

3. HYDRAULIC DATA ANALYSIS

50 Points

The purpose of this exercise is to enter all your field data into Excel, and then to calculate the basic geometric and hydraulic characteristics of the Tomorrow River. We will then use this information to test our hypotheses relating stream geometric hydraulic and bed texture characteristics. All computer work for this lab should be saved to your team folder in the *Geog 352* folder on the Department's *Classes* server. Each team folder contains an Excel file named 04_Hydraulic_Data_Analysis. There are three tables in the Excel file, two of which are similar to the data sheets on which you collected your field data (Tables A and B). Table C contains the summary geometric and hydraulic information for your transects.

YOU SHOULD BE ABLE TO:

- Enter data collected in the field into an Excel spreadsheet,
- Use Excel functions and formulas to calculate channel geometric and hydraulic characteristics; and,
- Create a scale diagram of a channel profile in Adobe Illustrator.

EXCEL FORMULAS AND FUNCTIONS

Use formulas and functions in Excel for *all* of your calculations. **Do not** use a calculator for any math operations. Formulas and functions in Excel always start with an equal sign =. Enter mathematical formulas into Excel the same way you would type them. For example, to calculate cross sectional area, you would multiply width times depth: =w*d. Suppose the width is in cell A4 and the depth is in cell B4 and you want the area in cell C4. In Excel, click on cell C4 (where you want the area), type an equal sign, click on the cell containing the width (A4), type an asterisk (*) and click on the cell containing the depth (B4). Hit enter.

$$=A4*B4$$

Cell C4 will now contain the result of the formula.

If you type in an equation with multiple operations, you may need to use parentheses to insure Excel does the math operations in the correct order. For example, suppose you want to calculate the Froude number, which equals velocity divided by the square root of depth times gravity. This formula requires the inclusion of a function, the square root function. Let's say that velocity is in cell A8, depth is in cell B8, and you want the Froude number in cell C8. Click on cell C8 (where you want the Froude number). Type an equal sign. Then click on the cell containing the velocity (A8) and then type a division sign (/):

$$=A8/$$

The square root function is "sqrt" followed by the number you want the square root of in parentheses:

$$=sqrt(\text{number})$$

In this case the number we want the square root of is the depth times gravity. Depth is stored in cell B8 and gravity is a constant 32.2. You need to type (B8*32.2) inside the parentheses so Excel knows to take the square root of the product of these two values, and not the square root of the depth. Your final formula should be:

$$=A8/(sqrt(B8*32.2)).$$

Note that the entire denominator is enclosed in parentheses. This set of parentheses is not necessary, but including the parentheses means there will be no mistake about the order of math operations; Excel now knows to do all the math in the denominator before doing any division. The set of parentheses surrounding $(B8*32.2)$ is necessary.

If you want to do an operation on an array of cells, you can either type in the address of the first and last cell in the array, or you can highlight the array. The starting and ending cell addresses are enclosed in parentheses. For example, if you want to sum up the contents of cells A1 through A20 you would type: $=\text{sum}(A1:A20)$. Or, you could type “ $=\text{sum}()$ ” and then highlight cells A1 through A20, and the type “)”. If you want to do an operation on a discontinuous array of cells, highlight the first set of cells, then press and hold down control (Ctrl) and highlight the remaining or the next set of cells, and then close your parentheses.

Formulas and functions, once entered into a cell, can be copied and pasted into other cells. The cell addresses in the formulas and functions are *relative addresses*; they are relative to the cell containing the formula or the function. This means that when you copy and paste the formula or function into another cell, the cells referenced in the formula or function will also change. For example, suppose you type the following formula into cell E2: $=C2*D2$. If you copy and paste this formula into cell E3, the formula will change to $=C3*D3$.

