ETH glaciology field-course 2021: glacier hydrology

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The aim of the glacier hydrology group is to quantify supraglacial and proglacial water runoff using different methods. Additionally, if available, we measure water level in boreholes. These measurement will provide insights into the glacier drainage system, as well as demonstrating how linking several measurements (salt-dilution gauging, stage measurements) can yield the desired quantity (discharge).

The text book by Hubbard & Glasser (2005, p73-79; a copy is in the field-material provided) gives an introduction to salt dilution gauging. I recommend reading this if you are not familiar with the method to get a description of it. Note though that they use a slightly different, but equivalent, approach.

1 Preparation at VAW

Pack-list:

- Misc:
  - several copies of these instructions
  - Puma-tape and string
  - hand-held GPS / smart phone which displays coordinates (preferably Swiss system)
  - Camera / smart phone
  - two or three radios (walky-talky)
  - one small bottle of fluorescent dye (just for fun!)
  - cord (20m, at least 7mm) & screw carabiner (to secure descent route at proglacial stream)
- Salt dilution:
  - WTW conductivity probes, logger and cheat-sheet
  - Keller DCX22 CTD autonomous conductivity probe and logger

  - salt, pre-packaged (for first day 8kg for proglacial stream, a few 100g in various package for the glacier streams)
  - 2x big bucket (10l) and stirring implement
  - 1l measuring pot
  - calibration solutions
  - poles: 2x 2m + connector to attach sensors when measuring lake outflow, 8x wooden poles to mark injection and detection points of two supraglacial streams.

- Stage of lake and streams
  - 2x Keller DCX-22 pressure sensor in protective casing to reduce risk of fine sediment clogging sensor
  - 1x Keller DCX-22AA dual pressure sensor (water & air)
  - cord (2-3mm), about 20 m in total
  - big ice picks
  - doppelmeter (yardstick)

- For Tiefenbach (base-camp / in car)
  - Dell field-laptop (vawnb24) and charger
  - USB stick
  - cable to download Keller sensors
  - WTW charger (probably in its box)
  - scales
  - spare salt (at least 10kg)
  - spare zip-lock bags
  - weight to attach to probe (for measurements in Gletsch)

1.1 Conductivity meters

You are using a conductivity meter by WTW and one by Keller.

The **WTW sensor** is a TetraCon 925, the logger is a Multi 3630 IDS. It has certain quirks, be sure to follow the steps outlined in section 2.2.4 and 3. Another gotcha is that it changes from mili to micro Simens on the fly. This may confuse you.

Be sure to set/check the clock on the datalogger to Swiss summer time.

The **Keller sensor** is a DCX22 CTD sensor and logger. It has no interface like the other but needs to be programmed with a laptop (the day/evening before). See 1.4 for the configuration, same as DCX-22.

1.2 Salt calibration solution

The aim is to produce a 1g/l and a 10g/l calibration solution here at the VAW (not in the field!). Steps:

- take salt which you are using for the experiments
- measure 10g of salt (there is a accurate scale in the "Analyseraum" at VAW)
- take 1l of distilled water (should have about 3 μS/cm), make sure to rinse the container first with distilled water
- dissolve it in the 1l, put 100ml in a rinsed, glass sampling bottles → 10g/l solution (should read about $17\times10^3\,\mu$ S/cm)
- take 10ml of the 10g/l solution and add it to 90ml distilled water (in one of those sampling bottles). → 1g/l solution. (should read about $1900\times10^3\,\mu$ on the WTW)

1.2.1 Test Calibration

First, be sure to set/check the clock on the datalogger to Swiss summer time!

Perform one calibration with distilled water: measure conductivity of 1l of distilled water after adding a total 0ml, 1ml, 5ml, and 10ml of the 1g/l solution. Repeat same with the 10g/l solution, starting with fresh distilled water.

1.3 Salt pre-packaging

Measure out zip-lock bags of 10x 10g, 10x 20g, 5x 50g, and 10x 1kg.

1.4 Pressure transducers

We'll employ a series of pressure transducers to record: lake-level, stream-level and, maybe, air-pressure.

DCX-22 (pressure only) and **DCX-22 CTD** (with conductivity). Configuration and download is with the field-laptop.

- check/set time and date of computer (to an accuracy 1 *second*, as for the flow speed measurements with the CTD we need that accuracy.)
- Open "Logger 5". **Note:** be patient with the program, sometimes it is rather slow.
- plug in cable K-104A & sensor to that cable
- press "F2" (scan ports) and after waiting a bit click "Programming"
- For **pressure-only (DXC-22)** modify settings to
  - Device memory: "Linear"
  - Device clock: check box "Adjust device clock..."

