

Training Workshop on Critical Zone Science

2023 Field Guide



May 15th - 17th at the University of Arkansas
Carbonate Critical Zone Research Coordination Network

1 Overview

1.1 Schedule

MAY 14TH — ARRIVAL AND INTRODUCTIONS

| | |
|---------------|---|
| | Students arrive and hotel check-in |
| 18:00 - 20:00 | Evening Icebreaker (Student Union, 507) |

MAY 15TH — FIELD DAY AT SAVOY EXPERIMENTAL WATERSHED

| | |
|---------------|--|
| 8:00 - 8:30 | Breakfast (GEAR 105) |
| 8:30 - 9:30 | Introductory Session (GEAR 101) |
| 9:30 - 17:00 | Field work at Savoy Experimental Watershed (lunch and snacks provided) |
| 18:30 - 20:00 | Dinner (can be provided or reimbursed) |

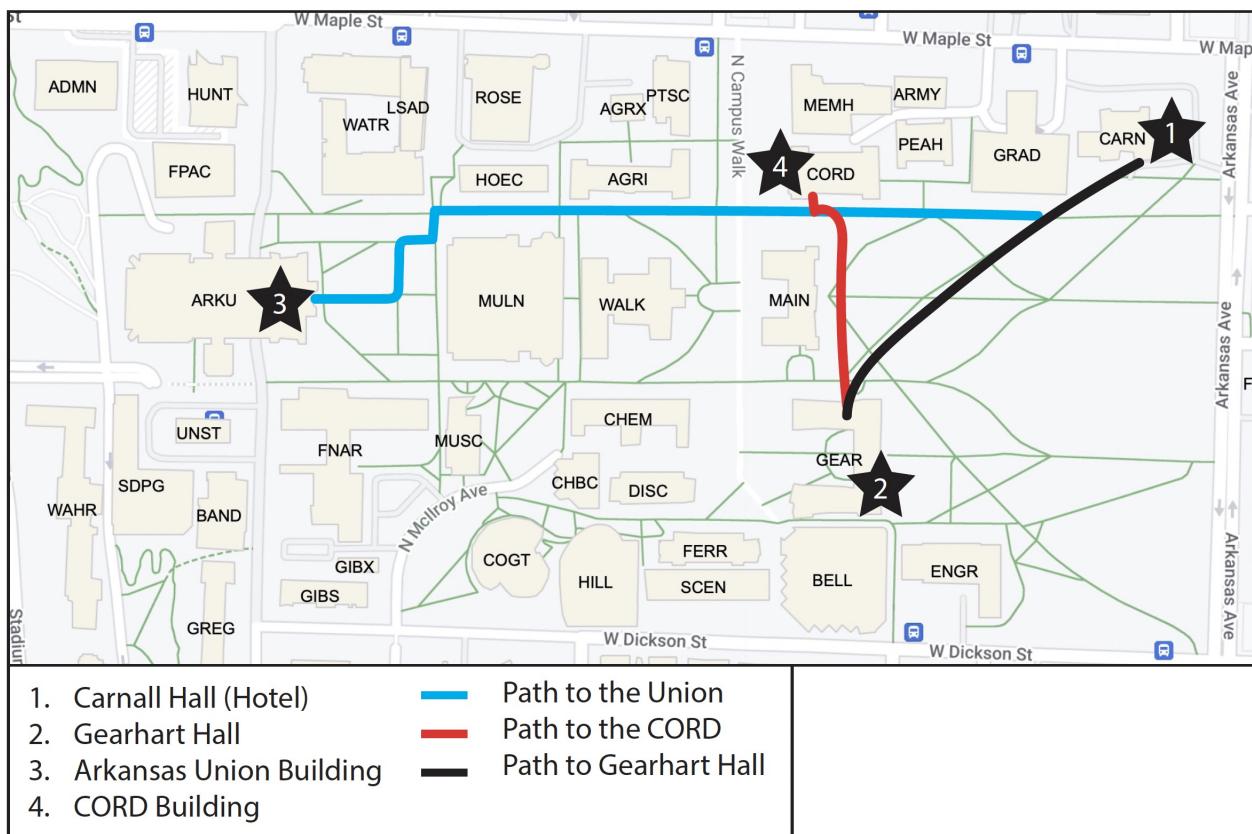
MAY 16TH - DATA ANALYSIS (GEAR)

| | |
|---------------|---|
| 8:00 - 8:30 | Breakfast (GEAR 105) |
| 8:30 - 12:00 | Morning computer lab session (GEAR 101, coffee break provided) |
| 12:00 - 13:30 | Lunch (provided) |
| 13:30 - 17:00 | Afternoon computer lab session (GEAR 101, coffee break provided) |
| 18:00 - 20:00 | Evening meet and greet event w/ workshop participants (Dinner Provided, Fossil Cove Brewing Co) |

MAY 17TH - FIELD TRIP WITH WORKSHOP PARTICIPANTS

| | |
|---------------|---|
| 8:00 - 8:30 | Breakfast (CORD 127) |
| 8:30 - 9:00 | Plenary session (CORD 127) |
| 9:00 - 17:00 | Field trip (Lunch and snacks provided) |
| 18:30 - 20:30 | Dinner Banquet (Arsaga's Mill District) |

1.2 Location Map



2 Field day at Savoy Experimental Watershed

2.1 Introduction

The **Savoy Experimental Watershed** is a collaborative research site for the study of nutrient management and groundwater flow in a mantled karst system [Brahana, 2011]. Since the site is also run as a cattle ranch, much of the previous work at the site has focused on the management of animal waste and nutrients in karst. The bedrock at the site is primarily limestone, which is a rock type that is highly soluble in natural waters. This enables the development of caves and underground karst conduits, as water infiltrates along fractures and dissolves enlarged flow paths. The limestone at the study site also contains a high percentage of chert, a silicate mineral that is not easily dissolved. Chert and other insoluble components of the limestone, such as clay minerals, have been left behind on the surface as the limestone dissolved away. These insoluble components create a thick regolith that covers the karstified limestone surface (Figure 1). It is this cover that makes the karst landscape of Northwest Arkansas a **mantled karst**.

