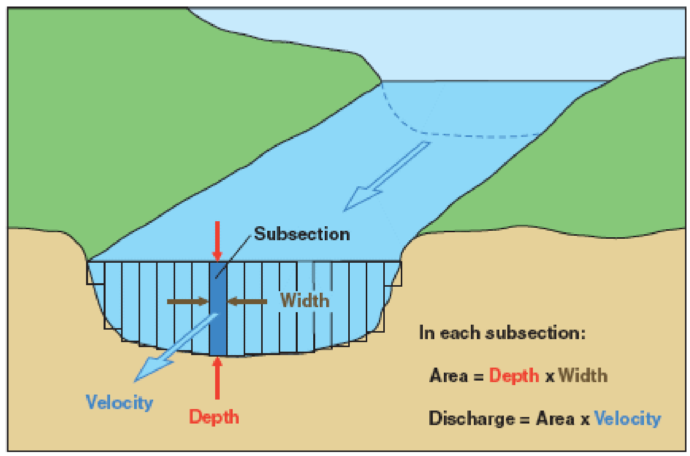
Lab Exercise #1: Stream flow

Objective:
To measure volumetric flow rate (Q) and mean velocity (υ) of a small local stream

Introduction

Streamflow is important to measure and document as it critical for determining water budgets, water scarcity, flood hazard and general "loading" of suspended or dissolved contaminants. There are many possible methods for measuring discharge (volumetric flow) and linear flow velocity in a stream, river, lake, etc. These include:

- Floating markers
- Drogues
- Tracers
- Mechanical current meters
- Acoustic current meters
- Laser doppler meters



In addition, there are methods employing weirs that can be used for estimating discharge, but not velocity. Since flow velocity may be variable at various points in a stream cross section, assessments of average velocity must be made at many points to capture the full range of values. All flow measurements require a timer (e.g., stop watch) and some additional equipment.

<u>Floating Markers</u>

Perhaps the easiest method makes use of near neutral buoyant objects. Due to their biodegradability, size and high visibility, it's common to use citrus (e.g., oranges, lemons). Some have also used Frisbees and disc cones.

<u>Tracer Methods</u>

Organic and inorganic tracers can be used for assessing flow characteristics in water bodies. Choices include inorganic ions such as chloride (measuring conductivity) or organic dyes such as rhodamine (fluorescence detection). In this lab we will use chloride. Use of tracers for measuring streamflow is sometimes referred to as "dilution gaging" A common and computationally simple approach is to pump a small volume of the tracer into a stream at a fixed rate over a duration similar to the sampling period (the constant rate method of injection). Collecting samples downstream allows one to measure the arrival of the tracer cloud (giving velocity) and the concentration after it fully arrives (giving flow)

The USGS offers a detailed description of this method at:
http://pubs.usgs.gov/wsp/wsp2175/pdf/chapter7_vol1.pdf

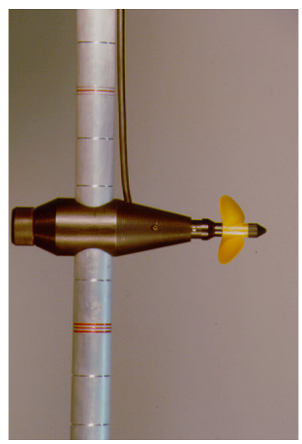
Another option, the instantaneous slug injection method, is also used for assessing longitudinal dispersion and general mixing. This method is simpler to implement as it doesn't require a stable constant injection rate.

Mechanical current meters

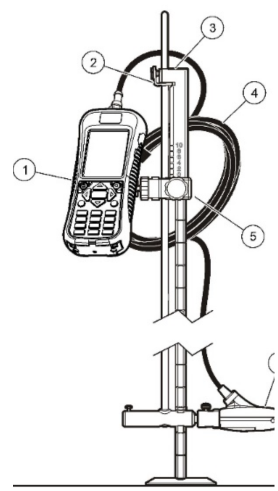
One of the most common methods is the use of current meters. For fast flowing waters mechanical current meters are an excellent choice. These are propeller driven devices that relate rotational speed to linear flow velocity. Examples include price meters, pygmy meters and swoffer meters. For slower velocities, electromagnetic meters may perform better.

