Stream Speed and Stream Discharge for Advanced Students

The measuring of stream speed is a simple activity yielding information that becomes very useful when determining discharge, the volume of water passing through a given point per unit of time, usually cubic feet or cubic meters per second. This activity is geared towards capable students with some background in physics or possessing strong math skills. Two volunteers are required for this activity.

This activity will have two distinct portions, the first to measure average stream speed and the second to record the depth of the stream at regular intervals along a transect of the stream. These depth measurements will be used to compute the area of a stream cross-section in order to determine discharge. It is in this activity that complex calculations are required.

Pre-Activity Discussion (Answers can be found in the Background Information section below)

Before beginning the activity ask students:
1) Why is stream speed important?
2) What is stream discharge and why is it important?
3) What can we learn from knowing stream discharge that stream speed alone cannot tell us?
4) How do stream speed and discharge affect turbidity (siltiness)? Erosion? Aquatic life?
5) How do impervious surfaces affect stream speed and discharge?

Stream Speed Activity

Equipment

Stopwatch
Surveyor's measuring tape
Yardstick or measuring stick for measuring stream depths, preferably calibrated in tenths of a foot)
4 Marker flags
2 Stakes for supporting the tape
A lot of small floating objects: Sticks, corncobs and apples work well and need not be recovered
Calculators (2) There is a lot of computation in this activity
Forms for data and calculations
Pencils (at least 2)
Small table, if available. Otherwise 2 clipboards will do.
Hip boots or waders (3 pairs may be needed, especially if there's no bridge)

Set-up

An ideal stream speed site has a run of 25 feet or more of fairly straight stream channel of fairly uniform width. Discuss with the students the fact that the speed of water in a stream is highly variable—slow in pools, moderate in runs, fast in riffles and rapids, reversed in eddies, variable around obstacles, slow at undercuts and in dense aquatic vegetation, etc.

The goal is to choose a stream section where the speed is reasonably uniform. This run should be free from obstacles (logs, brush, rocks, gravel bars, etc.). Access to the water's edge at both ends of the stream section should be easy and offer good visibility. Streams do not always provide perfect sites so selection may require making do as best one can. Advance scouting is helpful for this activity. Keep in mind that water levels vary so a site that looks good one day may not be so good the next. If necessary, improvise! And always keep safety in mind!

1. Select a site and place a flag at the bank at the upstream end of the run. Place another flag on the

opposite bank or identify a distinctive object (tree, rock, etc.) to use instead. These flags mark the starting line and should be at a point wide enough to toss a stick well into the stream and with clear visibility.

2. Mark the "finish line" of the run similarly with flags and/or objects at a distance downstream from the starting line of about 25 or 50 feet. (A small stream may necessitate a shorter run.) Use the measuring tape in your kit to measure the length of the run to the nearest tenth of a foot and record it on the data sheet. This measurement will show up as ***d*** in the calculations that will follow.

Procedure

1. One student will toss a float into the river a few feet upstream from the imaginary starting line that stretches between the two flags and call out "start" when it reaches the line. It is important to toss the object a few feet upstream from the starting line to give it a time to get moving at the speed of the water.

2. A second student will stand by the imaginary finish line and call out "stop" when the float crosses the line.

3. A third student, versed in the correct use of the stopwatch, will operate the stopwatch, starting it and stopping it when directed to do so by the other students. Be sure the students have their communication system down well to help ensure accurate measurements. Lastly, remind students not to reset the stopwatch until it has been verified that the time, ***t***, has been recorded

4. A fourth student can handle the clipboard and record the data.

5. There should be time for six trials. If you have more than 4 students in a group, rotate responsibilities so everyone is kept as involved as possible.

6. The students will discover that measurements at different positions along the transect of the stream ($^1/_4$, ½, and ¾ of the way across the stream) give different results. This is OK. Ask them for possible reasons for this and, if time allows, do more trial runs testing variables they may have suggested such as: 1) Size and/or shape of the sticks being used; 2) Tossing the stick into different channels of the stream.

Using the Data Sheet to Determine Velocity

1. For each run, divide ***d*** (distance) by ***t*** (time) and record the speed of that run on the data sheet. Example: If the run is 50 feet and 32 seconds are required then 50 feet ÷ 32 seconds = 1.56 feet/second.

2. To determine the average speed, add the velocity for each of the trials and divide by the number of trials. Example (six runs): 1.24 + 1.29 + 1.43 + 1.37 + 1.51 + 1.62 = 8.46 and 8.46 ÷ 4= 1.41 ft./sec.

Mathematically speaking, the formulas look like this:
For the first run: $v_1 = d/t_1$; for the second; $v_2 = d/t_2$, and so forth.

