GEOL 652. Poudre River Fieldtrip

One of the more difficult variables to measure and/or estimate when studying flow in natural channels is that of roughness. Roughness, usually approximated with Manning's *n*, includes all resistance to flow resulting from both internal and external characteristics. Roughness thus includes channel substrate (particle size and sorting, channel irregularities on the scale of meander bends, expansions/contractions, and bedforms), riparian vegetation, landforms (alluvial fans, talus cones, bedrock outcrops), structures (bridges, trailer parks, etc.) in the floodplain, and turbulence and secondary flow associated with channel-margin irregularities. There are four basic methods used to estimate channel roughness in mountain channels; (1) the Manning equation, (2) the Limerinos equation, (3) the Jarrett equation, and (4) visual estimation using both a table and the Cowan (1956) method, as detailed in Arcement and Schneider (1989). We will compare *n* values obtained with each of these methods for the same reach of channel, and determine the effect of these varying *n* values on calculations of flow velocity and discharge.

Field Tasks

Everyone should make a sketch map of the study reach. I usually draw plan and cross-sectional views, and although they are schematic, they include some sort of relative scale, a north arrow, and an indication of flow direction. Include any details of channel and valley morphology that you think are important, such as vegetation, general particle size, channel width and estimated depth, bedrock outcrops, debris flows reaching the valley floor, etc. This type of sketch and the accompanying notes are essential to good field work, because details fade rapidly from the mind (at least from mine), and the act of describing helps you to focus on the surroundings. The sketch map also serves as a framework on which to note locations of data collection. It may be most effective to make the sketch map once you are done with the group data collection, so that you can show the location of each group's cross section.

As a group, choose the location of your cross section. Survey the cross section, noting active channel width; high-flow channel width, as recorded by stage indicators such as driftwood lines, changes in vegetation, or stains on the rocks; flow depth; and particle size.

Measure flow depth and velocity at 10% increments. If depth is greater than 0.5 m, measure velocity at 0.2 and 0.8 times the depth. If depth is less than 0.5 m, measure velocity at 0.6 of the depth. Also, do one detailed vertical velocity profile in the thalweg of the cross section, with velocity measurements at 10% increments of the total depth.

Measure particle size on bars (and in the channel, where feasible), counting 100 clasts using a random-walk, grid, or line method. Measure only the diameter of the intermediate particle axis.

Estimate roughness (*n* values) for the channel, right overbank, and left overbank, using Table 3. Estimate the components of the Cowan equation using Tables 1 and 2.

Survey channel gradient 50 m upstream and 50 m downstream from your cross section, or at distinct breaks in slope (e.g. head of riffle).

Analysis

1) Using the survey data, calculate low (field conditions) discharge for your cross section using both the continuity equation and the Manning equation for discharge. Use your visually estimated *n* value for these calculations. Calculate high (paleostage indicators) discharge for the cross section using the Manning equation.

$$Q = w\ d\ v \qquad \text{(continuity)}$$

$$Q = 1/n\ A\ R^{2/3}\ S^{1/2} \qquad \text{(Manning)}$$

where
Q is discharge (m^3/s)
w is mean channel width (m)
d is mean channel depth (m)
v is mean flow velocity (m/s)
n is Manning's roughness
A is cross-sectional area (m^2)
R is hydraulic radius (area/wetted perimeter; m)
S is channel gradient (m/m)

[use weighted averages for w, d, and v]

2) Calculate roughness for the cross section, using the Manning equation for velocity:

$$v = 1/n\ R^{2/3}\ S^{1/2}$$

where v is measured velocity (m/s)

3) Calculate roughness for the cross section, using the Limerinos equation (note *units are in feet* for this equation):

$$n = \frac{(0.0926)\ R^{1/6}}{1.16 + 2.0 \log (R/D_{84})}$$

where D_{84} is the intermediate particle diameter that equals or exceeds that of 84% of the particle diameters measured (determine this value by plotting a cumulative frequency curve of particle diameters measured in your 100-clast count).

