VERDE RIVER: FLOW MECHANICS, ROUGHNESS, AND SHEAR STRESS

This lab will introduce you to some common field techniques and some general understanding of the geomorphic processes operating in a stream. The primary objective of this field project is to learn field and quantitative analysis of basic flow hydraulics (flow discharge, velocity, bed roughness, Manning's n, bed shear stress). Thus, the lab will focus on how the channel affects the flow -- on the various factors that cause resistance to flow and the large number of approaches to determining the amount and cause of that resistance. This effort will concentrate on data collection in 4 cross sections and additional vertical velocity profiles. We will alternate tasks in 4 research teams to take best advantage of the equipment we have and to maximize efficiency. There are three basic lines of evidence that you will pursue: (1) the distribution of sediment sizes as an indicator of differential sediment motion during channel-forming flows; (2) the behavior of the present flow (boundary shear stress, velocity, slope, etc.) in response to the various elements of channel geometry and roughness; and (3) estimating bankfull flow conditions.

We will compare our measurement of flow discharge among cross-sections and to nearby gage records to evaluate accuracy.

Part I of the lab is worth 5 points (separate handout, on website). **Due Wed. Oct 16**

Part II is worth 45 points. Due **Tuesday Oct 22.**

Field Equipment Required: field notebook (*bring those from the Cinder Cone project*), pencils, eraser, millimeter-scale ruler, clipboard, wading clothes (the water is warm, you will probably want to swim some), either sandals that strap on tightly or old tennis shoes (*good footwear is essential*) towel, change of clothes, lunch, lots of water. Bring something warm in case you get cold after some time in the water.

FIELDWORK

Split into four groups. Each group will work as a team all day, and a spirit of cooperation within the group, between groups, and also with the instructors will make the day much more enjoyable. All data will be shared with the entire class, as described below. However, everyone will do an independent analysis of the data collected.

The exercise consists of several parts: (1) mapping the area including the spatial pattern of sediment grain-sizes (pebble counts) on the bars and in the channel, (2) topographic surveys and average velocity measurements (4/10ths rule) at selected cross-sections, and (3) vertical velocity profiles at selected sites to evaluate (a) the 4/10ths rule and (b) map out any interesting patterns of local bed shear stress variation. We have 4 current meters but only limited surveying equipment, so groups will need to rotate their use throughout the day.

There is sufficient field equipment for the following rotation to work smoothly. At any one time: 2 groups can be collecting hydraulic and roughness data at their assigned cross-section (2 current meters); 1 group can be completing the topographic surveys of their cross-section and any other features of interest including vertical velocity profiles for local shear stress estimates (2 current meters); and 1 group can be completing their map and making observations on channel erosion/deposition processes. Try to pace yourself so that you can pass off field equipment when the next group is ready. The more efficient we are, the sooner we can head back to town.

Mapping of channel and banks and estimate manning's n visually

With some assistance the TA and I will complete a longitudinal profile survey of the thalweg, water surface, and channel pattern. This data can later be used to adjust field sketch maps to scale. Pacing distances or stretching out a long tape line along the river bank will help keep your field sketch map approximately to scale. In your sketch mapping, be sure to include:

- The Total Station survey conducted will provide a longitudinal profile of the channel bed, water surface, and (if possible) the bankfull (or high-flow) surface. The water surface slope is particularly important, especially near the gauging cross-sections.
- A good overall map, including the spatial distribution of erosion/deposition processes & landforms (bedforms, bars, etc), and the distribution of sediment sizes.
- Channel cross-sections at all gauging locations (these will be staked at the beginning of the day). The cross-sections should extend at least to bankfull width (if possible – you will likely have to make a rough estimate) and show banks, bed, and water surface.
- Any other notable features (bank under cutting or slumps, bedforms, weeds, woody debris, bedrock exposures or large boulders, etc)
- A permanent marker, for "absolute" elevation control, which will be established at the beginning of the day.

- While mapping, attempt to use Chow's method to estimate Manning's n for this channel (see page 5 of the lab handout and other summary tables of typical n values)

  On your sketch map, mark on it the distribution of vegetation, sediment sizes, bedrock outcrops, terraces, and anything else of interest. In particular, map in everything that affects the roughness of the channel.

Distribution of Sediment Grainsizes (Pebble Counts)

Pebble counts should be made at six localities, including the cross-sections where your group has gauged the stream flow. At the cross-section, measure 50-100 pebbles and cobbles (if present) distributed across the channel. Other sites might include the channel thalweg elsewhere, frequently inundated bars, or terrace deposits. Depending on the variability, 50-100 pebbles should be measured along their intermediate diameter and recorded to the nearest mm, or recorded into half-phi sizes (<5.6, 8, 11, 16, 22, 32, 45, 64, 90, 128, 180, 256 … you see the pattern. Note that an "11" is anything between 11 and 16 mm, for example). Each person in the group should take their turn at doing a pebble count (best done in pairs). You will be given a quick tutorial in making pebble counts in the morning.

Measurement of Flow Hydraulics: Stream Gauging

Each group will do one cross-section. The velocity measurements will yield three separate data sets: (1) discharge and mean velocity for use in the Manning equation (or other hydraulic formulae), (2) vertical velocity profiles for determining shear stress and roughness assuming a logarithmic profile, and (3) information on the local flow patterns (i.e. cross-stream currents or helical flow). The following must be measured:

- a series of depth measurements (roughly 20 per section – about 1 per meter) (these should be made using the laser range finder (or tape) and rod while your group is surveying)
- a series of mean velocity measurements (~20 per section using the 4/10 rule) (these will be integrated across the channel width to give an estimate of flow discharge)
- two or three vertical velocity profiles near the center of the channel (or high-velocity core)
- a series of measurements of flow direction (at positions both across-stream and in the vertical) to characterize the flow pattern: this is best done with colored flagging tape attached to a pole
- Additional vertical velocity profiles in areas of interest (within cross-section or between cross-sections) to evaluate spatial variations in shear stress. Working together we need a longitudinal transect with vertical velocity profiles every 5-10 meters.