Instream use a stadia rod or calibrated staff.

Swoffer meter



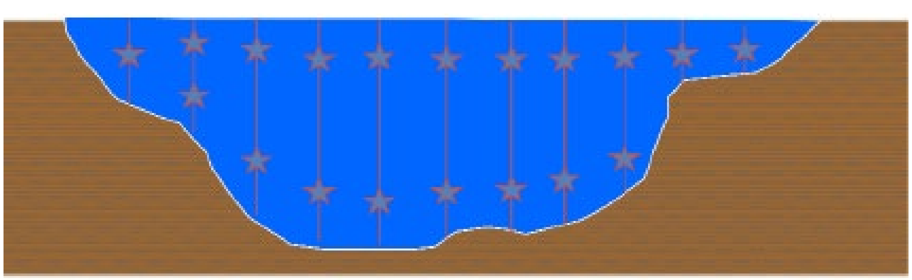
Hach FH950



Photos: from Swoffer & Hach Company

Typical current meter method

- Divide stream cross section into transects (8-15 total)
- Measure velocity in each with meter
    - at 60% depth in shallow water (<2ft)
    - or 20% and 80% depth in deep water



For more on general flow measurements, see the USGS website:
http://ga.water.usgs.gov/edu/streamflow2.html

Our preferred field site is the Mill River at the UMass WET Center on the west edge of campus.

Procedure

Week before

1. Select your group (3 people per group for this lab).
2. Decide on two methods[1] you will use and inform the TA right away. We can only accommodate a certain number of groups for some of the methods, so you may be asked to select an alternative method.
3. Write out a short plan and send by email to TA (copy professor)
4. Prepare a set of tables to help record (and remember to record) your field data

Day of the field tests:

5. Leave on time to reach the WET Center by 2:30 on your assigned lab date. Parking is limited, so we recommend you walk (~17-minutes from Marston). Make sure you have your notebook and that you are dressed for the weather and for wading in the river.
6. Select the location along the river for your measurements
7. Follow the TA's instructions as to which method you should try first and begin assessing flow and velocity with that method
8. Move on to your second method
9. Complete data collection and return equipment to TA in the WET Center

Follow-up

10. Measure conductivity on any samples collected from the Mill River
11. Analyze your data for flow and velocity for the two methods
12. Compare your estimates
13. Prepare a write-up (one per group) on the measurements. Use the guidelines for laboratory write-ups to help you structure and present the results.
14. Turn in your write-up no later than 1 week after your lab period.

Float method

Inexpensive and simple. This method measures surface velocity. Mean velocity is obtained using a correction factor. The basic idea is to measure the time that it takes the object to float a specified distance downstream.

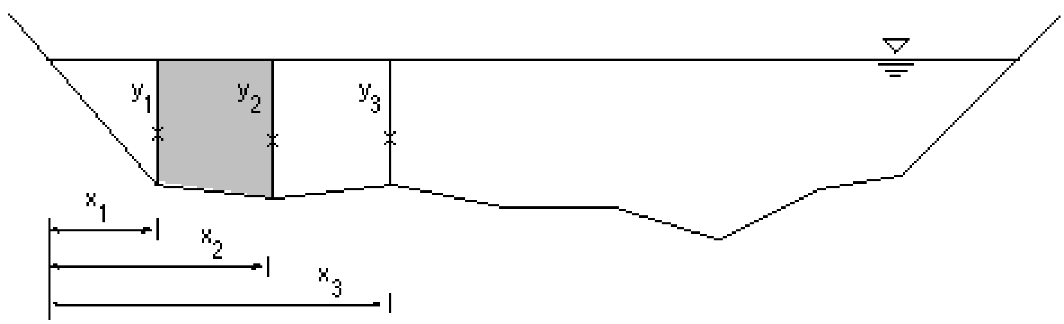
$$\upsilon_{surface} = \text{travel distance/ travel time} = L/t$$

