Earth and Planetary Sciences 162, *and* ***Engineering Sciences 162 (taught as combined course),***

Hydrology and Environmental Geomechanics

SYLLABUS AND READINGS, spring term 2017 *(as of 23 Jan 2017)*

Web link for spring 2017 ES&EPS162 offering – in Canvas format:
https://canvas.harvard.edu/courses/22759

Teaching Staff:

- **James R. Rice** (224 Pierce Hall, rice@seas.harvard.edu, 617-495-3445, 617-388-1927)
  Professor, School of Engin. & Appl. Sci and Dept. of Earth & Planetary Sci
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- **Annika M. Quick** (101b Geo Museum., annikaquick@fas.harvard.edu, 617-496-2292)
  Preceptor, Dept. of Earth & Planetary Sci
  Office hours, by appt. (made by e-mail or phone)

Questions are always welcome at the start of (and during) Lectures. Questions on course materials, homework, etc. can, of course, also be brought up in the Friday Supplemental Sessions.

Course Goals and Description:
This course shares our excitement about hydrology as a powerful approach to understanding water-related earth and environmental phenomena, and aims to foster your confidence in using the basic math and physics you've studied to help describe such processes. We assume only an elementary background in physics (focused on mechanics in particular), and beginning calculus. You will learn the details of how materials (including groundwater, surface water, soil, ice, and rock) move under pressure or stress, and why understanding this movement is significant. You will be able to apply this understanding to applications such as water resources, water contamination and remediation, landfills, liquefaction, stream flows, flooding, landslides, and ice sheets and glacier movement.

Class meetings:

- **Lecture Sessions**: MWF 11-12, Room 309 Cruft Lab
- **Supplemental Session**: Fri 1-2:30, meets most weeks, as announced, in 314 Sci. Cent, to discuss homework problems and issues from readings and lectures, and/or for a 1-3 pm laboratory session in 314a Sci. Cent. (take the Science Center elevator to the 3rd floor, and then walk to the right).
- **Fieldtrip (required)**: Towards the end of the term, we will experience field hydrology (well monitoring) at the Tufts University campus. Tentative dates are Friday, April 7th and/or Friday, April 14th (but the actual date, to be coordinated with our host at Tufts, Prof. Grant Garven, is yet to be determined). We will leave campus beginning at the regular scheduled time (1:00pm) for the Supplemental session.

Textbook from which most readings will be assigned:
Charles R. Fitts, *Groundwater Science*, 2nd Edition, 2013, Academic Press (Elsevier) is a "required" text; it would be a good idea to purchase this one. However, on the Syllabus Topics below, roughly comparable readings are listed within double brackets [[..]] from Fitts,

Groundwater Science, 1st Edition, 2002 of which copies are in Cabot & McKay libraries. Note that some topics covered in the 2002 edition are *not* included in 2013, and *vice versa*.

Supplemental readings: Several additional texts relevant to this course are held in reserve at the *McKay Library* on the 3rd floor of Pierce Hall (see list at the end of the syllabus). It is possible that during the term, the place of availability of these items will change to the *Cabot Science Library*, in the Science Center. A principal source for supplemental reading, frequently cited for "*Recommended reading*" below, is Middleton and Wilcock, *Mechanics in the Earth and Environmental Sciences,* 1994. It has all the right topics, and certainly the right spirit; one does wish that misprints were fewer, but they are not disabling to comprehension of the basic concepts.

Homework Problem Sets:

- Possible Homework Problems have been prepared, in three Sets, to correspond to topics on the course syllabus as indicated. You will be expected to acquire mastery (in the sense of knowing how to logically approach and solve them) of a subset of those problems that we will identify. The homework sets are
    1. Homework Problem Set 1 (Syllabus topics 1 to 3)
    2. Homework Problem Set 2 (Syllabus topics 4 to 7)
    3. Homework Problem Set 3 (Syllabus topics 8 and 9)

  We will ask you to address only a modest subset of the entire collection of problems, and it should be noted that in some years we barely get to Set 3.
- The particular problems, assigned for your special focus, will be identified weekly during the lecture meetings (or by e-mail to the class list). You should come to the Friday 1:00 pm supplemental sessions [in Science Center 314] **ready to coherently present, at the chalkboard**, the solution to those particular assigned problems -- and to politely but definitively critique such presentations by your classmates. (The presentations are typically done in small teams, with all team members participating and critiquing one another.)
- Additionally, you will be required to turn in, **in written form**, a few problems for grading. Such written materials should be ***models for clarity***, presented at a professional level. Mark each such homework solution with the problem number.
- And again, remember that you're responsible for knowing how to solve **all** of the assigned problems, not just the ones to be submitted in written form!
- **Lab write-ups** (3-4) will also be turned in during the semester according to instructions given in class or during the supplemental session.

