Using Wetlands to Teach Hydrogeology

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Introduction

Experiential learning in hydrogeology is essential to preparing successful hydrogeologists. Unfortunately, groundwater is not always readily accessible for direct study. Well installation and instrumentation can be costly. Wetlands, however, provide an ideal field laboratory for investigating surface-water/groundwater interaction because the water-table is so close to the land surface. With minimal expense and effort, wells and piezometers may be installed for data collection. If necessary, open auger holes may be used to determine the location of the water table. Myriad field exercises (surface-water, vadose-zone, and groundwater hydrology) are possible for students to learn hydrogeological concepts, techniques, and reasoning in the context of one or two field sites, and, thus, as an integrated whole rather than as piecemeal field exercises.

Students benefit in many ways from first-hand field experience in data collection and interpretation. Among these benefits are

- experience using standard field equipment,
- experience using standard field techniques,
- learning to write effective field notes,
- learning teamwork,
- learning about the precision and reliability of field data,
- learning to use common sense, and
- learning to make connections among various hydrological processes and characteristics.

Of course, the greatest benefits are that students get more excited about learning hydrogeology when they are in the field rather than a lecture hall, and they are better prepared to enter the workforce and be successful when they graduate.

Although I have developed a field laboratory on my campus, a permanent field laboratory is not necessary for using wetlands to study hydrology. All that is needed is access to a wetland field site for the semester. Temporary wells can be established for a day or a week at a time—local and state regulations permitting. Most of the labs I mention below can be conducted with relatively inexpensive equipment fabricated by students. For example, a Guelph permeameter kit is great for determining field-saturated hydraulic conductivity, but you could auger a borehole and maintain a constant head manually by adding water from a graduated cylinder while recording the volume added and the time elapsed. In a few instances, it is best to have the standard equipment, such as a pygmy current meter for measuring stream discharge. I highly recommend, and require for my students, Laura Sanders' *A Manual of Field Hydrogeology* to support the field labs.

I try to get my students out in the field at least four times a semester, more if possible. Consequently, I do not use all of the labs presented here in a particular semester. There are favorite labs that I always use in the required course, Hydrology (EES 322) offered each Fall Semester—these have an asterisk (*) after their titles below. I then pick and choose the other labs that I will add for that semester. What I don't use in the Fall Semester, I may use during the Spring Semester in my second course, Groundwater Hydrology (EES 422).

Short descriptions are presented below of some of the field labs that I use so that students are collecting and interpreting field data throughout the semester.

Stream Discharge Measurement Using the Area-Velocity Method and a Current Meter*

My first lab of the semester is usually measuring stream discharge. This field lab is not run in a wetland because I want the students to have their first experience of measuring stream discharge in a large, gaged stream. My reasons for this are as follows:

- The literature and training materials recommend making 25 - 30 measurements across the width of the stream. This is not usually feasible in wetland streams.
- The discharge measurement is taken near a USGS gaging station so that the students can compare their results with those posted on NWISWeb. Consequently, the students (1) are introduced to NWISWeb, which they will use for other assignments during the semester, and (2) build confidence as their discharge values are always very close to the posted station discharge.
- This is a team-building lab as the students combine their measurements to determine stream discharge. I try to limit the number of students in the field to 7 so that each student takes 3 to 4 readings—I do this by splitting the lab class and having the other students work on a computer lab, and the following week we switch. Each student, then, is invested in the other students using the equipment/technique correctly so that the calculated discharge is reliable.

We use the area-velocity method and a current meter—Price or pygmy depending on the flow conditions. I prefer to use headphones rather than the electronic system so that students have a better sense of the relation between the meter's rotation speed and stream velocity. I provide waders. We use a modified version of the USGS discharge measurement form and fill it out as completely as possible in the field, including the outside stage reading before and after we make our measurements. We also measure basic water quality parameters while in the field, such as temperature, conductivity, pH, and dissolved oxygen. Back in the lab, students access NWISWeb for real-time data on their stream.