[1] The methods you may select include: 1. Flow meter, 2. Tracer (conductivity), or 3. Floating marker

Because surface velocities are typically higher than mean or average velocities $\upsilon_{mean} = k\ \upsilon_{surface}$ where k is a coefficient that generally ranges from 0.8 for rough beds to 0.9 for smooth beds (0.85 is a commonly used value)

Procedures

1. Choose a suitable straight reach with minimum turbulence (ideally at least 3 channel widths long).
2. Mark the start and end point of your reach.
3. If possible, travel time should exceed 20 seconds.
4. Drop your object into the stream upstream of your upstream marker.
5. Start timing when the object crosses the upstream marker and stop timing when it crosses the downstream marker.
6. You should repeat the measurement at least 3 times and use the average in further calculations.
7. Measure stream's width and depth across at least one cross section where it is safe to wade. If possible, measure depth across the stream's width at the start and stop markers and average the two but if measuring one cross section choose the downstream side. Use a marked rod, a yard or meter stick to measure the depth at regular intervals across the stream. Ten depth measurements is the minimum required but more is better, especially in larger streams. Average your cross-sectional areas (A): Using the average area and corrected velocity, you can now compute discharge, Q.



Q = Cross section area (A) * mean velocity (υ)

Essentially the cross section technique estimates each of the terms on the right hand side of the equation(s) and multiplies them together. The cross section area of the channel is estimated at a transect, across which water depth and average water column velocities are measured at a series of points (verticals).

Optional steps:

If increased accuracy is desired and the stream is wide enough, you can divide the stream into 3 or more sections or float lanes, and measure surface velocities in each lane.

Tracer method

This discharge measuring technique involves mixing a tracer of known volume and concentration (usually in the form of a solution) into a stream and measuring the downstream concentrations over time, until the concentration of the tracer reaches the background level in the stream. Calculating the discharge from the slug injection method involves integration, or calculating the area under the curve of concentration vs. time,

$$Q = \frac{mass\ of\ tracer\ added}{area\ under\ C\ vs\ t\ curve} = \frac{C_t V_t}{\int_0^\infty (C - C_b)dt}$$

Where $\mathbf{C_t}$ is the concentration of the tracer in the tracer solution, $\mathbf{V_t}$ is the volume of tracer solution added, **C** is the measured tracer concentration at the downstream site as a function of time, and $\mathbf{C_b}$ is the background tracer concentration in water to which no tracer was added

The slug injection method has the benefits of not requiring a large reservoir for tracer and this makes it suitable for remote sites. It is also fairly quick (approximately half an hour from start to finish), and inexpensive. Some things to keep in mind for this method are that the sampling interval at the downstream end has to be **short enough** to catch the peak, and the tail of the curve may be fairly long due to eddies and instream storage.

