Stream Discharge

The volumetric flow rate of a stream is a very important variable. Technically it is known as the **stream discharge**, and is usually given in cubic feet per second, ft^3/sec, cfs, (U.S. engineers) or cubic meters per second [everyone else]). Plots of stream discharge versus time (hydrographs) give us information about the amount of water available for irrigation, industrial use, domestic use, and navigation. Hydrographs also give us information about the **flashiness** of a stream—the speeds and heights it reaches during rains, its tendency to flood, its tendency to erode its bed and banks, and, during dry spells, its tendency to have a very diminished (even zero) flow. Stream gages measure stream height, not discharge; to convert stream height (stage) to stream discharge it is necessary to make a calibration curve for the gage. This is a plot of stream height measured at the gage (x-axis) versus stream discharge (y-axis). In all the procedures described here we use English units (feet, accurate to 0.1 ft., seconds), as this is normal engineering practice in the U.S.
Although the pre and post discussions are necessary to provide important information about each topic, it is the activity that is most vital to this unit. Be sure to allow plenty of time to complete the activity.

Pre-Activity Discussion (Answers can be found in the Background Information section below)
Before beginning the activity, ask students:
1) How much water is going by here right now?
2) Does this amount ever vary? How does it affect living things?
3) What human activities affect the level of water in the stream?

The Activity

Equipment needed

Per group:
Small table (convenient but not essential)
1 gallon jug (empty)
4 marker flags
Surveyor's tape
2 rods to anchor surveyor's tape (or 2 flags)
4 colored clips to mark the depth points.
String long enough to mark width of the finish line. (30 feet or more)
1 stopwatch
3 tennis balls (or corncobs or sticks)
2 data forms
2 clipboards
6 calculators
yardstick or depth stick (home made, calibrated in tenths of a foot)
waders in 3 or 4 sizes, if needed
You are going to have a student or two in the stream, so they may need boots, water shoes or waders. They may also need a walking stick.
Optional: string, paper clips, or tape to mark depth points on surveyor's tape

Procedure for measuring stream speeds
Before students arrive
1. Select a reach of the stream in which there is at least 10 feet of stream of uniform width that is free from obstacles (rocks, woody debris, brush, aquatic vegetation, etc.). The stream must be safely wadeable. Avoid including pools or whirlpools in this section. It is preferable if there is not poison ivy along the bank. At the upper end of this 10-ft. section place a marker flag on the right side of the stream (the side that is on your right when you are facing DOWNSTREAM). Cross the stream and place a second marker flag on the left side of the stream <u>such that a line drawn between the two flags is at right angles to the direction of the current</u>.

2. From the marker flag on the right side of the stream measure 10.0 ft downstream from this flag and place a third marker flag on the bank at this point. Cross the stream and place a fourth marker flag on the left side of the stream <u>such that a line drawn between these two flags is at right angles to the direction of the current</u>. Attach a line between these two flags to mark the finish line.

3. Stretch a surveyor's tape across the stream from the first flag to the second, numbers increasing from right (facing downstream) to left. Secure the tape firmly so that it is taut and at least 6" above the water. This is your starting line. It may be convenient to have a couple of rods to stick into the stream bank to act as anchors for the tape. Record the width. Mark the surveyor's tape with colored clips, string or tape at distances 1/5, 2/5, 3/5, and 4/5ths of the way across the stream to indicate the points at which depths will be measured.

With students
4. You need four people to measure and record a stream velocity at some point in the stream.

1 is the "wet cat." 1 first measures the depth points along the surveyor's tape and tells them to 2 (the recorder). Then 1 stands in the stream about 5 ft. upstream from the tape at the desired point. 1 alerts the group, then drops the float into the water.

2 is the recorder. The recorder stands at the starting line to record the depths and the finish times. The recorder repeats the depths and the finish times out loud. If you have more than 4 students, have the 5th student also record the data on a 2nd data sheet. Just as the float passes the starting line, the recorder yells "Start".

3 runs the stopwatch. 3 stands at the finish line. When 3 hears 2 call "Start" he/she immediately starts the stopwatch. When the float crosses the finish line, 3 stops the stopwatch. 3 reports the time to the recorder (to 0.1 sec) . 3 does NOT re-set the watch until 2 (the recorder) repeats the finish time. (Make sure that 3 knows how to start, stop, and read the stopwatch before you begin!).

4 retrieves the float after it crosses the finish line and returns it to 1.