For average speed for six runs: $v_{ave} = (v_1 + v_2 + v_3 + v_4 + v_5 + v_6)/6$

Where v_1 is stream speed in ft/sec for the first run; d is the distance between the starting line and the finish line; t_1 is the time required by the stick to float from the starting line to the finish line for the first run. A side note: A convenient conversion factor to relate feet per second to miles per hour: **1ft/sec=0.682 mph**. (88ft/sec= 60 mph)

Stream Speed Data Sheet

Measure or get from the instructor the distance *d* from the start to the finish line of the run between the two marked flags) using the surveyor's tape.

Distance from start to finish of float run: *d* = _______________ft

You will make 3 pairs of trials with 6 different sticks—that is, you will drop a stick into the stream a short distance upstream from the starting line and time its movement from the starting line to the finish line a total of 6 times. Make 2 trials starting at a distance 1/4th of the way across the stream, 2 trials at a distance 1/2 the way across the stream, and 2 trials 3/4th of the way across the stream.

Stopwatch reading at end of run 1: ________________sec

Stopwatch reading at end of run 2: ________________sec

Stopwatch reading at end of run 3: ________________sec

Stopwatch reading at end of run 4: ________________sec

Stopwatch reading at end of run 5: ________________sec

Stopwatch reading at end of run 6: ________________sec

Velocity 1 = Distance / Time 1 =_______________ft/sec

Velocity 2 = Distance / Time 2 =_______________ft/sec

Velocity 3 = Distance / Time 3 =_______________ft/sec

Velocity 4 = Distance / Time 4 = _______________ft/sec

Velocity 5 = Distance / Time 5 = _______________ft/sec

Velocity 6 = Distance / Time 6 = _______________ft/sec

Stream speed = average velocity = (Velocity 1 + Velocity 2 + Velocity 3 +

Velocity 4 + Velocity 5 + Velocity 6) / 6 = _____________ft/sec

Calculating Stream Discharge

In order calculate stream discharge, one must measure stream depth along a transect to determine the area of a cross-section of the stream. This data, together with stream speed, are what is required to determine discharge.

1. Starting from the left side of the stream while facing downstream, secure the end of the surveyor's tape to a shrub or stake a short distance downstream from the stream speed starting line. Stretch the tape across the stream at right angles to the stream flow. Securely tie the tape to a shrub or stake on the right bank of the stream, *making sure that the tape is high enough and taut enough that it is not touching the water.* This is the transect along which the depth of the water will be measured at regular intervals beginning at the left bank. Left and right are always determined while facing downstream. One person (the Measurer) will take the measurements and the other person (the Recorder) will write them on the data sheet. To assure accuracy, the Recorder should repeat the measurements to the Measurer.

If the transect measurements are occurring during the stream speed activity, avoid interfering with those measurements by staying at least 3 feet away from the floats.

2. Beginning at the left bank, the Measurer will call out the measurement on the tape (w_1) and the depth of the stream at that point for the Recorder to enter on the data sheet. Since the first measurement w_1 is at the bank, h_1, = 0.

3. At evenly spaced distances along the tape- $w_2, w_3, w_4, \ldots, w_{n-1}$ - the Measurer calls out the measurement on the tape and the corresponding stream depths $h_2, h_3, h_4, \ldots, h_{n-1}$. The Recorder verifies and records the data. The last measurement, w_n, is the distance along the tape to the right edge of the water, and $h_n = 0$. The number of points (n) should typically be in the range 10-12.

Measurements of w should be in decimal feet, not inches. Use the side of the tape that is calibrated in tenths of a foot, not the side that's calibrated in inches. *Measurements of stream depths h may be in inches but a calculation will be required to determine the area (A) of the cross-section in square feet (ft^2). This is obtained by dividing A by 12 in/ft in order to get the stream cross-sectional area in sq. ft. (ft^2).*

4. The cross-sectional area $\boldsymbol{A}$ of the stream is then given by

$$\boldsymbol{A} = \sum_{i=1}^{n-1} (1/2)\cdot[w_{i+1} - w_i]\cdot[h_i + h_{i+1}]$$

The stream discharge $\boldsymbol{Q}$ is then given approximately by

$$\boldsymbol{Q} = f \cdot A \cdot v_{ave}$$

where $f = 0.9$ is a factor that takes into account the fact that water at the surface of the stream flows more rapidly than water at some depth below the surface, and $\boldsymbol{A}$ and v_{ave} have been calculated above. The factor f actually varies a little, being smaller for streams with very rough, rocky bottoms and larger for streams with very smooth, even bottoms (perhaps lined with concrete, like portions of the Rouge). 0.9 is a reasonable compromise.

Post-activity discussion questions:

1) Did stream speed measurements vary? If so, why? 2) Look at the streambanks, the riparian zone and areas nearby. Are there conditions present that could affect stream speed? 3) What can be done to protect a stream from receiving too much runoff? 4) Stream speed affects discharge. Why is it important to understand discharge?