4) Calculate roughness for the cross section, using Jarrett's (1984) equation (note *units in feet*):

$$n = 0.39\, S^{0.38}\, R^{-0.16}$$

5) Calculate *n* using the Cowan (1956) method:

$$n = (n_b + n_1 + n_2 + n_3 + n_4)\, m$$

where n_b is a base value of n for a straight, uniform, smooth channel in natural materials
n_1 is a correction factor for the effect of surface irregularities
n_2 is a value for variations in shape and size of the channel cross section
n_3 is a value for obstructions
n_4 is a value for vegetation and flow conditions
m is a correction factor for meandering of the channel

[see Tables 1 and 2 at end from Arcement and Schneider (1989) for sample values of these variables]

How does your field estimate of *n* compare to the values calculated in parts 2, 3, 4, and 5?

6) Substitute the calculated *n* values from parts 2-5 into your calculations of discharge using the Manning equation in part 1. How do these differing *n* values change your calculated discharge? Do you think these changes would be magnified or reduced for high discharges through this cross section, and why?

7) Substitute the calculated *n* values from parts 3-5 into the Manning equation for velocity, this time solving for velocity. Which result is closest to your measured velocity?

8) Plot the detailed velocity profile from your cross section. How does it compare to Jarrett's general profile for Colorado mountain streams?

Based on the above calculations, which approach to estimating n values is most appropriate at low flows on the Poudre River?

References

Arcement, G.J. and Schneider, V.R. 1989. Guide for selecting Manning's roughness coefficients for natural channels and flood plains. U.S. Geological Survey Water-Supply Paper 2339, 38 pp.

Jarrett, R.D. 1984. Hydraulics of high-gradient streams. ASCE, Journal of Hydraulic Engineering 110: 1519-1539.

Limerinos, J.T. 1970. Determination of the Manning coefficient from measured bed roughness in natural channels. U.S. Geological Survey Water-Supply Paper 1898-B.

Van Haveren, B.T. 1986. Water resource measurements. American Water Works Association, 132 pp.

Wohl, E. 2000. Mountain rivers. American Geophysical Union Press, Washington, D.C. (pp. 79-82 on resistance coefficient).

Table 1. Base values of Manning's n (Table 1, Arcement and Schneider, 1989)

Bed material	**Median size of bed material (mm)**	**Base n value**	
		Straight uniform channel	**Smooth channel**
Sand channels			
Sand	0.2	0.012	---
	0.3	0.017	---
	0.4	0.020	---
	0.5	0.022	---
	0.6	0.023	---
	0.8	0.025	---
	1.0	0.026	---
Stable channels and flood plains			
Concrete	---	0.012-0.018	0.011
Rock cut	---	---	0.025
Firm soil	---	0.025-0.032	0.020
Coarse sand	1-2	0.026-0.035	---
Fine gravel	---	---	0.024
Gravel	2-64	0.028-0.035	---
Coarse gravel	---	---	0.026
Cobble	64-256	0.030-0.050	---
boulder	> 256	0.040-0.070	---

Table 2. Adjustment values for factors that affect the roughness of a channel (Arcement & Schneider, 1989)

