We will be making some stream flow measurements in an ‘auwai (irrigation ditch) that takes water from Mānoa Stream and diverts it to the Hawaiian Studies Dept.’s kalo lo‘i. We will also measure the flow at a location on Mānoa stream itself, downstream from the lo‘i. Then we’ll be able to calculate how much water is being diverted. Please remember that the water in Mānoa stream is NOT fit for drinking, and that you should not get the water on any cuts or scrapes. Wash your hands after this lab, and if you have any cuts or scrapes on your hands or feet, don’t get stream water in them.

If you just look at flowing water, it is reasonably easy to figure out how fast the surface is moving – just throw some leaves in and measure how long it takes them to float down a known distance. Distance divided by time equals velocity.

But we want to know more than merely the surface velocity. We want to know how much volume is flowing per unit time. Also, we need to realize that the surface velocity does not represent the velocity of all the water. Specifically, water near the banks and near the bottom goes slower than the surface because both the banks and the bottom provide a drag force. What this means is that we can’t just make one measurement and assume that all the water in the stream is flowing at this same velocity.

Figure 1 shows the method that stream hydrologists have come up with. The top part shows a sketch of a stream flowing between its banks. Notice that the arrows showing the flow direction are not the same length; the middle of a stream flows faster than the sides. This means that if you only measured the velocity in the middle you would over-estimate the flowrate, and if you only measured velocity at the sides you would underestimate it. Hydrologists divide the stream into sections (labeled A-I in the bottom part of Figure 1). By measuring the flowrate in each section, and then adding them all up, you end up with a much more accurate result. Remember also that velocity not only varies across a stream, it also varies from top to bottom. Hydrologists have
determined that in a shallow stream, measuring the velocity 2/3 of the way down from the water surface gives the best result.

So how do you get flow rate from a measurement of flow velocity? Think of the sections in Figure 1 as a bunch of ~square tubes of toothpaste placed side-by-side. The volumetric flow rate in any one tube will depend on how fast you squeeze the tube, but it will also depend on how big the tube is – a wider or taller tube will produce a greater flow rate than a narrower or shorter tube, if the squeezing rate is the same.

What this means is that if we know how wide and how tall each section is, and how fast water is flowing in it, we can figure out the volumetric flow rate in each section. The units work out really nicely. The width is going to be in units of length. The depth will also be in units of length. The flow velocity will be in units of length divided by time. So if you multiply all of these together, you end up with length x length x length/time or length$^3$ time$^{-1}$. Probably a more familiar unit of volumetric flow rate is cubic feet per second, sometimes written as cfs or ft$^3$s$^{-1}$.

So the lab is pretty straightforward: At each measurement point on the ‘auwai or stream, we’ll divide it into sections, measure the dimensions (depth and width) of each section, measure the flow velocity of each section, multiply depth x width x flow velocity for each section, and then add up all the results. We should end up with a pretty accurate measurement of the volumetric flow rate within the ‘auwai and Mānoa stream.

How do we measure the flow velocity? With what is called a pygmy flow meter. It is kind of like a windmill for water. It has been calibrated very carefully so that if we know how fast it is spinning, we know how fast water is flowing past it. We painted one of its cups yellow, and we’ll use the old fashioned method of counting revolutions with a stopwatch for timing.

Errors of velocity measurement will arise if the current meter:
* Is placed closer to the boundary than 1-2 rotor diameters
* Is used to measure velocities less than 0.5 ft/s or out of the range of calibration. Overdriving the rotor can damage bearings
* Is not held steady in one position during the time measurement
* Is used in significant waves, such as those caused by wind
* Is used in flow which is not parallel to the axis of the propeller meter or is oblique to the plane of the cup-type meter
* Is impeded by weeds or debris

Unfortunately, some of the equipment measures in meters and other equipment measures in English units. Hydrology, at least in the USA, is one branch of geology that hasn’t yet made much of an effort to change to the metric system. Regarding the equipment, although it looks simplistic, it makes very accurate measurements. It is also very expensive to replace!! So please treat it kindly. Mahalo.

The ‘auwai is about 3 feet wide, and 5-10 inches deep in most places. The USGS stream flow guides say that any stream <5 feet wide should be divided into 0.5 foot sections. And remember,
we make flow rate measurements in the midpoints of each section. So if you are able to put one end of the tape measure right at the edge, section one would extend from 0 to 0.5 ft, flow rate one would be measured at 0.25 ft., and depth one would be the depth at 0.25 ft. Section two would extend from 0.5 ft. to 1.0 ft, flow rate two would be measured at 0.75 ft., and depth two would be the depth at 0.75 ft. And so on. Previous semesters’ classes have had some trouble keeping all the measurements straight, and ended up over-estimating the flow rate because they somehow doubled the measured width of the ‘auwai! One way to make sure that this isn’t happening will be to add up all your partial ‘auwai-width measurements and make sure that they come pretty close to the single measurement of the ‘auwai width.

Our particular wading rod has metric markings. The single scratches are at 2 cm intervals, the double scratches are at 10 cm intervals, and the triple scratches are at 50 cm intervals. The water depth in the ‘auwai is way less than 2.5 feet, so we will only need to make a single flow rate measurement in each section. This measurement needs to be made at 0.6 of the depth of the water, measured from the top down (same thing as saying it is at 0.4 of the water depth from the bottom up). The wading rod is designed to make the 0.6 depth adjustment easy.

Let’s say you measure a water depth of 52 cm. That means you want to make the flow rate measurement at 0.6 x 52 cm = 31.2 cm below the surface. The way to do this is line up the 5 on the skinny rod (the one that slides up and down) with the 2 on the vernier on the handle, and the flow meter will automatically be at the right depth. Again, please be very careful with the flow meter!

