ENG5300 Engineering Applications in the Earth Sciences:

Measuring River Discharge

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I. Introduction and Background

River discharge is an important property and is frequently monitored along many of the major rivers and streams in the U.S. (see http://water.usgs.gov/realtime.html). The discharge (flow) can not be measured directly in a river or stream like it can from a pipe or hose because the rate is too high (cubic feet per second, cfs) and it is distributed across too large of a cross-section. Thus, the discharge (Q) must be calculated from the average stream velocity (V) and cross-sectional area (A):

$$Q = V \cdot A \tag{1}$$

Where Q is the stream discharge (flow), V is the *average stream velocity*, and A is the cross-sectional area perpendicular to flow. Actual velocities vary along the river length, width, and depth. A typical velocity profile is depicted in Figure 1. Stream velocities also vary similarly along the width, that is the velocity is near zero at the edges and reach a maximum in the central part of the stream. Deviations from ideal velocity profiles occur often, especially along bends in the river, around structures that disrupt the flow, and irregular bottom shapes.

Because of the complex variations in velocities that occur naturally in streams/rivers, it has become a well established practice (see http://www.usbr.gov/wrrl/fmt/wmm/) to subdivide a river cross-section into several parts (Figure 2), measure stream velocities at 1-3 depths within each part at a particular cross-section (Figure 3), and calculate the discharge in each part:

$$q_i = v_i \cdot a_i \tag{2}$$

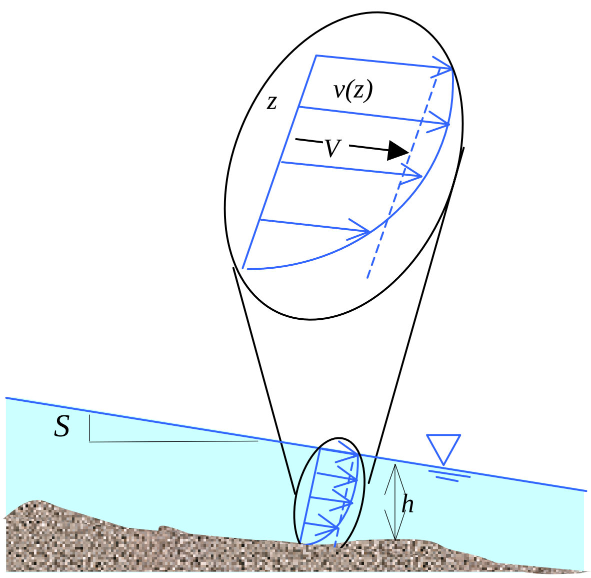

Figure 1. Schematic of a river profile depicting an idealized variation in the stream velocity with depth. The velocity is zero at the stream bottom and increases towards the surface.

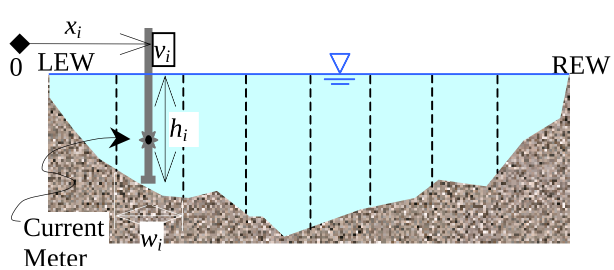

Figure 2. River cross-section shown schematically to illustrate subdivisions based on velocity measurement locations. View is upstream: LEW=left edge of water and REW = right edge of water. The center of each section, i, is defined by the location of the velocity measurement, taken a distance x_i from a common (initial) measuring point.