  - Start record: “Immediatly when writing configuration”
  - Measure interval: 1 minute
  - Channels: “P1”, “TOB1”
  - Click “Write configuration” (click through warnings), wait some time until it says “Record active” at the bottom
- For **dual pressure-sensor (DXC-22aa CTD)** modify settings to
  - Device memory: “Linear”
  - Device clock: check box “Adjust device clock...”
  - Start record: “Immediatly when writing configuration”
  - Measure interval: 30 Sec (should give approx 8 days recording time)
  - Channels: “P1”, “P2”, “TOB1”, “TOB2”
  - Click “Write configuration” (click through warnings), wait some time until it says “Record active” at the bottom
- For **conductivity (DXC-22 CTD)** modify settings to
  - Device memory: “Linear”
  - Device clock: check box “Adjust device clock...”
  - Start record: “Certain time and date” Time: 8:30, date: the next day
  - Measure interval: 1 **second** (gives about 10.5h recording with 3 channels)
  - Channels: “P1”, “TOB1”, “ConRaw”
  - Check: “Measuring range” is 0...200μS/cm (the 0...2000μS/cm shows a non-linear response and is thus hard to calibrate/use)
  - Click “Write configuration” (click through warnings), wait some time until progress-bar is done and it says “Record prepared” at the bottom
- Unplug sensor, close “Logger 5”

The pressure transducer for the lake should go into a casing to avoid it getting clogged by fine lake sediments.

2 In the Field

2.1 Mapping

Wander around the glacier and map moulin locations with a handheld GPS. Remember that the accuracy of the hand-help GPS is about 5-10m, so no need to lean over the moulin to get more accuracy. For each moulin write down the coordinates (CH LV95) and an estimate of maximal daily discharge going into the moulin (on a scale 1-10).

During this mapping you should also select the supraglacial stream which you will be gauging with the salt dilution tracer method (see below).

Separately, probably on another day, map a few catchments with the Trimble GPS (or the handheld if the Trimble is not available). The catchment mapping may be more difficult: the idea is to walk along the watershed (Wasserscheide) and record the coordinates. Depending on the watershed it will be tricky to determine its exact location.

2.2 Stream gauging

2.2.1 Stream selection

You probably want to select one of the biggest streams. Also check back with the mass-balance group, ideally you gauge the catchment in which their surface melt measurements take place (for later comparison). The most important selection criteria is safety: you should be able to do the salt injection and conductivity measurements from a stable platform, and do the conductivity measurement at least 5m upstream from the moulin. Also, do not venture into areas of rock-fall danger.

The injection site should be at least 20 stream-widths above the measurement site, more if the mixing is poor; probably around 20m will be good. This is to ensure that the tracer is fully mixed by the time it passes the sensor. Also this will draw out the tracer cloud over several 10s of seconds which is good as we're logging at a 1 second interval.

2.2.2 Supraglacial stage measurements

Manual:
Whenever you are at the stream, do a stage measurement. As the stream should be fairly small it should be easy to measure depth and width with a yardstick. Measure always at the same location, probably somewhere between the salt injection and detection site.

Record: time, width, depth

Automatic:
At the supraglacial stream which you will do most salt dilation experiments, install an automatic stage measurement station.

For this place a pressure sensor into a pool of water. As the stream is probably small, make a pool with the big ice pick. Place the DXC-22aa sensor into it, secure it to a pole (get the group with the drill you a hole).

2.2.3 Water flow speed measurements and hydraulic roughness

The elevation difference is what drives the flow in a channel, and the friction is what hinders the flow. This is captured in the Darcy-Weisbach relation $\Delta h = \frac{1}{2g} f v^2 / D$ where h is elevation, v speed, D hydraulic diameter, g gravitational acceleration, and f a friction factor. We want to get f, so we need the rest:

- The time between detection of the salt peak at two different stations divided by the flow path length gives the flow speed v.
- Flow speed divided by the discharge gives a mean cross sectional area A.
- The measured width and depth give an indication of the wetted perimeter P. The hyd. diameter is then $D = 4A/P$.
- The elevation difference Δh comes from RTK GPS measurements: measure both detection points. As the accuracy is about 10 cm, make sure that you get enough elevation difference to get a good signal to noise ratio. (For this you need to talk to one of the two groups with the RTK GPS).
- if you have enough time the RTK GPS, then you can measure the flow path length more accurately with the RTK by making a track along all the channel's bends (i.e. you get the sinuosity then).
- take photographs covering the whole length of the test section, to later gauge its morphology (sinuosity, step-pools, etc).

Measure: salt concentration at two locations, stream length (with RTK), stream elevation difference (do this with the RTK), mean stream width, mean stream depth (with yardstick)

Note your salt injections in your field-book in table like given in the next section.

2.2.4 Steps for salt dilution experiment on glacier

At injection site:

1. select amount of salt depending on discharge (this will take some practice). Probably in the range 10g to 100g.
2. prepare injection solution in the 1l measuring beaker
3. take photograph of stream
4. wait for ready signal from concentration measurement crew(s) and inject the salt
5. inject the salt in one go

At measurement site:

1. if discharge is too low to fully submerge the sensor, make a depression with the ice axe.
2. place WTW sensor in stream (the sensor itself is fully waterproof), ideally with the sensor located in the central part of the stream
3. place Keller CTD sensor close-by

4. let the sensor temperature stabilise ($\sim$2min)
5. write down the background conductivity of the WTW
6. signal to others to initiate injection
7. check the sensor readout during the tracer passage. Make sure that:
   - maximum concentration does not go above 200μS/cm (if it does, repeat with less salt)
   - that concentration rises by at least 10μS/cm to get a good signal to noise ratio (if not repeat with more salt)
   - the time interval is more than 15 seconds during which the signal is at least 5μS/cm above background (if not repeat but inject salt further up in the stream. This may necessitate a larger quantity.)

