GEOS 6007 – Groundwater Hydrology
Fall Semester, 2018

Location: Sparks Hall, room 135
Time: MW; 12:30 pm – 1:45 pm
Instructor: Luke Pangle, PhD
Office: Langdale Hall, room 745
Office Phone: 404-413-5771
Office Hours: By appointment; e-mail or in-class requests will be fine for scheduling.

Prerequisites:
Single-variable integral and differential calculus
Basic physical mechanics
Basic understanding of geology and soils

Other beneficial courses:
Multi-variable/vector calculus
Ordinary differential equations
Physical Hydrology or other Hydrology course

COURSE OVERVIEW:

Or, what should I expect from this class? Water in subsurface aquifers has proven to be an essential resource for human civilizations. As a result, there is a fairly expansive history of research and knowledge development regarding the geography, geology, and hydraulic properties of aquifers. Beyond these practicalities, the storage and movement of water in aquifers influences, and is influenced by, myriad other ecosystem processes, making scientific research in hydrogeology/groundwater hydrology relevant across multiple disciplines. Given the breadth of existing knowledge, our coverage of the field over a 15-week semester will be inevitably superficial.

With that limitation in mind, at least two approaches to organizing this class are possible: 1) try to expose students to the full breadth of knowledge in the discipline, providing necessarily brief coverage of any details related to a particular topic, or 2) narrow the range of topics that are presented to students—omitting entirely some topics—and spend more time investigating the details of the chosen subset of topics. Both approaches have merits and drawbacks. Since this is a graduate-level class, and since many of you may have already taken a hydrogeology class as part of your undergraduate curriculum (not essential), I’m adopting the second approach. This class will be very much focused on groundwater flow under a range of geological and hydrological conditions. There will be much lighter coverage of other topics, such as the physical geography and stratigraphy of different aquifer systems, and variable aspects of groundwater chemistry. There are other classes in the department dedicated to these topics. Inevitably, though, we will cover these topics to some extent because they strongly influence groundwater flow (e.g. presence/absence of confining layers or nature of consolidated material). That said, the main learning objectives for this course are outlined below.

- Understand the significance of groundwater in the overall hydrologic cycle at basin to global scales
- Understand some principles of fluid mechanics, and physical properties of water, that are essential for studying groundwater flow, especially Darcy’s Law and its application
- Understand the derivation and application of theoretical models used to interpret data from aquifer tests
- Understand the varied mechanisms by which aquifers are recharged (i.e. partially filled with newly incoming water)
- Understand the basic hydraulic properties of soils, be able to apply some common quantitative methods for modeling infiltration and groundwater recharge, and know what assumptions are implicit in their application
- Understand physical and hydraulic properties of more consolidated geologic media (variably consolidated sediments and rocks) and different methods employed to quantify these properties (many utilizing well tests).
- Understand how water pressure is distributed throughout saturated aquifers (unconfined and confined) and be able to interpret maps illustrating these distributions
- Understand and apply some common quantitative methods for modeling flow in unconfined aquifers, and know what assumptions are implicit in their application
- Understand and apply some common quantitative methods for modeling flow in confined aquifers, and know what assumptions are implicit in their application

I hope this class gives you a strong foundational knowledge of how water flows through porous geologic material below the land surface, and some practice in applying that knowledge to practical problems. Equally, I hope you will develop the interest and self-confidence needed to expand on this foundation, as may be required for your chosen research focus or ensuing career.

**COURSE STRUCTURE AND LEARNING RESOURCES**

**Online:**
We’ll use a class site on iCollege for distribution of all class materials unless otherwise stated.

**Textbook:**
I will not require you to buy a specific text for this class. I will utilize several different texts while preparing material for this class, and references to those texts will be noted in course slides, so that you can find and utilize those texts if desired. If your research or career aspirations involve any aspect of hydrogeology then you will probably want to invest in a good text. There are many good ones. The text *Fundamentals of Groundwater* by F.W. Schwartz and H. Zhang is good, and used by Dr. Brian Meyer here at GSU for the undergraduate section of Hydrogeology. The old classic *Groundwater* by R.A. Freeze and J.A. Cherry is still entirely relevant, and you can get the .pdf online ([http://hydrogeologistswithoutborders.org/wordpress/original-groundwater-by-freeze-and-cherry-1979-now-available-online/](http://hydrogeologistswithoutborders.org/wordpress/original-groundwater-by-freeze-and-cherry-1979-now-available-online/)). There are many, many more, especially when focusing your study on specific aspects of hydrogeology, such as contaminant fate and transport, subsurface characterization, and/or well pumping tests.