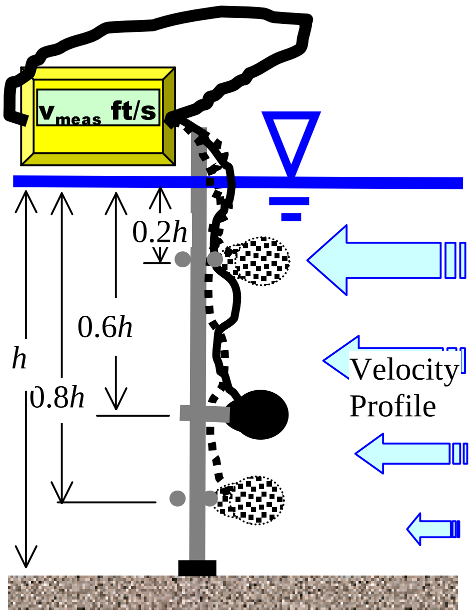

Figure 3. Typical depth locations for measuring stream velocities with a current meter.

The total discharge (Q) and cross-sectional area (A) are obtained from summing the flow and area, respectively, for the individual sections (q_i and a_i, i=1, 2, …, N=number of individual sections):

$$Q = \sum_{i=1}^{N} q_i \qquad (3a)$$

$$A = \sum_{i=1}^{N} a_i \qquad (3b)$$

The area of each individual section is taken as the product of its average depth in the middle (h_i) and the width (w_i) between the midpoints of the adjacent sections (see Figure 2):

$$a_1 = h_1 \cdot w_1 = h_1[(x_2 + x_1)/2 - x_{\mathrm{LEW}}] \qquad (4a)$$

$$a_i = h_i \cdot w_i = h_i(x_{i+1} - x_{i-1})/2 \quad \text{for } i = 2,\ldots,N-1 \qquad (4b)$$

$$a_1 = h_1 \cdot w_1 = h_1[x_{\mathrm{REW}} - (x_N + x_{N-1})/2] \qquad (4c)$$

The velocities of the river/stream sections can be measured in a variety of ways (http://www.usbr.gov/wrrl/fmt/wmm/): weirs, flumes, orifice plates, surface velocity, tracer velocity, and profile velocity. The "float method" uses the velocity of the river surface, which can be measured by timing a prescribed distance traveled by a floating object. Recently this approach has become more sophisticated using acoustic velocity meters (*e.g.*, Doppler type) (http://www.usbr.gov/wrrl/fmt/wmm/). Surface velocities need to be adjusted to obtain the average velocity; a reasonable adjustment is to multiply the surface velocity by 0.85 (see Dingman (2002)).

The velocity profile of the section is usually measured at a particular fraction of the depth (h) of the measurement area (Figure 3). This approach is the most common. For streams where the depth is less than 2.5 feet, the velocity is usually measured at the 60% depth (0.6 method) and this measurement is taken to be the average velocity in the individual section (v_i):

$$v_i = v_{i,\mathrm{measured@0.6depth}} \qquad (5a)$$

For depths greater than 2.5 feet, then measurements are taken at the 80% and 20% depths and the two measurements are averaged:

$$v_i = (v_{i,\mathrm{measured@0.8\,depth}} + v_{i,\mathrm{measured@0.2\,depth}})/2 \qquad (5b)$$

Alternatively, velocities can be measured at all three depths (20, 60, and 80%) and averaged as follows:

$$v_i = \left[v_{i,\text{measured@0.6 depth}} + (v_{i,\text{measured@0.8 depth}} + v_{i,\text{measured@0.2 depth}})/2 \right] / 2 \qquad (5c)$$

The measurements and calculations are well suited for a table format, as depicted in the example in Table 1 (a blank data sheet is given in the appendix).

Table 1. Example calculations for stream discharge measurements using a current meter. Note that the number of measurement points was selected to minimize the amount of calculations presented in this example. In practice, each section should be selected so that the flow in each is roughly 5-10% of the total.

