HWRS 561b Physical Hydrogeology II
Spring 2026

Instructor and Contact Information

Dr. Bo Guo (he/him)
Lecture time & location: M/W/F 2-2:50 pm, Harshbarger 110
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Course Description

This course is the second part of Physical Hydrogeology and focuses on the physical principles governing water flow and solute transport in variably saturated porous media. The course approaches these topics from a fundamental multiphase flow and transport perspective, with an emphasis on developing strong physical intuition. Building on this intuitive foundation, we formulate mathematical models and examine the physical behavior of solutions describing variably saturated flow and transport processes. The course also introduces selected cutting-edge topics related to the fate and transport of emerging contaminants in the subsurface, such as PFAS.

Course Prerequisites or Co-requisites

No pre-requisites

Must be enrolled in the MS Hydrogeology program

Required co-registration in HWRS 562b Chemical Hydrogeology II, HWRS 563b Hydrogeologic Measurement Methods II, HWRS 564b Hydrogeologic Analysis Tools & Methods II, and HWRS 565b Communications in Hydrogeology II

Required Textbooks/Materials

Selected chapters from the following textbooks will be used in this course. Scanned copies of the required chapters will be provided.

- *Contaminant Hydrogeology* — C. W. Fetter, T. Boving, and D. Kreamer (2018)
- *Subsurface Hydrology* — G. F. Pinder and M. A. Celia (2006)
- *Soil Physics* — W. A. Jury and R. Horton (2004)

Course Objectives

Students will

1. Gain an understanding of the physical concepts and pore-scale controls underlying water flow and solute transport in variably saturated media.
2. Gain an understanding of the assumptions behind macroscopic governing equations for flow and transport in variably saturated media.
3. Gain an understanding of the analytical and numerical methods for solving flow and transport equations in variably saturated media.
4. Be able to apply analytical and numerical solutions for flow and transport in variably saturated media to analyze problems under a wide range of conditions to gain physical intuition.
5. Be able to apply concepts and tools to analyze contaminant transport in the vadose zone.

Expected Learning Outcomes

Students will be able to

1. Characterize saturation-dependent soil hydraulic properties, both qualitatively and quantitatively, and develop an understanding of the relationship of those properties with pore scale air and water distributions.
2. Develop appropriate physical and mathematical representations of water flow and solute transport through fully and partially water saturated porous media at multiple scales in 1D, 2D, and 3D.
3. Synthesize and contextualize knowledge of data collection methods, quantitative models of flow and solute transport, and fundamental conceptual understanding for the purposes of supporting water resources decision-making.

Course Format and Teaching Methods

The course will consist of a mixture of lectures, in-class discussion and exercises.

Planned Field Trips

The class will begin this course with a field trip during the entire first week of class, and will apply to all courses in the MS Hydrogeology Fall semester (this course, but also HWRS 562b, HWRS 563b, HWRS 564b, and HWRS 565b). The field trip will begin on the first Monday of the first full week. Students should plan to be out of town for the entire week, including camping overnight.

Schedule of Topics & Activities

The course will be organized around month-long projects that provide a unifying learning context across all five co-convened classes. It follows a theory–data–prediction framework, combining case-based theoretical development with project-based methodological practice. The scheduled activities are outlined below.

Week	Monday date	Topics covered this week	Assignment due this week
1	1/12	**Field trip** – No class	
	Module 1: Solute transport in saturated media		
2	1/21	Conservative solute transport: Pore-scale controls, macroscopic formulation, governing equations, BCs, 1D Taylor-Aris dispersion	
	1/23	Conservative solute transport: Pore-scale controls, macroscopic formulation, governing equations, BCs, 1D Taylor-Aris dispersion	
3	1/26	Conservative solute transport: Analytical solutions, breakthrough curves.	
	1/28	No class (Bo traveling)	
	1/30	No class (Bo traveling)	HW 1: Solute transport 1
4	2/2	Conservative solute transport: Analytical solutions, breakthrough curves.	
	2/3 [special lecture] 9:30-11:10	Reactive solute transport: retardation, kinetic/equilibrium adsorption	
	2/4	Reactive solute transport: Analytical solutions, breakthrough curves.	
	2/6	Reactive solute transport: Analytical solutions, breakthrough curves.	HW 2: Solute transport 2
	Module 2: Pore-scale controls and macroscopic description of variably saturated flow		
5	2/9	Pore-scale fluids distribution (capillary tubes)	
	2/10 [special lecture] 9:30-10:20	Pore-scale fluids distribution (capillary tubes)	
	2/11	Pore-scale fluids distribution (advanced porous medium models)	
	2/13	No class (Bo traveling)	
6	2/16	Macroscopic descriptions of air/water distribution	
	2/18	Macroscopic descriptions of air/water distribution	
	2/20	Macroscopic descriptions of air/water distribution	HW 3: Pore-scale fluids distribution
7	2/23	Two-phase flow. Richards' assumptions; Richards' equation.	
	2/24 [special lecture] 9:30-10:20	Two-phase flow. Richards' assumptions; Richards' equation.	
	2/25	Two-phase flow. Richards' assumptions; Richards' equation.	
	2/27	No class (Bo traveling)	

