, it presents the general differential equation for three-dimensional flow and three-dimensional transport and specific solutions, always for one-dimensional flow, and particular boundary conditions [7-3P]. Lastly, the unit states its detailed learning outcomes [7-4P]. In addition, with examples from the three problems solved using the solution of the equation for one-dimensional transport [7-2-1SP, 7-2-2SP, 7-2-3SP], comments are made concerning the expected differences between one-dimensional simplified solutions and solutions of higher fidelity to the real problem [7-2-1SP] and the importance of selecting parameters and problem simplifications [7-2-3SP], returning thus to the subject of Unit 5 (Modelling).

**Unit 8: Remediation technologies for contaminated sites**

The theoretical background of this unit coincides with that of Unit 7, because for the remediation of contaminated groundwater we depend to a large extent on the same processes involved in contaminant transport. The unit offers an overview of the methods used for contaminated site restoration [8-1P], categorized as follows: (1) monitored natural attenuation, (2) contaminant containment and lastly either (3) above-ground treatment of the contaminated medium following its removal through soil excavation (unsaturated zone) or groundwater pumping (saturated zone), or (4) in situ treatment of the contaminated medium (often the preferred solution, if doable). The technology of permeable reactive barriers is described as an example of further study required for familiarity with every technology [8-2P], and solved problems are given for selected technologies [8SP-1, 8SP-2, 8SP-3].

This unit answers to a large extent the question “what can we do to reduce the danger?”, which with the background from Unit 2 is restated with greater precision as “what can we do to reduce risk?” (if risk exceeds acceptable limits).

**Unit 9: Landfill liner design and materials**

Landfills [9-1P] are constructed with bottom liners consisting of materials suitable to protect the underlying natural soil [9-2P]. The design of the bottom liner, which involves choice of thickness and properties of the materials used [9SP], is an application of the knowledge acquired in Unit 7.

**Unit 10: Wrapping up**

The course closes with highlighting the connection between course contents and the answers to the essential questions that motivate the study of Environmental Geotechnics.