In addition to providing important water resources, karst aquifers are a host to a variety of underground fauna, many of which are cave obligate species (meaning they cannot survive in the surface environment) and many of which are rare or endangered. The lack of extensive caves at the Savoy Experimental Watershed limits our ability to observe such fauna. However, some species that inhabit karst aquifers have been observed in the springs at Savoy (Figure 2).

The groundwater basin that we will be studying contains two base-level springs that emerge near the bottom of the St. Joe limestone, Langle Spring and Copperhead Spring. During high flow levels, both of these springs receive water from the sinking stream located near the middle of the study area (Figure 3). At low flow, all of the water from the sinking stream emerges at **Langle Spring**, which is at slightly lower elevation and is the **underflow spring**. **Copperhead Spring** is an **overflow spring**, meaning that it receives water from the sink whenever the capacity of the conduit feeding Langle Spring is overwhelmed, acting as a kind of pressure relief valve. As a result, Langle Spring has higher flow during dry conditions and somewhat limited flow variability. Copperhead Spring has very low flow during dry periods but higher flow during floods, exhibiting very high discharge variability.

The sinking stream is fed by a set of epikarst springs. **Epikarst** is the uppermost part of the sub-surface karst system, which often acts as a reservoir that stores water and slowly releases it. The **epikarst springs** are part of a shallow flow system that drains the hillslope above and reemerges onto the surface before reaching the main karst aquifer. It is hypothesized that these springs are perched on top of a continuous bed of chert, which stops vertical flow and directs the water down the dip and out the hillside. This water flows on the surface for only a short distance, before it sinks back into the ground and flows to Copperhead and/or Langle Spring. Some of the sink points are **estavelles**, meaning that they act as sink points during low flow and as springs during high flow. In addition to the springs and sinks, there are two wells within the study basin that will allow us to characterize groundwater

further away from the main karst flow paths.

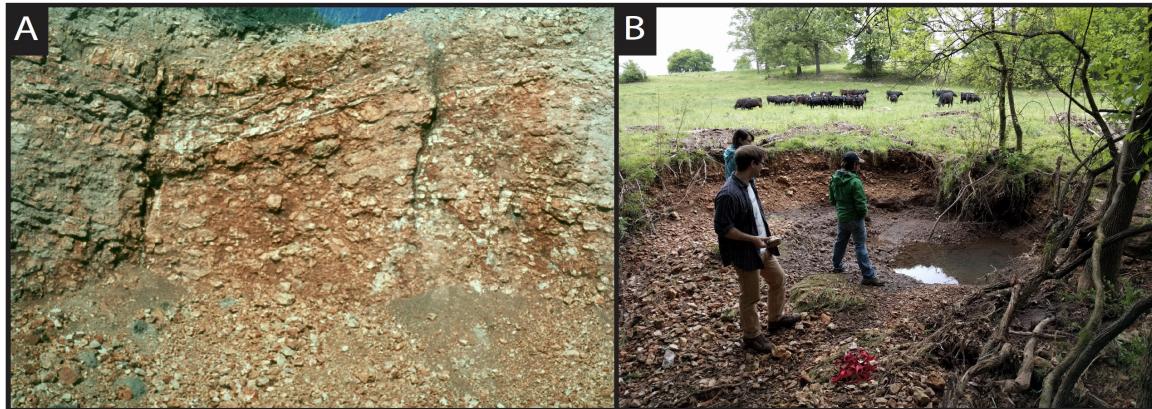
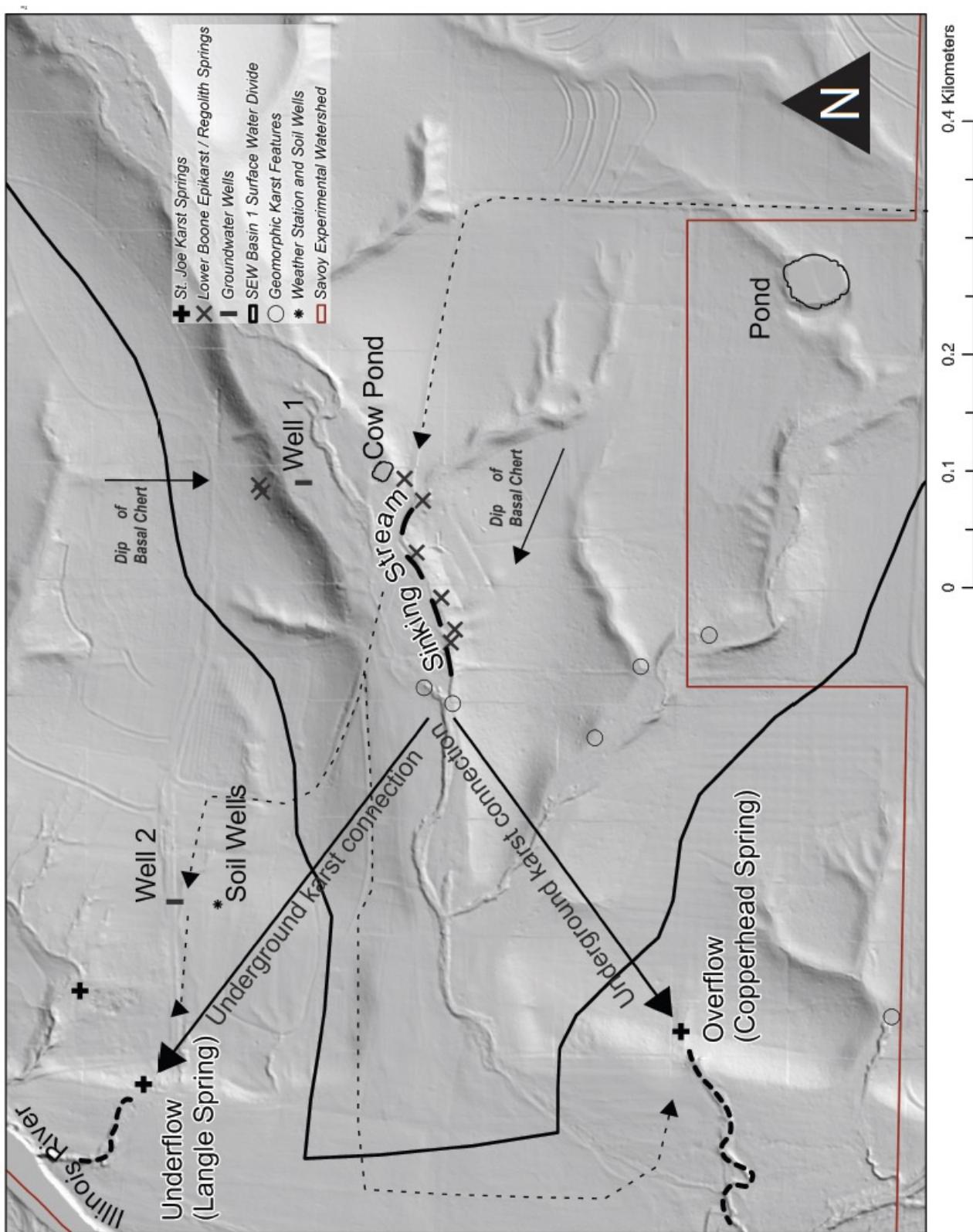


