HWRS 505: Vadose Zone Hydrology

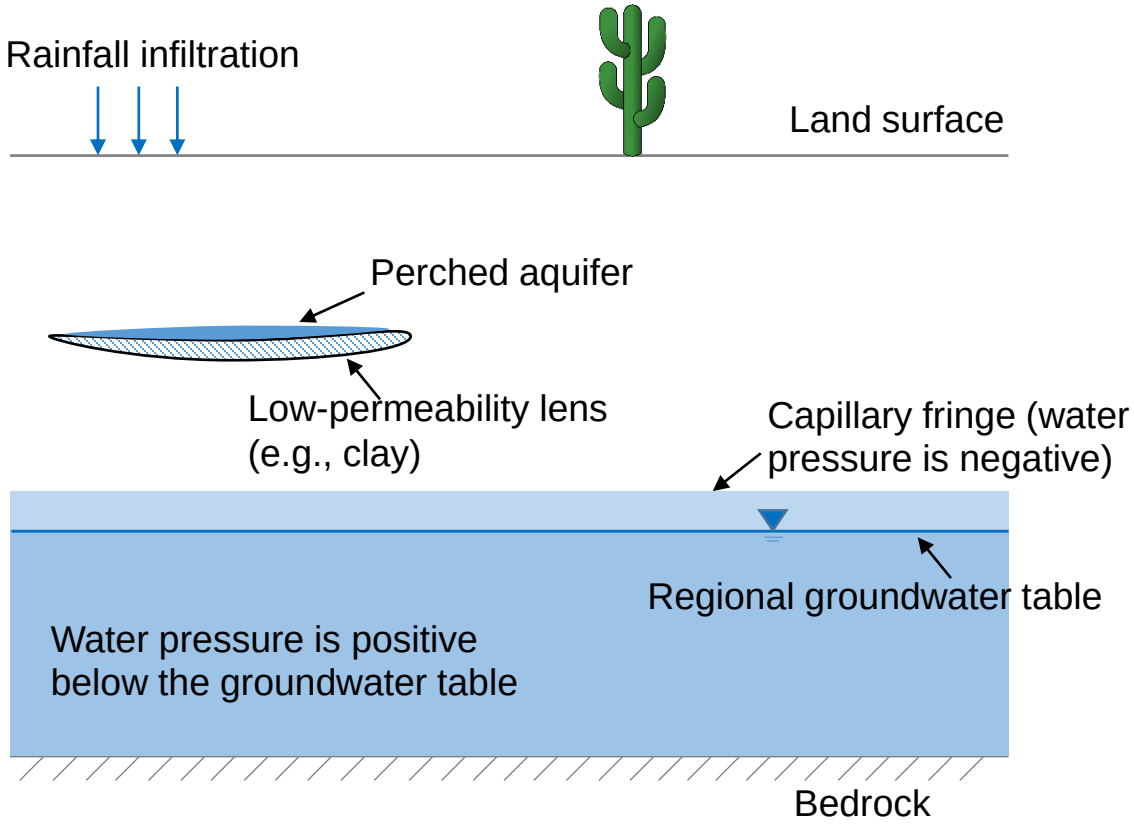
Lecture 1

8/22/2023

Today:

1. Overview of the course
2. Review: Steady-state saturated flow

Vadose Zone: Conceptual picture



Vadose zone
(sometimes also
referred to as
unsaturated zone)

Critical zone

Plants
+
Vadose zone
+
Groundwater
(until bedrock)

VZ and CZ are both complex systems:

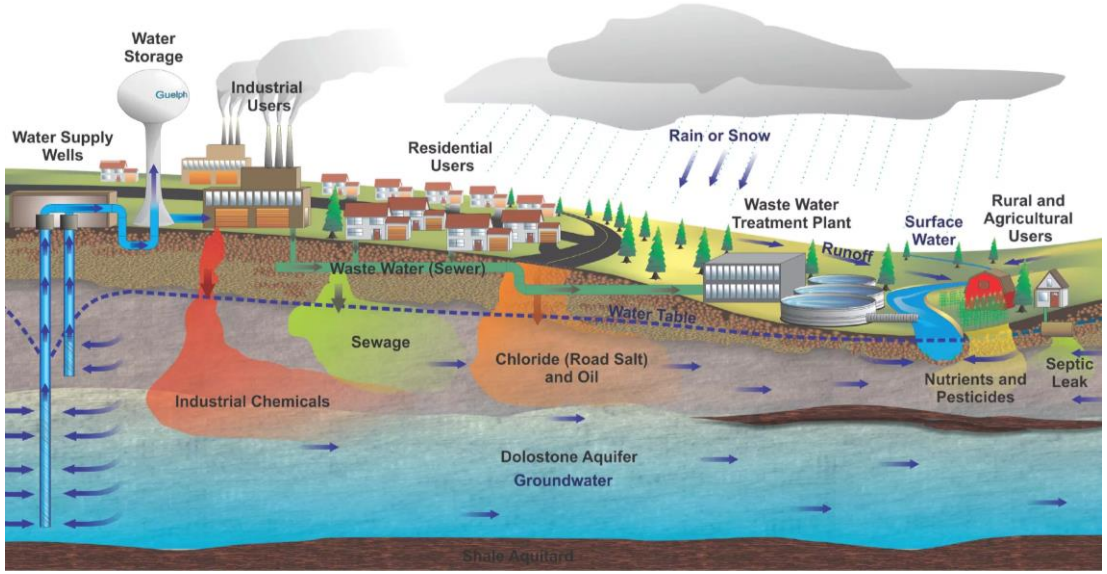
- Fluid flow processes
- Geomechanical processes
- Geochemical processes
- Microbial processes

…

Vadose Zone: Context and who cares?

Agriculture and food production

Drinking water safety



Other examples?

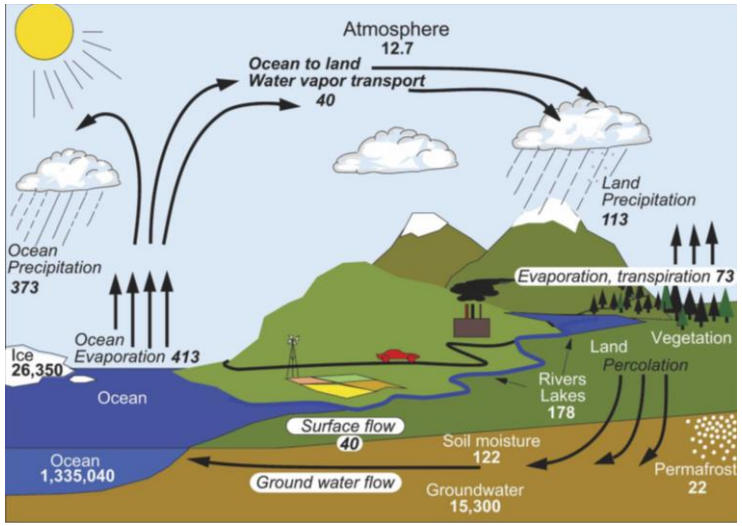
- Natural hazards management (flooding, landslide, and erosion)
- Infrastructure development (buildings, roads, bridges, …)
- …

Vadose zone processes can have profound societal impacts

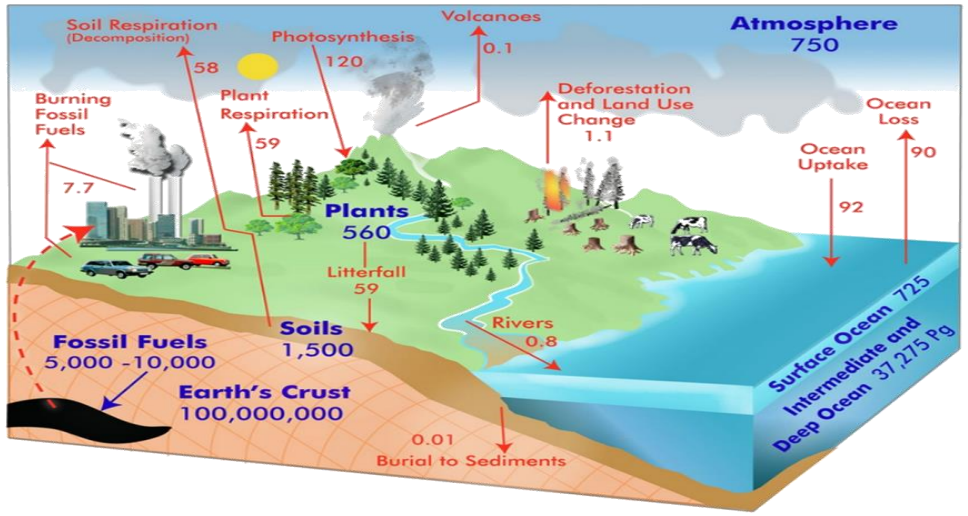
https://jooinn.com/agricultural-lands.html
https://g360group.org

Vadose Zone: Context and who cares?