Write into field-book:

- Time
- amount injected
- WTW peak value
- WTW peak time
- WTW background value
- WTW back to background time (i.e. the time at which cloud completely passed)
- upper CTD sensor #
- lower CTD sensor #
- middle ...

2.3 Steps for sensor calibration

The sensors should be calibrated a few times. Also it should be calibrated for the range of conductivity measured.

Steps:

1. place sensors in ice water and let their temperatures equilibrate for a few minutes
2. rinse and fill 1l measuring beaker with water from the stream (probably transfer it to the slightly bigger bucket)
3. for WTW take zero reading and write in a table as below
4. for Keller: take note of the time, use about 15s at each concentration level
5. add a specific amount of the 1g/l or 10g/l calibration solution (using the totals suggested below, or other quantities if measurements demand).
6. take reading
7. repeat points 5 & 6

Make sure that the temperature of the water stays approximately as in the stream, i.e. don't let the beaker stand around before doing the calibration. The WTW sensor is temperature corrected but it is still better to do the calibration at the stream temperature.

Time	total ml added of **1g/l**	WTW readout (μS/cm)
HH:MM:SS	0	...
	1	...
	2	...
	5	...
	10	...

Rise beaker and get fresh water:

Time	total ml added of **10g/l**	WTW readout (μS/cm)
HH:MM:SS	0	...
	2	...
	4	...
	9	...
	13	...

Note: 1ml of the 10g/l should give a change of $\sim 20\mu$S/cm.

Depending on your typical recorded concentrations, you may not do the full calibration each time (but do the full one at least once).

2.3.1 Proglacial stream gauging

If you do a gauging of the proglacial stream at the lake outlet or at Gletsch, do a separate calibration using the stream water. The discharge of the stream at Gletsch can be checked on the BAFU website `https://www.hydrodaten.admin.ch/de/2268.html`, and should be in the range of 1 to 20m^3/s; select at least 300g of salt per m^3/s discharge. Use a big bucket to dissolve the salt. Here you need the radios for communications.

Get a safety briefing before doing gauging at the lake outlet!

2.3.2 Gauging of other streams

You may want to gauge the Rhone in Gletsch or the Muttbach before it flows into the Rhone. For Gletsch, be sure to inject the salt well above the place of measurements as previous groups found that mixing was poor.

2.3.3 Proglacial lake level measurements

Use the autonomous Keller pressure transducers to measure the lake level (and one to measure air pressure), type DC-22SG (0.8-1.8bar, or other). See section 1.4 on detail of setting the transducer up. Place the transducer in a strategic place.

Additionally, get the GPS group to measure the lake level with their differential GPS once a day. That way you can reference the lake level to an absolute datum, which can be used to relate to previous years measurements.

3 In the evening at base-camp (aka Tiefenbach)

Overview:

- Charge radios
- Charge WTW datalogger.
- Download the data from the Keller DCX22 CTD (this takes long, at least 20min per sensor!) & re-program for the next day.
- Check data visually using the Jupyter notebook provided (see below)
- Make sure there is enough pre-measured & bagged salt available for the next day; otherwise make more.
- Take it easy.

Download and re-program Keller DCX22 CTD:

- start field-laptop in Windows
- open Logger 5.0 program
- connect DCX22-CTD and press F2 to scan for it
- click “Read data” and press “F4” (if it asks “To set a mark” click “Yes”)
- now wait for a long long long long time (about 20min to download it all). Once done a window with a plot will open.
- There click “Export” (on the left), a new window opens:
  - check “UTF-8”, click “CSV2”
  - export directory: “Documents/Feldkurs_Rhone/YEAR” (create in the Explorer if does not exist)
  - click “Convert”
- store data onto USB stick
- **re-program for the next day**, see Sec 1.1; note down the starting time (suggested 8:30) in the fieldbook.

Important: data backup. Make sure that the data is stored in at least two places

- copy Keller-data from laptop onto USB-stick
- take photos of your field-book pages

Visual checking of data:

- start field-laptop in Linux (Ubuntu)
- cd to ....
- run textttjupyter notebook
- open `Data-visual-inspection.ipynb`

4 References

Hubbard & Gasser, Field techniques in glaciology and glacial geomorphology, 2005. Pages 65-79, in particular p.73-79. However, note that they use a different calibration strategy.

Schuler, Investigation of water discharge through an alpine glacier by tracer experiments and numerical modeling, PhD thesis, VAW ETHZ, 2002.