	Module 3: Steady-state and transient variably saturated flow		
8	3/2	Steady-state 1D unsaturated flow.	
	3/4	Steady-state 1D unsaturated flow.	
	3/6	Steady-state 1D unsaturated flow.	HW 4: Richards equation and steady-state unsaturated flow
9	3/9	No class: Spring break	
10	3/16	Steady state unsaturated flow in multiple dimensions and with heterogeneities.	
	3/18	Steady state unsaturated flow in multiple dimensions and with heterogeneities.	
	3/20	Midterm exam (oral)	
11	3/23	Transient 1D unsaturated flow. Simplified models (Green-Ampt, Philip's models).	
	3/25	Transient 1D unsaturated flow. Simplified models (Green-Ampt, Philip's models).	
	3/27	Transient 1D unsaturated flow. Simplified models (Green-Ampt, Philip's models).	HW 5: Transient unsaturated flow 1
12	3/30	Transient 1D unsaturated flow. Numerical solutions of Richards equation.	
	4/1	Transient 1D unsaturated flow. Numerical solutions of Richards equation.	
	4/2	Transient 1D unsaturated flow. Numerical solutions of Richards equation.	
13	4/6	Unsaturated flow in multidimensions.	
	4/8	Unsaturated flow in multidimensions.	
	4/10	Solute transport with unsaturated flow.	HW 6: Transient unsaturated flow 2
	Module 4: Risk assessment of contaminant transport in the vadose zone and groundwater		
14	4/13	Transport of pesticides/nutrients in the vadose zone.	
	4/15	Transport of pesticides/nutrients in the vadose zone.	
	4/17	Transport of pesticides/nutrients in the vadose zone.	
15	4/20	Transport of PFAS in the vadose zone.	
	4/22	Transport of PFAS in the vadose zone.	
	4/24	Transport of PFAS in the vadose zone.	HW 7: Contaminant transport
16	4/27	Transport of PFAS in the vadose zone.	
	4/29	Transport of PFAS in the vadose zone.	
	5/1	Transport of PFAS in the vadose zone.	
17	5/4	Final exam.	

Course Assessments and Grading Breakdown

You will be assessed on the basis of weekly assignments. You will also be assessed based on how you apply the understanding gained in this class to the projects. Finally, you will receive completion credit for completing weekly self-assessments.

Assignments are assigned Monday, and they are due on Thursdays by 10 pm. Each assignment will be given a time budget. This will give students an indication of the level of effort expected for each assignment. Students will report the time spent on the project. If individual students are spending more time than the average, the instructor will meet with them to identify and solve any issues. If many students are spending more than the assigned time, then the assignments will be modified for the remainder of the term and for subsequent years. It is expected that students will spend no more than 2.5 hours per week on these class assignments.

Projects are assigned monthly. These projects are designed to synthesize the content/skills you are learning in all 5 courses that month to address a hydrogeologic problem/task. This means that the projects are not specific to any one course. However, you will be assessed on the content/skills related to each specific course separately within the single project. To do this, a rubric filled with criteria as it applies to each hydrogeologic topic/course will be used. You will receive a score of either mastery, proficient, basic, or below basic for each project in each of the 5 areas:

- physical hydrogeology
- chemical hydrogeology
- hydrogeologic measurement methods
- hydrogeologic analysis tools and methods
- communication in hydrogeology

The grade you receive for the physical hydrogeology skills/content portion of the projects will be used to calculate your total course grade in Physical Hydrogeology II for the semester.

Class participation will be earned by participating in designated class discussions.

The percentage distribution of your grade will be as follows.

Course Assignments	: 45%
Projects – physical hydrogeology component	: 10%
Mid-term exam	: 20%
Final exam	: 20%
Participation	: 5%
Art of porous media flow	: 5% (bonus)

University policy regarding grades and grading systems is available at this link.

Examinations

There are midterm and final examinations in this course. The midterm exam will be oral, and the final exam will be written. Both will be in-person. The final exam will be scheduled during the exam week. A review session will be scheduled before both exams. In addition, students will be completing projects this semester that cut across all courses in the MS Hydrogeology program, and will require students to utilize and synthesize the skills they learned in all 5 courses to address a hydrogeologic question/problem.

Grading Scale

Your final grade will be informed via D2L. Letter grades are determined using the following scale:

A: >= 90%

B: >= 80 - 89%

C: >= 70 – 79 %

D: >= 60 to 69 %

E: below 59 %

University policy regarding grades and grading systems is available at https://catalog.arizona.edu/policy/courses-credit/grading/grading-system.

Late work Policy

No late work will be accepted for a grade, but students will receive feedback on all submitted work.

Incomplete (I) or Withdrawal (W):

Requests for incomplete (I) or withdrawal (W) must be made in accordance with University policies, which are available at this link associated with the registrar.

University of Arizona Course Policies

All University of Arizona course and syllabi policies, as well as other helpful information and resources, can be found at this link.

If you are in need of basic needs care, here is another helpful link, in addition to what you can find at the policy link above.

Subject to Change Statement

Information contained in the course syllabus, other than the grade and absence policy, may be subject to change with advance notice, as deemed appropriate by the instructor.