Figure 1. (A) Regolith covering the Boone Limestone in Northwest Arkansas. It is primarily composed of insoluble chert and clay minerals that are left behind when the limestone dissolves. (B) An estavelle near the sinking stream shortly after a flood event. During low flow it is a sink point and during high flow it is a spring.



Figure 2. (A) The Cave Salamander (*Eurycea lucifuga*) and (B) Grotto Salamander (*Eurycea spelaea*) are two species commonly observed in caves and groundwater in Northwest Arkansas. Such species are sensitive to human disturbances that degrade water quality within karst conduits and caves.



2.2 Site Descriptions

| | |
|-------------------|---|
| Langle Spring | Underflow spring that has larger discharge during low flow periods but limited flow variability. |
| Copperhead Spring | Overflow spring with low discharge during low flow and high discharge during floods. |
| Wells 1 and 2 | Two deep wells that were drilled through bedrock and reach the water table. Water level is about 2 meters below ground surface at Well 1 and 7 meters below ground surface at Well 2. |
| Epikarst Springs | Small discharge springs and seeps that flow out into a surface channel. We will number them 1 through 6 from east (upstream) to west (downstream). Spring 2 is also called Tree Spring. Spring 6 is Red Dog Spring. |
| Sinking Stream | Short section of surface stream channel that sinks entirely during low flow. There are multiple sink points and the final sink point migrates depending on flow level. |
| Soil Wells | Site of shallow and intermediate soil wells with CO ₂ and O ₂ sensors deployed in them. We cannot sample here, but we have ongoing data collection with loggers. There is also a weather station. |

2.3 Field Methods

2.3.1 Stratigraphy and the Critical Zone

Materials Needed:

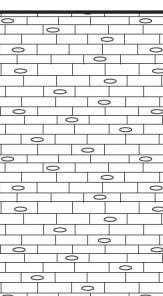
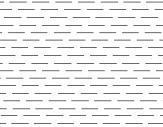
- Jacob's Staff
- Hand lens
- Rock hammer
- Stratigraphic column
- Brunton Compass

Stratigraphy is the study of the spatial and temporal relationships of rock units [MacLeod, 2005]. Stratigraphers are interested in how rock units relate to each other for a variety of reasons: to date events, to create geologic histories, to understand hydrogeologic systems, etc. In our case, we are interested in what controls the location of our karst springs, the source of the overlying regolith and soil, and ultimately- what units make up the critical zone in this location and how the properties of the rocks influence critical zone processes.

To characterize the stratigraphy of an area, stratigraphers rely on a variety of tools: hand lenses, rock hammers, compasses, and measuring sticks (Jacob's Staffs). We use these tools

to accurately describe the rock units, sometimes down to a scale of a centimeter. The goal of this is to create a stratigraphic column – a to-scale, representative description of rock units and their relationship to each other. A stratigraphic column has been presented to you below.