Stream Discharge Measurement Methods

Measurement of stream discharge, method 1 (simplest)
Measure the stream width W (ft.). Calculate W/5.
Measure the stream depths d_1, d_2, d_3, d_4, at points 1/5, 2/5, 3/5, and 4/5ths of the way across the stream, going from stream right to stream left, and mark these points on the tape with string, paper

clips, or flagging tape. (Stream right is the right bank of the stream when you're facing downstream. Use a depth measure calibrated in tenths of a foot, if possible. A yardstick can be used, although it gives the depths in inches, not feet).
Measure the stream velocities v_1, v_2, v_3 , and v_4 at these points.
Calculate the cross-sectional area A of the stream from the formula

$$A = (1/5)*W*(d_1 + d_2 + d_3 + d_4);$$ (1/5 is correct—end effects)

Calculate the average stream velocity v_{ave} from

$$v_{ave} = (1/4) * (v_1 + v_2 + v_3 + v_4)$$

Then the stream discharge Q is given by

$$Q = A * v_{ave}$$

Q is given in cubic feet per second IF the depths d_i and the stream width W are measured in feet. If the depths are in inches, Q is given in square feet inches per second! Ouch!
To convert Q to cubic feet per second (cfs), divide this result by 12 in/ft. If the depths AND the stream width are given in inches, Q is given in feet square inches per second. Divide by 144 in^2/ft^2 to convert it to cfs.

Measurement of stream discharge, method 2 (almost as simple)
This method requires exactly the same measurements as method one, but does a better job of calculating the average velocity. It uses a depth-weighted average of the velocities that takes into account the fact that more water is flowing through the deeper parts of the transect across the stream (main channel) than through the shallower portions of the transect, other things being equal. The cross-sectional area A of the stream is again given by

$$A = (1/5)*W*(d_1 + d_2 + d_3 + d_4)$$

The average velocity is calculated by

$$v_{ave} = (v_1d_1 + v_2d_2 + v_3d_3 + v_4d_4) / (d_1 + d_2 + d_3 + d_4)$$

Then, as before and after some cancellation,

$$Q = A * v_{ave} = (1/5)*W*(v_1d_1 + v_2d_2 + v_3d_3 + v_4d_4)$$

As before, if the d_i (and W) are measured in inches, Q must be divided by 12 (144) to put it into units of cubic feet per second (cfs).

Post-activity discussion questions/Background

1. **How did your measured stream discharge amount compare to your initial prediction?**

(Answers will vary)

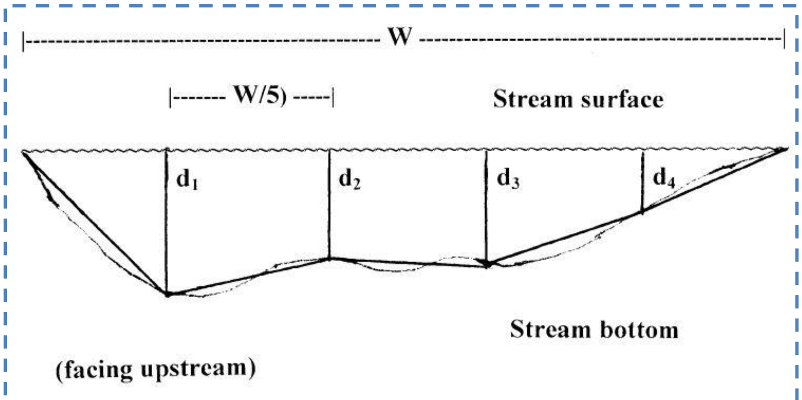
2. **Under what circumstances might the discharge amount vary?**
   (Rain events, drought, snow melt, etc.)
3. **How do varying amounts of water affect this stream?**
   (Greater amounts of water cause bed and bank erosion, add silt to stream, cause flooding, flush out the BMI's. Lesser amounts of water warm faster, hold less DO, may affect plants in riparian areas.)
4. **How do human activities contribute to "flashiness" or fast variations in stream discharge amounts?**
   (Agriculture may take out too much water; runoff from cultivated fields can be rapid unless suitable farming methods are used; overgrazing and destruction of riparian vegetation may cause bank erosion, loss of plant sponges that hold back or slow rain water; impervious surfaces speed rain water flow to streams; channelizing streams increases stream speed.
5. **What can ordinary citizens do to improve this?**
   (Rain gardens and rain barrels slow down runoff. People can support community storm water management.)
6. **How do people use stream discharge data?**
   (This kind of data can help people predict if stream flow is enough to support agricultural irrigation, to provide sufficient drinking water, and to meet the needs of industry. We use these data to decide how big and strong a dam should be, and to predict flooding.)

For this and all other units, advanced level information is available if desired. Contact the HRWC and request an electronic version of the unabridged manual.

