Channel Design Exercise – Provo River

This exercise is designed to give you experience with the steps involved in incorporating sediment transport into a channel design layout. The exercise is based on a section of the Provo River that was reconstructed in fall 2003 and spring 2004. You will visit this reach tomorrow to see what was actually built and how it has performed! You will hear from Tyler about the choices he made in designing the reach and hear about lessons learned.

The sequence of steps followed here use the principles covered in class. Although there are other approaches, we offer this sequence in order to bring practical application to some of the concepts and ideas discussed in the course.

The client’s objectives are that you create a channel and floodplain that is natural in function and appearance. Yes, you have to figure out what that means. The design should be capable of maintaining a sustainable native riparian vegetation community and a recreational trout fishery. This will require that flows access the floodplain on a regular basis. The project area is intended to be a visual and recreation focal point for the Heber Valley. It is expected to attract both visitors and new residents. There is a clear economic incentive.

The client’s goals are very general and do not inform how the channel is to be built. You must develop a design strategy to achieve the project goals. This design strategy should be built on your interpretation of how these ecological and recreational goals can be achieved. You need to turn generalities into specific channel attributes. Be specific about how you want the channel to behave (e.g. static v. dynamic; sediment surplus v. deficit, etc.).
We use flow from the Charleston USGS gage, which has operated since Jordanelle Dam was completed (plus earlier, providing an idea of how releases to the river have changed over time).

Flood frequency data (standard Weibull plot) is given at right. We use flood frequency information to determine how frequently (what fraction of years) the channel will flood. Based on operations of dam releases since 1992, the annual peak flow will exceed about 1,000 cfs two years out of three and will exceed about 1,350 cfs every other year.
There is a sediment supply from the next reach upstream (the ‘never channelized’ reach). Sediment transport has been measured in the reach approaching the design reach. The rate of sediment supply is given in (a). The grain size of the supply increases slightly with discharge (b). A flow duration curve from the downstream USGS Charleston gage is given in (a). We use flow duration to estimate how much sediment is delivered over time. The product of transport rate and flow duration gives the amount of sediment transported through the supply reach at each flow, and their sum gives the total sediment delivery in an average year. Note that nearly all of the sediment is delivered at flows 1,800 cfs and above. This is why the grain size of the total sediment delivery in (b) is nearly identical to the grain size of transport for Q > 1600 cfs.
You now have all the pieces you need to come up with a channel layout. The flood frequency curve suggests that a rather small bankfull discharge (less than 1400 cfs, say) would be needed if the channel were to access its floodplain frequently, which may be desirable for a project with ecosystem priorities. At the same time, flows of 1400 cfs and smaller deliver only about 1% of the total sediment supply. More than 80% of the sediment is delivered at flows of 1800 cfs or greater! The 1.5-yr flood is about 1000 cfs and the effective discharge (2100 cs) is more than twice that and has a six-yr return interval.

This ‘mismatch’ between flood frequency and sediment supply should not be taken as representative of natural channels, but it does illustrate the difficulty of using standard templates for designing channels. The history of the middle Provo R and its flood frequency and sediment delivery “is what it is”. The combination of channel width and slope needed to transport the supplied sediment is given by iSURF STAB for 14 different discharges. Which discharge should be chosen to design the channel? Consider: A bankfull discharge of 1400 cfs (about the 2-yr flood; bright green line) produces slopes in the range of 0.4% to 0.5% for ‘reasonable widths of 25 m to 35 m. Compared to the valley slope of 0.68%, this gives a channel sinuosity of 1.4 to 1.7 (ratio of valley slope to channel slope), giving the opportunity for channel curviness that could provide fish habitat, fisherman vistas, and the seed for future channel dynamics. But a slope picked from the 1400 cfs line would be at- or over-capacity for only about 15 t of sediment supply, which is about 1% of the overall sediment supply! That means it would be under-capacity for basically all of the sediment supply ... the channel will accumulate sediment.

