What controls the shape of river channels?
Quantifiying the hydrologic and sedimentologic characteristics of river channels

Background

Geomorphology is the branch of geology that investigates how the Earth's surface changes. The Earth's surface is a dynamic system that affects and is affected by the atmosphere, biosphere, hydrosphere, and, of course, the geosphere through processes such as volcanism, mountain building, and erosion. Rivers are the most effective component of the geomorphic system for erosion and transport of surface material. Like all other parts of the geomorphic system, rivers behave and are shaped by the interaction of driving and resisting forces. The driving forces, those forces that drive change, are represented by a certain volume of water flowing in a channel over time, called discharge (Q), the velocity at which that water is flowing (V or U), and the slope of the water surface (S), which is typically very close to the slope of the channel. The resisting forces, those forces that resist change, include the size, shape and volume (Qs) of sediment in the channel as well as the composition of a stream's banks or vegetation along the banks. For rivers that flow directly over bedrock or have very little sediment in the channel, the resisting force also involves the type of bedrock in the channel.

Most people readily recognize that streams or rivers do not flow in straight channels, like the concrete ditches in Albuquerque, but rather consist of a series of bends. These rivers are referred to as meandering and are a common channel pattern. Meandering streams tend to carry fine-grained sediment, have deep, steep-walled channels, and relatively gentle channel slopes or gradients. A good example of a meandering stream in New Mexico is the Rio Puerco. Anyone who has fished in New Mexico knows that you do not catch trout in the Rio Puerco; rather, you tend to have much more luck in cold, mountain streams. Mountain streams usually do not have well-developed meanders, tend to be rather shallow, carry coarse gravel and sand in their bed, and have relatively steep channels. Every fisherman has their favorite "hole" or pool in gravelly mountain streams. Typically, pools in mountain streams are separated along a stretch of river by shallows or riffles; these sections are the "babbling" parts of mountain rivers. A schematic diagram of a pool and riffle stream is shown in Figure 1. A good example of a pool and riffle stream in New Mexico is the Jemez River, the river which is the focus of our investigation.

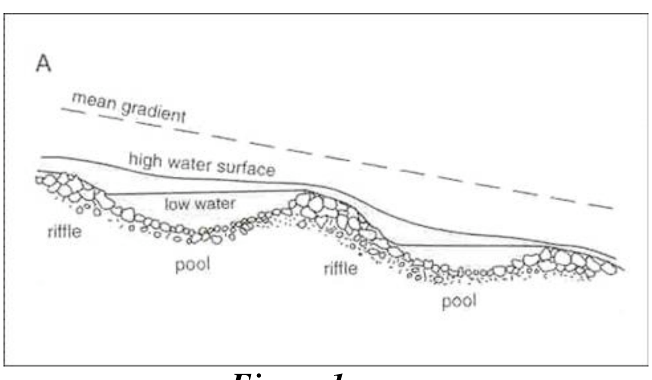

Figure 1

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Goals

The general goal of our project is to investigate the driving and resisting forces of the Jemez and Guadalupe river system. Specifically, we will use the Jemez and Guadalupe Rivers near their confluence to:

- Measure actual discharge at four locations,
- Estimate bankfull discharge at four locations,
- Investigate whether bed sediment should be moving at those discharges, and
- Investigate what velocity is required to move the largest clasts on the bed and compare that to bankfull velocity.

Hydraulic Geometry

For a moment, let's imagine that rivers have preferences… Rivers are incredibly lazy. They do the bare minimum of work necessary to maintain flow and transport the sediment provided to the channel. At the same time, rivers hate extremes, so they also strive to perform uniform work, that is, they want to minimize raising or lowering their bed as much as possible. Unfortunately for rivers, these two desires are somewhat incompatible, so a compromise must be struck. This compromise is characterized by the shape the river attains, which is a function of the river's effort at performing minimum and uniform work. The shape of a river's profile is constantly adjusting as the amount of water or sediment changes, but can be quantified by measuring several variables collectively known as hydraulic geometry.

Quantitatively, hydraulic geometry simply relates discharge (Q) to various other parameters including channel width (W), depth (d), slope (S), velocity (U), and bed roughness (n). These parameters are relatively easy to define in the field and discharge data is provided by gaging stations or measured in the field, which is what we'll do in this study.