**Primary Literature:**
As graduate students, you should be spending equal or more time reading peer-reviewed journal articles as you do reading texts. Interesting and well written papers are fun to read, whereas
poorly written papers can zap your enthusiasm and leave you feeling uncertain about what, if anything, you actually learned. Effectively searching for and finding the best articles that are most relevant for your purpose can be a real challenge. We will regularly read and discuss journal articles in this class, which I hope will help you through this learning curve. This should also help expose you to various applications of the fundamental concepts and quantitative techniques you will be learning. Assigned readings will be noted in class and via iCollege announcement.

Also, though the course content will deal largely with how we quantify the magnitude and movement of water within the subsurface, we also need to have a basic understanding of how the subsurface is organized. If you have completed an undergraduate degree in Geology or similar field, you already have this knowledge. But not everyone in a graduate program has the same traditional educational background. As such, we will supplement our lectures and reading of the primary literature by also studying an excellent resource published by the US Geologic Survey called the Groundwater Atlas of the United States. The entire document can be viewed online here: https://pubs.usgs.gov/ha/ha730/gwa.html. Specific sections will be assigned for review and class discussion throughout the semester.

Software resources:
We will utilize some open source modeling software called HYDRUS 1d (downloadable here: http://www.pc-progress.com/en/Default.aspx?hydrus-1d) for some applied exercises. I am exploring the possibility of using other groundwater-flow-modeling software for exercises later in the semester. This is currently indefinite, but I will keep you updated throughout the semester.

We will also be using software called AQTESOLV, which is a popular, commercially-available software application used for analyzing results from aquifer tests. We’ll be covering the derivations and applications of different equations used for analyzing aquifer tests, then you can follow up by gaining experience with this software, which is commonly utilized in research and environmental consulting.

Organization of Class Sessions:
We’ll divide class time among 1) lecture, 2) taking quizzes, 3) working on applied problem sets, some of which may involve laboratory work or computer simulations, and 4) presenting and discussing research articles.

Assignments:

Quizzes:
We will have in-class quizzes on a weekly basis. Their content may include conceptual questions, quantitative problems, or other types of questions. I will explain to you very clearly what will be on the quiz. I have no interest in trying to trick you. It’s your job to study and earn full credit. These will typically be administered over the first 15 minutes of class. I will use these quizzes to enforce those fundamental concepts and/or techniques that I think you should be able to describe/perform on call. Each week, the quiz will include original questions related to concepts we’ve covered most recently (i.e. since the last quiz), and one additional question that will be repeated from one of the previous quizzes. My purpose with the repeat question is to
keep you looking back at those previous quizzes and continually reinforcing those key concepts/techniques. Memorization is not the primary focus of your education, yet it is impossible for any of us to work effectively in any field if we don’t have a “mental toolbox” of sorts – some collection of facts, procedures, techniques, etc. that are so fundamental, and used so regularly, that we benefit from keeping them on the forefront of our mind.

I also reserve the right to give pop quizzes if I feel like the whole class is not reading the assigned papers. I will make this determination based on the quality of class discussions, and the breadth of participation in the discussions by all students. If everyone reads the assigned readings and is prepared to participate in discussion about them, these quizzes won’t be necessary.

**Problem sets:**

You will be assigned quantitative problem sets throughout the semester. These will form the bulk of the work you do in this class. I may request that you work on these individually, in groups, or in many cases we may work on them together in class. Even if you work on the problems in a group (which I usually encourage), your presentation of your quantitative results and written responses should be your original work, not copied from a peer.

**Reading and participation in class discussions:**

We will read and discuss journal articles throughout the semester. On one instance during each semester, each student will provide an 8-minute oral presentation, with visual aids, summarizing an article they have read. One of the most important skill sets for you to develop during your graduate studies is the ability to effectively communicate research orally. These presentations are meant to be a low-stakes opportunity to improve this skill. Your presentation should address the following:

- What is the rationale for the study? What gap in knowledge do the authors claim exists?
- What is the explicit objective of the work, or hypothesis being tested?
- What methodological approach is chosen, and what is the logic for this selection?
- What is the most salient result of the work, and what conclusion is ultimately drawn from this result?
- What sources of uncertainty remain, and potentially limit the inference that can be made from the work?