***Exam*s:**

- ***Mid-term exam:*** Wed 8 March, 11am-noon.
- ***Final exam:*** Early May, time TBA between Thu 4 May and Sat 13 May.

Exams in this course are based entirely on issues raised in the homework problem sets, and labs, including the lecture/reading background and basic concepts underlying them.

Evaluation:

Required homework problems and laboratories:	25%	Mid-term exam: 20%
Class participation, evidence of reading and self-study:	15%	Final exam: 40%

Policy on collaboration:

Discussion of class topics and homework problems with fellow students is highly encouraged, but for any assigned work to be handed in (or to be presented orally), your personal mastery must be such that you can defend the basis for, and reasoning underlying, everything presented. Please read Harvard's policy on academic integrity at: http://honor.fas.harvard.edu/honor-code.

Academic Accommodations:
Any student needing academic adjustments or accommodations is requested to present their letter from the Accessible Education Office (AEO) and speak with the professor by the end of the second week of the term. Failure to do so may result in the Course Head's inability to respond in a timely manner. All discussions will remain confidential, although AEO may be consulted to discuss appropriate implementation.

Earth and Planetary Sciences 162, *and* ***Engineering Sciences 162*****,**

Hydrology and Environmental Geomechanics

SYLLABUS: TOPICS, spring term 2017

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(1) Hydrologic cycle, surface and groundwater, aquifer, pore pressure and hydraulic head concepts. Properties of water and of particulate surficial materials. Introduction to slow laminar fluid flows.

Required reading:

1. Fitts, *Groundwater Science*, 2nd Edition, 2013:
    a. Chp. 1 (Water and groundwater overall perspective)
    b. Chp. 2 (Physical properties of water and aquifer materials).
    c. -or- [[Fitts, *Groundwater Science*, 1st Edition, 2002: Chp. 1 (Groundwater overall perspective), Chp.2 (Physical properties of water and aquifer materials).]]

(2) Introductory fluid mechanics, partly by dimensional analysis, in connection with channel or sheet flows, flow resistance, drag force and settling velocity of particles in fluids. Darcy law for seepage flows, hydraulic conductivity and permeability. Microscale interpretation of permeability.

Required reading:

1. Visuals set and Notes handouts covering creeping flows in slits and tubes.
2. Fitts, *Groundwater Science*, 2nd Edition., 2013:
    a. Chp. 3 (Darcy's law and principles governing seepage flows);
    b. Chp. 5 (Geology and groundwater; major aquifers).
    c. -or-[[Fitts, *Groundwater Science*, 1st Edition, 2002: Chp. 3 (Darcy's law and principles governing seepage flows); Chp. 4 [except for Sect 4.2 which is recommended but optional] (Geology and groundwater; major aquifers).]]

Recommended reading:

3. Middleton and Wilcock, *Mechanics in the Earth and Environmental Sciences,* 1994:
    a. Chp. 3 including Rev. Prob. 3.7.1 to 3.7.4 (Dimensional analysis applied to fluid flow and theory of physical models);
    b. Chp. 9, Sect. 9.8, 9.9 [note that all 3 equations should have the sign changed on the r.h.s.], and 9.11 (Elementary mathematical models of creeping fluid flows).

(3) Groundwater flow analyses; flow nets for aquifers, dams and levees; flows with

phreatic surfaces. Well capture zones. Seepage forces due to fluid flow. Effective stress concept for strength and deformation of water-saturated materials. Soil failure by quick conditions and piping; safety of dams and levees. Salt water intrusion.

Required reading:

1. Fitts, *Groundwater Science*, 2nd Edition., 2013:
    a. Chp. 6, Sect. 6.2, 6.4, 6.5 and 6.6 (Effective stress concept and pore pressures effects in liquefaction and failure of earth materials).
    b. Chp.7 (Modeling steady flows with basic methods, various solutions for seepage configurations).
    c. Chp. 4 (Wells and field exploration).
    d. –or-[[Fitts, *Groundwater Science*, 1st Edition, 2002: Chp. 5 (Deformation, storage, and general flow equations); Chp. 6 (Various solutions for seepage configurations).]]