The basis for field measurement of hydraulic geometry comes from the channel cross section (figure 2). A cross section, measured perpendicular to flow, has a certain width (W) and depth (d), which define a cross sectional area (A). If you know the velocity (U) through that cross section, you can calculate the discharge (Q):

$Q = U * A$ *where U is measured in meters per second (m/s), A in meters squared (m^2), and Q in cubic meters per second (m^3/s).*

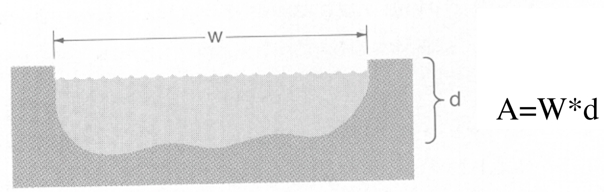

Figure 2

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Since discharge typically changes seasonally and over longer timescales with climatic variations, one important question is, what relative magnitude of discharge is most important in determining the geomorphic characteristics of a given stream channel? We can address this question by identifying what is referred to as the "bankfull discharge" of the stream.

Bankfull Discharge: The Channel-forming Flow?

Streams tend to be shaped not by everyday flows or discharges, but by higher magnitude events that move lots of sediment. These events may occur only once or twice a year and, in New Mexico, are associated with melting snow in the spring and/or large rainfall events. Many studies have demonstrated that the most effective flow that shapes channels is called the ***bankfull stage.*** Bankfull stage is the discharge that will fill a channel from bank to bank, without spilling out onto the floodplain. (The floodplain is the relatively flat area that parallels the river channel). The bankfull level can often be recognized by a change in slope at the channel margin, change in vegetation, and the occurrence of fine-grained deposits outside the channel. Although huge floods can drastically enlarge a channel, they occur quite infrequently, so that the channel might readjust by filling in with sediment during lower flows. Conversely, the majority of the time, discharge is too low to move much bed sediment, so despite their high frequency of occurrence, these low flows account for little channel adjustment. Data from streams in semiarid to humid areas of the U.S. indicate that bankfull discharge has a recurrence interval of approximately 1.5 years (in other words, it occurs on average 2 times in three years), although there is substantial variation among streams. With the data we collect, we will be able to determine the bankfull discharge and the recurrence intervals for the Jemez and Guadalupe Rivers – this could be important if you ever decide to buy a summer cabin along the Jemez!

Another very important channel property that helps define the pool and riffle sequence of the Jemez River is the sediment that this stream carries. For hydraulic geometry analyses, this parameter is usually derived from observations and is called bed roughness (n). In the field we will be a bit more quantitative and actually measure grain sizes to more accurately calculate bed roughness and try to determine the conditions under which the channel bed will move.

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Measuring Hydraulic Parameters

Field observations: Take 5-10 minutes to make general observations about the stream. Does the nature of the water surface change in any predictable way? Does the width of the channel change – if so what is the width change related to? Does it look like all the water in the channel is flowing at the same speed – if not, where is it slower or faster? Is the speed related to anything you notice? Is the vegetation telling you anything here? You will probably notice lots of things! **Write these observations in your field notebook.**

Cross-sectional area: We need two accurate profiles of the channel bottom measured normal to the stream banks. Along the same "line", one of the profiles should reflect the actual wetted perimeter; the second should record the bankfull stage cross-section. To measure the sections, you will stretch a tape across the channel and then use a meter stick or graduated rod to measure depth along the tape at breaks in slope. After all our field data has been collected, we will plot the cross-section on graph paper and "count the squares" to estimate channel area.

Before you start: Think about the process you will use to make these measurements. Describe the process in your own words in your field notebook. What equipment will you need to make these measurements? How will you (your group) set up your data table? What problems do you think you'll encounter in measuring channel cross-sections? What observations did you use to determine the bankfull elevation?

Velocity: Velocity can be measured three ways.

1) The first is very simple – throw something bright (an orange) or something that floats (a stick) into the water and time its movement downstream over a measured distance.
2) The second is to employ a "standing wave" estimate:

$$U = \sqrt{2gh} = (2gh)^{0.5}$$

where h is the height to which water "backed up" against a meter stick stick held in the flow rises relative to the surface of the river (in meters) and g is the acceleration due to gravity (9.8 m/s^2).

3) The third is to actually measure the flow in each compartment (see figure 3) using a flow meter.

