HWRS 505: Vadose Zone Hydrology

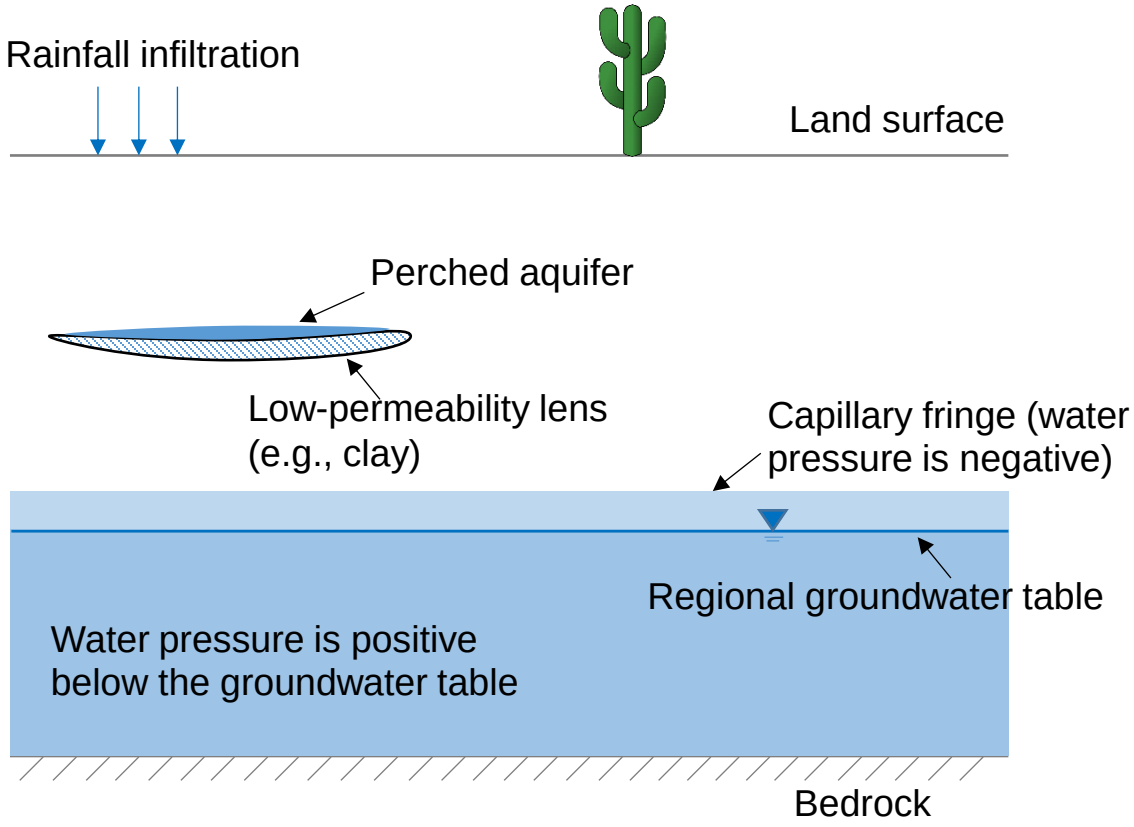
Lecture 1

8/27/2024

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:

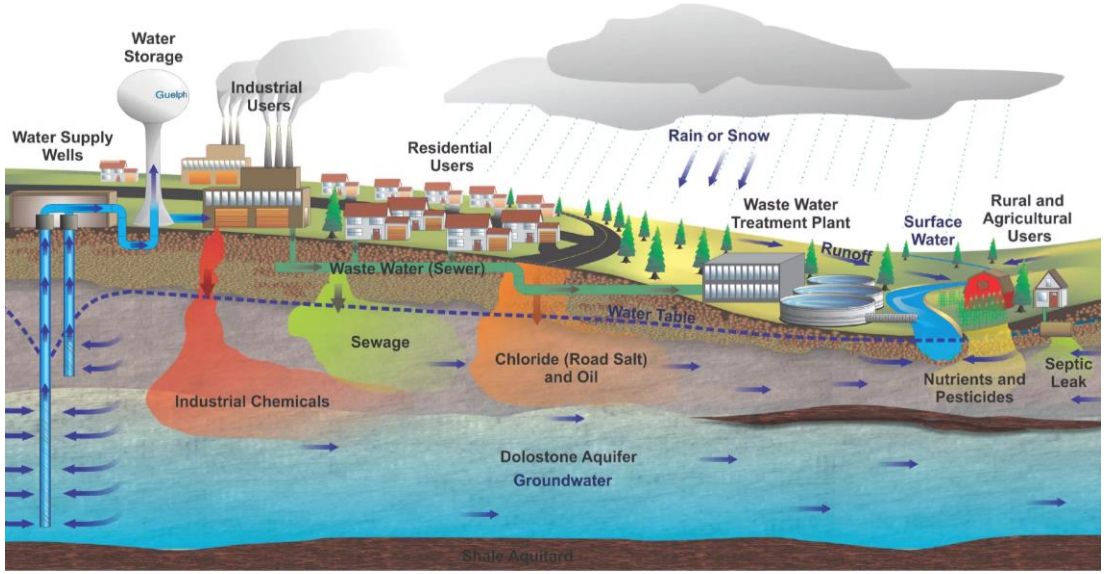
- Fluid flow processes
- Geomechanical processes
- Geochemical processes
- Microbial processes

