Geomorphology
Geology 450/750 – Spring 2004

Fluvial Processes Project – Analysis of Redwood Creek Field Data

Due Wednesday, May 26

This exercise is intended to give you experience using field data you collected to analyze the fluvial processes that occur in Redwood Creek, and the landforms that result. You'll recall from our two visits to the reach above the Frank Valley bridge that we wondered how the channel was evolving over decadal to millennial time scales. Our interpretation (or hypothesis) was that the channel was actively incising into a deep valley fill, eroding both laterally and vertically, producing elevated rates of sediment delivery to the Big Lagoon at the mouth of the river not far downstream of our study site. The analysis below will provide some quantitative information that you can use to assess this hypothesis.

You will not have to write a formal project report for this exercise. Rather, you will answer a series of questions as you go through the analysis. Each question that requires an answer (with a number and/or some thoughtful prose) will be preceded by a double 'bullet' (••). As you've done before, show all your work on separate sheets. You'll be receiving an email with two files attached, a spreadsheet with the survey data used to generate the attached plots, and a photograph of the channel that will come in handy in Part A.

Part A: Hydraulics and Flood Frequency

In this first part you will analyze the response of this channel to various discharges, building on your work in Lab Exercises 4. For simplicity, you will focus most of your calculations on cross-section 'C', the downstream most cross-section of our survey. (Make sure you work with the right cross-section!)

Your task here is to estimate the magnitude of the discharges required to fill the channel to the elevation of:

(a) the top of bank (i.e. the "bankfull discharge"),
(b) the lower terrace surface, which at 'C' is a narrow bench on the left bank,
(c) the upper terrace surface, on the right bank where the road is.

You will then estimate the recurrence intervals for these discharges, using the flood frequency analysis you did previously for Lagunitas Creek, the nearest stream with a long gauged record of discharge.

Step 1: Estimate the average water surface slope for the entire study reach. ••How steep do you think the water surface is when there's enough water flowing in the channel to fill it bank to bank? Use the attached longitudinal profile to make your estimate. Note that at low flow (as it was during our field trip), the water surface slope changes from nearly flat to locally steep, following the bar-pool sequence. Keep in mind that when the flow is deep enough to fill the channel, these differences will be somewhat smoothed out, and the water surface will have a nearly constant slope through the reach. ••Draw the slope on the long profile attached. ••Explain the reasoning behind your method for estimating the water surface slope.

Step 2: Measure the cross-sectional area *(A_x)* and wetted perimeter *(P_w)* and calculate the hydraulic radius *($R = A_x / P_w$)*, for each of the three water surface levels. (You don't have to be ultra-precise in this measurement – but don't forget to show your work!). For the deep flow that would reach the elevation of the road, assume that the left bank is vertical above the plotted points. ••Tabulate these values along with the estimates of mean velocity, discharge and recurrence interval that come next.

Step 3: Calculate the mean flow velocity for the three cases, using the 'Law of the Wall' equation for the turbulent logarithmic velocity profile. Recall from lecture that we can express the depth-averaged velocity as

$$\bar{u} = \frac{u^*}{k} \ln\left(\frac{h}{ez_o}\right)$$

where u^* is the shear velocity [$u^* = (gRS)^{1/2}$], h is the flow depth, k is von Karman's constant (k = 0.4), e is the base of natural logarithms [e = ln(1) = 2.17…], and z_o is the roughness parameter that can be approximated as 0.1 D_{84} for natural gravel beds. To estimate the D_{84} you'll need to use the attached plot of the grain size distributions you measured with your pebble counts. Note how similar the pebble counts were, with the exception of cross-section 3 – which was just upstream of the big bend in the middle of the study reach. ••Add the velocity estimates to your table.

Step 4: Multiply the average velocity by the cross-sectional area to obtain the estimated discharge for each of the three cases. ••Add the discharge estimates to your table.