Basic math operations used in equations:

- Addition: +
- Subtraction: –
- Multiplication: *
- Division: /
- Raise to a power: ^

Basic functions:

- Sum: Use to add the contents of an array of cells. $=\text{sum}(\text{cell array})$
You can specify the cell array either by highlighting the array of cells or by entering the address of the first and the last cell. For example, to add all the cells in column B from row 2 to row 10 you would enter: $=\text{sum}(B2:B10)$.
- Average: Use to find the average (mean) of an array of cells: $=\text{average}(\text{cell array})$
As with the sum function, you can either highlight the array of cells or enter the address of the first and the last cell in the array.
- Square root: use to find the square root of a value: $=\text{sqrt}(\text{value})$ or $=\text{sqrt}(\text{cell address})$
The value may be a number, or it may be a formula.
- Power: used to raise a number to a power: $=\text{power}(\text{number}, \text{power})$
For example if you want to calculate five cubed (5^3), you would enter $=\text{power}(5,3)$. Instead of typing the five, if the five is in a cell, you can enter that cell address in the formula. Assume the value of 5 is in cell D8, you would enter $=\text{power}(D8,3)$. You can also use the ^ symbol to raise a number to a power. This would be a formula, not a function: $=5^3$.

Formatting numbers:

- Determining the number of decimal places: click on the cell containing the number you want to format. Do a right-mouse click and from the drop-down menu select Format Cells. Select the Number tab. Click on “Number” and set the decimal places.

PROCEDURE

There are two methods for measuring discharge, the mean-section method and the mid-section method (Rantz 1982; WMO 2010). We are going to use the mean-section method, and with this method, each vertical represents the edge of a section, not the middle of a section.

Measurements at Each Vertical

Enter the data for your upstream transect (our first set of measurements above the bridge in the riffle) in Table A and the data for your downstream transect (our second set of measurements below the bridge in the pool) in Table B. Figure 3.1 shows a diagram and a matching sample spreadsheet to accompany the instructions below.

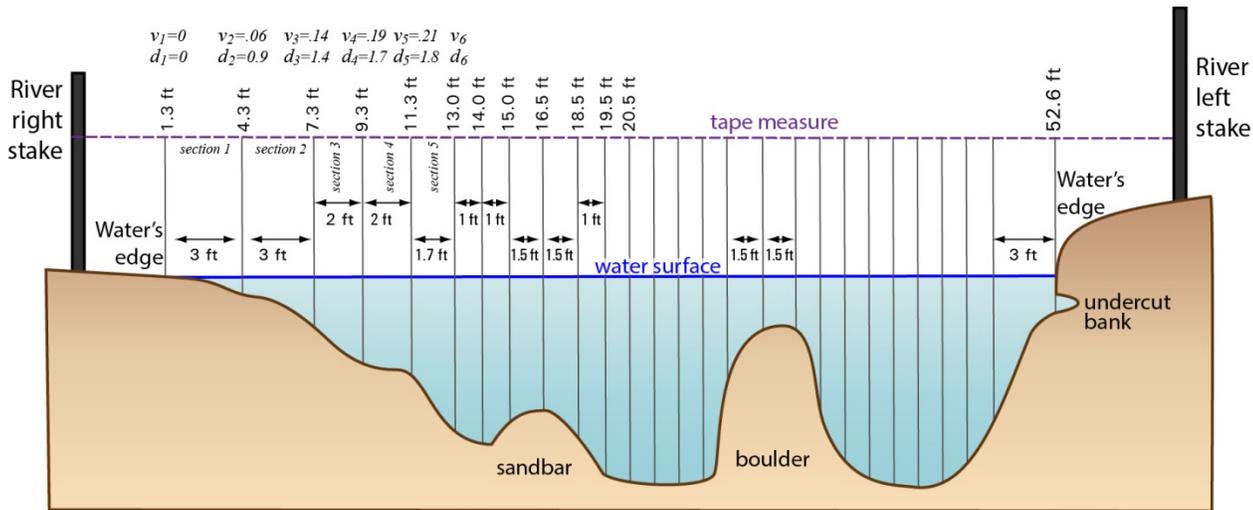
1. **Columns A through D.** Enter your field data for feet along the tape measure (column A), water depth (column B), and flow velocity (columns C and D) under the columns titled “Measurements at Each Vertical.” If you took just one velocity measurement at 0.6d, this value goes in column C. If you measured velocity at 0.2d and 0.8d, enter those velocities in columns C and D.
2. **Column E** equals the average velocity at that vertical. If you measured velocity at 0.6d, this velocity equals the average velocity at that vertical (point), so the value in column E will equal the value in column C. If you measured velocity at 0.2d and 0.8d, the value in column E equals the average of the values in columns C and D. You can calculate the average in two ways: $=(C3+D3)/2$ or $=\text{average}(C3:D3)$. If you use the first version of this formula, be sure to include parentheses so Excel knows to add before dividing.