Distance from initial point[a]	**Width**[b]	**Total Depth**[a]	**Observation Depth**[c]	**VELOCITY**		**Area**[f]	**Discharge**[g]
				At Point[d]	**Mean in Vertical**[e]		
(feet)	**(feet)**	**(feet)**	**(fraction)**	**(ft/s)**	**(ft/s)**	**(ft^2)**	**(cfs)**
2.1 (LEW)[h]		0					
3.6	3.0	0.75	0.6	1.11	1.11	2.25	2.50
6.6	3.0	1.10	0.6	2.25	2.25	3.30	7.42
9.6	3.0	3.30	0.8	2.58	2.15	9.90	21.28
9.6			0.2	1.72			
12.6	2.5	0.55	0.6	0.55	0.55	1.10	0.60
13.6 (REW)		0					
Total/*Average*:	**11.5**[i]	***1.44***[j]			***1.93***[k]	**16.55**[i]	**32**[i]

[a]See Figure 2 for location and measurement reference.
[b]Width based on distance between midpoints of adjacent measurements (see Figure 2 and Eq. 4).
[c]See Figure 3 for location reference.
[d]Meter reading at measurement location (see Figure 3 for location reference).
[e]Mean velocity calculated according to Eq. 5.
[f]Area calculated according to Eq. 4.
[g]Discharge calculated according to Eq. 2.
[h]Initial point is 2.1 ft from the left edge of water (LEW) in this example.
[i]Total is summation of the individual section values (see Eq. 3).
[j]Average depth is the total area divided by the total width.
[k]Average velocity is the total discharge divided by the total area.

The measurements outlined above are straightforward and can be performed with a minimum level of training to show how to take measurements and use a current meter (see http://www.usbr.gov/wrrl/fmt/wmm/). Frequent discharge measurements, which are needed to accurately perform hydrological budget analyses, are tedious using the current meter approach. For most rivers under uniform flow conditions, there is a singular relationship between the river *stage* and discharge. The river stage is the elevation of the water surface. A *rating curve* is a location specific calibration between stage and discharge (see Figure 4), and these can change with time if the river bottom changes, for example due to scour or sedimentation. If a rating curve exists (e.g., Figure 4), then one only needs to measure river stage and then discharge can be calculated.

Devices for measuring river stage vary in sophistication from as simple as a staff gage (a large "ruler") to pressure transducers that record water pressure and transmit the data via satellite or phone-link to a publicly available data base (http://water.usgs.gov/realtime.html). Stage measuring devices are summarized at (http://www.usbr.gov/wrrl/fmt/wmm/).