Step 5: Now, calculate the mean flow velocities again, this time using the Manning equation (as you did in lab exercise 4). You'll need to come up with an estimate of the roughness parameter (*n*). In the absence of any gauging data with which to back-calculate *n* from a known flow depth, you'll have to use the photographs and other information contained in the 1968 classic USGS professional paper by Barnes, which (although it can't be purchased from any booksellers – and has been stolen from many libraries) can be found in digital form on the web at

http://manningsn.sdsu.edu/

I'll send you by email a photo of our reach to use for the comparison. Remember when making your comparisons of photographs that Mannings *n* accounts for all forms of resistance to flow, including vegetation, bars and other bedforms, as well as the grain roughness accounted for by the Z_o term in the Law of the Wall. ••Add the new velocity estimates to your table. ••How do your results using these two different methods for estimating mean velocity compare? Use the Manning equation to back-calculate a value of *n* from your Law of the Wall mean velocity estimates. ••From the photos of channels with that *n* value, do you think that could be a reasonable roughness value? ••Which method of estimating velocity do you think is more accurate, and why? ••From your mean velocity estimates using Mannings equation, calculate the discharge for each of the three flow levels and add the results to your ever-expanding table.

Step 6: Now, estimate the recurrence interval for each of the three discharge levels, using the discharge result of whichever of the two velocity methods you prefer. Because there is no long-term record of discharges on Redwood Creek, you'll have the make the assumption that the rainfall pattern and watershed response is essentially the same at Lagunitas Creek, for which you developed a flood frequency curve in lab exercise 4. You can then scale the magnitude of the expected discharge for a given recurrence interval by the ratio of the drainage areas of the two creeks. Lagunitas Creek, at the gauge site, has a drainage area of 212 km^2, while our reach of Redwood Creek at Santos Meadow has a drainage area of 17.1 km^2. So, for example, if your estimated ten year flood on Lagunitas Creek was 190 cubic meters per second, then for our reach of Redwood Creek you would have a ten year flood of

$$Q_{w\text{-}10} = 190\ m^3/s * 17.1\ km^2 / 212\ km^2 = 15.9\ m^3/s.$$

••Add these recurrence intervals to your table. ••How does your recurrence interval estimate for the 'bankfull' event compare with the expected value of around 2 years? ••If it doesn't agree well, do you think we may have mis-identified the 'top of bank' – could that lower terrace be a piece of active floodplain instead? ••Do you think the road is in any danger of flooding in an extreme rainfall event?

Step 7: Although there isn't a long-term discharge record, there was some intensive monitoring of the creek done this winter by Jimmy Kulpa of Environmental Data Solutions, for the National Park Service. Jimmy and the Park Service have been kind enough to share their data with us. Take a look at the attached plot of discharge measured at the Muir Woods bridge, upstream of our study reach. You'll see that the December 29th storm was the largest of the winter, and that the February 25th event that was so extreme at SFSU was more of a typical storm this year in Redwood Creek. Use your results from Lagunitas Creek to estimate the recurrence interval of the December 29th event in Redwood Creek. To do this you need to know the drainage area of the Muir Woods bridge (9.9 km^2), and the magnitude of the peak discharge (read it off the figure); use the drainage area ratio to scale up to your flood frequency curve for Lagunitas. ••What is your estimate of the recurrence interval for the December 29, 2004 flood? ••Is this a reasonable estimate, why or why not?

Step 8: Take a look at the plots of some of the other cross-sections we surveyed. Choose one of them to compare to cross-section C. ••Without doing any quantitative analysis speculate on how the three discharges you calculated for cross-section C would fill the channel and valley. ••From this hydraulic analysis alone, what inferences can you make about the pattern of valley evolution at this reach of Redwood Creek?

Part B: Threshold of sediment motion

In this second part, you will consider the conditions at the threshold of bed sediment motion at cross-section C, building on your work in lab exercise 5.

Step 1: ••What is the (dimensional) shear stress required to initiate grain motion on the bed, at cross-section C? Use the value of 0.05 for the non-dimensional critical shear stress τ_c* and the estimate the D_{50} from the grain size distribution measured in the pebble count.