A bankfull discharge of 1800 cfs (about the 2.5-yr flood; bright blue line) is more likely to transport the sediment supply, putting the channel close to a sediment balance, although channel widths smaller than 25 m would be needed and the slope would have to be close to the valley slope (a straight channel).
What to do? Well, that depends on your goals for the project.

If you had little space and could not allow the channel to move around, then a channel width of 20 m and a slope of 0.6% might make sense. This channel would be able to transport the sediment supplied to it, reducing the chance that sediment might accumulate in bars and push the channel around. You would want to also check for threshold conditions to evaluate the potential for channel scour. The native material in the area has a fair amount of larger sediment, such that the channel bed might be resistant to scour. This channel design would not be particularly dynamic (although some hardened structures for fish and fishermen habitat could be installed), but then the purpose is to make sure that the channel is NOT dynamic!

An alternative approach would be to encourage at least some sediment deposition as part of a ecosystem restoration with a dynamic channel. The conditions for this project indicate that a channel that floods with regularity (at least every other year) will not be able to move most of the sediment. Deposition in bars and active bar-push channel migration is desirable. But we should probably check how much deposition is likely and whether the channel might just fill up and choke!

The average annual sediment supply is 1,618 tons, or 1,471 Mg. Using a bulk density of 1.65 Mg/m$^3$, that comes out to about a 900 m$^3$ deposit for the total annual supply. Is that a big number or little number? Well, suppose one third of the sediment is either transported through the reach or fills in spaces between the bigger grains in the bed. If the remaining 600 m$^3$ deposited in bars, each year would build a bar that is 5-m wide, 120-m long (about four channel widths), and 1-m deep. Seems like a nice idea. There are LOTS of bends in a channel with sinuosity 1.4 to 1.7 and, for the purposes of this project, they all would benefit from active deposition and gradual bend migration. As shown above, this is about what Tyler designed {except he had no post-dam flow information, no sediment supply information, and no tools like you have used in this exercise}. His design resulted from many long winter nights making sediment transport calculations and laying out dozens of version of the channel. It turns out that the as-built channel did ‘grow’ a number of bars, resulting in desirable channel resculpting and shifting.
Note: we can solve for the slope that provides transport capacity that matches the sediment supply averaged over the year. That slope might produce a bit of aggradation at some flows and a bit of scour at other flows, but averaged over time, it provides just the slope needed to transport the supplied sediment over all the flows. This is precisely the definition of a graded river. For the case of the middle Provo design reach, this slope is about equal to the valley slope for a channel width of about 30 m.
Now, to lay out the channel. Let’s use the 0.044% slope that Tyler used. That leads to a sinuosity of 1.55 and a channel length of about 6,460 ft, compared to the 4,000 ft straight-line distance between start and finish dots.
Many factors go into laying out the channel (Tyler says he tried dozens of options), including using existing hydrologic and vegetation features. In the end, one wants to follow the design slope with some consistency to avoid excessive excavation!

The topographic extraction tool provided by Scott David shows that the as-built channel closely follows the topography to maintain a slope close to 0.044% throughout.

Slope = 0.0044
Other design thoughts.

The bankfull flow capacity of the as-built channel is not rigidly maintained. The channel banks are intentionally lower in spots where Tyler would like to see more frequent flooding and ponding, or to feed secondary channels that pre-diversion history indicates were common.

It takes quite a bit of work to design the entire channel length such the bankfull flow is achieved (or not) everywhere. Bends, riffles, pools, lateral topography are all elements that need to be added and that will influence the water surface elevation. A 1d hydraulic model is the appropriate tool for this hydraulic design (but probably not for routing sediment through the reach).

Much of a stream designer’s work focuses on vegetation and (where needed) on bed and bank protection. Other than designing a threshold channel (which involves specifying the bed material), we don’t cover such topics in this sediment transport class. A compleat stream designer must become expert in hardening or stabilizing banks where needed (hopefully only a small fraction of banks in a project intended to promote ecosystem benefits) and in selecting the types, elevations, hydrographic regimes, establishment, and maintenance needed for vegetation restoration.