Hydro4X Theory of Subsurface Hydrology

Summer 2025

Instructor:	M. Afzal Shadab, PhD	**Time:**	Every Sunday
Email:	mashadab@princeton.edu	**Place:**	E201 Engineering Quad

Description: The course introduces geoscientists and engineers to the theory of subsurface hydrology. The students will work on conceptual and theoretical problem and will be applying the concepts to solve problems in subsurface hydrology.

Course Page: https://mashadab.github.io/theo_subsurface_hydrology/

Lecture Schedule: Lecture will be uploaded on Youtube every Sunday.

Office Hours: Mon noon-1 pm ET on Zoom or schedule via email.

Prerequisites: An undergraduate-level understanding of partial differential equations will be helpful.

Tentative Course Outline:

- Introduction ..... 1 lecture
  - Water cycle
  - Water in the subsurface: soil moisture and ground water
  - Scaling argument: Pore scale to Darcy scale (REV)
  - Volume averaging
  - Multi-phase flows in porous media
- Fundamentals of subsurface hydrology ..... 3 lectures
  - General balance equation derivation
  - Curvilinear coordinate transformation
  - Darcy's experiment and phenomenological law
  - Richards equation from two-phase flow equation
  - Discussion on Richards equation (PDE type, non-dimensionalization)
  - Capillary forces and soil type
- Theory of infiltration ..... 4 lectures
  - Introduction, effects of evapotranspiration and capillarity
  - Diffusion limit (parabolic PDE)
  - Kinematic wave limit (hyperbolic PDE, wetting and drying fronts)
  - Green-Ampt approach
  - Effect of subsurface heterogeneity
- Theory of perching ..... 1 lecture
- Theory of groundwater dynamics ..... 5 lectures
  - Introduction to types of aquifer: confined and unconfined
  - High vs low aspect ratio aquifers and seepage face
  - Derivation of vertically integrated groundwater model
  - Analytic solutions of quasi-two-dimensional, unconfined aquifers: steady drainage, sudden rainfall, late-stage drainage
  - Streamfunction, potential function, and groundwater age

- Advanced topics ..... 2 lectures
  - Snow hydrology (inclusion of thermodynamics)
  - Coupled subsurface hydrology and reactive-transport modeling

Grading Policy: Homework and quizzes (50%), Midterm Project (20%), Final Project (30%).

Important Dates:

Midterm Project ..... 1 July, 2025
Final Project ..... 1 September, 2025

Course Policy:

- Please officially enroll in the course by signing up via Google form provided. It will be helpful and will be accounted for in the development of the course certificates.

Class Policy:

- Regular attendance is essential and expected.

Academic Honesty: Lack of knowledge of the academic honesty policy is not a reasonable explanation for a violation.

Main References: This is a restricted list (emboldened ones are preferred) of various interesting and useful books that will be touched during the course. You need to consult them occasionally.

- **Freeze, R.A. and Cherry, J.A., 1979. *Groundwater*. Prentice-hall.**
- **Pinder, G.F. and Celia, M.A., 2006. *Subsurface Hydrology*. John Wiley & Sons.**
- Chow, V.T., Maidment, D.R. and Mays, L.W., 1988 *Applied Hydrology*. International Edition, McGraw-Hill Book Company, New York.
- Polubarinova-Kochina, P.Y., 2015. *Theory of Ground Water Movement*. Princeton University Press
- Bear, J. and Cheng, A.H.D., 2010. *Modeling groundwater flow and contaminant transport* (Vol. 23, p. 834). Dordrecht: Sprin

Journal articles will be shared throughout the course.

Few books that the instructor recommends from the broader sciences:

- Kundu, P.K., Cohen, I.M., Dowling, D.R. and Capecelatro, J., 2024. *Fluid Mechanics*. Elsevier.
- LeVeque, R.J., 1992. *Numerical Methods for Conservation Laws* (Vol. 132). Basel: Birkhäuser.
- Greenberg, M.D., 2013. *Foundations of Applied Mathematics*. Courier Corporation.
- Bear, J., 2013. *Dynamics of Fluids in Porous Media*. Courier Corporation.
- Schey, H.M., 2005. *Div, Grad, Curl, and All That: An Informal Text on Vector Calculus*.
- Barenblatt, G.I., 1996. *Scaling, Self-similarity, and Intermediate Asymptotics: Dimensional Analysis and Intermediate Asymptotics* (No. 14). Cambridge University Press.