Step 2: ••How deep does the flow have to be to generate the threshold of motion shear stress that you calculated in the previous step? Assume that the ratio of the surface width to mean depth will be large, so that you can use depth rather than hydraulic radius in the calculation (otherwise you have to iterate to find a solution because depth appears in both the numerator and denominator of the equation for the hydraulic radius. Once you've solved for depth, check that the width to depth ratio is around 20 or greater. (If it's much less than 20 you may have done something wrong).

Step 3: ••What is the discharge required to put the bed into motion?

Step 4: ••Can you estimate the recurrence interval for this discharge? If so, what is it?

Step 5: ••Using the measurements of discharge at the Muir Woods bridge from this past winter (and scaling by drainage area to our study reach), how often this winter would you estimate that the bed was mobilized? ••Draw a line across the plot of discharge versus time at the threshold of motion flow, and estimate (roughly) the duration in days that the bed was mobile over the past winter.

Step 6: Recall that when we did the pebble counts, we didn't include any grains less than 2 mm. The reason is that we expect that when the bed is mobilized, the sand (and finer) sized grains will go into suspension and thus shouldn't be considered part of the mobile bed. You can test this assumption now by calculating the grain size that would be at the threshold of suspension when the bed is at the threshold of motion. Recall from lecture that grains tend to travel in suspension when the shear velocity [$u* = (gRS)^{1/2}$] is equal to the grain settling velocity in still water w_s. Calculate the shear velocity for the critical flow depth you got in step 2, and then setting that equal to the settling velocity, use the attached graph of settling velocity to find the corresponding grain size. ••Is your estimated grain size at the suspension threshold in the neighborhood of 2 mm? ••What would be the grain size at the threshold of suspension for the discharge that fills the channel to the elevation of the lower terrace?

Part C: Sediment transport

Step 1: Take a look at the attached table from Jimmy Kulpa's storm sampling over the past two winters. Note that for the Muir Woods road site he obtained six measurements of discharge, suspended sediment concentration (SSC) and bedload flux over the two years (including the measurements of zero flux). Also attached are Jimmy's plots of the grain size distribution of the bedload and suspended sediment concentrations (SSC) ••Make a plot of bedload flux versus discharge (discharge on the horizontal axis) for the six points. ••If you had to use these data to create a sediment rating curve (a predictive model of bedload flux as a function of discharge), what shape of curve would you use (it doesn't have to literally 'curve')? ••Sketch in such a curve (by hand is OK) on your plot of Jimmy's data. ••Explain your reasoning.

Step 2: A key question for the feasibility of the proposed restoration of Big Lagoon downstream is what fraction of the total sediment load is in the coarse, bedload size class, and what fraction is in the fine, suspended load size class. The fine sediments may get flushed out to sea periodically, but the coarse sediments probably won't. ••For the December 29, 2003 event, calculate the combined sediment flux and the relative contributions (fractions) of the bedload and suspended sediment load. You'll need to convert SSC (in milligrams per liter) to grams per min (to match the bedload units) by multiplying SSC by the discharge (which is m^3/s).

Step 3: Finally, make the (rather huge) assumption that the total sediment flux throughout the year can be approximated by multiplying the total flux you calculated in the previous step by the duration (in days) of bedload mobility that you calculated in Part B – step 5. ••What is your estimate of the total annual sediment flux (in kg) through the reach where Jimmy made these measurements? ••What is the equivalent rate of annual sediment production (in tonnes/km^2), assuming sediment is supplied uniformly from the drainage area of 9.9 km^2? ••The sediment budget for Redwood Creek recently done by Stillwater Sciences suggested that the current annual sediment production rate might be as high as 180 tonnes/km^2. ••How does your annual sediment flux estimate compare with their number? ••Assuming that the difference between these two numbers (yours and theirs) has at least the right sign (negative or positive), what are the implications for the continuing evolution of the reach of Redwood Creek where we did our field survey.