Background

Importance of stream speed: Stream speed is important because it affects the erosive power of the stream—its ability to tear up its banks and wash mud, silt, sand, gravel, and cobbles downstream. The greater the speed of the water, the greater is its power to erode stream banks, and the larger the particles that it can carry downstream. A slow-moving stream may be able to carry fine clay particles. A stream with a fairly large gradient that is in flood may easily carry cobbles and rocks, even boulders. (Gradient is the rate at which the stream is losing elevation along its length, often measured in feet per mile.) The faster the water is moving, the more sediment and the larger the particles it can carry.

Stream speed also affects aquatic life. Some organisms are designed to be able to deal with rapidly moving water—suction cups or strong legs and claws to hang on tightly; low profiles to reduce the force of the water on them; small size so that they can find shelter from the water's force by living down in the gravel or under rocks. Flat-headed mayfly nymphs (juvenile forms), blackfly larvae, and water penny beetles are good examples. Others, such as damselfly and dragonfly nymphs require more slow-moving water.

Stream speed is important to commerce on navigable waterways. Changes in speed can greatly affect times of delivery.

Stream speed is also of value when taken in context of bank and nearby conditions. All streams fluctuate seasonally and due to weather conditions. High water and faster flows in general will cause higher levels of erosion and turbidity than lower, slower flows, thereby increasing the damaging effects on stream life. When a stream's riparian zone is healthy and has a variety of flora stabilizing the ground along the stream bank, it is better equipped to deal with fluctuations in water levels. This is not the case if streambanks are not properly vegetated and there are impervious surfaces or farm fields nearby that quickly transfer high volumes of water to a stream during and after a rain or sudden thaw. In this case, erosion, turbidity, habitat destruction, and the warming of water are much more serious problems.

Stream speed and discharge: Stream speeds are also important because they are needed in the calculation of stream discharge (the volumetric flow rate of the stream), the rate at which the stream is carrying water. Stream discharge is generally reported in units of cubic ft per sec (cfs, ft^3/sec) or cubic meters per sec (m^3/sec). In the U.S. cfs is commonly used. Stream discharge measurements are needed for assessing flooding potential downstream, for evaluating stream capacity for generating hydroelectric power and providing cooling water to thermal and nuclear power plants, for estimating the amount of water available for irrigation, and for predicting low-water problems for river shipping downstream and for industrial and municipal water supplies.

Stream Cross-sectional Area Data Sheet

i	w_i (ft)	h_i (ft or in)	$w_{i+1} - w_i$	$h_i + h_{i+1}$	$[w_{i+1} - w_i] \cdot [h_i + h_{i+1}]$
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					

$$A = \sum_{i=1}^{n-1} (1/2) \cdot [w_{i+1} - w_i] \cdot [h_i + h_{i+1}] = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

The stream discharge Q is then given approximately by

$$Q = 0.9 \cdot A \cdot v_{ave} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \text{ ft}^3/\text{sec}$$

Advanced information on calculating stream discharge (stream volumetric flow)

If you find this section a bit tough, don't worry; you won't need it unless you're dealing with very advanced students. Don't use it with general audiences. Students who are taking calculus may find it intriguing—numerical integration.

The method used above for measuring stream speeds and discharges gets you into the right ballpark, but if you want to measure the discharge (volumetric flowrate) of a stream more accurately, things are a bit more complicated. The Huron River Watershed Council proceeds as follows:

1. Set up a transect across the stream, tying a surveyor's tape across it at right angles to the direction of stream flow. You'll be using some sort of water velocity meter for measuring stream speeds; the HRWC uses Marsh-McBirney meters for this, costly and accurate tools.

2. Measure the stream velocity and the stream depth along the transect at approximately 20 equally spaced points (not closer together than 0.5 ft; if the stream is small, use fewer points). The first point (1) should be at the water's edge at one bank of the stream; the last point (*n*) at water's edge at the other bank. At each point *i* record (a) the reading on the tape w_i, (b) the stream depth h_i, and (c) the stream velocity v_i. Stream velocities can be measured with a velocity meter (most accurate) or by means of the stick and stopwatch method the students are using.

3. The stream discharge Q is then given by

$$Q = \sum_{i=1}^{n-1} (1/4)\cdot[w_{i+1} - w_i]\cdot[h_i + h_{i+1}]\cdot[v_i + v_{i+1}]$$

If you are using a velocity meter, measure the velocity at a distance of 0.6 times the depth from the surface of the water if the depth is 3 ft or less. If the depth is greater than 3 ft, measure the velocities at distances of 0.2 and 0.8 times the total depth and average these. If you are using the stick and stopwatch method, multiply the final result for Q by $f = 0.9$ to adjust for the fact that the water at the surface of the stream is flowing at speeds slightly higher than the average speeds of the water; the drag of the stationary stream bottom slows the water down as one goes deeper in the stream. If your distances w and depths d are in feet and your velocities v are in feet per second, Q**,** the stream discharge, is in cubic feet per second, abbreviated cfs. If you're using a yardstick marked in inches to measure depths, divide your depth measurements by 12 to get decimal feet. Or (easier) leave the depth measurements in inches and divide your calculated value of **Q** by 12, which gives **Q** in cubic ft per sec.