Exception! If your current meter would not provide readings every 90 seconds and you had to record nine velocities for each measurement, insert eight columns between columns D and E and enter your nine velocities in columns C through K. Record the average of those nine readings in column M. If you took nine readings at 0.2d and 0.8d, insert another nine columns for the additional set of readings. Average the 18 readings to determine the average point velocity.

Section Measurements

1. **Average section depth.** To determine the average depth for each section, average the depths of the verticals that define the section edges. For example, the average depth for section one equals the average of your first two depth measurements. Type the formula into the first cell and then copy and paste that formula into the cells below; do not type the formula repeatedly.
2. **Section width.** The section width equals the difference in the distance along the tape measure between every two verticals. For example, the first section width equals the distance along the tape measure for vertical two minus the distance along the tape measure for vertical one (water’s edge). Type this subtraction formula in once, and then copy and paste it into the cells below; do not type the formula repeatedly.
3. **Section area.** The section area equals the average section depth times the section width. Again, type the formula once and then copy and paste it into the cells below.
4. **Average section velocity.** The average section velocity equals the average of the two point velocities defining the vertical edges of the sections. For example, the average velocity for section one equals the average of the average point velocity at vertical one (water’s edge; column E) and the average point velocity at vertical two (also column E). The formula in cell J4 would be either: $=(E3+E4)/2$ or $=\text{average}(E3:E4)$. If you use the first version of this formula, be sure to include parentheses so Excel knows to add before dividing.
5. **Section discharge.** The section discharge equals the section area times the average section velocity.
6. **Comments.** Enter your field notes in the last column for both transects. You can type as much text as you want in these cells. It doesn’t matter if your text is longer than the cell is wide. If you have more text than can fit in the default width of the cell, you can do one of two things: 1) make the column wider, or 2) format the cells so the text wraps around onto multiple lines and make the row taller. Please ask if you need help with this.

FIGURE 3.1 View of a Transect Looking Upstream Showing Sections and Measurements of Velocity (v) and Depth (d), and Associated Spreadsheet



| | A | B | C | D | E | F | G | H | I | J | K |
|---|---------------------------------------|------------------------|------------------------------------|-------------------------|----------------------------|---|----------------------------|----------------------|----------------------|------------------------------|-------------------------|
| 1 | Measurements at Each Vertical (Point) | | | | | | Section Measurements | | | | |
| 2 | Feet along tape measure | Point water depth (ft) | Velocity at 0.6d OR at 0.2d (ft/s) | Velocity at 0.8d (ft/s) | Avg. point velocity (ft/s) | | Average section depth (ft) | Section width (feet) | Section area (sq ft) | Avg. section velocity (ft/s) | Section Discharge (cfs) |
| 3 | 1.3 | 0.0 | 0.00 | | 0.00 | | | | | | |
| 4 | 4.3 | 0.9 | 0.06 | | 0.06 | | = $(B3+B4)/2$ | = $A4-A3$ | = $G4*H4$ | = $\text{average}(E3:E4)$ | = $I4*J4$ |
| 5 | 7.3 | 1.4 | 0.14 | | 0.14 | | = $(B4+B5)/2$ | = $A5-A4$ | = $G5*H5$ | = $\text{average}(E4:E5)$ | = $I5*J5$ |
| 6 | 9.3 | 1.7 | 0.19 | | 0.19 | | = $(B5+B6)/2$ | = $A6-A5$ | = $G6*H6$ | = $\text{average}(E5:E6)$ | = $I6*J6$ |
| 7 | 11.3 | 1.8 | 0.21 | | 0.21 | | = $(B6+B7)/2$ | = $A7-A6$ | = $G7*H7$ | = $\text{average}(E6:E7)$ | = $I7*J7$ |
| 8 | 13.0 | 2.6 | 0.18 | 0.42 | = $(C8+D8)/2$ | | = $(B7+B4)/2$ | = $A8-A7$ | = $G8*H8$ | = $\text{average}(E7:E8)$ | = $I8*J8$ |
| 9 | | | | | | | | | | | |