Five to 7 minutes for class discussion will follow the presentation. I expect the discussions to be led by the students (i.e. you need to have actually read the article). Your participation in discussions will be noted with regard to the class-participation component of your grade.

**GRADING AND ATTENDANCE POLICIES:**

**Grading:**

The fractional contributions of each class activity to your overall grade are outlined here:

Quizzes = 30%
Problem Sets = 50%
Oral Presentation = 10%
Class Participation = 10%

Late assignments will receive an initial grade reduction of 10 points (whole letter grade). After being overdue for 1 week, the grade will receive additional reductions of 5 points per day. Once the submitted assignments have been graded and returned, no further late submissions will be accepted – this rule supersedes the previous two.

98 ≤ A+ ≤ 100
94 ≤ A < 98
90 ≤ A- < 94
87 ≤ B+ < 90
84 ≤ B < 87
80 ≤ B- < 84

Attendance:
I don’t formally take roll each day, but I notice and take note of when people are absent. Persistent absence will affect your grade. Absences due to documented health concerns or emergencies are excused. Absences due to research activities or conference participation are excused (please let me know ahead of time). Other absences should be discussed with me, ideally beforehand. I am agreeable in most cases, so long as you notify me beforehand.

ETHICAL STANDARDS AND PROFESSIONALISM IN COMMUNICATION:

All students are expected to have read and understand Georgia State University’s policy on academic integrity, which can be found in .pdf format here: http://deanofstudents.gsu.edu/faculty-staff-resources/academic-honesty/

It is imperative that students realize that lack of knowledge of any aspect of this policy does not constitute an acceptable rationale for any violation. Please take the time to read the policy on academic integrity and raise any questions you may have during the lecture sessions (so the topic can be discussed by all), or in a private conversation with the instructor. Be aware that any faculty member or teaching assistant that believes there is strong evidence to suggest academic dishonesty by a student is required (as dictated in that policy) to submit a notification of academic dishonesty. Confirmed cases of academic dishonesty can result in a failing grade for the class, and possibly additional penalties at the departmental or university level.

In addition to the regulations regarding academic integrity that are formally described in the University’s policy on academic honesty, I also require that students comply with certain ethical standards within the classroom. Demonstrate respect for your fellow students, instructors, and teaching assistants by adhering to the following standards:

- Refrain from all forms of bullying. This includes derogatory verbal remarks or bodily gestures that are intended to insult or belittle any other person, performed in a personal exchange or through digital communication.
• Respect your peers’ right to ask questions, express their opinion, and to make mistakes without fear of insult. Please refrain from interrupting people when they have been designated to speak to the class.

• Refrain from using your cell phone in class. Please keep it stored out of sight and with the ringer silenced. You may keep it with you and on vibrate mode, if you feel that necessary. If your cell phone is visible to me then it is not properly stored. If your cell phone is not properly stored during an in-class assignment or exam, that will be grounds for a failing grade on that assignment.

During your graduate education you should conduct yourself in a professional manner, comparable to how you would expect to conduct yourself in your eventual career. Speak respectfully and thoughtfully to me and to one another. If we communicate by e-mail, compose your email in a concise and well-written format. I will try to respond to your e-mails within 24 hours. If you send me sloppy or incoherent e-mails, I’ll likely ignore them. If you need to speak to me urgently, an office visit or phone call is most appropriate.

ACCOMMODATIONS FOR STUDENTS WITH DISABILITIES:
Any student with a documented disability that influences their participation in this course needs to visit the Georgia State University Disabilities Services office in the Student Center-East, Suite 205. The website for GSU Disabilities Services is here: http://disability.gsu.edu/. In most cases, you will first need to have your disability documented by GSU Disabilities Services. Once that is complete, you can schedule a meeting with the instructor to discuss how we can accommodate your full participation in the class. That meeting should conclude with signing of some forms that are outlined at the website above. **IMPORTANT:** Please take action to have your disability documented and addressed as soon as possible. If you require alternative testing conditions, for example, there are some deadlines that must be met to make sure you receive that accommodation in time for the first quiz/exam. Please always communicate with me about any issues you are having so we can address them promptly.