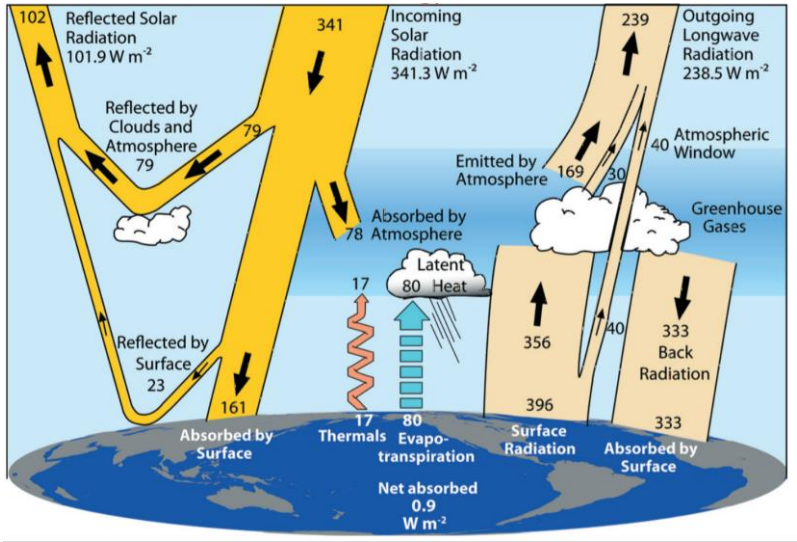
Hydrological cycle



Carbon cycle



Surface energy balance



Vadose zone processes play key roles in the global water, carbon, and energy balances

http://www.cgd.ucar.edu/cas/adai/papers/Trenberth_etal_JHM07.pdf
https://www.nasa.gov/topics/nasalife/features/globe-workshop.html
http://www.cgd.ucar.edu/staff/trenbert/trenberth.papers/BAMSmarTrenberth.pdf

Vadose Zone Hydrology: Scope of the course

water + solutes

Energ potential.

Goal:

- Understanding and quantifying the processes related to matter and energy in the vadose zone

Approach:

- Conceptual pictures
- Physical laws and fundamental principles
- Mathematical formulations and analytical/numerical solutions
- Model vs. reality (measurements)

Syllabus + Readings

SCHEDULE OF TOPICS

Week	Date	Topic	Readings	Problem Sets
1	8/22	Introduction; Steady-state saturated flow	L01	
	8/24	Steady-state saturated flow	L01	
2	8/29	Transient saturated flow; saturated solute transport	L02	
	8/31	saturated solute transport	L03	
3	9/5	Multiphase fluids in capillary tubes	L04	Release #1
	9/7	Multiphase fluids in capillary tubes	L05	
4	9/12	Porous medium models and characteristic curves	J&H Ch 3	#1 DUE
	9/14	Macroscopic description of two-phase flow	P&C – Ch 11	Release #2
5	9/19	Richards' assumptions; Richards' Equation	P&C – Ch 11	
	9/21	Steady-state unsaturated flow	L08	#2 DUE
6	9/26	Numerical solution of steady-state unsat. flow	L09	Release #3
	9/28	Numerical solution of steady-state unsat. flow		
7	10/3	Transient unsaturated flow	J&H Ch 3	
	10/5	Transient unsaturated flow		
8	10/10	Transient unsaturated flow	J&H Ch 3	#3 DUE
	10/12	Numerical solution for transient unsat. flow	Celia 1990	
9	10/17	Use HYDRUS to study 1D transient unsat flow (In class)		
	10/19	2D unsaturated flow	L12	
10	10/24	Review session for the midterm exam		Release #4
	10/26	***Midterm Oral Exam***		
11	10/31	Comments on midterm; Measurement methods	L15	
	11/2	Visit the soil physics lab of Dr. Markus Tuller (TBD)		#4 DUE
12	11/7	Parameter estimation/Inverse modeling; Use spreadsheet model	L13	
	11/9	Inverse modeling w/ HYDRUS (in class)	L16, L13a	
13	11/14	Introduction to PFAS		
	11/16	Transport of PFAS under unsat. flow	Guo 2020	Release #5
14	11/21	Fluid-fluid interfacial area		
	11/23	Thanksgiving recess (no class)		
15	11/28	Informal presentation of "*Art of Porous Media Flow*"; Review session for the final exam		#5 DUE
	11/30	No class (work on final project)		
16	12/5	Presentation of final projects		
	12/7	No class (reading day)		
	12/8	***Final Exam***		

