GEOL 473/573
Hydrogeology
Winter 2020

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Office Hours: 10-11 am M W F, or by arrangement

Text: Applied Hydrogeology, C. W. Fetter, 4rd Edition, 2001 (recommended, not required)

Learning Objectives

My objectives for this course are to help you understand (1) how the properties of fluids, porous media and energy influence saturated and unsaturated groundwater flow; (2) the physical and mathematical relationships that integrate these concepts; (3) mathematical modeling approaches for resolving groundwater related problems; and (4) the importance of groundwater in a variety of geologic processes. Please see the learning outcomes on the last page.

Assessment

Problem Sets

An effective way to learn the material in this course is to do problems. Problem sets will be given out each week or so and will be due the following week at the beginning of class. You will be required to use ArcGIS and Python/Jupyter. Problem sets will be deducted 10% for each day it is late. Problem sets will not be accepted after corrected works are returned.

Note: Graduate students will be responsible for an independent research project that will be worth 10% of the Geol573 grade.

Exams

One midterm exam and a comprehensive final exam will be given. My exams are typically short answer essay with an emphasis on process description. I want you to be able to tell me in words, what controls groundwater processes. I also integrate problems into exams that require equation manipulation and calculations. You will be required to take all exams. Make-up exams will be given only in the case of official emergencies. An excused absence form from the office of Student Affairs is required.

Grading

The grading break down will be as follows:

Problem Sets ……40% (30% for graduate students and 10% for the term project)
Exam 1…………..30%
Final Exam………30% (Tuesday March 17, 8:00 – 10:00 am)

A grading scale will be as follows (a curve is possible but not certain):
100-93 = A, 92-90 = A-, 89-88 = B+, 87-83 = B, 82-80 = B-, 79-78 = C+, 77-73 = C, 72-70 = C-, 69-68 = D+, 67-63 = D, 62-60 = D-, 60 or below = F

I reserve the right to change the syllabus as required throughout the term to better meet the instructional needs of the class.

Reading Resources

In addition to Fetter, other classic hydrogeology books and resources include:

Groundwater, R. Allan Freeze and John Cherry, Prentice Hall, 1979.

Physical and Chemical Hydrogeology, P. A. Domenico and F. W. Schwartz, 2^{nd} Ed, John Wiley and Sons, Inc 1998.

Basic Ground-Water Hydrology, Ralph Heath, USGS Water Supply Paper 2220.

Other USGS Training Resources

Please review the WWU Policies for Students https://syllabi.wwu.edu

Student Services
Western encourages students to seek assistance and support at the onset of an illness, difficulty, or crisis.

- Reasonable accommodation for persons with documented **disabilities** should be established within the first week of class and arranged through the Disability Access Center: telephone: 360-650–3083; email: drs@wwu.edu; online: https://disability.wwu.edu/
- In the case of a medical concern or question, please contact the Health Center: 650-3400 or https://studenthealth.wwu.edu/
- In the case of an emotional or psychological concern or question, please contact the Counseling Center:
  650-3400 or https://counseling.wwu.edu/
- In the case of a health and safety concern, please contact the University Police: 650-3555 or http://www.wwu.edu/ps/
- In the case of a family or personal crisis or emergency, please contact the Dean of Students: 650-3775 or https://wp.wwu.edu/students/
- To seek confidential support related to sexual violence, please contact CASAS (650-3700), the Student Health Center, and/or the Counseling Center. To report sexual violence, please contact University Police, Bellingham Police, and/or the Title IX Coordinator in Western's Equal Opportunity Office (650-3307).

Attendance is not required but it is expected. It is your responsibility to get notes for the classes you miss. I encourage you to visit my office for help and clarification, but do not use my office hours to obtain lecture material that you miss (unless you have an excused absence). Please feel free to **talk to me** anytime about your performance in the course or possible ways you can improve.

Your **professional conduct** in this course is important. I facilitate my courses in a professional manner and have the same expectations of you. By professional, I mean having a respectful demeanor, arriving to class on time, no texting or internet surfing during class, communicating with courteous emails, producing neat organized and well written student works, and by all means, maintaining academic honesty. Think about how you would like me to communicate your professionalism to a potential employer.

I am committed to establishing and maintaining a classroom climate that is inclusive and respectful for all students and an environment free of discrimination and harassment. Learning includes being able to voice a variety of perspectives, and classroom discussion is encouraged. While students' expressed ideas may vary and/or be opposed to one another, it is important for all of us to listen and engage respectively with each other. Federal and State laws, as well as WWU University policies, protect students, faculty and staff against discrimination.

Hydrogeology Topics

Introduction (Chapter 1 and pp. 95-98)

1. Ground water--what is it, where is it, and why is it important?
2. Aquifers – definition of an aquifer, depositional environments that form aquifers, scales of aquifers. Whatcom County aquifers.