Spend some time looking at the three major units of SEW. Make descriptions of unit thickness, any fossils you see, a general description of the rock, and think about what relationship this unit may have to the critical zone. We will discuss afterwards.

| Age | Name | Lithology | T | Fossils | Description | Critical Zone Relationship |
|----------------------------|--|---|---|---------|-------------|----------------------------|
| Mississippian (358-323 Ma) | Lower Boone Fm. Limestone |  | | | | |
| Devonian (419-358 Ma) | St. Joe Mem. Limestone Northview sh. |  | | | | |
| Chattanooga Shale | |  | | | | |

Fm: formation. **Mem:** member. **T:** thickness (meters) of unit at field site. *Note:* the St. Joe is a member of the Boone Formation. Lithology swatches are derived from the USGS FGDC Digital Cartographic Standard for Geologic Map Symbolization. Figure by E.W. Oleson.

2.3.2 Dye Tracing

Materials needed:

- Rhodamine dye
- Two Cyclops7 field fluorometers
- latex gloves

One of the biggest challenges of managing karst groundwater resources is that underground water can travel quickly from one place to another along karst conduits (solutionally

enlarged flow paths that act like pipes). These flow paths are often impossible to explore directly or to predict based on surface observations. The most common tool to prove underground flow connections, and to determine travel times, is dye tracing [Alley, 2019]. To conduct a dye trace, a location is chosen for a dye injection, normally some point where water enters the subsurface, such as a sinkhole, sinking stream, or cave. Then one attempts to detect dye at potential outlet points, or sometimes within the aquifer in a cave or well.

Dye can be detected a number of ways, depending, in part, on the dye used in the trace. All tracer dyes are non-toxic, and most of them are fluorescent at specific wavelengths. This fluorescence can be detected at very low concentrations, and different dyes that fluoresce at different wavelengths can be distinguished. Common methods for detecting dye include water sampling, activated charcoal packets, and field fluorometers. Dye receptors are placed in potential downstream or down gradient locations called monitoring locations. The dye is carried by the flow, and receptors will detect the dye if it arrives at the monitoring location, proving a flow connection. In addition to proving a hydrological connection, dye can also provide information about travel time, tracer dispersion (spreading), and dilution. This information helps us to understand how water moves from one place to another and how water systems are connected. Tracing can be helpful in aquifer monitoring, pollution tracking, and water resource management development. For example, determining how dye travels between water sources will show how pollutants will travel between the same water sources.



Figure 4. Fluorescent dye travels downstream from an injection site moments after injection.

For this workshop we will use a nontoxic fluorescent dye called **rhodamine**, and the receptors will be **field fluorometers**. Fluorometers are instruments that are able to detect fluorescent dyes in water at very low concentrations. A field fluorometer enables what is called a quantitative trace, meaning that you obtain information not only about detection or non-detection but also about how the concentration of the dye changes over time. Quantitative traces are needed to precisely determine travel time, dispersion, and dilution.

We will place fluorometers at Langle Spring and Copperhead Spring, and we will inject dye in the sinking stream. The fluorometers will be collected the next day to analyze data. There may be no detection yet, as the dye may not reach the monitoring locations within this short time frame.



Figure 5. Cyclops-7-Logger Fluorometers that will be used in the dye trace.

2.3.3 Discharge

Materials needed:

- stopwatch (phones)
- graduated cylinder
- tape measure
- HOBO SpC datalogger
- laptop to download data and USB cable
- protractor to measure angles of weirs
- bucket and stirrer
- salt (lots of salt)

Discharge is the volume of water flowing through a stream or spring per unit time. Quantifying discharge is important in understanding and interpreting water quality data. For more details on discharge procedures, see Rantz [1982].

Discharge is frequently measured using a transect across a stream channel with many measurements of depth and velocity (Figure 6). However, this method can be both time consuming and impractical in some situations, particularly in small streams and springs like the ones we will work in at Savoy. Here, we will learn how to calculate discharge using 1) weirs (multiple techniques) and 2) tracers.

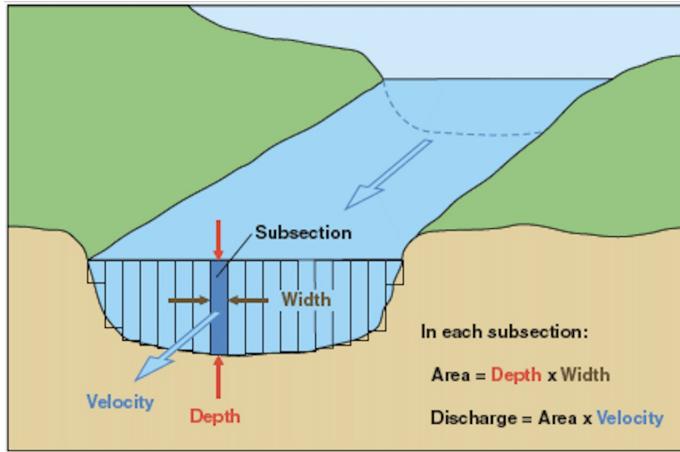
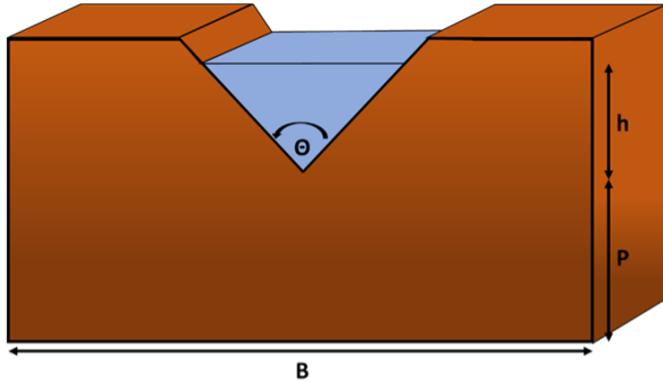


Figure 6. Conceptual explanation of velocity-depth discharge measurements. Courtesy USGS.