Readings:

1. ***Ferre, Vadose Zone Hydrology Lecture Notes***
2. **Jury & Horton, Soil Physics (sixth edition), 2004**
3. Pinder & Celia, Subsurface Hydrology, 2006
4. Stephens, Vadose zone Hydrology, 1995

Grading:

Undergraduate students

Homework	55%
Midterm exam (oral)	20%
Final exam (written)	20%
Participation	5%

Graduate students

Homework	35%
Midterm exam (oral)	20%
Final exam (written)	20%
Final project	20%
Participation	5%

Art of porous media flow submission +5%

Class websites:

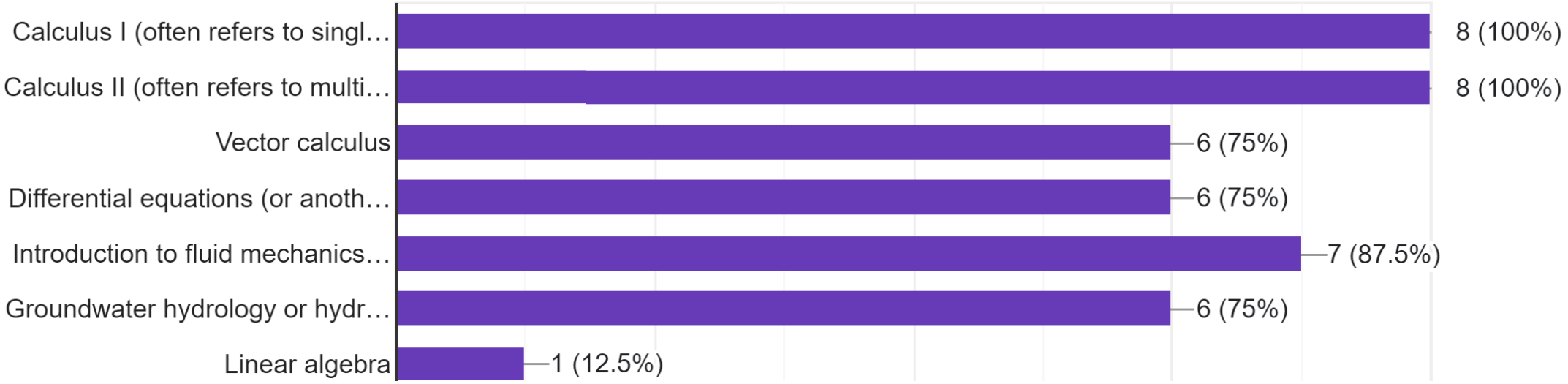
1. GitHub

- https://github.com/GuoPorousMediaLab/HWRS505-405-2023Fall
- The **primary** site that we use for sharing course materials.

2. D2L

- Materials for Homework and Exams.
- Submit Homework and Exams.

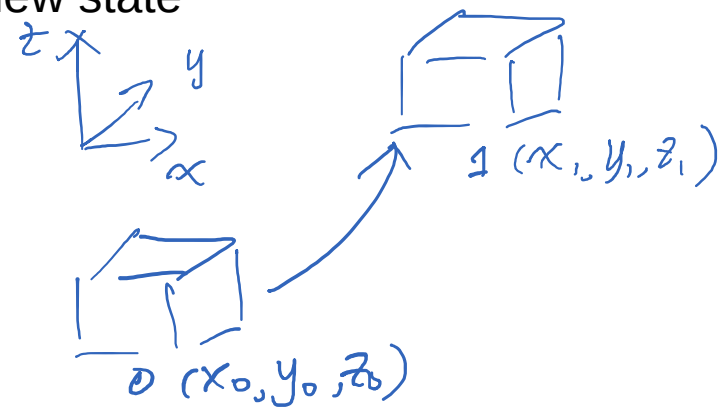
Results of Pre-class Survey



- Glad to see many of you have taken most of the classes.
- No worries if you have not taken one or multiple classes. I will introduce the basic concepts when we use them.
  - ✓ Make sure to ask questions in class if an unfamiliar concept is used and I do not explain it.
  - ✓ Come to office hours.
  - ✓ Use Wikipedia and other resources to establish a basic understanding of these concepts.