Channel conditions		n value adjustment	Example
Degree of irregularity (n_1)	smooth	0.000	Compares to the smoothest channel available in a given bed material
	minor	0.001-0.005	Compares to carefully dredged channels in good condition but having slightly eroded or scoured side slopes
	moderate	0.006-0.010	Compares to dredged channels having moderate to considerable bed roughness and moderately sloughed or eroded side slopes
	severe	0.011-0.020	Badly sloughed or scalloped banks of natural streams; badly eroded or sloughed sides of canals or drainage channels; unshaped, jagged, and irregular surfaces of channels in rock
Variation in channel cross section (n_2)	gradual	0.000	Size and shape of channel cross sections change gradually
	alternating occasionally	0.001-0.005	Large & small cross sections alternate occasionally, or the main flow occasionally shifts from side to side owing to changes in cross-sectional shape
	alternating frequently	0.010-0.015	Large & small cross sections alternate frequently, or the main flow frequently shifts from side to side owing to changes in cross-sectional shape
Effect of obstruction (n_3)	negligible	0.000-0.004	A few scattered obstructions, which include debris deposits, stumps, exposed roots, logs, piers, or isolated boulders, that occupy < 5% of the cross-sectional area
	minor	0.005-0.015	Obstructions occupy < 15% of the cross-sectional area, and the spacing between obstructions is such that the sphere of influence around one obstruction does not extend to the sphere of influence around another obstruction. Smaller adjustments are used for curved smooth –surfaced objects than are used for sharp-edged angular objects.
	appreciable	0.020-0.030	Obstructions occupy 15-50% of the cross-sectional area, or the space between obstructions is small enough to cause the effects of several obstructions to be additive, thereby blocking an equivalent part of a cross section.
	severe	0.040-0.050	Obstructions occupy >50% of the cross-sectional area, or the space between obstructions is small enough to cause turbulence across most of the cross section.
Amount of vegetation (n_4)	small	0.002-0.010	Dense growths of flexible turf grass, such as Bermuda, or weeds growing where the average dept of flow is at least two times the height of the vegetation; supple tree seedlings such as willow, cottonwood, arrowweed, or saltcedar growing where the average dept of flow is at least three times the height of the vegetation.
	medium	0.010-0.025	Turf grass growing where the average depth of flow is from one to two times the height of the vegetation; moderately dense stemmy grass, weeds, or tree seedlings growing where the average depth of flow is from two to three times the height of the vegetation; brushy, moderately dense vegetation, similar to 1- to 2-year-old willow trees in the dormant season, growing along the banks, and no significant vegetation is evident along the channel bottoms where the hydraulic radius exceeds 2 ft.

Amount of vegetation (n_4) (continued)	large	0.025-0.050	Turf grass growing where the average depth of flow is about equal to the height of the vegetation; 8- to 10-year-old willow or cottonwood trees intergrown with some weeds & brush (none of the vegetation in foliage) where the hydraulic radius exceeds 2 ft; bushy willows about 1 yr old intergrown with some weeds along side slopes (all vegetation in full foliage), or dense cattails growing along channel bottom; trees intergrown with weeds & brush (all vegetation in full foliage)
	very large	0.050-0.100	Turf grass growing where the average depth of flow is less than half the height of the vegetation; bushy willow trees about 1 yr old intergrown with weeds along side slopes (all vegetation in full foliage), or dense cattails growing along channel bottom; trees intergrown with weeds & brush (all vegetation in full foliage).
Degree of meandering (m)	minor	1.00	Ratio of the channel length to valley length is 1.0 to 1.2.
	appreciable	1.15	Ratio of the channel length to valley length is 1.2 to 1.5.
	severe	1.30	Ratio of the channel length to valley length is greater than 1.5.

Table 3. Values of Manning's roughness coefficient (from Van Haveren, 1986)