Fluid Mechanics (Read Handout)

3. Water in aquifers – introduction to fluid properties and fluid mechanics. Fluid Properties handout. Fluid flow in aquifers requires the knowledge of three fluid quantities (density, dynamic viscosity and compressibility).
4. Fluid properties - the importance of the hydrogen bond and properties such as density, compressibility and thermal expansion
5. Fluid statics – pressure, pressure head, buoyancy (effective stress), abnormal fluid pressures in sedimentary basins and accretionary prisms.
6. Fluid dynamics – steady state vs transient, 1-, 2-, 3-D flow, laminar, turbulent, compressible vs incompressible, Reynolds #, dynamic viscosity, and energy.

Properties of Porous Media (Chapter 3)

7. Properties of Porous media – in general, knowledge of three earth-material quantities are required to understand ground-water flow (porosity, intrinsic permeability, aquifer compressibility).
8. Porosity – quantitative and qualitative description, range of magnitudes and what controls the magnitude (mainly grain-size distribution and consolidation/compaction), primary vs secondary, effective porosity, and how is it determined? Porosity's relationship to other quantities such as specific yield and water content.
9. Intrinsic Permeability - quantitative and qualitative description, range of magnitudes and what controls the magnitude (mainly grain-size and consolidation/compaction). How is it quantified—empirical relations using sediment characteristics and backing-it-out from hydraulic conductivity values.
10. Hydraulic Conductivity – combination of material properties (intrinsic permeability) and fluid properties (density and dynamic viscosity). Quantitative and qualitative description, range of magnitudes and what controls the magnitude (intrinsic permeability).
11. Heterogeneity –geology deposits that form aquifers are inherently heterogeneous and quantifying aquifer properties for such deposits is the most challenging aspect of assessing groundwater flow in a region. Heterogeneity is "scale" dependent. Effective hydraulic conductivity (parallel and perpendicular to flow).

Energy, Head, Gradients and Darcy's Law (Chapter 4)

12. Hydraulic Head – total hydraulic head = elevation head + pressure head. Explain all three in terms of energy. Hydraulic conductivity is a measure of "energy loss" due to friction as fluid encounters grain surfaces.
13. Hydraulic Gradient – 1-D (horizontal and vertical) and 2-D using the classic three point problem. Introduce a "regression" technique for estimating a 2-D gradient using many wells.
14. Darcy's Law – combines hydraulic head and hydraulic gradient to describe the flow of water through a cross-sectional area.
15. Special Topic – effective stress and the seepage force (quick sand and liquefaction). Seepage Force results from a hydraulic gradient (and buoyancy) across the length of a grain. Quick sand Demonstration.

Unsaturated Flow and Recharge (Chapter 6)

16. Unsaturated Zone – soil water and capillarity
17. Soil-water saturation and pressure head
18. Unsaturated hydraulic conductivity and water flow in the unsaturated zone
19. Recharge – rainfall, runoff, soil storage, evapotranspiration, and recharge

MIDTERM EXAM

Ground-Water Flow Equations (Chapter 4)

20. Steady-state ground-Water Flow Equations – derivations of PDEs from a mass-balance point of view (coupling Darcy's Law with the Continuity equation). Handouts
21. Ground-Water Flow Equations – Solution techniques and xamples
22. Flow nets as a solution technique to PDEs
23. Aquifer Compressibility and Specific Storage
24. Transient groundwater flow equations

Well Hydraulics (Chapter 5)

25. Well hydraulics – establish the assumptions of the conceptual picture and Theis solution (mathematical similitude with heat flow).
26. Well hydraulics – Theis solution (pump tests) multiple wells and superposition of W(u)
27. Well hydraulics – Jacob and Thiem pump-test approximations (examples).
28. Well hydraulics – Specific Capacity test (using the Jacob-cooper approximation)
29. Pump Tests –Deviations from the Theis solution (bounded, leaky, and unconfined aquifers)
30. Slug Test – Hvorslev method

Sea-Water Intrusions (pp. 327-338)

31. Sea-water Intrusions – theory
32. Sea-water Intrusions – Islands (with examples)

Ground-Water Modeling (Chapter 13)

33. Ground-water Modeling – Use the Toth conceptual picture (and analytical solution) to introduce the finite-difference numerical approach.