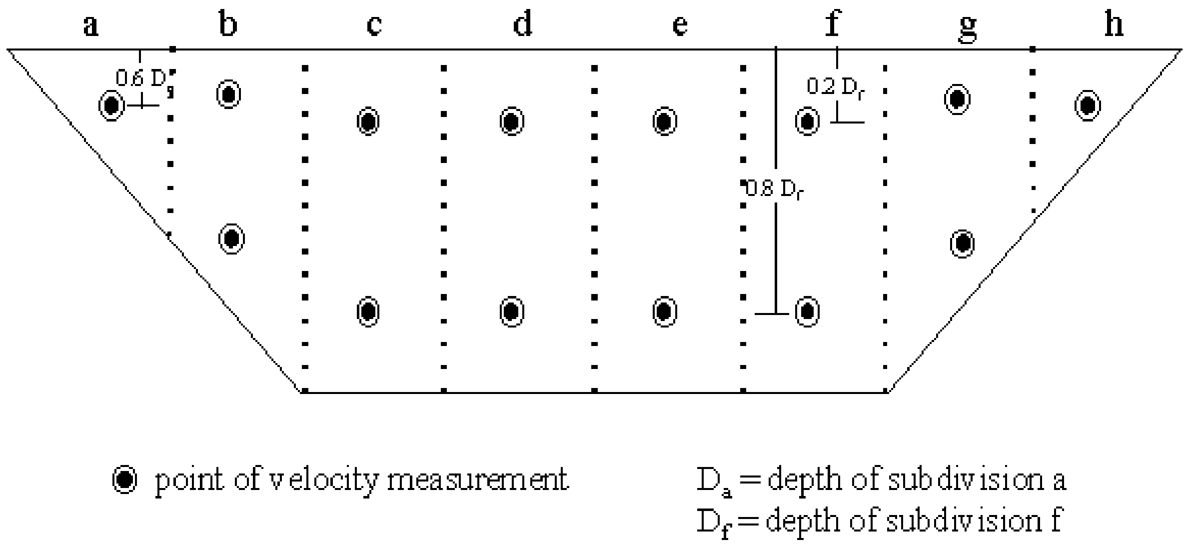
Procedures

1. Secure a known volume of the tracer solution from the TA. The TA will have prepared a large volume of tracer solution ahead of time; 1kg table salt in 6L of water.
2. Select measurement reach.
3. Use a pipette to extract a known volume of injection solution (e.g., 10 mL) and add to the secondary solution bottle. Cap the bottle and store upright.
4. Record background electrical conductivity (EC) and water temperature at the downstream end of the measurement reach, and upstream of the injection point.
5. Set up the conductivity probe at the downstream end of the mixing reach. Record the background EC and water temperature. If you have a data logger, start recording EC.
6. Inject a known volume of salt solution at the upstream end of the mixing reach.
7. Record the passage of the salt wave, continuing until EC returns to background. If EC does not return to background, measure EC upstream of the injection point again to determine whether the background changed.
8. Plot the salt wave at downstream end in the Mill River (conductivity vs. time) and calculate the discharge.

Typical current method

In order to determine the "average" flow in the river, one must estimate the cross-sectional area and an "average" current velocity in the channel. In practice, this is accomplished by subdividing the cross-section of the channel, determining the "average" flow for each subdivision, and summing the subdivision flows into a total flow for the channel. In a deep stream subsection, the average velocity is estimated by the average of velocities measured

20% depth (0.2D) and 80% depth (0.8D). In a shallow stream subsection where measurement at two depths is difficult, the average velocity is determined by measuring velocity at 60% of the depth (0.6D). This is shown schematically below:



The flow for each subdivision is determined by multiplying the cross-sectional area (width x height) of the subdivision by the average flow velocity within the subdivision. The volume flow through this channel, for instance, would be:

$$Q = (A_a\upsilon_a) + (A_b\upsilon_b) + (A_c\upsilon_c) + (A_d\upsilon_d) + (A_e\upsilon_e) + (A_f\upsilon_f) + (A_g\upsilon_g) +(A_h\upsilon_h)$$