Each group will be responsible for supplying the data for their gauging sections to the class by **Wednesday Oct 10, before lab**. This should include for each gauging station: section #, hydraulic radius, topographic survey, discharge, mean velocity, surface slope, flow patterns (velocity directions) and average grain size. All data must be entered into the provided Spreadsheet Template to facilitate sharing of data with minimal confusion. Remember that the flow will evolve as it makes its way down the channel: only your group has the information every group needs for a given part of the channel.

DATA ANALYSIS AND REPORT

Complete ALL calculations, provide charts of all data, including captions, and provide short answer (several sentences) to all questions posed below.

1) Prepare a good sketch map of the river reach based on your field sketches – use this to indicate where various data were collected and indicate location of flow resistance elements, velocity/flow depth patterns, etc.

2) Include a plot of the longitudinal profile (bed elevation and water surface elevation, indicating bankfull elevation where known, all on one figure) derived from the survey done by instructor and TA. ***Comment*** on implications for a steady, uniform flow approximation (where $\tau_b = \rho g h \sin\alpha$).

3) Determine a best estimate for water surface slope (S) at each cross-section position (determine the slope over a reach 5-10m above and below your cross-section).

4) Plot depth-averaged velocity (using 4/10$^{\text{th}}$s rule) as a function of distance across the river at **each** cross section (your data and that from other groups). From these data, compute river discharge (m^3/s) (explain how this was done). ***Compare*** the value determined from your cross-section with that determined by other groups and reported by the USGS gauging station. ***Discuss*** any significant differences and attribute likely causes.

5) Determine the pre-dam equivalent recurrence interval of the flow we observed. What fraction of "bankfull" (recurrence interval = 1.5 years) was this flow? (We will provide the data and explain the analysis needed in lab). Use data from above the dam (Horseshoe).

6) Discuss how the dam has altered the probability distribution of flow discharges (***compare*** the Horseshoe and Bartlett gages).

7) Determine Manning's n at each cross section based on:
   a) direct calculation using R_h, S, and Q
   b) grain size (D_{84}, equation for f from Leopold et al.)

   and ***compare*** these values with your estimates for the whole reach based on your mapping, visual estimate, and by using the chart from Chow (below). ***Comment*** on your findings – discuss similarities and differences.

8) Plot your vertical velocity profiles by computing ln(z) and plot u vs. ln(z). Use linear regression to determine u_* from the slope of the line (thus τ_b from $u_* \equiv \sqrt{\tau_b/\rho}$) and z_O. from the y-intercept (z_o is the height where the logarithmic velocity profile goes to zero). Use consistent units and pay attention to units of derived quantities. ***Compare*** this shear stress value with what you would calculate using the depth-slope product ($\tau_b = \rho ghS$). ***Compare*** this estimate of z_o to the expectation for grain roughness alone ($z_o = D_{84}/30$). ***Comment*** on you findings.

   In a discussion paragraph, focus on (a) the pattern in velocity profiles across your cross-section (3 minimum) and (b) velocity profiles at channel center (thalweg) along the longitudinal profile. How much spatial variability do you see and does it make sense? Does local shear stress determined from the velocity profiles differ from the value expected for steady, uniform flow in a sensible manner? [Its OK to discard any vertical profiles that are messy or just make no sense to you – just say why you focus on the ones you do (e.g., $z_o >> D_{84}/30$ suggests the flow is disturbed and not comparable to other sections].

I. Visual Estimates of Manning's n:

1. Visual estimate of field conditions using experience, "type" photographs, and published tables. Tables are found in most geomorphology texts. "Type" photos are in Water Supply Paper 1849. Listed below are a few examples (from Richards, 1984) (see also tables at end of lab handout):

Description	Manning's n
Artificial channel, concrete	.014
Excavated channel, earth	.022
Excavated channel, gravel	.025
Natural channel, < 30 m wide, clean, regular	.030
Natural channel, < 30 m wide, some weeds, stones	.035
Mountain stream, cobbles, boulders	.050
Major stream, > 30 m wide, clean, regular	.025

2. Chow's Method:

n is estimated from the formula

$n = (n_o + n_1 + n_2 + n_3 + n_4)n_5$

Material n_o	
earth	0.020
rock	0.025
fine gravel	0.024
coarse gravel	0.028
Degree of surface irregularity, n_1	
smooth	0.000
minor (e.g. only minor slumping)	0.005
moderate (e.g. moderate slumping)	0.010
severe (e.g. badly slumpted, or irregular rock surfaces)	0.020
Variation of channel cross section, n_2	
gradual	0.000
alternating occasionally	0.005
alternating frequently	0.010-0.015
Relative effect of obstructions (e.g. debris, roots, boulders), n_3	
negligible	0.000
minor	0.101-0.015
appreciable	0.020-0.030
severe	0.040-0.060
Vegetation, n_4	
none	0.000
low	0.005-0.010
medium	0.010-0.025
high	0.025-0.050
very high	0.050-0.100
Degree of meandering, m_5 (multiplier)	
minor (sinuosity <1.21)	1.00
appreciable (sinuosity 1.2-1.5)	1.15
severe (sinuosity > 1.5)	1.30