Steady-state saturated flow

Energy potential (Φ): work done on a unit mass of fluid in transferring it from a reference state to some new state



$W_1 = mg(z_1 - z_0)$

$W_2 = V(P_1 - P_0)$

Total work applied:

$$W = W_1 + W_2 = mg(z_1 - z_0) + V(P_1 - P_0)$$

Energy potential: "per unit mass"

$$\Phi = \frac{W}{m} = g(z_1 - z_0) + \frac{1}{\rho}(P_1 - P_0)$$

Hydraulic head: "per unit weight"

$$H = \frac{W}{mg} = (z_1 - z_0) + \frac{1}{\rho g}(P_1 - P_0)$$

P_0: often chosen as atmospheric pressure ($P_0 = 0$)

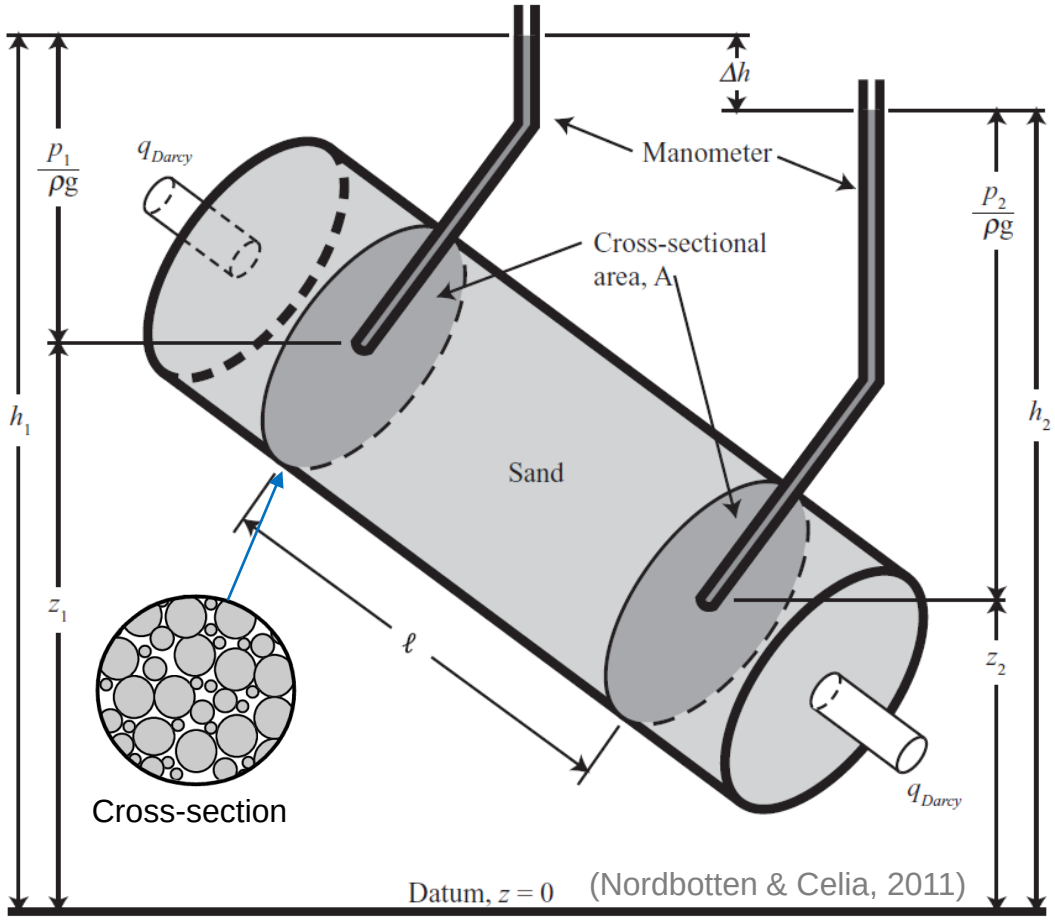
z_0: datum ($z_0 = 0$)

$$H = z + \frac{P}{\rho g}$$

Elevation head

pressure head ($\psi = \frac{P}{\rho g}$)

Steady-state saturated flow



(Nordbotten & Celia, 2011)

Schematic of Darcy's experiment [1856]

Flux Law: Darcy's Equation

$$Q = -\underline{K} A \frac{h_2 - h_1}{L} \qquad [L^3/T]$$

$\underline{K}$: Saturated hydraulic conductivity $[L/T]$ (property of the porous medium and fluid)

permeability $[L^2]$

$$\underline{K} = \frac{k\rho g}{\mu_w}$$

$$q = \frac{Q}{A} = -\underline{K} \frac{h_2 - h_1}{L} \qquad [L/T]$$

q: Darcy flux

$$v = q/\phi \qquad [L/T]$$

ϕ: porosity

v: Interstitial velocity (Pore water velocity)