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LAB 4. *Stream Profiles and Mass Balance: Supply vs. Capacity*

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We have seen the utility of numerical models in our hillslope diffusion experiments. We will now examine a slightly more complicated profile-evolution model by incorporating simplified fluvial transport and erosion processes. In today's lab, we will examine the controls on longitudinal channel profile shapes.

The Questions:

I. Why do streams generally have concave profiles and hillslopes have convex profiles?
II. What physical characteristics (landscape and atmospheric) affect stream profiles?
III. What processes affect stream profiles?

Materials:

Numerical models for Matlab: Profile_TransLim and Profile_DetachLim

A Numerical Model of Stream Channel Profile Evolution

What is a numerical model? Take II.

You will remember from the previous lab we tinkered with a numerical model of hillslope evolution. Similarly, this lab will model stream channel profiles based on grain size (i.e. the loose material in the stream), precipitation, drainage area, channel characteristics (width & slope), and transport efficiency (erosion). As we remember from last lab, to set up a numerical model we will need to have:

1) a **model** for how the stream profile might evolve, cast in a mathematical form;
2) **initial conditions** for starting the model off and running;
3) **boundary conditions** for the edges of our model, since we are not modeling the entire world; and
4) a **time step** over which we will carry out our model runs.

Terms to Know by the End of This Lab

1) Transport efficiency (*K*): the ability, or competence, of flowing water either to move cohesionless material or to detach (erode, entrain) cohesive material (usually a constant).
2) Precipitation (*P*): rainfall, snow, sleet, hail, cats & dogs…
3) Contributing Area (*A*): the surface area that drains exclusively to the stream
4) Hydraulic width (*w*): measure of the width of the wetted channel
5) Grain diameter (*D*): empirically measured diameter of stream bed grain (cobble, gravel, sand, etc.); equations commonly use median diameter (D_{50})
6) Transport limited: the amount of lowering is limited by the capacity of the stream (or whatever) to transport sediment. The stream (or whatever) can detach all it can carry, so capacity is limiting.
7) Detachment limited: the amount of lowering is limited by the stream's (or whatever's) ability to detach material from the bed. The stream (or whatever) can carry all it can detach, so detachment is limiting. Once the material is eroded it will not be re-deposited (i.e., a stream with ample capacity—it's just that the stuff it's eroding is tough).
8) Unit stream power (ω): rate of potential energy loss per unit width and distance.
9) Base level: the lowest elevation in a system.

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Hillslope Profile Formation –v- Stream Profile Formation

We have seen examples both in the field and in lab of downslope steepening (i.e., profile convexity). We attribute this to the hillslope trying to keep up with supply from weathering and base level lowering; for the hill to keep up, slope must get steeper further from the top (aka 'divide'). Why is this? Simply put, more power is necessary to move more material—an increasing slope provides this balance.

Yet… we see that most stream profiles are concave. How can this be? What is different about streams? Think about the forces acting upon each. For hillslopes, the processes that are stirring stuff up act equally along the entire profile, so that stuff moves in proportion to the downslope component of gravity—greater slope means greater downslope component and greater "transport capacity".

Of course, gravity also applies to streams (we can all agree water flows downhill), but unlike hillslopes the erosional force at work is attributed to moving water. Give brief answers to the following:

1) Is the power of a stream constant along its entire length? What changes in stream features might (a) change that power and/or (b) change the amount of "work" that power can accomplish?

The question of how important different physical attributes of a stream system are to its shape is important but not easily pinned down. We will examine two simplified physical models that explore this question: **transport-limited systems**, and **detachment-limited systems**. As noted above, the assumption that a system is **transport limited** implies that the amount of lowering in any given landscape is limited by the amount of material a stream is able to carry. The assumption that a system is **detachment limited** implies that all eroded material is transported out of the model (i.e. no deposition). The two cases may be expressed in the equations below:

Equations Governing Stream Profiles

Transport Limited:

(A) $$\frac{\Delta z}{\Delta t} = K_t \frac{\Delta\left(x^m \frac{\Delta z}{\Delta x} \right)}{\Delta x}$$

where z is the stream bed elevation; t is time; x is distance; K_t is the transport efficiency and is a function of grain size and density, climate/hydrology, channel geometry, and bed roughness; and m is a constant related to the rates of change of grain size, hydraulic width, and discharge with distance downstream (it will be larger if grain size is decreasing at a greater downstream rate, width is increasing less quickly, and/or discharge is increasing more quickly). Note that this looks a lot like the diffusion equation for hillslopes except for the term, x^m. Therefore, you might think of this as a diffusion equation with a diffusivity that increases downstream.

Detachment Limited:

(B) $$\frac{\Delta z}{\Delta t} = K_d \left[x^m \left(\frac{\Delta z}{\Delta x} \right) \right]^p$$