…

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, …)
- …

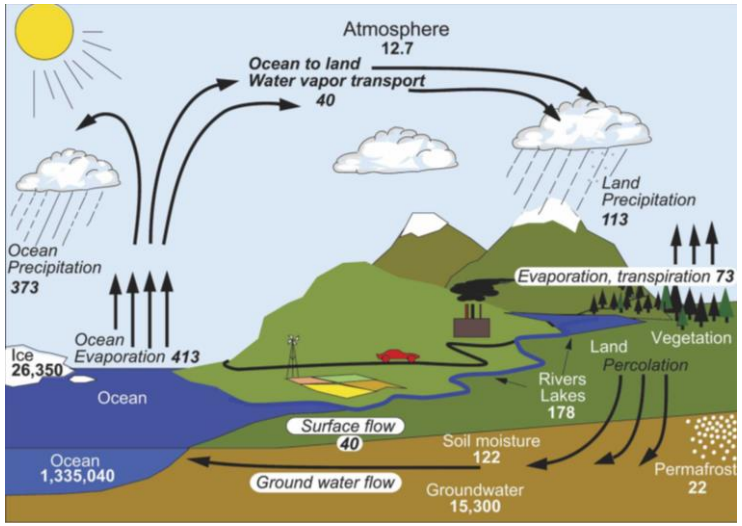
Vadose zone processes can have profound societal impacts

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

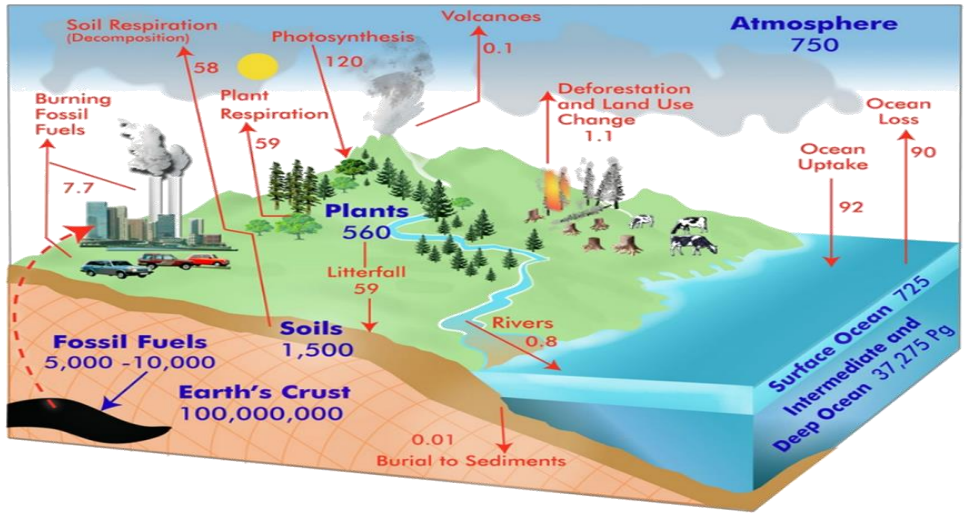
Vadose Zone: Context and who cares?