Summary Statistics: Table C

Calculate summary geometric and hydraulic characteristics for both of your transects and enter this data in Table C. Use formulas or functions for all of the math in Table C. Some of your formulas or functions will address cells in Tables A or B. When you get to a point in a formula or function where you want to include a cell from Table A or B, click on the tab for Table A or Table B and then click on the cell that contains the information you want. Then, click on the tab for Table C and finish typing your formula or function.

1. Stream width, w , equals the final tape measure distance minus the first tape measure distance listed in Table A and in Table B.
2. Average water depth, \bar{d} , equals the average of all your individual depth measurements. Use the =average function and select all the cells in column B of Tables A and B. Be sure to have parentheses bracketing the cell range you are averaging.
3. Total cross-sectional area, a , equals the sum of all the section areas. Use the =sum function and select all the cells in column I of Tables A and B. Again, insure the cell range is enclosed in parentheses.
4. Wetted perimeter, $P_w = w + 2\bar{d}$, where w is the stream width (cell B3 or C3) and \bar{d} is the average water depth (cell B4 or C4). Include parentheses in your formula so Excel knows to multiply before adding.

5. Hydraulic radius, r , equals A/P_w , where A is the cross-sectional area and P_w is the wetted perimeter. Use a formula for this calculation.
6. Average transect velocity, \bar{v} , equals the average of the average velocities at each vertical (average of values in column E from Tables A and B).
7. Total discharge, Q , calculated using sections equals the sum of the section discharges (sum of values in column K from Tables A and B).
8. Total discharge, Q , calculated as area times velocity, equals cross-sectional area (cells B5 and C5) times average transect velocity (cells B9 and C9).
9. Water temperature. Teams that measured temperature will report this in class. Enter the reported values.
10. Kinematic viscosity, ν , is a function of water temperature. Look up the correct value in your handout on *Fluvial Symbols, Formulas and Constants*.
11. Water density, ρ , is a function of water temperature. Look up the correct value in your handout on *Fluvial Symbols, Formulas and Constants*.
12. Calculate the slope, s , is measured in feet per foot (ft/ft) for each transect. For example, if we measured a one-foot drop in elevation over 100 feet of river, one divided by 100 gives a slope of 0.01 ft/ft. We will do this calculation in class as only several people were involved in the slope measurements. Enter the value we calculate.
13. Acceleration due to gravity, g , is a constant 32.2 ft/s/s. Enter this value
14. Reynolds number, Re , equals $v \times r / \nu$ where v is the average transect velocity, r is the hydraulic radius, and ν is the kinematic viscosity. Use an equation that references the correct cells.
15. Froude number, Fr , equals $\bar{v} / (\text{sqrt}(g * d))$ where \bar{v} is the average transect velocity, g is gravity, and \bar{d} is the average water depth. Use an equation that references the correct cells.
16. Bed shear stress, t_b , equals $\rho \bar{d} g s$ where ρ is the water density, \bar{d} is the average depth, g is gravity and s is the channel slope. Use an equation that references the correct cells.
17. Unit stream power, ω , equals $t_b \bar{v}$ where t_b is the bed shear stress and \bar{v} is the average transect velocity. Use an equation that references the correct cells.