Discharge with Weirs



A **weir** is a specially designed dam, where the discharge of water is a direct function of the depth of flow over the weir. One of the most common types of weirs is a V-notch weir. Discharge can be found using a V-notch weir by simply measuring the head (or height) of the water within the weir and the angle of the weir notch, and then calculating discharge with the equation below.

$$Q = 4.28C * \tan\left(\frac{\theta}{2}\right)(h + k)^{\frac{5}{2}} \quad (1)$$

Where: Q is discharge in cfs (cubic feet per second), C is the discharge coefficient, θ is the weir notch angle in degrees, h is the head height (feet), k is the head correction factor (feet). To calculate C and k :

$$C = 0.607165052 - 0.000874466963\theta + 6.10393334 * 10^{-6}\theta \quad (2)$$

and,

$$k = 0.0144902648 - 0.00033955535\theta + 3.29819003 * 10^{-6}\theta^2 - 1.06215442 * 10^{-8}\theta^3 \quad (3)$$

Note: There is no need to calculate discharge using the weir equation in the field, we will do this in Python later.

Record your data in **Table 7** at the end of the packet.

Discharge with Bucket and Stopwatch

We can also use the volumetric method with weirs, by simply measuring the time taken to fill a container of known volume. The water flowing over the weir can be conveniently captured in a bucket or graduated cylinder. Then discharge can be calculated by dividing the volume of water collected by the time required to collect the water. Since measurement of time can be imprecise, we will use duplicate measurements to reduce our error. Each bucket and stopwatch measurement should be repeated 5 times at each site, so that measurements can be averaged.

Record your data in the **Table 9** at the end of the packet.

Discharge using Tracers

Tracer dilution discharge measurements use the extent of dilution of a concentrated tracer to calculate discharge, where the tracer is injected upstream, and concentration is measured at a point downstream. When we plot the concentration through time over the duration of a tracing experiment, we get what's called a "breakthrough curve" which we can use to calculate discharge. Tracers may include common salt, which can be detected using a conductivity meter, or fluorescent dyes, which can be detected with a fluorometer. The tracer can be introduced using a pump that runs continuously at a fixed rate, or as a sudden injection of tracer with a known total mass. Here, we will use the sudden-injection technique.

Tracer dilution discharge measurements assume that the tracer is well-mixed through the stream cross-section at the downstream measurement point. Therefore, **it is important that the measurement point be far enough downstream to allow mixing**. For small streams, a distance of 10 to 20 channel widths is typically sufficient, but there are also formulas available to estimate the required mixing length. If you go too far downstream, then too much dispersion and dilution may have occurred in order to detect the tracer.

Steps to calculate discharge from a tracer:

1. Choose site where you will place specific conductivity logger, place logger, and measure and note background conductivity levels using handheld meter. Ideally place the logger near the center of the flow.
2. Walk upstream and measure the distance from injection to logger site.

3. Fill bucket with stream water, add salt and mix until dissolved.
4. Note the time and dump the salt mixture into stream. Dumping in the middle of the flow enables faster mixing across the stream.
5. Use the conductivity meter to track conductivity over time as salt begins to travel downstream.
6. The speed of the stream will influence how long you will need to measure conductivity. Stop continuous measurements a few minutes after specific conductivity reaches background levels (use the handheld meter to determine this, as the logger does not have a display).

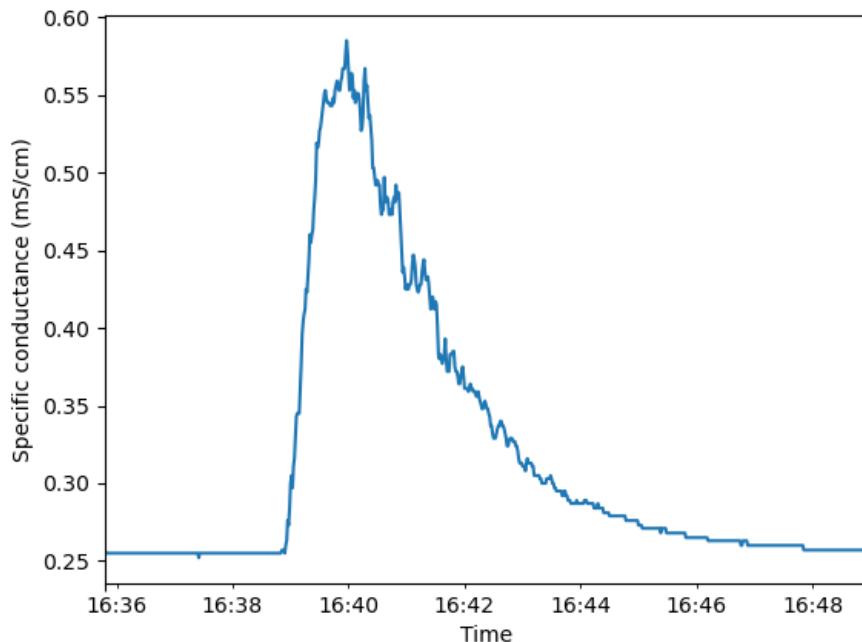


Figure 7. Example breakthrough curve of specific conductance (SpC), as measured by the HOBO logger. Note that there is a natural background SpC of about 0.25 mS/cm.