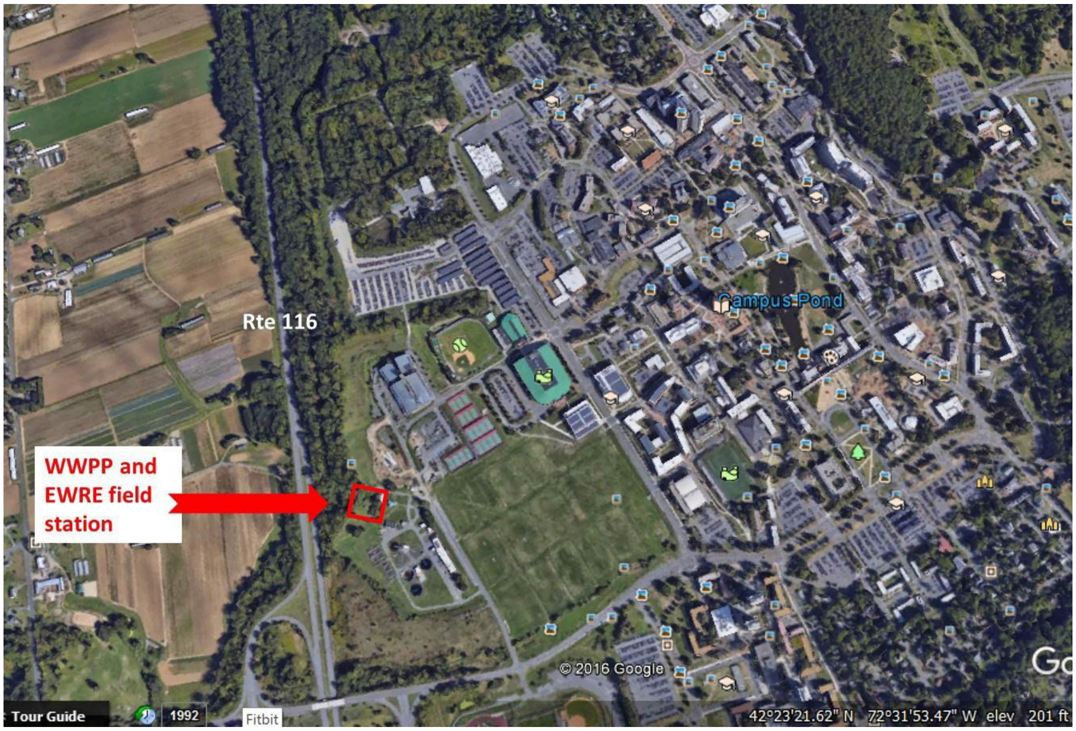
where $A_{a,}$, A_b, ...A_h = cross-sectional areas of subdivisions a, b, ...h
$\upsilon_{a,}$, υ_b, ...υ_h = average flow velocities of subdivisions a, b, ...h

The number and widths of the subdivisions depend upon accuracy desired.

Procedures:

1. Read the quick guide to use of our Hach FH950 velocity flow meters
2. Decide on the widths of the cross sections you will use
3. Measure and record average depth of the first cross section and decide if velocity should be measured at one depth or two, and what those depths should be in English or metric units.
4. Measure velocity at the one or two depths selected
5. Repeat steps 3-4 for each cross section
6. Calculate total streamflow (Q) using the equation above.

Directions to Field Site



The WET Center (WWPP and EWRE field station) is located on the west edge of campus. You can walk there by crossing the athletic fields just south of the Champions Center.

Special Topics to include in the write-up

In-Situ

a) Comment on how velocity changes with position (depth, proximity to bank) in the stream.
b) Which of your methods do you think is more accurate and why.
c) What are some of the real-world limitations of each method? Can you think of examples where one method may be more appropriate than the other?

Ex-Situ

a) Visit the National Water Information System website (http://waterdata.usgs.gov/nwis).
b) Once you have navigated here, select the blue bubble entitled 'Surface Water'. This will bring you to a page that contains all the surface water data measurements USGS has for the nation (a lot of data!).
c) Some of these data are real time, but a majority of these data are measured by gages that are not updated in real time. We will look for the Mill River Northampton gage to do our analysis. Note that this is an entirely different Mill River than the one in Hadley/Amherst. We use this one because our Mill River doesn't have a USGS gaging station and the Northampton Mill River shares many similar features. Select the blue bubble entitled 'Daily Data'. This will bring up a page with check boxes.
d) Check the box 'State/Territory' under the Site Location Field and click submit. This will help us narrow down our search for the Mill River gage. Select Massachusetts from the State/Territory box. Next scroll down the page a little bit and look over all the parameters the USGS measures. At some point in your career, class work, or research, you may need to find similar data. This website has a wealth of knowledge, all for free!
e) Look of the parameter 'Streamflow, ft^3/s' and check this box. It is under the Water Level/Flow Parameters about two thirds down the page. Click 'submit'.
f) A long list of stations should now appear. These are all the gauging stations within Massachusetts that the USGS makes measurements. Now scroll all the way down until you find the Mill River Northampton (site number 1171500) and click 'submit'.
g) You are now where the data for the Mill River Northampton resides. Under the blue box that says "Available data for this site", select 'Site Map' from the drop down menu. **Record the drainage area.** Note that the drainage area for our Mill River at the WET Center is about 24 square miles.
h) Now go back to 'Time-series: Daily Data" from the previous drop down menu. Let's first generate a graph and then get some data to play with. Make sure the Graph button is selected and then put in any two years (be mindful of the period of record!). **Include a copy of your handmade graph in the lab-writeup.**
i) Let's get some data. Select 'Tab-separated' from the output format box and pick the dates 1/1/1976 – 1/1/1996. This will give us 20 years of daily streamflow data to play with. Click submit and it will bring up an ugly large text file of our data.