HWRS 505
Bo Guo
Fall 2024

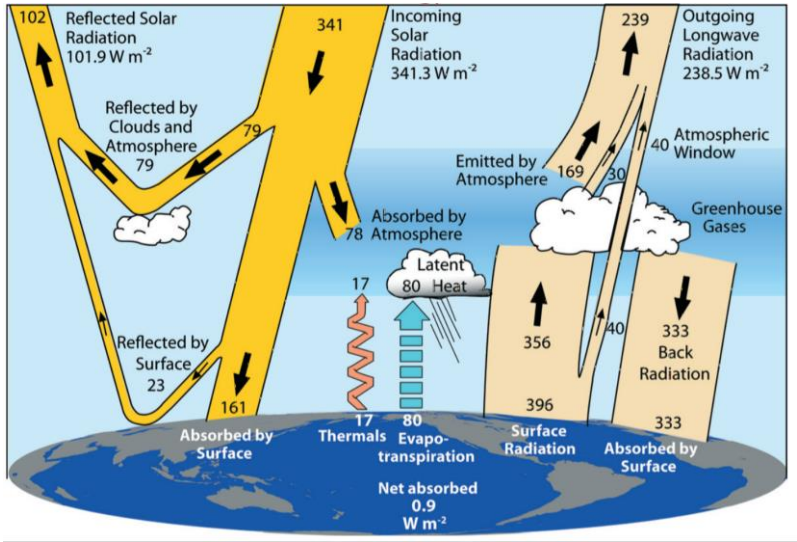
Hydrological cycle



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

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	8/27	Introduction; Steady-state saturated flow	L01	
	8/29	Steady-state saturated flow	L01	
2	9/3	Transient saturated flow; saturated solute transport	L02	
	9/5	Saturated solute transport (recorded lecture)	L03	
3	9/10	Multiphase fluids in capillary tubes	L04	Release #1
	9/12	Multiphase fluids in capillary tubes	L05	
4	9/17	Porous medium models and characteristic curves	J&H Ch 3	#1 DUE
	9/19	Macroscopic description of two-phase flow	P&C – Ch 11	Release #2
5	9/24	Richards' assumptions; Richards' Equation	P&C – Ch 11	
	9/26	Steady-state unsaturated flow	L08	#2 DUE
6	10/1	Numerical solution of steady-state unsat. Flow (recorded lecture)	L09	Release #3
	10/3	Numerical solution of steady-state unsat. flow (recorded lecture)		
7	10/8	Review of week 6's materials	J&H Ch 3	
	10/10	Transient unsaturated flow		
8	10/15	Transient unsaturated flow	J&H Ch 3	#3 DUE
	10/17	Numerical solution for transient unsat. flow	Celia 1990	
9	10/22	Use HYDRUS to study 1D transient unsat flow (In class)		
	10/24	2D unsaturated flow	L12	
10	10/29	Review session for the midterm exam		Release #4
	10/31	***Midterm Oral Exam***		
11	11/5	Comments on midterm; Measurement methods	L15	
	11/7	Visit the soil physics lab of Dr. Mark Brusseau (TBD)		#4 DUE
12	11/12	Parameter estimation/Inverse modeling; Use spreadsheet model	L13	
	11/14	Inverse modeling w/ HYDRUS (in class)	L16, L13a	
13	11/19	Introduction to PFAS		
	11/21	Transport of PFAS under unsat. flow	Guo 2020	Release #5
14	11/26	Fluid-fluid interfacial area		
	11/28	Thanksgiving recess (no class)		
15	12/3	Presentation of final projects		#5 DUE
	12/5	Informal presentation of "*Art of Porous Media Flow*"; Review session for the final exam		
16	12/10	No class (review for final exam)		
	12/16	***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:

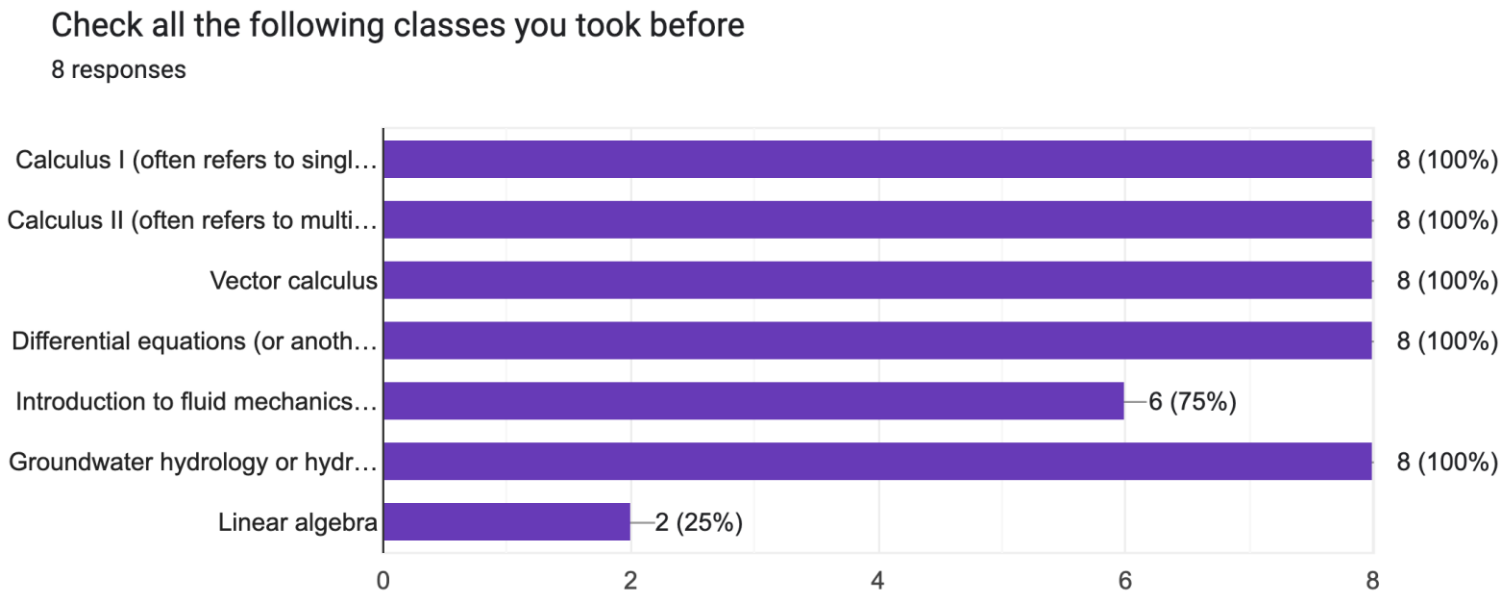
1. GitHub

- https://guoporousmedialab.github.io/HWRS505-405-2024Fall/
- 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 when 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 the atmospheric pressure ($P_0 = 0$)

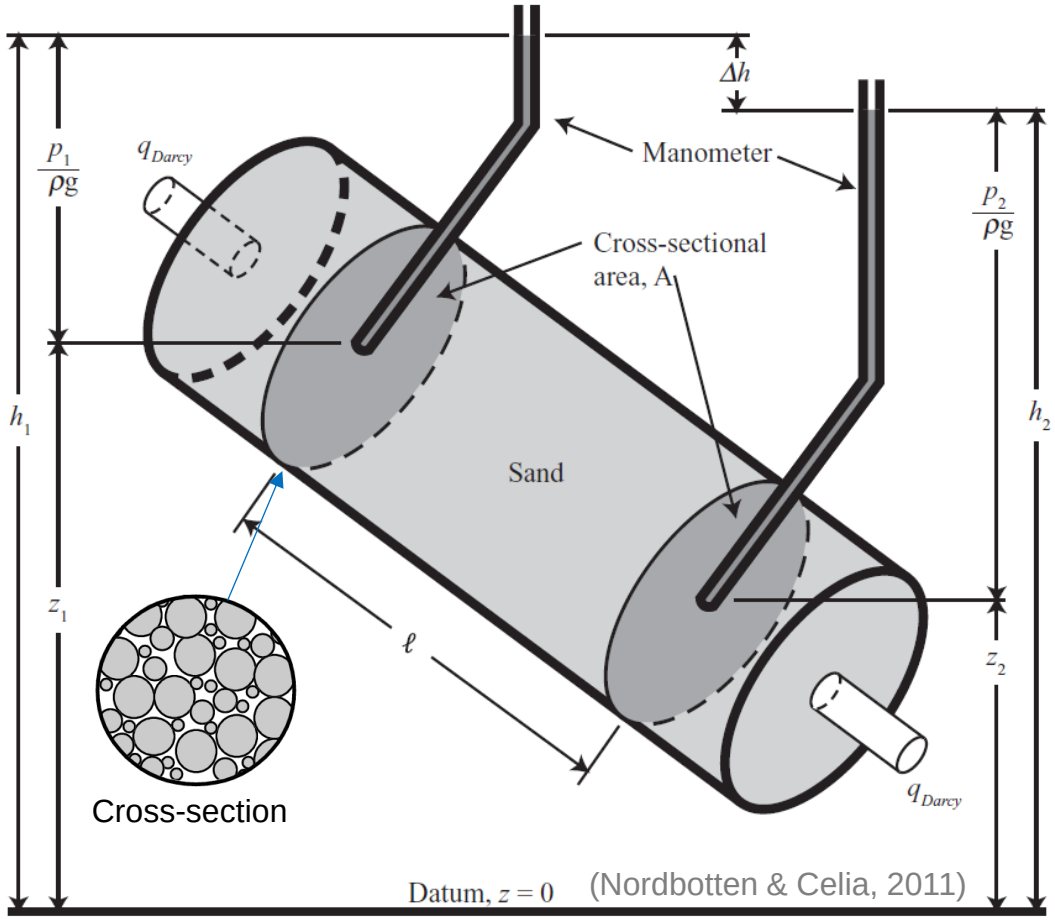
z_0: datum ($z_0 = 0$)

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

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

$$Q = -K A \frac{h_2 - h_1}{L}$$

$[L^3/T]$

Saturated hydraulic conductivity $[L/T]$

(property of the porous medium & the fluid)

porous medium property: permeability

$$K = \frac{k \rho g}{\mu}$$

density (ρ)
viscosity (μ)
(fluid property)

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

Darcy flux

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

ϕ ← porosity

v: Interstitial velocity (porewater velocity)