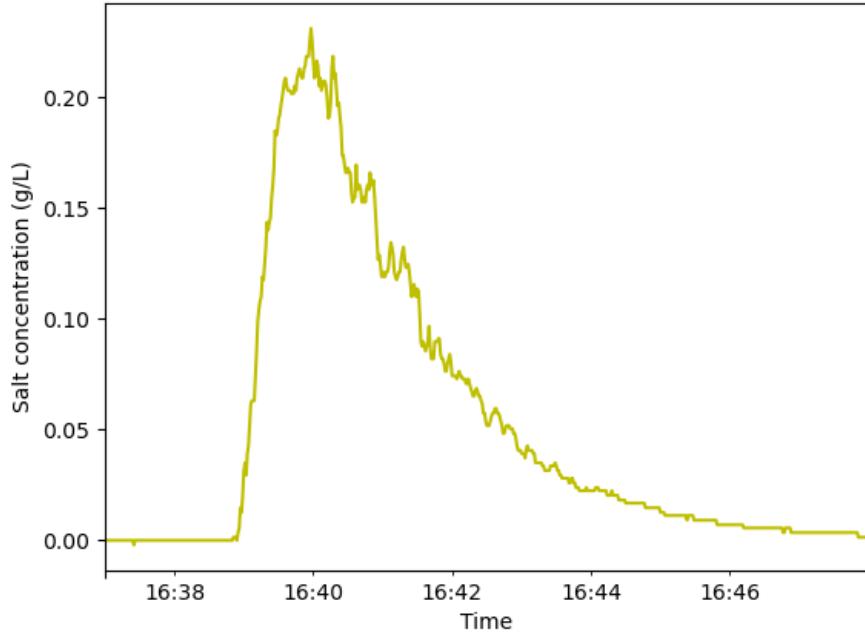


Figure 8. Example breakthrough curve converted into salt concentration by subtracting the background SpC and multiplying by the conversion constant k . Note that concentration is now near zero before and after the pulse.

We will calculate discharge on the computer in Python. However, the basic principle of the calculation is that specific conductance (SpC) is converted into equivalent salt concentration using the equation

$$C_{\text{salt}}(t) = k[\chi(t) - \chi_{\text{bg}}], \quad (4)$$

where C_{salt} is the salt concentration in g/L, χ is the SpC, and χ_{bg} is the background SpC in mS/cm. k is a constant quantifying the increase in conductivity from the addition of salt. It is approximately 0.5 to 0.7.

Once you have a breakthrough curve for salt concentration (Figure 9), then you can calculate discharge using the known mass of salt you injected and an assumption that all of the salt passes by your observation point (conservation of mass). This leads to

$$Q = \frac{m_{\text{salt}}}{\int_{t_i}^{t_f} C_{\text{salt}}(t) dt}, \quad (5)$$

where Q is discharge (L/s), and t_i and t_f are times before and after the tracer pulse, respectively.

While we will do this calculation in the computer lab, you should record the basic information about your tracer injection in **Table 12** at the end of the packet.

2.3.4 Water Quality Measurements in surface water (streams and springs)

Equipment needed:

- YSI Proplus multiparameter meter

Water quality monitoring is usually conducted for many purposes, including 1) characterizing and identifying changes in the geochemistry of water bodies, 2) identifying and quantifying emerging water quality problems, 3) and understanding the dynamics of hydrologic systems. Field water quality monitoring equipment allows us to measure water quality parameters in situ during field visits and without the need to collect physical samples and bring them back to lab. For more information on water quality see Wilde [2008].

Record your data in the **Table 14** at the end of the packet.

During field visits, it is also important to take notes about the weather conditions, the characteristics of the waterbody, and any features that might modify the water quality variables. When taking notes and thinking about water quality at each waterbody, consider the following questions:

1. How clear is the water?
2. Are there any signs of biological activity (e.g., algae growth)?
3. What is the surrounding land use? Are there any activities that could be impacting the water quality (e.g., urbanization, agricultural activities, etc.)?

2.3.5 Measurement of dissolved CO₂

Equipment needed:

- Vaisala GMM252 sensor (waterproofed with PTFE membrane)
- Logger to record CO₂ over time

Many of our research questions at the site relate to CO₂ production, consumption, and movement through the basin. One can calculate dissolved CO₂ concentrations (normally as a partial pressure) using pH and the concentrations of major ions in the water. However, it is also possible to directly measure the partial pressure of CO₂ with a field instrument. Here we have repurposed a CO₂ gas sensor, intended to be used in air, following techniques described by Johnson et al. [2010]. The sensor has been waterproofed with a breathable PTFE membrane (like Gore-tex). This membrane protects the sensor from water but enables gases to exchange across it. If the waterproofed sensor is submerged in water, it gradually equilibrates to the gas concentrations dissolved in the water. Full equilibration typically requires 30-45 minutes.

Procedure:

1. Make sure that sensor is turned on and logger is logging.
2. Note time of submersion.
3. Put sensor into the water so that it is fully submerged and note initial CO₂ concentration displayed on logger.
4. Leave for 30-45 min until reading stabilizes.
5. Note time, and remove logger from water.

Record your data in **Table 15** at the end of the packet.



Figure 9. Waterproofed Vaisala CO₂ sensor used for direct measurement of the partial pressure of CO₂ within water.