We will not use a flow meter for this exercise – we're going "low-tech".

At Las Casitas, work with your group to determine how you plan to measure velocity. Check with your instructors before you begin! After all field data is collected, we will calculate the average velocity using both methods.

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Before you start: What equipment will you need to make velocity measurements? Will you subdivide the flow into compartments? How will you divide the flow into compartments? How will you (your group) set up your data table? What problems do you think you will encounter in measuring velocity by these different methods? How similar or different do you think the velocity estimates will be using the different methods?

*ONLY USE THE FIRST METHOD AT LA JUNTA (3rd and last field day).

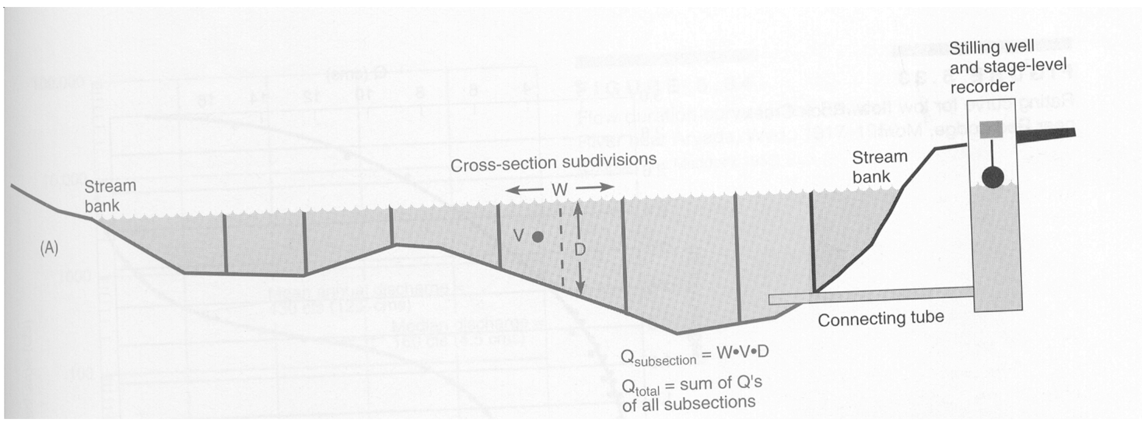

Figure 3

Discharge: After collecting your field data, you will calculate discharge using the relationship between A and U outlined above. ***Wait on this step until all field data have been collected – we will have time to work on this step at the end of the day or on Friday.***

Measure slope: Slope is the ratio of the difference in elevation at two points along the channel and the distance between them, or "rise over run." Parallel to the channel and at the waters edge (water surface), place one rod upstream and one rod downstream of your cross-section. Tie the string on the upstream rod at a "fixed" position. Pull the string tightly to reduce sagging and adjust the height on the downstream rod using the level at each end to determined when the string is level. Measure the distance from the ground to the string at each rod, and then use the measuring tape to get the distance between the rods. Next, try to measure slope along the bankfull bank.

Before you start: What equipment will you need to make these measurements? You may consider drawing a picture of your setup before you start. Why do we worry about the string sagging between the rods? How will you calculate slope? What are the units associated with slope? Do you think slope will differ between pools and riffles? If so, how? How does slope influence the driving force?

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Grain-size data: We will collect data on bed sediment in the river channel. If bankfull discharge is the discharge that shapes the channel, bed sediment must move at bankfull discharge for the channel to adjust. To investigate this idea, we will first estimate the **bed shear stress (τ)** that the stream exerts at bankfull discharge:

$\tau = \rho_w g d S$ *where* $\boldsymbol{\rho_w}$ *is the density of water (1000 kg/m*^{3}*),* ***g*** *is acceleration due to gravity (9.8 m/s*^{2}*),* ***d*** *is the average depth of flow (in meters), and* ***S*** *is the slope of the bankfull bank.*

We will compare the bed shear stress at bankfull discharge to the **Shields criterion for critical shear stress** (τ_c), which is the stress needed for initial motion (entrainment) of bed sediment of a given mean grain (clast) size (D_{50}). The following is an empirical relationship:

$\tau_c = 0.045(\rho_s - \rho_w) g D_{50}$ where $\boldsymbol{\rho_s}$ is the average density of clasts (2700 kg/m^3) and $\mathbf{D_{50}}$ is the median grain size (in meters).