Description of Channel	Minimum	Normal	Maximum
A. Excavated or dredged			
1. Earth, straight and uniform			
a. Clean, recently completed	0.016	0.018	0.020
b. Clean, after weathering	0.018	0.022	0.025
c. Gravel, uniform section, clean	0.022	0.025	0.030
d. With short grass, few weeds	0.022	0.027	0.033
2. Earth, winding, sluggish			
a. No vegetation	0.023	0.025	0.030
b. Grass, some weeds	0.025	0.030	0.033
c. Dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
d. Earth bottom and rubble sides	0.028	0.030	0.035
e. Stony bottom and weedy banks	0.025	0.035	0.040
f. Cobble bottom and clean sides	0.030	0.040	0.050
3. Dragline-excavated or dredged			
a. No vegetation	0.025	0.028	0.033
b. Light brush on banks	0.035	0.050	0.060
4. Rock cuts			
a. Smooth and uniform	0.025	0.035	0.040
b. Jagged and irregular	0.035	0.040	0.050
5. Channels not maintained, weeds and brush not cut			
a. Dense weeds as high as flow depth	0.050	0.080	0.120
b. Clean bottom, brush on sides	0.040	0.050	0.080
c. Same as above at highest stage of flow	0.045	0.070	0.110
d. Dense brush, high stage	0.080	0.100	0.140
B. Natural streams			
1. Minor streams with width at flood stage < 100 ft			
a. Streams on plains			
(1) Clean, straight, full stage no rifts or deep pools	0.025	0.030	0.033
(2) Same as above but more stones and weeds	0.030	0.035	0.040
(3) Clean, winding, some pools and bars	0.033	0.040	0.045
(4) Same as above but some weeds and stones	0.035	0.045	0.050
(5) Same as above but lower stages, more ineffective slopes and sections	0.040	0.048	0.055
(6) Same as (4) but more stones	0.045	0.050	0.060
(7) Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
(8) Very weedy reaches, deep pools or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
b. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
(1) Bottom consists of gravels, cobbles, and few boulders	0.030	0.040	0.050
(2) Bottom consists of cobbles with large boulders	0.040	0.050	0.070
(3) Bottom consists of large boulders and some large organic debris, sinuous flow	0.050	0.070	0.100
2. Floodplains			
a. Pasture, no brush			
(1) Short grass	0.025	0.030	0.035
(2) High grass	0.030	0.035	0.050
b. Cultivated areas			
(1) No crop	0.020	0.030	0.040
(2) Mature row crops	0.025	0.035	0.045
(3) Mature field crops	0.030	0.040	0.050

11.15 Values of the Manning Roughness Coefficient, n (continued)

Description of Channel	Minimum	Normal	Maximum
c. Brush			
(1) Scattered brush, heavy weeds	0.035	0.050	0.070
(2) Light brush and trees in winter	0.035	0.050	0.060
(3) Light brush and trees in summer	0.040	0.060	0.080
(4) Medium to dense brush in winter	0.045	0.070	0.110
(5) Medium to dense brush in summer	0.070	0.100	0.160
d. Trees			
(1) Dense willows, summer, straight	0.110	0.150	0.200
(2) Cleared land, tree stumps no sprouts	0.030	0.040	0.050
(3) Same as above, with heavy sprout growth	0.050	0.060	0.080
(4) Heavy stand of timber, a few downed trees, little undergrowth, flood stage below branches	0.080	0.100	0.120
(5) Same as above, but with flood stage reaching branches	0.100	0.120	0.160
3. Major streams with width at flood stage > 100 ft			
a. Streams on plains			
(1) Sand channels	0.025	0.035	0.045
(2) Boulder channels	0.028	0.040	0.045
(3) Vegetation-lined channels at flood stage	0.045	—	0.120
b. Mountain streams			
(1) Cobbly bottom, no debris jams	0.028	0.035	0.040
(2) Cobbly bottom with debris jams	0.032	—	0.060
(3) Bottom with large boulders, no debris jams	0.045	0.050	0.070
(4) Bottom with large boulders, debris jams in channel	0.050	—	0.100
C. Channels in swales with vegetation			
1. Depth of flow up to 0.7 ft			
a. Bermuda grass, bluegrass, buffalo grass			
(1) Height 2–4 in.	0.045	—	0.060
(2) Height 4–6 in.	0.060	—	0.090
b. Good stand, any grass			
(1) Height 6–12 in.	0.060	—	0.180
(2) Height 12–24 in.	0.180	—	0.300
c. Fair stand, any grass			
(1) Height 6–12 in.	0.050	—	0.140
(2) Height 12–24 in.	0.140	—	0.250
2. Depth of flow 0.7–1.5 ft			
a. Bermuda grass, bluegrass, buffalo grass			
(1) Height 2–4 in.	0.035	—	0.055
(2) Height 4–6 in.	0.040	—	0.060
b. Good stand, any grass			
(1) Height 6–12 in.	0.050	—	0.120
(2) Height 12–24 in.	0.100	—	0.200
c. Fair stand, any grass			
(1) Height 6–12 in.	0.040	—	0.100
(2) Height 12–24 in.	0.080	—	0.170