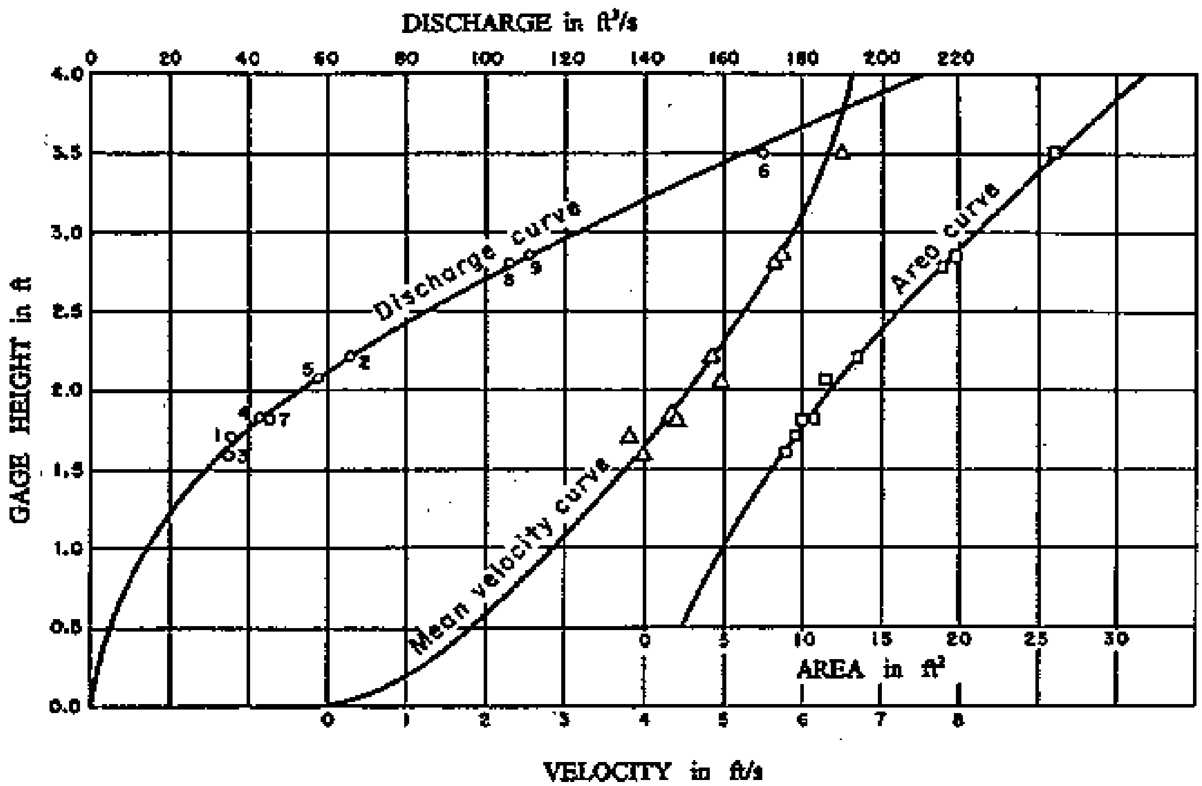

Figure 4. Example rating curve for a canal (http://www.usbr.gov/wrrl/fmt/wmm/fig/F10_18L.GIF).

II. Field Activities

A. Float Method

Specialized equipment is typically needed for measuring stream velocities beneath the river surface (see below). The surface velocity can be measured easily with a stopwatch and small floats (small enough that their movement is unaffected by wind, *e.g.*, ping pong balls). A surveying tape is needed to measure the river/stream width and the distance traveled. It is more convenient to have 2 tapes placed transverse to the river flow just above the surface at two sections separated a distance at least 2 or 3 times the nominal river width so that it is easy to note when the float passes the start and finish positions (Figure 5).

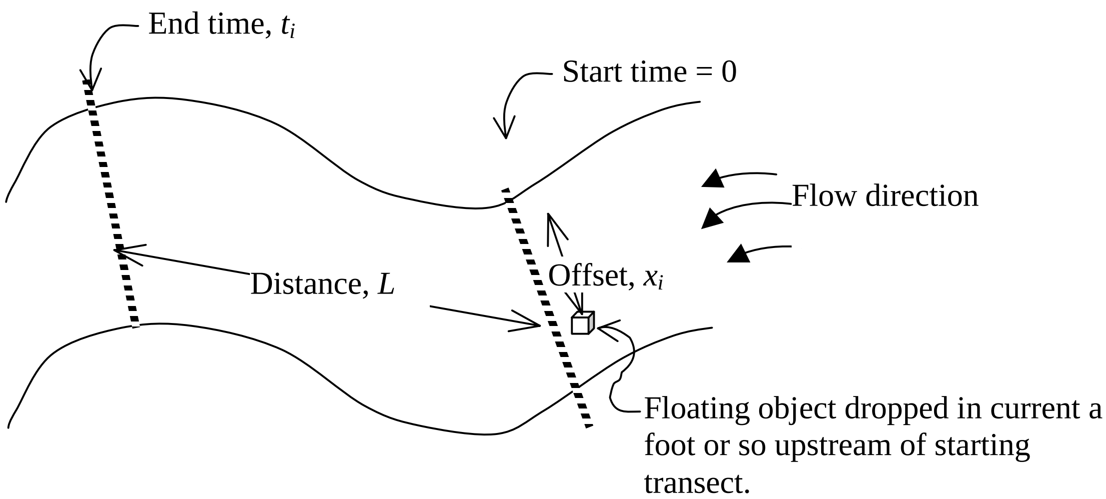

Figure 5. Float-method setup for measuring the stream/river surface velocity distribution. The velocity of section, i, is equal to L/t_i.

The format for recording data can follow Table 2.

Table 2. Data sheet for stream discharge measurements using the float method.