2.3.6 Measuring water quality within wells

Equipment Needed:

- Water level meter
- Submersible pump and battery

- Bucket
- YSI Proplus multiparameter meter

Wells provide access to measure water quality deeper within the subsurface and also enable us to measure the depth of the water table or potentiometric surface. To measure the depth to the water table, we use a water level meter, which is a tape measure that beeps when the tip is submerged in water. To do so, the tip of the tape measure is slowly lowered down the well until it beeps, then the depth of the water from the top of the well casing is recorded. We also have to measure the distance from the top of the well to the ground so the height of the well casing can be subtracted. This allows us to determine the depth of the water below the surface.

When wells are unused for a period of time, water can remain stagnant inside the well casing and interact with the atmosphere, leading to water quality conditions that are not representative of the surrounding groundwater. Thus, to measure water quality within wells, we first have to purge the well to make sure that we are measuring fresh water. To accomplish this, we can follow different strategies, such as purging water up to 3 to 5 well volumes before data/sample collection, or purging until chemical parameters are stable.

The purge volume method requires us to determine the volume of water that is stagnant in the well. To do this, we need to measure the casing diameter and the water depth, as well as know the total depth of the well. With this information we can then calculate the volume of the cylinder ($V = \pi r^2 h$) of water, which will correspond to one well purge. Pay attention to the units!

The chemical stabilization method requires that, for at least three consecutive measurements, the pH remains constant within 0.1 pH units, and the specific conductance varies no more than 5%. For more information see EPA.

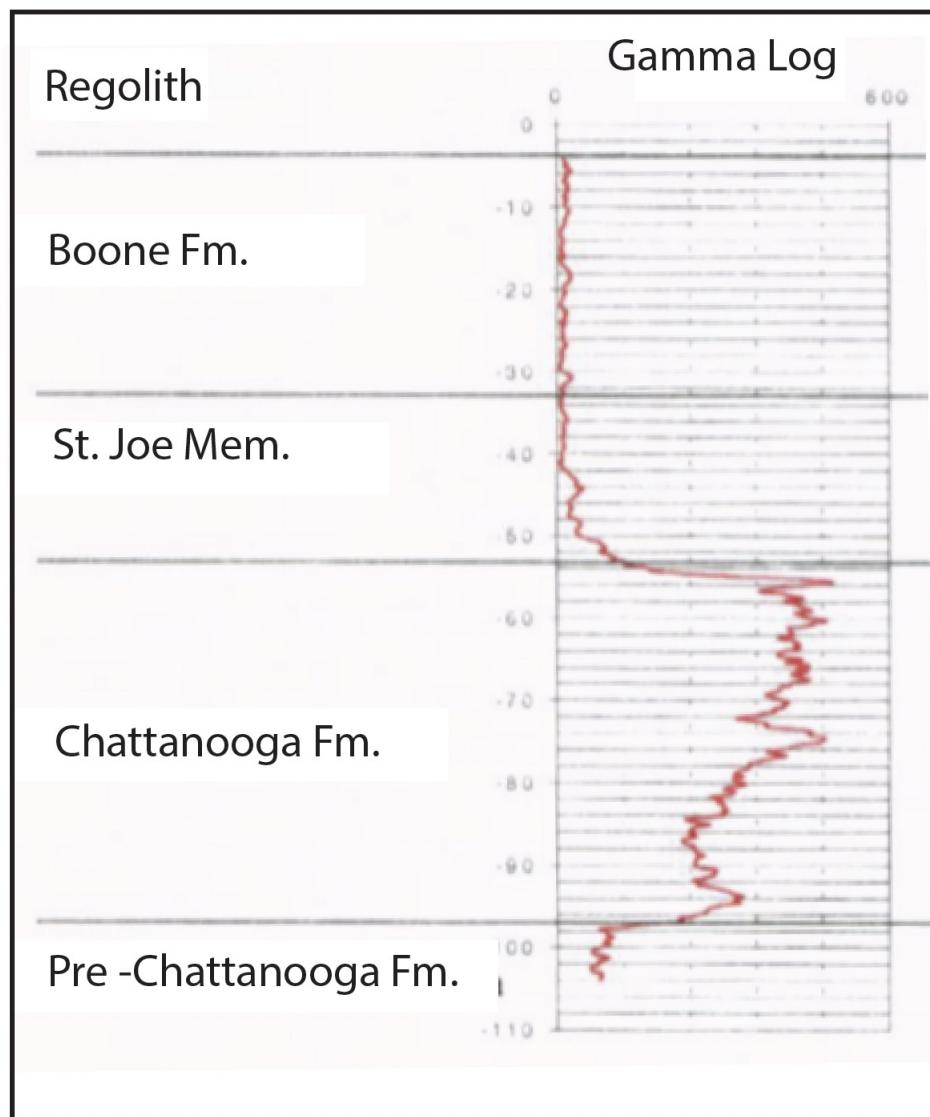


Figure 10. Gamma Log from Well 1. Showing results from the Pre-Chattanooga through Boone Fm.