Learning Outcomes for Geology 473/573

GEOL 473 Course Student Learning Outcomes: Students will understand:

1. **regional glacial and alluvial history and the deposits that form Puget Sound aquifers**
   Course objectives: Students will be able to:
   a. describe the depositional environments for glacial and alluvial deposits
   b. distinguish between glacial outwash, till, glaciomarine drift; and alluvium, and their relationship to hydrogeology

2. **the equations and variables that describe groundwater flow in aquifers and other geologic systems**
   Course objectives: Students will be able to:
   a. determine when the influence of fluid density and viscosity becomes important in groundwater systems
   b. differentiate between the porosity, intrinsic permeability, and hydraulic conductivity of aquifer sediments
   c. quantify the pressure head, elevation head and total head and hydraulic gradients
   d. apply Darcy's Law to calculate fluxes and velocities in one and two dimensions

3. **unsaturated flow and the factors that control aquifer recharge**
   Course objectives: Students will be able to:
   a. estimate recharge from rainfall, soil, aquifer, and vegetation data in ArcGIS
   b. apply Darcy's law in an unsaturated sediment

4. **mathematical modeling approaches for resolving groundwater related problems**
   Course objectives: Students will be able to:
   a. recognize the appropriate groundwater flow equation (PDE) that describes an aquifer conceptual picture (1,2 or 3-D, heterogeneous or homogenous, steady state or transient flow)
   b. apply the groundwater flow equations to pumping wells

5. **site characterization requirements for a hydrogeological assessment**
   Course objectives: Students will be able to:
   a. draw aquifer cross sections from well log information
   b. measure the pressure head, elevation head and total head at monitoring wells
   c. contour total head values and determine hydraulic gradients in one and two dimensions
   d. estimate the hydraulic conductivity of an aquifer from pump test, slug test, and specific capacity data

GEOL 573 Course Student Learning Outcomes: Students will understand:

1. **the GEOL 473 course outcomes and objectives**

2. **how to analyze and interpret scientific data**
   Course objectives: Students will be able to:
   a. Apply groundwater principles to a topic outside the realm of GEOL 473

Geology 473/573 - Hydrogeology provides information for the following Geology degree program outcomes:

	B.A. Geology	B.S. Geology	B.S. Geophysics	GUR	M.S. Geology
Program Outcomes	*2. Earth's surface is affected by dynamic processes on a range of timescales.* *6. Geology and society are fundamentally inter-related* *7. Graduates have developed their observational, analytical and quantitative skills (field, lab, computer, and classroom)*	*2. Earth's surface is affected by dynamic processes on a range of timescales.* *6. Geology and society are fundamentally inter-related* *7. Graduates have developed their observational, analytical and quantitative skills (field, lab, computer, and classroom)* *10. Graduates (alone or in teams) will be able to present geological information clearly*	*2. Earth's surface is affected by dynamic processes on a range of timescales.* *6. Geology and society are fundamentally inter-related* *7. Graduates have developed their observational, analytical and quantitative skills (field, lab, computer, and classroom)* *10. Graduates (alone or in teams) will be able to present geological information clearly*	*1. Analyze and communicate ideas effectively in oral, written, and visual forms.* *3. Use quantitative and scientific reasoning to frame and solve problems.*	*3. Analyze and interpret scientific data;* *4. Communicate scientific concepts and results effectively through both written and oral means, and to a range of audiences.*

Geology Department Program Student Learning Outcomes

Geology BA Degree

Cognitive outcomes: Our students will have a deep understanding of the following foundational geologic principles:

1. Earth has a history of biological and physical change over billions of years.
2. Earth's surface is affected by dynamic processes on a range of timescales.
3. Earth's composition varies and these compositions provide the raw materials for the rock cycle.
4. Earth's interior is dynamic and drives plate tectonics.
5. Earth scientists use repeatable observations and testable ideas to understand and explain our planet.
6. Geology and society are fundamentally inter-related.

Skills: Our students will have critical skills required by professional geologists. Graduates:

7. Have developed their observational, analytical and quantitative skills.

Geology BS Degree (all of the above plus)

Skills:

8. Can create maps and understand what they tell us about the Earth.
9. Will be able to apply physics, chemistry, and mathematics concepts to the study of Earth.
10. Will be able (alone or in teams) to present geological information clearly.

Geophysics BS Degree (all of the above plus)

Skills:

11. Will be able to demonstrate general proficiency with concepts and quantitative problems involving Newtonian mechanics, energy, and momentum.

MS Degree Learning Goals

The goals of the Geology MS degree are to support student learning and improvement in: A) foundational knowledge and skills; B) quantitative skills; and C) critical thinking. It is our expectation that our graduates will apply these as professionals who can integrate chemical, physical, biological, and other specialized knowledge in order to understand geological processes.

MS Student Learning Objectives

To meet the Geology Graduate Program goals, when students graduate from the MS program, they will be able to:

1. Explain and evaluate the theories and concepts of geological science and related disciplines;
2. Design and conduct scientifically-rigorous and relevant scientific research in their chosen environmental discipline;
3. Analyze and interpret scientific data; and
4. Communicate scientific concepts and results effectively through both written and oral means, and to a range of audiences.