GEOL 473/573
Hydrogeology
Fall 2016

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Office Hours: 1-2 pm M W F, or by arrangement

Text: Applied Hydrogeology, C. W. Fetter, 4th 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 <u>required</u> to use Mathcad to compose your problem-set solutions. 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 ……35% (25% for graduate students and 10% for the term project)
Exam 1…………..30%
Final Exam………35% (Wednesday, December 7, 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

Readings

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, Patrick A. Domenico and Franklin W. Schwartz, 2nd Ed, John Wiley and Sons, Inc 1998.

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

Other USGS Training Resources

Academic honesty is an important part of every course at WWU. For students, academic integrity means challenging yourself, striving for excellence, taking risks and learning from your mistakes, doing your own work, and giving credit whenever you use the work of others. It boils down to caring about your schoolwork and always being honest in carrying it out.

I begin with the assumption that you come to Western and this class with integrity. However, academic integrity and honesty can be challenging due to such things as ignorance, confusion, stress, bad advice, and bad choices. So to help you keep your integrity and good reputation intact, I have resources for you (meaning, by the way, that ignorance will not be an excuse):

- WWU's Integrity Website http://www.wwu.edu/integrity/ provides all the information you need, including why integrity is important, how to promote it, as well as types of academic dishonesty and how to avoid them, particularly plagiarism. It also includes WWU's policy and procedures on academic honesty (appendix D of the WWU Catalog).

- See me if you have any concerns or questions about academic integrity regarding yourself or your classmates. An ounce of prevention is worth a pound of cure, especially where penalties and one's reputation are at stake. I am here to help. Please read the Integrity section

Please feel free to **talk to me** anytime about your performance in the course or possible ways you can improve, including if a situation arises where you cannot turn in a problem set on time.

If you have a documented **disability** you must report to me during the first week of class to discuss your needs. If you need disability-related accommodations, please notify Student Support Services at 650-3083 (phone) or 650-3725 (TTY) or http://www.wwu.edu/depts/drs/

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).

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

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 3 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. Demonstration.
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 – Discuss the inherent heterogeneous nature of most geologic deposits—quantifying aquifer properties for such deposits is the most challenging aspect of assessing ground-water 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. Measurement of each. Make use of a DEMONSTRATION. Emphasize that hydraulic conductivity is a measure of "energy loss" due to friction loss 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. Demonstration.
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.
16. Aquifer Compressibility and Specific Storage.

Unsaturated Flow and Recharge (Chapter 6)

17. Unsaturated Zone – infiltration and water flow in the unsaturated zone.
18. Recharge – rainfall, evapotranspiration, and recharge.

Ground-Water Flow Equations (Chapter 4)

19. Ground-Water Flow Equations – derivations of PDEs from a mass-balance point of view (coupling Darcy's Law with the Continuity equation). Handouts.
20. Ground-Water Flow Equations – Solution techniques. Examples.
21. Flow nets as a solution technique to PDEs

MIDTERM EXAM

Well Hydraulics (Chapter 5)

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

Sea-Water Intrusions (pp. 327-338)

28. Sea-water Intrusions – theory
29. Sea-water Intrusions – Islands (with examples)

Ground-Water Modeling (Chapter 13)

30. 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: Student 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: Student 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
Outcomes	*2. Earth's surface is affected by dynamic processes on a range of timescales.* *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.* *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.* *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.*