Students are required to submit a short report the following week. The report must address what they did and what they found out (who, what, where, when, how, and why), and it must contain (1) a table showing their data and calculations (I require that they use Excel), (2) a figure showing the stream cross-section with the velocity measurements and sections identified (I require that they use GRAPHER), and (3) in the appendix, the original field worksheet and equipment list.

Seepage in Wetland Streams Using Stream Discharge

Having already measured stream discharge in the ideal setting of a large stream, the students are now faced with a more typical situation—a stream too small to limit discharge in each section to less than 10% of the total discharge. This lab is designed to

- allow students to revisit stream discharge measurement by the area-velocity method,
- measure stream discharge in a small stream where only 3 - 5 measurements can be taken across the width of the stream,
- introduce students to measuring discharge with a flume, and

* A lab that I always use in the required course, Hydrology (EES 322)

- investigate groundwater/surface-water interaction.

I divide the class into teams of two. One student is responsible for the upstream discharge measurement and the other for the downstream measurement. Each team measures discharge upstream by the area-velocity method with a pygmy current meter at a location I determine beforehand—one that will yield a good measurement. We then move downstream to the second predetermined site. Along the way, we observe whether any tributaries flow into the stream—there should be none for this lab. At the second site, discharge is determined either by the area-velocity method or with a Parshall flume. I had a flume installed in the stream and was able to use it for a few years before it was vandalized. A portable Parshall flume, installed temporarily for the lab, would offset this problem. The discharge values at the upstream and downstream sites are compared and a determination made as to whether the stream is gaining, losing, or neither. The site I use always is gaining. We then measure the distance between the two sites to assess the contribution of groundwater between the two sites per foot or meter, depending on the units we used for the discharge measurements.

Students are required to submit a short report the following week. The report must address what they did and what they found out (who, what, where, when, how, and why), and it must contain (1) a figure showing the locations of the two discharge measurement sites on a topographic map, (2) a table showing their data and calculations (I require that they use Excel), and (3) in the appendix, the original field worksheet and equipment list.

Seepage in Wetland Streams Using Water-table Wells*

Another lab that investigates the groundwater/surface-water interaction within the wetland involves establishing the topographic profile and water-table configuration across the stream valley. The students are charged with assessing whether the stream is gaining, losing, throughflow, or none of those, and whether "puddles" encountered along the transect are simply puddles or locations where the water table intersects the land surface. This lab is designed to

- allow students to investigate groundwater/surface-water interaction using an approach that complements the previous lab,
- introduce students to basic surveying concepts, equipment and techniques, and
- introduce students to measuring depth to water in a well and determining hydraulic head.

For this lab, I have installed six water-table wells (< 5 ft deep) along a 250-ft transect across the valley, three on either side of the stream. Before I had the wells, we hand augered holes to the water table and temporarily installed PVS pipe. Because the wells are in or adjacent to a wetland, the water table is very near the surface.

Students use an auto-level and electronic distance measurer (recently I have been using a laser distance measurer) to develop the topographic profile of the stream valley along the transect with the water-table wells. Measurements are made on the top of the well casings and depth to water is measured using either chalk and tape or an electronic sounder—I have at least two students take a depth-to-water measurement at each well. In addition, the stream bed and water elevation in the stream and "puddles" encountered along the transect are surveyed. The stream I use is always gaining, and the "puddles" are points where the water table intersects the land surface. The students rotate the jobs of surveyor, rod person, distance measurers, and depth-to-water measurers so that each student gets experience doing every task.

Students are required to submit a short report the following week. The report must address what they did and what they found out (who, what, where, when, how, and why), including a determination regarding status of the "puddles" and the stream. In addition, the report must

* A lab that I always use in the required course, Hydrology (EES 322)

contain (1) a figure showing the location of the transect on a topographic map, (2) a table showing their data and calculations (I require that they use Excel), (3) a figure showing the stream valley topographic profile and water table with the locations of the wells, stream, and "puddles" identified (I require that they use GRAPHER), and they must draw groundwater flow lines on the figure indicating the direction of flow around the stream and puddles, and (4) in the appendix, the original field worksheet and equipment list.