Recommended reading:

2. Middleton and Wilcock, *Mechanics in the Earth and Environmental Sciences,* 1994:
    a. Chp. 6, Sect. 6.5 to 6.13 (Potential theory for 2D seepage flows, basic solutions; saltwater intrusion)

(4) Coupled deformation and groundwater diffusion. Time-dependent consolidation. Fluid withdrawal and land subsidence. Well hydraulics.

Required reading:

1. Visuals set and Notes handouts on theory of consolidation in fluid-saturated earth materials and well hydraulics.
2. Fitts, *Groundwater Science*, 2nd Edition, 2013:
    a. Chp. 6, Sect. Sect. 6.3 and Sect. 6.7 to 6.10 (Deformation, storage and general flow equations; solutions for transient well hydraulics).
    b. Chp. 8 (Transient flows involving consolidation and storage changes; well hydraulics).
    c. –or-[[Fitts, *Groundwater Science*, 1st Edition, 2002: Chp. 7 (Transient flows involving consolidation and storage changes; well hydraulics).]]
3. Middleton and Wilcock, *Mechanics in the Earth and Environmental Sciences,* 1994:
    a. Chp. 5, Sect. 5.9 to 5.11, and Chp. 6, Sect 6.15 (Consolidation and one-dimensional consolidation theory for fluid-saturated materials).

Recommended reading:

4. Fitts, *Groundwater Science*, 2nd Edition., 2013:
    a. Chp. 9 (Computer-assisted flow modeling).

(5) Capillary and fluid invasion; drainage and wetting (imbibition) of earth materials. Electrolyte state in pore water, electric double-layer; electro-osmosis.

Required reading:

1. Notes handout on *Theory of Double Layer Near Electrically Charged Mineral Surface in an Electrolyte Solution*.

(6) Shear strength of soils, rocks and ice. Stress states and transformations. Deformation and failure under conditions of fluid saturation. Landslides and debris flows. Glaciers and ice sheets.

Required reading:

1. Visuals set and Notes handouts on Mohr's circle for stress, slope and embankment

failures, landslides, glacial processes.

2. Fitts, *Groundwater Science*, 2nd Edition., 2013:
    a. Chp. 6, Sect 6.5 and 6.6 (Slope instability, earthquakes induced by fluid pressure)
3. Middleton and Wilcock, *Mechanics in the Earth and Environmental Sciences,* 1994:
    a. Chp. 4, Sect. 4.1 to 4.2 and 4.4 to 4.5 (Friction, dilatancy, triaxial characterization of strength); Sect. 4.6 to 4.11 (Stress components, Mohr circle for stress transformation); Sect 4.12 to 4.16 (Frictional failure and faulting, slope instability analysis);
    b. Chp. 5, Sect 5.9 to 5.12 and Rev. Prob. 5.13.3 (Effect of pore pressure on strength);
    c. Chp. 6, Sect. 6.14 (Effect of pore pressure on slope instability);
    d. Chp. 10, Sect. 10.3 to 10.6 and Rev. Prob. 10.8(1) and 10.8(3) (Flow of material down slopes, ice sheet deformation, debris flows).

(7) Groundwater contamination and cleanup. Solute motion in groundwater; diffusion, dispersion, and adsorption-retardation. Remediation strategies: pump and treat, barrier walls, bio-remediation, air sparging, reactive blankets. Landfill site planning.

<u>*Required reading:*</u>

1. Visuals set and Notes handouts on groundwater contaminant transport.
2. Fitts, *Groundwater Science*, 2nd Edition., 2013:
    a. Chp. 11 (Solute motion, groundwater contamination, and remediation strategies).
    b. –or-[[Fitts, *Groundwater Science*, 1st Edition, 2002: Chp. 9 (Physical chemistry of groundwater; contaminants); Chp. 10 (Solute motion, groundwater contamination, and remediation strategies).]]