Stream Discharge Data Sheet, Version A Date___________ Time________ Location ___________

Team members ____

1. Stream width (W) _________ft Length of stream reach (L) ___________ft
Depth in feet d1:________ d2:________ d3:_________ d4:_________



	Time (t)	Velocity (v) = L/t
t_i		
t_2		
t_3		
t_4		

2. Calculate.

$A = (1/5)*W*(d_1 + d_2 + d_3 + d_4) =$ _______ ft^2 $v_{ave} = (1/4) * (v_1 + v_2 + v_3 + v_4) =$ ____ft/sec $Q = A * v_{ave} =$ ______________ ft^3/sec	Note: 1 cubic feet per sec is the equivalent of about 7.8 gallons per second. How much water per second is passing by you right now?

3. How do varying amounts of water affect this stream?

4. How do human activities contribute to "flashiness" or fast variations in stream discharge amounts?

5. What can ordinary citizens do to improve this?

6. How do people use stream discharge data?

Stream Discharge Data Sheet, Version B

Date____________ Time_________ Location _________________________

Team members ____

1. Stream width (W) _________ft   Length of stream reach (L) ___________ft

Depth point	Depth in feet (d)	Time in sec (t)	Velocity L/t_i = v, ft/sec	Discharge v_id_i, ft^2/sec
1	d_1=	t_1	$L/t_1 = v_1$	v_id_i =
2	d_2=	t_2=	$L/t_2 = v_2$	v_2d_2 =
3	d_3=	t_3=	$L/t_3 = v_3$	v_3d_3 =
4	d_4=	t_4 =	$L/t_3 = v_3$	v_4d_4=

2. Calculate for discharge (Q).

$$Q = (1/5)*W*(v_1d_1 + v_2d_2 + v_3d_3 + v_4d_4) = \_\_\_\_\_ ft^3/sec$$

Note: 1 cubic foot per sec is the equivalent of about 7.8 gallons. How much water is passing by you right now?

3. How do varying amounts of water affect this stream?

4. How do human activities contribute to “flashiness” or fast variations in stream discharge amounts?

5. What can ordinary citizens do to improve this?

6. How can people use stream discharge data?

Stream Discharge Lesson Narrative (50 minutes)

Intro. 5 – 8 minutes. The mission is to make these points: Stream discharge measurements tell us how much water is flowing past a point in a certain amount of time. You may also choose to have students make their initial predictions after they measure the stream depths.

1. My name is _________ and I'm a volunteer with the Stream Discharge station. Please tell me your names. (Go around)
2. How much water is going by here right now? (a little, a lot, don't know…)
3. Hold up the empty gallon jug. Say "This is a gallon. I'm going to ask you to guess how many gallons are going by in this stream in 10 secs. Here is a stop watch. (Show a student how to use it.)
   I'll say start, you start the stop watch and the rest of you make your mental calculations. In other words guess and count. The stop watch person will yell STOP after 10 seconds.
4. Count 10 seconds. Listen to some guesses/predictions.
5. Now we are going to really measure how much water flows past per second. This is a little more complicated.

The Activity. 15 – 20 minutes. Decide if you are using Student Data Form A or B. Assign the roles.

Walk through their roles on dry land. Then go to the stream to measure and record the depths at points 1/5, 2/5, 3/5, and 4/5ths of the way across the stream. Then at each of these points, measure and record the time required for the float to move from the starting line to the finish line.

1. If poison ivy is present, show it to students or pick a spot to access the stream that doesn't have any poison ivy.
2. Show that the surveyor's tape measures the width of the stream at the starting flag points. Tell the recorder the width..
3. Explain that the group is going to measure 4 depth points across the transect of the stream. The tape is marked with 4 clips showing the points.
4. Then the team will measure the time required for a float to move along a 10 foot length of stream for 4 times (once from each depth point.) Then everyone will gather to calculate the stream velocities at the 4 depth points, after which we will calculate the stream discharge. Explain and assign the student roles.

   1 is the "wet cat." 1 first measures the depth at points 1/5, 2/5, 3/5, and 4/5 of the distance across the stream (using the surveyor's tape) and tells them to 2 (the recorder). You may want to double check that these measurements are in tenths of a foot.

   Then 1 stands in the stream about 5 ft. upstream from the tape at each of the four specified points. 1 alerts the group and drops the float into the water.

   2 is the recorder. The recorder stands at the starting line to record the depths and the finish times. When the float passes the starting line, the caller yells "Start". When the recorder hears the timer (3) call the time, the recorder records it, then repeats the time out loud. If you have more than 4 students, have the 5th student also record the data on a 2nd data sheet.

   3 runs the stopwatch. 3 stands at the finish line. When the float crosses the starting

line (2 calls "Start") 3 immediately starts the stopwatch. When the float crosses the finish line, 3 immediately stops the stopwatch. 3 reports the time to the recorder (to 0.1 sec) . 3 does NOT re-set the stopwatch until 2 (the recorder) repeats the finish time. (Make sure that 3 knows how to start, stop, and read the stopwatch before you begin!).