Distance from Stream Bank	**Width**[a], w	**Average Depth**[b], h	**Distance Traveled**[c] L	**Elapsed Time**[d] t	**VELOCITY,** V[g]		**Area**[h], a	**Discharge**[i], q
					Surface, v_s[e]	**Mean,** v[f]		
(feet)	**(feet)**	**(feet)**	**(feet)**	**(s)**	**(ft/s)**	**(ft/s)**	**(ft^2)**	**(cfs)**
Total[j]/***Average***[k,l]**:**					V^l =		A =	Q =

[a]Width based on distance between midpoints of adjacent measurements (see Figure 2 and Eq. 4).
[b]Estimate of average depth of section.
[c]Approximate travel distance taken by float downstream (see Figure 5).
[d]Elapsed time of travel.
[e]Float velocity at the surface, L/t.
[f]Mean velocity in section based on surface velocity (Eq. 6)
[g]Average stream velocity, Q/A.
[h]Initial Section area, $a = w \cdot h$.
[i]Discharge in section, $q = v \cdot a$.
[j]Total is summation of the individual section values.
[k]Average depth is the total area divided by the total width.
[l]Average velocity is the total discharge divided by the total area.

B. Current-Meter Method

Select a stream cross-section that is less than 4-feet deep, free of obstructions, and the flow is relatively uniform (minimal turbulence). Prepare the current meter by according to the owner's manual. Span the stream with a surveyor's tape between two fixed posts, stakes or other object to which the tape can be temporarily attached. The tape should be taught, relatively level, and 1-3 feet above the stream surface. The zero end of the tape should be attached to the stake on the left side of the stream viewing upstream. This is the "initial point" to which all the width calculations are made (see Figure 2 and Table 1). Determine the offset at the LEW according to Figure 2 and record the data on a copy of the data sheet in the appendix using a format similar to Table 1. Traverse the stream, taking velocity measurements at either the 0.6 and/or 0.8/0.2 depths following the guidance provided above, finishing at the REW. Record the data following the format in Table 2. It is valuable to conduct the measurements twice, using different persons measuring and different segment widths. This will give an estimate in the error in the measurement. Choosing a river with a USGS gaging station will allow comparison to established values (http://water.usgs.gov/realtime.html). Comparisons to the float method are also interesting.

III. Appendix: Discharge Measurement Data Sheet for a Current Meter; Adapted from the USGS Form 9-275-F.

Distance from initial point	Width	Total Depth	Observation Depth	VELOCITY At Point	VELOCITY Mean in Vertical	Area	Discharge

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Completed by: ________

Discharge Measurement Notes
(Adapted from USGS 9-275-F)

Sta. No.____________ Checked by: ________

Date: ______________ Party: ____
Width: _________ Area: __________ Vel.: __________ G.H.: __________ Disch.: __________
Method: ________ No. secs.: _________ GH. change: _________ in: _________
Meter Type: ____________________________ Meter No.: _______________________________
Zero Reading Before: ___________ After: ___________ Ave. Correction: ____________

GAGE READINGS					
Time	Inside				Outside
Weighted MGH					
GH correction					
Corrected MGH					

WATER QUALITY MEASUREMENTS
No ______ Yes ______ Time _______
Samples Collected
No ______ Yes ______ Time _______
METHOD USED
EDI ______ EWI ______ Other _______

SEDIMENT SAMPLES
No ______ Yes ______ Time _______
Method Used
EDI ______ EWI ______ Other _______

BIOLOGICAL SAMPLES
No ______ Yes ______ Time _______
Type ____________________________

Wading, cable, ice, boat, upstr., downstr., side bridge _________ feet, mi., above, below gage.
Measurement rated excellent (2%), good (5%), fair (8%), poor (>8%), based on the following condition:____
Cross section:____
Control: ____
Gage Operating ________________ Weather ____
Temperatures: Air __________, Water ____________, Time ___________
Gage Height of zero flow __________________
Remarks ____
____
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Sheet No. ________ of _________ sheets