COURSE REVIEW:
Part of your participation in this course includes you taking the time at the end of the semester to provide a constructive and thoughtful course review. The only way the quality of this course is enhanced is through modifications that are motivated by your feedback. If there is some aspect of this class that you think could be much improved, or a curriculum change that you think would leave you better prepared for your professional pursuits in the field of water resources science or management, then please let me know.

COURSE TIMELINE:
This timeline is subject to change as needed. We will adapt as we go, depending on which topics prove more or less difficult, and require more time for coverage. Topics are listed generally here. For most topics, we will focus on conceptual understanding of processes, techniques and methods for quantifying physical and hydraulic properties of the system, and how those properties are employed to quantify flow through the system.

<p>| Week | Topics: |</p>
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<th>Date</th>
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| 8/20/2018 | Course Introduction  
Overview of hydrogeological systems  
Overview of groundwater role in regional and global water balance |
| 8/27/2018 | **SECTION: FLUID MECHANICS AND DARCY’S LAW**  
The content and potential (for motion) of water in porous media  
Fundamental fluid-mechanics principles relevant to groundwater flow |
| 9/3/2018  | Darcy’s Law of fluid flow in porous media  
Conceptual and quantitative basis of hydraulic conductivity of porous media  
Experimental test of Darcy’s Law (in the lab) |
| 9/10/2018 | **AQUIFERS AND AQUIFER-TESTING METHODS**  
Overview of aquifer types and their characteristic porosities  
Overview of the anatomy of wells in confined and unconfined aquifers  
Hydraulic Properties of Aquifers: Relationship between hydraulic head and water-volume storage in confined and unconfined aquifers |
| 9/17/2018 | Overview of “aquiﬁer-testing” methods (involving manipulation and measurement of water levels in wells).  
**Test-type 1**: Steady-state pumping tests in confined aquifers – derivation and application of analytical model |
| 9/24/2018 | Practical considerations of designing and planning aquifer tests  
**Test-type 2**: Steady-state pumping test in unconfined aquifers – derivation and application of analytical model including the Dupuit-Forschheimer assumptions  
Overview of concepts relevant to testing unconfined aquifers, including well losses and the seepage-face boundary condition |
| 10/1/2018 | **Test-type 3**: The Theis model for analysis of non-steady-pumping tests in confined aquifers  
Overview of the concept of a well function  
Diagnosing features of drawdown data when correspondence with the well function is poor |
| 10/8/2018 | Applicability of Theis’s well-function approach to pumping tests in non-ideal aquifers.  
Methods for quantifying aquifer hydraulic properties by analysis of drawdown recovery. |
| 10/15/2018| Slug tests in wells: overview of methods, derivation and application of some analytical models for quantifying aquifer hydraulic properties. |
| 10/22/2018| **QUANTIFYING GROUNDWATER FLOW IN AQUIFERS**  
Derivation of governing equation for flow in confined aquifers  
Quantifying steady-state flow in confined aquifers  
Flow nets: their utility for interpreting groundwater flow pathways and rates, and underlying assumptions |
| 10/29/2018| Derivation of governing equation for flow in unconfined aquifers  
Quantifying steady-state flow in unconfined aquifers  
Some key results from hydraulic groundwater theory and their application to flow problems in unconfined aquifers |
<p>| 11/5/2018 | Some other modes of whole-basin groundwater analysis: baseflow recession analysis and hydrograph separation. |</p>
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<tr>
<th>Date</th>
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<tr>
<td>11/12/2018</td>
<td>Understanding surface tension and its relevance for vadose zone hydrology. Conceptual overview of the capillary fringe, derivation and application of the Young-Laplace equation describing capillary-rise height. The relationships between soil-water content, water pressure, and hydraulic conductivity: the hydraulic “fingerprint” of different soil types. Extending Darcy’s Law to unsaturated flow conditions in the vadose zone: Derivation of the Richards Equation: governing equation for variably-saturated flow in porous media.</td>
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<td>11/19/2018</td>
<td>Thanksgiving Break</td>
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<td>11/26/2018</td>
<td>Simplified methods of quantifying infiltration, their underlying assumptions, and examples of applications (e.g. Green-Ampt infiltration theory). Mechanisms of groundwater recharge in different landscapes and hydro-climatic regimes.</td>
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<tr>
<td>12/3/2018</td>
<td>Unscheduled time left for additional coverage of topics as needed.</td>
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