Optional if using tennis balls or oranges: 4 stands in the water below the finish line to retrieve the float and return it to student 1.

5. Troubleshoot if necessary and repeat for the rest of the depth points.
6. If you have time, repeat this at a different, previously marked off location in the stream.
7. Take the data forms back to a table. Students can meet in 1 or 2 groups to perform their calculations. Distribute a second data sheet so that all students can see the formulas. You may need to walk some groups through each step. Supervise the calculations closely, as errors are common.
8. Once the calculations are complete, ask the groups what they found. You can convert the discharge to gal/sec by multiplying your cubic feet per second by 7.8 gal/cu. ft. One comparison is that a common bathtub is filled by 10 cubic feet, or 80 gallons.
9. Ask "Under what circumstances would this amount ever vary?" (Rain events, drought, snow melt, dam breach, etc.)
10. Explain that when rain events cause a big pulse of water to enter the stream, we call it a flash. Streams with big variations in discharge amount are called "Flashy." What might be some impacts on the stream? (a bigger pulse of water can cause bed and bank erosion, adds silt to the stream, causes flooding, can sweeps away the BMI's).
11. How do human activities contribute to flashiness? (Runoff from cultivated fields can be rapid unless farming techniques to avoid this are used; overgrazing or destruction of riparian vegetation may cause bank erosion, loss of plant sponges that hold back or slow rain water; impervious surfaces speed rain water flow to streams; channelizing streams increases stream speed.
12. What can ordinary citizens do to reduce local stream flashiness? (If you have streamside property, keep a good vegetation buffer [trees, shrubs, grass and other plants] along the banks of the stream. Others can make rain gardens to hold back or slow down the runoff. Rain barrels also can hold back a certain amount of water. Citizens can also support improvements in local storm water management. Examples of this include regulating the discharge of storm water from new or improved construction projects, installing pervious surfaces when possible, planting trees and rain gardens.)
13. Let's circle back to the question of measurement. How do we use stream discharge data? (We can use it to figure out when a stream or river is approaching flood stage; how strong dams need to be; how much water is available for drinking, for irrigation or for industry; for navigation. Another example is more complicated. Algae blooms when lake levels fall below a certain amount. But various rules govern dam discharges. When Ford Lake falls below a certain level, the lake water stratifies, permitting upper levels to warm, and for algae to form.)

    There are US Geological Survey stream gages at various point along large streams and rivers.

    - Allens Creek outlet near Main St., Ann Arbor. Gage 04174490
    - Huron River near Wall Street, Ann Arbor. Gage 04174500
    - Malletts Creek near Chalmers Drive, Ann Arbor. Gage 04174518

- Malletts Creek at Mary Beth Doyle Park, Ann Arbor. Gage 04174517

Gages just measure depth, but these discharge measurements can be used to make calibration curves for the gages in order to calculate stream discharges from gage readings. Also OPTIONAL: You may wish to discuss the math behind the formulas used in today's calculations. There is a discussion and diagram at the end of the lesson.

14. Thanks for visiting with me today. It's time for you to go to your next station

Derivation of the formula for stream cross-sectional area

This approximate formula for the stream cross-sectional area is about the best we can do with the data we have—the stream width and the stream depths at points 1/5, 2/5, 3/5, and 4/5ths of the way across the stream. We approximate our stream profile as follows:

```
|-----------------------------------W------------------------------------|
              |----W/5-----|
__________________________________________________________________________
              |            |            |            |
    A1        |d1    A2    | d2    A3   | d3    A4   | d4   A5
              |            |            |
                           |            |
                           |
```

Then

$A_1 = (W/5)*d_1/2$ (triangle)

$A_2 = (W/5)*(d_1 + d_2)/2$ (trapezoid)

$A_3 = (W/5)*(d_2 + d_3)/2$ "

$A_4 = (W/5)*(d_3 + d_4)/2$ "

$A_5 = (W/5)*d_4/2$ (triangle)

The sum of these areas gives us our approximation to the cross-sectional area of the stream,

$A = (1/5)*W*(d_1 + d_2 + d_3 + d_4)$.

The formula is easily generalized from four depths and five segments to n depths and n + 1 segments; the larger n, the greater the accuracy of the approximation. This result is essentially the trapezoidal rule from integral calculus. Even more generally,

$$A = 1/2*\sum_{i=1}^{n-1} (w_{i+1} - w_i)(d_i + d_{i+1}) \qquad Q = 1/4*\sum_{i=1}^{n-1} (w_{i+1} - w_i)(d_i + d_{i+1})(v_i + v_{i+1})$$