<u>*Recommended reading:*</u>

3. Fitts, *Groundwater Science*, 2nd Edition., 2013:
    a. Chp. 10 (Physical chemistry of groundwater; contaminants)

(8) Navier Stokes equations for viscous fluids, Euler inviscid fluid flow description, Bernoulli equation, potential flow equations. Waves in deep and shallow water; tsunamis. Open channel flows, Froude number, critical flows, hydraulic jumps and tidal bores. Flood surges, flood control strategies.

<u>*Required reading:*</u>

1. Visuals set handout on fluid dynamics, waves and hydraulic jumps.

<u>*Recommended reading:*</u>

2. Middleton and Wilcock, *Mechanics in the Earth and Environmental Sciences,* 1994:
    a. Chp. 9, Sect. 9.1 to 9.4 (Viscous fluids and Navier-Stokes equation of fluid dynamics); Sect. 9, Sect. 9.5 (Euler inviscid flow model).
3. Paterson, *A First Course in Fluid Dynamics*, 1983:
    a. Chp. 10 and 11 (Inviscid flow, Kelvin circulation theorem, Bernoulli equation, velocity potential, time-dependent form of Bernoulli equation);
    b. Chp. 13, Sect. 1 to 4, and Sect 6 to 7 (Linear water wave theory, phase and group velocity, wave energy flux, shoaling);
    c. Chp. 15 (Surface waves along channels, hydraulic jumps, tidal bores).

(9) Resistance to fluid flow. Viscosity, boundary layers, Reynolds number and elementary

turbulence concepts. Law of the wall, bed shear stress, and open-channel flow resistance. Critical bed shear stress for erosion and sediment transport. Sediment suspension in turbulent flows.

<u>*Required reading:*</u>

1. Handouts (Visuals sets) on resistance to rapid flows.

<u>*Recommended reading:*</u>

2. Middleton and Wilcock, *Mechanics in the Earth and Environmental Sciences,* 1994:
    a. Chp. 9, Sect. 9.7 (Boundary layer concept);
    b. Chp. 11, all, including Rev. Prob. 11.7.2 (Turbulent boundary layers, law of the wall; turbulent mixing.)
3. Sturm, *Open Channel Hydraulics*, 2001:
    a. Chp. 4, Sect. 4.1 to 4.7, and 4.18 with series of stream photographs (Flow resistance in open channels, Chezy and Manning forms, derivation from logarithmic law);
    b. Chp. 10 (Critical shear stress for sediment motion, bed forms, sediment suspension in turbulent flows, discharge, stream evolution, scour).

Books held on Reserve at Gordon McKay Library (3rd Floor, Pierce Hall); may move to Cabot

AUTHOR/EDITOR	TITLE	CALL NUMBER
Charbeneau, Randall J.	Groundwater hydraulics and pollutant transport (2000, reprinted 2006)	TC 176 .C43 2006 TC 176 .C43 2000
Dean, Robert G. & Robert A. Dalrymple	Water wave mechanics for engineers and scientists	BLUE HILL TC 172 .D4 1991
Domenico, Patrick A. & +Disk Franklin W. Schwartz	Physical and chemical hydrogeology	GB 1003.2 .D66 1998
Fitts, Charles R.	Groundwater science (2nd ed.)	GB 1003.2 .F58 2013 (2 cop.)
Fitts, Charles R.	Groundwater science	GB 1003.2 .F58 2002 (2 cop.)
Ingebritsen, Steven E., Ward Sanford & Chris Neuzil	Groundwater in geologic processes (2nd ed.)	GB 1003.2 .I54 2006
Middleton, Gerald V. & Peter R. Wilcock	Mechanics in the earth and environmental sciences	QA 808 .M49 1994
Mitchell, J.K. & K. Soga	Fundamentals of soil behavior (3rd ed.)	TA 710 .M577 2005
Patterson, A.R.	A first course in fluid dynamics	QA 911 .P37 1983x
Rahn, Perry H.	Engineering geology: an environmental approach	TA 705 .R28 1996

Rouse, Hunter	Elementary mechanics of fluids	QA 901 / 27
Sturm, Terry W.	Open channel hydraulics	TC 175 .S774 2001
Terzaghi, Karl, Ralph B. Peck, & Gholamreza Mesri	Soil mechanics in engineering practice	TA 710 .T39 1996
Watson, Ian & Alister D. Burnett	Hydrology: an environmental approach	GB 661.2 .W38 1995 + Diskette