Seepage in Wetland Ponds Using Seepage Meters

Wetland ponds (e.g., open-water marshes and vernal pools) provide another useful laboratory for investigating groundwater/surface-water interaction. In this lab, we install seepage meters to estimate the rate and direction of water flow across the pond floor. This lab is designed to

- allow students to investigate groundwater/surface-water interaction using an approach that complements the previous two labs,
- provide students another opportunity to use basic surveying equipment and techniques,
- introduce students to surveying software,
- introduce students to measuring seepage using seepage meters,
- introduce students to mapping seepage variations in the pond, and
- revisit the concept of weighting point data to estimate an areal value, in this case, net seepage.

I used to use piezometers in combination with the seepage meters to estimate the hydraulic conductivity of the pond sediments, but that part of the lab didn't always work well, so I have dropped it. The seepage meters are made from 5-gallon buckets following Sanders (1998) except that I use medical urinary bags in place of the plastic bag. These medical bags have two outlets allowing transfer of fluids without removing the bag from the seepage meter.

I divide the class into teams of two. I distribute the teams over the pond area as evenly as possible. Each team is responsible for one seepage meter. The seepage meters are installed and after an hour or so, the change in volume is recorded. During the wait, the students survey the locations of the seepage meters and the edge of the pond. Clearly a small pond is a plus; I usually use a vernal pool. The students then calculate the specific discharge across the pond floor for their seepage meter and share their data and results with the other teams.

Back in the lab, the students create a pond map by plotting the locations of the seepage meters and pond edge using SURVEY (RockWorks). The seepage rates are then added to the map and zones of inflow and outflow identified. As a final step, the net seepage for the pond is estimated using the pond map and the Thiessen polygon weighting method.

Students are required to submit a short report within two weeks. The report must address what they did and what they found out (who, what, where, when, how, and why). In addition, the report must contain (1) a figure showing the pond location on a topographic map and the map they created of the seepage meter locations in the pond, (2) a table showing their data and calculations (I require that they use Excel), (3) a figure showing the Thiessen polygons they used, (4) a figure showing the zones of inflow and outflow in the pond, and (5) in the appendix, the original field worksheet and equipment list.

Infiltration Using a Ring Infiltrometer*

In this lab, the students work together to develop an infiltration curve and determine constant infiltration capacity using a double-ring infiltrometer. Students learn

* A lab that I always use in the required course, Hydrology (EES 322)

- to use an equipment manual to set up and use a double-ring infiltrometer,
- to work independently (of the instructor) to complete the infiltration test, and
- to follow an ASTM method for reporting the results.

Each student is given a copy of the manual (I use a SoilTest double-ring infiltrometer) that comes with the infiltrometer and a copy of the ASTM method a week before the lab to read up on what they will be required to do. During the lab, I give the students minimal advice while occasionally asking them questions to get them going in the right direction. Most of my students enter the workforce within a semester or two of taking my course, so preparing them to work independently on the job is a high priority. I tell the students that there will be many times in their careers when they will be called upon to use new equipment and/or to work in a team, and that they should think of the lab as a practice session. This is one of two labs (the second lab follows this one) in which I require the students to figure it out on their own with an equipment manual.

I choose a site that will allow equilibrium conditions to be approached within an hour or so; usually it is in the upland (of the wetland) and near the transect that the students used to survey the topographic profile and water table. Before any readings can be taken, the infiltrometer must be driven into the ground using a sledge hammer. I provide safety glasses and ear plugs for this procedure. It is common in this lab for the male students to "take over" beginning with swinging the sledge hammer and continuing throughout the lab. I encourage all the students, in particular the female students, to take part in setting up the infiltrometer and taking the readings. I find it interesting that the students will continue to take readings even after semi-equilibrium has occurred—I often have to ask them, "When should we end the test?" to get them to realize that I am not going to tell them when to quit. Sometimes the students don't know that they have reached equilibrium because they have failed to do the calculations in the field, and my query then has them rushing to do the calculations.