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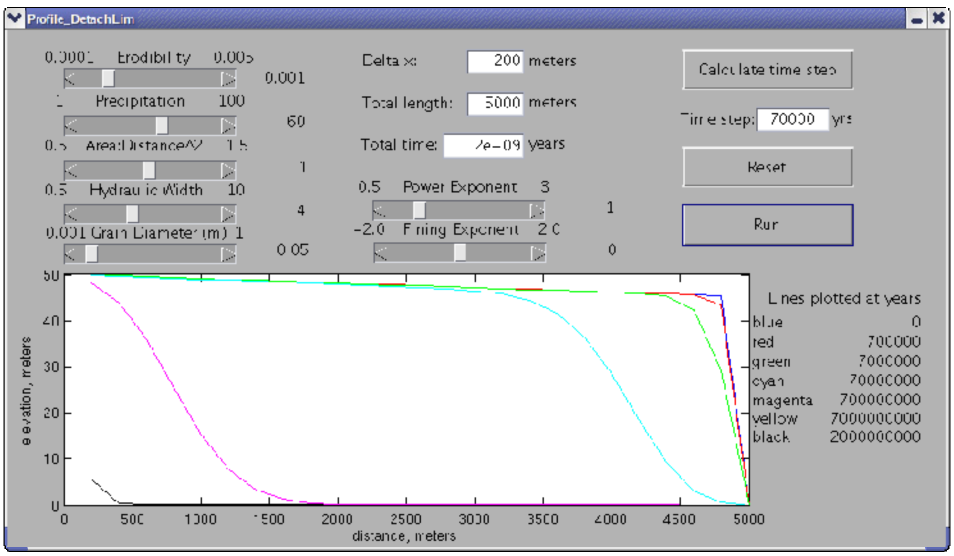
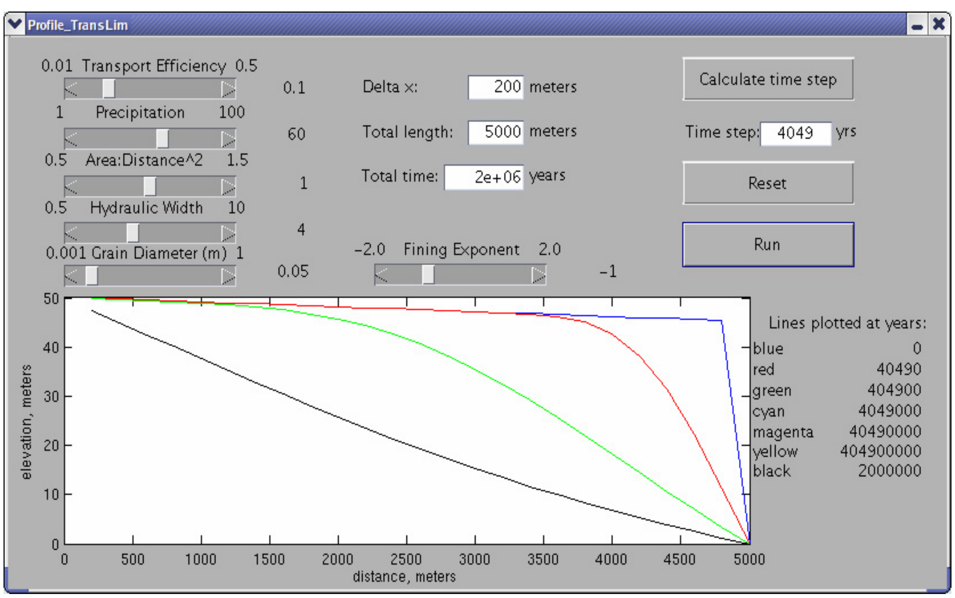
where K_d is an erosional efficiency factor that lumps information related to lithology, climate, channel geometry, and perhaps sediment supply (because sediment can act as “tools” to erode bedrock); m is a constant similar to m above and is related to changing hydraulic width, discharge downstream, and the rate of downstream “fining” (or think of it as rock getting easier to erode or as tools becoming more abundant); and p is a constant related to the particular process by which bedrock is detached, or eroded (e.g., abrasion, plucking). Both of these equations assume that transport or detachment is related to unit stream power.

The computer model does all the calculation for you. Even so, it is strongly recommended that you become familiar with the aspects of these equations to understand how different terms affect outcomes. See your lecture notes.

Computer Model

Open the Matlab program, navigate to the directory into which you have put the model files, and type in Profile_DetachLim and, subsequently, Profile_TransLim (or just follow TA instructions). You should see the following:





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When using these models note that, although the time step is calculated for you, the calculation may not always be reliable. Reducing the time step can often solve problems of stability. Increasing it can solve problems of slowness.

Detachment-Limited Model (Profile_DetachLim):

2) Making the Fining Exponent smaller (e.g., <0) makes *m* larger, and making the Fining Exponent larger (e.g., >0) makes *m* smaller (I know; *mea culpa*). What happens to the shape of the profile with Fining Exponent <0, =0, and >0? Describe the differences among these three cases.

3) Changing the Power Exponent directly manipulates *p*, which determines how sensitive detachment is to stream power. What happens to the style of profile evolution with *p* <1, =1, and >1? Describe the differences among these three cases.

4) Manipulate any combination of the adjustable parameters. What extremes of stream profile are you able to model? Under what conditions do these extremes occur (i.e. what are your model settings)? Pay special attention to different combinations of the Fining and Power Exponents.

Transport-Limited Model (Profile_TransLim):

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5) Again, the Fining Exponent changes *m* as described above. What happens to the shape of the profile with Fining Exponent <0, =0, and >0? Describe the differences among these three cases.

6) And finally, manipulate any combination of the adjustable parameters. What extremes of stream profile are you able to model? Under what conditions do these extremes occur (i.e. what are your model settings?)

Mass Balance

Paraphrasing John Muir, "tug on anything in nature and find the world attached." A similar metaphor could be applied to fluvial systems. You have seen above how modifying one parameter affects overall stream form. Putting together all we have discussed and learned about Transport-Limited and Detachment-Limited systems…

7) What are the major differences between Transport Limited and Detachment Limited systems as represented by these models?

Close the matlab program. Enjoy the rest of your day.