In your browser (I use Firefox) use the select all command to copy the data (In Firefox it is under the Edit menu). Copy this data and open Microsoft Excel. Now paste the data into Excel.

j) The format is ugly, but we can fix this. First, delete the header information from the data (This is about the first 27 rows of data in Excel). Now that is done, highlight Column A (or whichever column you pasted the data into). Under the data tab, select Text-to-Columns. This function will separate the data into separate columns for us so we can do some analysis. Choose 'delimited' and then select 'Next'. Check the 'Space' Box and make sure that it looks like it will 'parse' the data correctly. Now click finish. You should have five columns of data. We really only care about the date field and the field that has the streamflow measurements in it immediately to the right of the date field (you can delete the others). You should have 7306 rows of streamflow data, now let's do some processing.

k) Let's calculate 'mean annual flow' for each year and plot this. Start by creating a column of numbers that begin with 1976 and incrementing by 1 up to 1995 (I used column H). Hint: type in the first few numbers by hand than highlight these cells. Once highlighted, a black box will appear around them, click the little black square in the bottom right hand corner of the black box and drag down. This will automatically fill in the numbers for you. If you can't get this to work, you'll have to enter them by hand.

l) Now that you have the years created, we will need to create a column of values that we can look up. Use the year command in excel to create a column that has only the year values from the date column. In my spreadsheet, my date column was C, so my formula looked like '=YEAR(C1)'. Drag this down to make sure each of your 7306 rows has a cell with the year in it.

m) Use the 'averageif' command to find mean annual flow for each year. In the cell next to the column that has the values 1976 through 1995 (mine was Column H from above), I typed '=AVERAGEIF($F$1:$F$7306,H2,$D$1:$D$7306)', because my YEAR column was in Column F (that is the range in the averageif function), Column H contained my Criteria (i.e., the year over which I wanted to average; with H2 being the cell contining "1976"), and Column D contained the range of streamflows I wanted to Average Over (Average Range).
    a. A side note: The dollar signs are used to lock references, a dollar sign in front of a letter means that the column is fixed, no matter how I drag my cell with the equation in it, a dollar sign in front of the number means that the row is fixed. You can play around with this to make sure you get them correct.

n) Your first value (1976) should be 67.07 cfs and your last value (1995) should be 53.01 cfs. **Create a plot of all the values against time and submit this with your lab report.**
    a. **Is there a lot of variability annually?**
    b. **What year had the highest mean annual streamflow, which year had the lowest?**
    c. **What is the ratio between these two years?**

  d. **What is the mean annual streamflow over the 1976-1995 period? (Hint: Should be close to 1986's value)**

o) Now we will leave figuring out how to calculate mean monthly streamflow up to you. I would recommend using the '=Month()' command to create a columns of months next to your year column and following what we did above. **Create a plot of average monthly streamflow for our period.** It should have months 1-12 on the x-axis and streamflow on the y-axis.

  a. **What month has the highest average flow? Why do you think this month has the highest flow?**

  b. **What month has the lowest flow? Why do you think this month has the lowest flow? (Hint: Precipitation is equally distributed over the year for Western MA, so rain falls about equally in each month)**

p) Lastly, we want to find the minimum and maximum streamflow. Use ='Min()' and '=Max()' to help with this. **What day did these occur on?** (Use Find to help you find the value). Hint: Low flow should be in September, High flow in May.