Procedure:
1. Use the long tape measure to determine the distance from where the ‘auwai leads off from the stream to the first measurement location.

2. Stretch the tape across the ‘auwai, and secure it with stones so that it won’t move (Figure 2). Set it so that you are looking at the side showing feet and tenths of feet, not feet and inches. Stand over the tape and look vertically down at the near edge of the ‘auwai.
3. Carefully note the number that directly overlies the edge of the water. We will call this number \( b_0 \).

4. Repeat for the far edge. We will call this number \( b_n \).

5. The difference between these numbers (\( b_n - b_0 \)) is the width of the ‘auwai. Determine this width.

6. \( b_0 \) will be the near boundary of Section 1. The far boundary of Section 1 will be \( b_1 \), and it will be equal to \( b_0 + 0.5 \) ft. \( b_1 \) will also be the near boundary of Section 2. The far boundary of Section 2 will be \( b_2 \), and it will be equal to \( b_1 + 0.5 \) ft., and so on. Figure 3 shows how this works. Determine what the width values will be and enter them in the column labeled “width (ft)” in Table 1. This can get a little confusing (and Figure 3 looks a bit complicated), but it isn’t too bad. Remember that \( b_0, b_1, b_2 \ldots b_n \) are the boundaries of the sections, and how far apart these boundaries are determines the widths of the sections. Probably all the widths except for the last one will be the same.
7. The last section will probably not be 0.5 ft. wide. Instead, it will have a width of \( b_n \) minus the value at the far edge of the last full 0.5 ft.-wide section. In Figure 3 that happens to be: \( b_n - b_5 \). IMPORTANT: ALL OF THESE INDIVIDUAL SECTION WIDTHS NEED TO ADD UP TO THE TOTAL WIDTH, NOT LESS, NOT MORE!

8. Positions 1, 2, 3, etc. are at the centers of each section, and it is here where you will measure both the depth of each section and the flow velocity of each section. These are at the halfway points of each section, and in Figure 3 they are labeled pos. 1, pos. 2, etc., and correspond to depth measurements that are labeled \( d_1, d_2, d_3 \)...

For the last section this will be the value at the far edge of the last full section plus half the width of the last (not full) section. In Figure 3 this is pos. 6, and it would be at: \( b_5 + [(b_n - b_5)/2] \)

9. Next, measure the water depth at position 1 (in the middle of Section 1). Convert this measurement to feet. To convert cm to feet, multiply the value in cm by 0.0328 ft/cm. Example: 11 cm \( \times 0.0328 \text{ ft/cm} = 0.3609 \text{ ft.} \) (notice how the cm units cancel because one is in the numerator and the other is in the denominator)

Multiply width in feet by depth in feet to get area in \( \text{ft}^2 \). Note that you do not multiply position by depth. Position tells you where you are making the flow velocity and depth measurements, but position is not a number that you will use when calculating flow rate.

10. Use the vernier instructions to set the flow meter at 0.6 x this depth below the surface. Place the flow meter in the water at position 1, making sure that the wading rod is vertical. Let the flow meter spin for about 20 seconds. Then, at the same instant, start counting revolutions and start the stopwatch. One cup has been spray-painted yellow to help.
11. At 60 seconds, the stopwatch person says “stop”, and the revolution-counting person stops counting revolutions. Record the number of revolutions. Divide the number of revolutions by 60 to get \( R \), in revolutions/second.

12. Repeat steps 9, 10, and 11 for the rest of the positions.

13. For each section, use the following formula to get the flow velocity in feet per second:

\[
V = (0.9604 \times R) + 0.0312
\]

- \( V \) = velocity in feet per second (what you want)
- \( R \) = revolutions per second (from step 11)

14. Next, multiply velocity by area to get the flow rate for each section, \( Q \), in cubic feet per second (\( \text{ft}^3 \text{s}^{-1} \), sometimes abbreviated cfs).

15. Another common unit of flow rate is gallons per minute. You get to do more of your favorite thing – convert units!! There are 7.48 gallons in one cubic foot, and there are 60 seconds in one minute:

\[
Q \ (\text{ft}^3 \text{s}^{-1}) \times (7.48 \text{ gal/ft}^3) \times (60 \text{ s/min}) = Q \ (\text{gal min}^{-1})
\]

Below is how things cancel. Notice that cubic feet (\( \text{ft}^3 \)) occurs first in the numerator and then in the denominator, so they cancel each other (double strike-through). Also, seconds (s) occurs first in the denominator and then in the numerator, so they cancel each other also (single strike-through). All that is left is gal in the numerator and min in the denominator:

\[
Q \ (\text{ft}^3 \text{s}^{-1}) \times (7.48 \text{ gal/ft}^3) \times (60 \text{ s/min}) = Q \ (\text{gal min}^{-1})
\]

One quick way to do the conversion is to notice that you are multiplying the value of \( Q \) in \( \text{ft}^3 \text{s}^{-1} \) by 7.48 and then by 60.

16. Another common unit of flow rate is gallons per day. We’ll let you do the conversion yourself.

17. Finally, remember that you have only calculated flow rates for individual sections across the ‘auwai. What you really want is the total flow rate. You get this by adding up the flow rates for all the individual sections.
18. Next…move to the stream near the UH dorms and repeat the whole process. We will measure the flow at a location where it is funneled through a break in a low weir (Figure 4). We will make the measurements twice both to try and average out any variations and to make sure that everybody gets to wear rubber boots!

Figure 4. Set-up for stream near UH dorms.