Students are required to submit a short report the following week. The report must answer what they did and what they found out (who, what, where, when, how, and why). In addition, the report must contain (1) all the items listed in the ASTM method, section 10.1, (2) a figure showing the test location on a topographic map, (3) a table showing their data and calculations (I require that they use Excel), (3) a figure showing the infiltration curves with the constant infiltration capacity identified (I require that they use GRAPHER), and (4) in the appendix, the original field worksheet and equipment list.

Hydraulic Conductivity (K_{fs}) of the Unsaturated Zone Using a Constant-Head Permeameter Test*

Directly related to constant infiltration capacity is field-saturated hydraulic conductivity. In this lab, students learn

- to describe a soil profile,
- to use an equipment manual to set up and use a field (Guelph) permeameter, and
- to work independently (of the instructor) to determine field-saturated hydraulic conductivity and matric suction.

Each student is given a handout on describing soil profiles and a copy of the permeameter manual a week before the lab to read up on what they will be required to do. During the lab, I give the students minimal advice.

I divide the class into two groups. One group is assigned a location in the upland, near the location of the infiltrometer test; the other group in the wetland. To describe the soil profile,

* A lab that I always use in the required course, Hydrology (EES 322)

each group uses a soil probe to collect a continuous soil sample to approximately 2 feet. Together they determine the horizon boundaries and describe each horizon. Once the soil description is complete, the students in each group auger a borehole and set up a Guelph permeameter to determine field-saturated hydraulic conductivity and matric suction. As with the infiltrometer test described above, the students will often continue to collect data after equilibrium has been reached. Unless the lab is running late, I will wait until they become restless before asking them how long we need to collect data. That question is usually enough to make them realize we have wasted a lot of time because they were not paying attention to what they were doing. When both groups are finished, they come together and compare the soil profiles and field-saturated hydraulic conductivity values for the two sites—this comparison provides an opportunity to discuss the nature of wetland soils.

Students are required to submit a short report the following week. The report must address what they did and what they found out (who, what, where, when, how, and why). In addition, the report must contain (1) a figure showing the test location on a topographic map, (2) the soil profile written in standard format, (3) a table showing the permeameter data and calculations (I require that they use Excel), and (4) in the appendix, the original field worksheet and equipment list.

Hydraulic Conductivity (K) of the Saturated Zone Using a Slug Test

Having determined the hydraulic conductivity of the upland soil, we turn our attention to the water-table aquifer. Slug tests are performed in water-table wells that are located along the stream valley transect (mentioned above), to determine the hydraulic conductivity of the aquifer material. In this lab, students learn

- to use pressure transducers and dataloggers to collect drawdown data,
- to estimate hydraulic conductivity using aquifer-test software (AQTESOLV),
- to consider parameter sensitivity in estimating model parameters (e.g., aquifer thickness), and
- how different hydraulic conductivities influence well recovery times.

I usually have the students do two slug tests, one in each of two different materials. The principle field site I use is underlain by two different glacial materials, and the boundary between the materials generally follows the stream. Each material has a unique hydraulic conductivity ($K_{Qx} = 10^{-5}$ ft/s; $K_{Qw} = 10^{-3}$ ft/s). The students conduct one slug test in the Q_x material (uncorrelated stratified drift) on one side of the stream and one slug test in the Q_w material (morphosequence stratified drift) on the other side of the stream. The two-orders of magnitude difference in the hydraulic conductivity translates into a noticeable difference in recovery rates in the wells—giving students the opportunity to experience what numerical values mean hydrologically. The slug test is conducted using a pressure transducer and datalogger. Both a rising head and a falling head test are conducted. Before I had the pressure transducer, I used the well with the slowest recovery time and an electronic sounder—this method requires considerably more teamwork and attentiveness than using a pressure transducer/datalogger.