Scale Diagram of Each Transect

You need to draw a scale diagram of each of your transects in Adobe Illustrator. Use the Illustrator file called 04_Hydraulic_Data_Profile to draw your profile. This file contains a labeled grid so all of the class profiles will have the same scale. You need to add a dot for each of your verticals at the appropriate distance along the tape measure and the appropriate water depth. There is a black dot on the left side of the graph. Select the dot, then copy it (Ctrl C) and then paste the dot multiple times (Ctrl V). The pasted dots will stack up on top of one another. Select a dot and move it to the distance and depth for river right (the start of your transect). Select the next dot and move it to the correct position for the next vertical. Continue selecting dots and moving them to the correct positions until you have a dot for each vertical. If you run out of dots, just select a dot, copy it, and paste it again.

Once you have all your dots in the correct positions, including dots for river right and river left, you need to connect the dots in a smooth line. Use the pen tool to draw your line. Clicking on a spot with the pen tool creates a vertice, a junction between two line segments. If you just click on a spot, the vertice will create an angular junction between the two line segments. If you click and hold the mouse button down and drag the mouse a short distance in the direction your line is going, this will create a smooth vertice, rather than an angular one. Click on each of your dots to create a series of connected line segments so the entire line extends from river right to river left. To end your line, double click on the last dot. At this point, you can go back and adjust the position of any of the vertices, or if the vertices are smooth vertices, you can adjust the degree of curvature at the vertice. In this way, you can adjust the shape of your line to accurately reflect the channel topography.

After finishing your line, you may want to add notes indicating things such as boulders or sand bars or other features located along your transect. Use the type tool for this. You can also create polygons and color them to represent the water as opposed to the channel bed. Please ask for help with this.

REFERENCES

- Rantz, S.E. 1982. Measurement and computation of streamflow: Volume 1. Measurement of stage and discharge. *U.S.G.S. Water Supply Paper 2175*. Washington, D.C.: U.S. Geological Survey.
http://pubs.usgs.gov/wsp/wsp2175/html/WSP2175_vol1_pdf.html
- WMO. 2010. *Manual on Stream Gauging: Vol. I – Fieldwork*. WMO-No. 1044. Geneva, Switzerland: World Meteorological Organization (WMO). http://www.wmo.int/pages/prog/hwrp/publications/stream_gauging/1044_Vol_I_en.pdf

GRADING RUBRIC

| Profile in Illustrator 10 points | Point Value | Upstream Points Earned | Downstream Points Earned |
|---|-------------|------------------------|--------------------------|
| Tables A and B | | | |
| 1. Enter feet along tape measure (column A) | 4.0 | | |
| 2. Enter water depths (column B) | 4.0 | | |
| 3. Enter velocities (columns C and D if necessary) | 4.0 | | |
| 4. Calculate average point velocities (column E) | 1.5 | | |
| 5. Calculate average section depths (column G) | 1.5 | | |
| 6. Calculate section widths (column H) | 1.5 | | |
| 7. Calculate section areas (column I) | 1.5 | | |
| 8. Calculate average section velocity (column J) | 1.5 | | |
| 9. Calculate section discharges (column K) | 1.5 | | |
| 10. Enter comments from field notes (column M) | 3.5 | | |
| Table C: Summary Statistics | | | |
| 1. Calculate stream width | 1.5 | | |
| 2. Calculate average water depth (from column B in Tables A & B; exclude 0's) | 1.5 | | |
| 3. Calculate total cross-sectional area (sum column I from Tables A & B) | 1.5 | | |
| 4. Calculate wetted perimeter ($P_w = w + 2d$) | 1.0 | | |
| 5. Calculate hydraulic radius ($r = A/P_w$) | 1.0 | | |
| 6. Calculate average transect velocity (average column E from Tables A & B) | 1.5 | | |
| 7. Calculate total discharge (sum column K from Tables A & B) | 1.5 | | |
| 8. Calculate discharge as area x depth | 1.0 | | |
| 9. Record water temperature, viscosity, density, slope, gravity | 1.0 | | |
| 10. Calculate Reynolds number | 1.0 | | |
| 11. Calculate Froude number | 1.0 | | |
| 12. Calculate bed shear stress | 1.0 | | |
| 13. Calculate unit stream power | 1.0 | | |
| Total Points | 40 | | |
| Average of upstream and downstream points | | | |
| Total Points/Group Grade | | | |