IN THE FIELD: At each cross-section, we will quantify bed sediment size by performing a pebble count. To do this, start at one end of the cross section, bend over, and place your finger on the channel bed next to your toe, then grab the first clast you touch…no peeking! Repeat this process across the entire channel. Along each cross section, measure at least 40 clasts greater than 2 mm (coarse sand or larger) with a ruler to the nearest mm. Each clast can be thought of as having a long (a), intermediate (b), and a short (c) axis. Clast length measurements should reflect the b-axis. Clearly mark in your notes which cross-section the sediments are from and whether your cross section is located in a pool or riffle or a transitional reach.

***Before you start:** How will you "choose" where to sample each sediment clast along the cross-section? We are you not allowed to "peek" at the bed sediment? Why are we measuring the intermediate axis of the sediment clasts? What problems do you think you'll encounter in measuring b-axis diameter? How will you (your group) set up your data table? How will you determine the median grain size? Can you see a difference in clast size between pool and riffle segments? What is stress and how is it related to discharge and sediment movement?

We will also investigate the **competence** of our streams, that is, the maximum size of sediment that the stream can move, and whether these clasts are likely to be entrained at the velocity corresponding to bankfull discharge. The critical velocity (V_c) required to initiate motion of these clasts is estimated to be:

$V_c = 0.18D_{max}^{0.487}$ where D_{max} is the b-axis diameter (measured in mm). The value for V_c will be in m/s.

IN THE FIELD: Measure the intermediate axis (b-axis) of the 5 largest clasts that you can find at each cross-section (be sure to identify by cross-section).

We will also measure D_{max} of the 30 largest clasts in each terrace so that we can roughly estimate the competence of the stream in the past.

In summary, this is a simplified list of things to do at all field sites:

- Before you start on any measurement, answer the *"before you start"* questions in your field notebook. You only need to answer these questions the first time you perform a given measurement.
- At each reach, measure cross-sectional area 1) through the wetted-perimeter and 2) at the bankfull elevation. You will do this for a pool and a riffle at Las Casitas and only at a representative cross-section at other sites.
- Measure velocity using two methods at Las Casitas, but using only the first method at La Junta.
- Measure slope at each reach (both water surface and bankfull bank slope).
- Measure median grain size of sediments (from 40 clasts) along each cross-section (pebble counts).
- Record the size of the 5 largest clasts along each cross-section.
- Measure the size of 30 largest clasts in each terrace.

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Some results and interpretations to include in your final paper:

Use data collected June 3 to answer this question:
1. How does the riffle discharge you measured at Las Casitas compare to the discharge you measured in the pool? How do the sediment sizes compare? Explain your data.

June 3 and June 4 data:
2. How does measured discharge on the Jemez River at Las Casitas compare to the Jemez River discharge you measured just upstream of the confluence? Explain.

Use data collected June 4 to answer the following questions:
3. Can the measured discharge move the **median** channel bed sediment at each cross-section (two above and one below the confluence)? Explain.

4. Can the estimated bankfull discharge move the **median** channel bed sediment at each cross-section? Can it move the **largest** sediment in the channel at each cross-section? Explain.

5. Does the sum of the measured upstream discharges equal the measured discharge below the confluence? Discuss why they might be different. How does your measured discharge below the confluence compare to the discharge reported at the gage for the same day?

6. The largest flow since the gage was installed in 1938 on the Jemez River was 170 m^3/s in 1958. Assuming that the channel area hasn't changed, could that discharge move the largest clasts in the cross-section below the confluence? (Is the assumption that the channel area hasn't changed a good assumption?) If the largest clasts in the terraces were located in the modern channel, could the largest recorded discharge move them?

Use the flood recurrence interval graph to answer the following question:
7. Estimate the recurrence interval for your estimated bankfull discharge below the confluence. How does it compare to the standard of 1.5 years?

Use your new knowledge of streams to speculate on this "big picture" question…
8. Climate scientists predict that annual precipitation may decrease and average annual temperatures may increase in the future here in the southwest. Water resource managers are already planning for decreased winter snow packs and more variable summer monsoon precipitation events. How do you think these changes will affect mountain streams like the Jemez River? How might those changes affect farmers along the Rio Grande or other water users, like the City of Albuquerque?