Back in the computer laboratory, the hydraulic conductivity values are then estimated using AQTESOLV and the Bouwer-Rice method. The water-table wells partially penetrate the aquifer, and the thickness of the aquifer is not known. Using AQTESOLV, the students are able to see the sensitivity of the resulting hydraulic conductivity values to inputting different thickness values. We then have a short discussion relating the water-table configuration across the transect with the hydraulic conductivity values—the side of the stream with the low hydraulic conductivity material has a much higher water table than the side of the stream with the high hydraulic conductivity material.

Students are required to submit a short report the following week. The report must address what they did and what they found out (who, what, where, when, how, and why). In addition, the report must contain (1) a figure showing the slug test locations on a topographic map, (2) figures of the slug test matches from AQTESOLV, and (3) in the appendix, the original field worksheet and equipment list.

Groundwater Flow by Triangulation (3-Point Problem)

In this lab, the students work together to estimate the specific discharge through the site. Three water-table wells are used to determine the direction of groundwater flow and to estimate the hydraulic gradient. A slug test is conducted on one of the wells to estimate the hydraulic conductivity of the aquifer material. With this information, the specific discharge can be estimated. In this lab, students

- expand their surveying skills,
- revisit measuring depth to water and conducting slug tests, and
- learn to use geological software (RockWorks) to (1) translate surveying data into (x,y,z) coordinates and (2) determine the direction and gradient of the water table from three data (water-table levels).

I divide the class into three teams. Each team is responsible to first locate and second survey the elevation and location of a well using a given bench mark and third measure the depth to water in the well. To survey the well locations, the students use a geologist's surveying compass (a Brunton could also be used) and electronic distance measurer or laser distance measurer. Elevation is surveyed with an auto level. Depth to water is determined either with chalk and tape or an electronic sounder. Later in the lab, students use SURVEY (RockWorks) to generate the locations in (x,y,z) coordinates, and the combined data then are used with 3-POINT (RockWorks) to determine the direction of flow and the gradient (which needs to be converted from degrees to ft/ft).

Once the wells are surveyed and the water levels recorded, the teams gather at one of the wells to conduct falling head and rising head slug tests using a pressure transducer and datalogger. The field data are interpreted in the lab using AQTESOLV and the Bouwer-Rice method for a partially penetrating well. The students are then able to calculate the specific discharge at the field site.

Students are required to submit a short report the following week. The report must address what they did and what they found out (who, what, where, when, how, and why). In addition, the report must contain (1) a figure showing the field site location on a topographic map, (2) a table of the surveying and water depth data used for the triangulation, (3) a figure of the 3-point problem showing the direction of flow and the hydraulic gradient from RockWorks, (4) figures showing the slug test matches from AQTESOLV, and (5) in the appendix, the original field worksheet and equipment list.

Other Field Labs

A few field labs that I use exclusively in the Groundwater Hydrology course include

- Water-table Well Installation and Development,
- Groundwater Sampling,
- Geoelectric Section of a Vernal Pool, and

- Seismic Section of a Vernal Pool.

These labs are generally conducted at a vernal pool, so that when the pool is dry monitoring wells can be installed and geophysical surveys can be conducted. I locate a vernal pool and obtain permission to study it for two-to-three years. Each Groundwater Hydrology class contributes to the overall knowledge of the site and benefits from earlier classes. I recently published one such study in *Northeastern Geology and Environmental Sciences* (Vol. 25, No. 1, 2005, p. 71 - 79), "Hydrogeology and Geoelectric Section of a Vernal Pool in Eastern Connecticut." Conducting labs as on-going research helps students transition from students to professionals as they build camaraderie and confidence.

* A lab that I always use in the required course, Hydrology (EES 322)