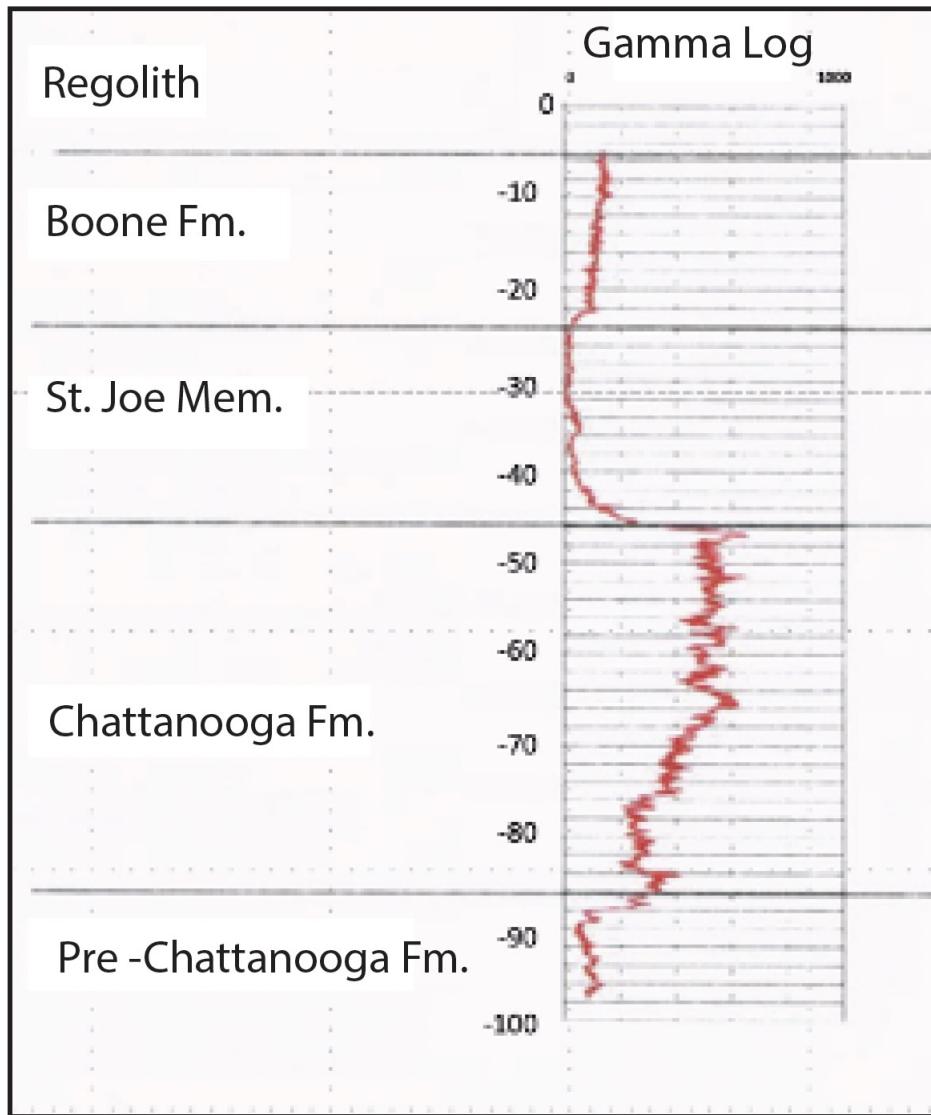
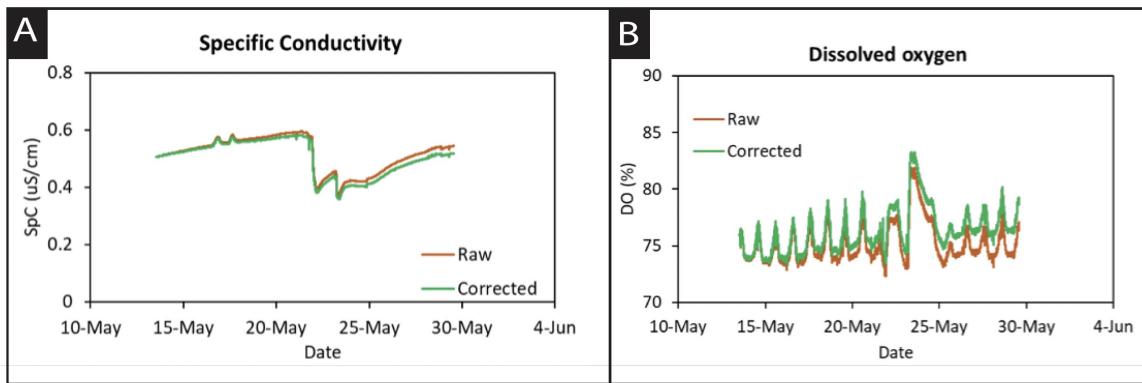


Figure 11. Gamma Log from Well 2. Showing results from the Pre-Chattanooga through Boone Fm.

2.3.7 Loggers and Time Series Data

Water quality monitoring loggers can be deployed in waterbodies to continuously monitor water quality parameters and obtain high-frequency long-term datasets. However, field loggers need to be calibrated periodically to correct for drift in the sensors and obtain high-quality data. In addition to periodic instrument calibration, data can also be reprocessed in the laboratory to correct for this incremental drift. Below are examples of two real datasets for specific conductivity and dissolved oxygen (DO) before (raw) and after (corrected) drift correction. Drift can be corrected using spot measurements of water quality parameters with recently calibrated instruments.



References

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Field sketch of sinking stream site

Final Conceptual Model

Notes

Table 7: Table to record data for discharge by weir.

Table 9: Table to record data for discharge by bucket and stopwatch. V is the volume of water collected. T is the time it took to fill the volume.

Table 11: Table to record data discharge by tracer.

Table 13: Table to record data for water quality.

Table 15: Table to record data for Dissolved CO₂.