

Lab 4: Bedrock Channel Profile Modeling (1-D) (40 pts)

DUE: November 19

In this lab you will work with a Matlab script (`detach_ftfs.m`) to explore geological and climatic controls on channel profiles and fluvial relief. `Detach_ftfs.m` is a code for modeling channel profile evolution under imposed sets of processes and boundary conditions (these are the geological and climatic conditions) for the simple detachment-limited stream power model. The goal is to teach you a little bit about numerical simulation and to develop your understanding of the dynamics of fluvially-sculpted landscapes.

There are a series of exercises given below to guide you through an analysis of the controls on river profile evolution under a variety of conditions. Some of the questions pertain to steady state response of channel systems, others to transient responses. Use common sense to determine whether an *analytical* (i.e. coding a steady state solution in matlab or another spreadsheet) or *numerical* solution is most appropriate for each question. For instance, at for problems regarding steady-state, analytical solutions are most convenient, for transients numerical solutions are more often needed. Answer all questions. If meaning or scope is unclear, ask your instructor or TA.

For each exercise you are asked to turn in: (a) print-outs of modeled profiles that demonstrate your findings, including a complete list of model parameters used (use figure numbers and captions to enhance readability); (b) a brief explanation of (1) why you chose the parameter values you did (and whether you used an analytical or numerical solution) and (2) your interpretation of the results; and (c) brief answers to any direct questions asked below (that is, *all sentences that end in a question mark*).

Be complete but do not go overboard - this is a lab exercise, you are not asked for a lengthy report on each exercise: limit yourself to a paragraph or two maximum for each exercise. ONLY include figures that help illustrate your answers/findings. DO NOT hand in a massive collection of print outs for your instructor to wade through. Note that the last 3 exercises are worth more points than the first two.

Exercise 1. Boundary Conditions (5 pts).

All numerical solutions are completely dependent on boundary conditions. We have two boundaries to deal with: the divide ($x = 0$) and the outlet ($x = L$). What are the right boundary conditions?

At the upstream end the parameter X_{crit} determines where the first node in the solution lies. Your scripts include options for 3 boundary conditions at the downstream end. At the downstream end the parameter `bcflag` allows for: (1) holding the outlet elevation constant; (2) lowering the outlet at a fixed rate of baselevel lowering; or (3) holding the slope fixed at the value of the slope of the last two nodes.

For all the problems below, use an initial condition of a linear sloping ramp:
 $islope = 0.1$; $L = 3000m$; $m/n = 0.5$; $n = 1$; $U = 0.001$ m/yr; $K = 0.00005$.

1. Set $X_{crit} = 0$ (solve for elevations all the way to the divide where drainage area goes to zero) and set the outlet to hold a constant slope (`bcflag = 3`). Set uplift to 1 mm/yr. Is steady state achieved? How does the river respond to different uplift rates? Why?

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2. Set $X_{crit} = 0$ and set the outlet to hold a constant elevation ($bcflag = 1$). Set uplift to 1 mm/yr. Is steady state achieved? How does the river respond to different uplift rates? Why?
3. Set $X_{crit} = 300$ m and set the outlet to hold a constant elevation ($bcflag = 1$). Set uplift to 1 mm/yr. Is steady state achieved? How does the river respond to different uplift rates?
4. Set $X_{crit} = 300$ m and set the outlet to lower at a constant rate = 1mm/yr ($bcflag = 2$). Set uplift to 0 mm/yr. Is steady state achieved? How does the solution compare to the case of constant uplift with fixed baselevel (case 3)?

Exercise 2. Verify Analytical Solution for Steady State (5 pts).

Code a solution for Steady State in a Matlab script (code for this is included under one of the initial conditions ($icflag = 3$) and can be cut-and-pasted to an appropriate place in the code). Plot this relation (either as z vs. x , or S vs A -- or both) for comparison with numerical results for a given set of model parameters. Ask for help with code modification if you need it. Boundary conditions: $X_{crit} = 300$ m; fixed outlet at baselevel ($bcflag = 1$).

Confirm that the numerical solution converges on a steady state and matches the analytical result for *Any* initial condition (try three: flat surface; initial ramp; initial plateau). Comment on the result (ie. How sensitive to Δx ?).

Exercise 3. Elevation, Fluvial Relief and Denudation Rates (10 pts).

Some researchers (e.g. Pazzaglia and Brandon, 1996: Basin Research) claim that a reasonable, simplified, model is to take long-term erosion rate as proportional to elevation. For the case of steady-state fluvial landscapes, what is the expected relationship between erosion rate and elevation *within* a catchment? What is the expected relationship between drainage basin relief or mean elevation and erosion rate among different catchments (which may have different lithologies, climates, or rock uplift rates)? How are these relationships (erosion rate vs. elevation at a point and erosion rate vs. basin relief) affected by non-steady conditions (consider both a rising condition [transient response to an increase in uplift rate] and a declining condition [transient response to a decrease in uplift rate])?

Perform the requisite analyses to develop the insight to answer these questions, if needed. It is *possible* to answer them simply by reasoning it through, however you may find it beneficial to run some simulations to aid your thinking.

Exercise 4. Response to Spatially Non-Uniform Uplift (10 pts).

Consider the effects of spatially variable uplift rate on equilibrium channel profile form and slope-area relationships. Run some simulations to explore how are these impacted for conditions of: (1) uplift increasing (linear) from the outlet to the divide; (2) uplift decreasing (linear) from the outlet to the divide.

How sensitive are these responses to the exponent n ?

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Derive the analytical result that $\theta = m/n - \alpha/hn$ for a channel in steady-state with rock uplift that varies as a power-law with distance downstream: $U(x) = U_0x^\alpha$. Show your work. Confirm this result with numerical simulations. Recall $S = k_sA^{-\theta}$ and $A = k_a x^h$.

Exercise 6. Transient Forms and Fluvial Response Timescale (10 pts).

Generate a steady state channel profile adjusted to an uplift rate of 1 mm/yr for three values of n (2/3, 1, 2) to use as a set of initial conditions. At time = 0 impose a sudden increase in uplift rate to 4 mm/yr. Run models for each value of n .

Determine the approximate response time (time to new steady state) for each run. Observe the *pattern* of the transient response in each case. How does the channel concavity (slope of $\log S - \log A$ plot) vary during a transient response? How would estimates of m/n from S-A data be impacted when analyzing channels that are *not* at steady state (i.e., if you were to assume $\theta = m/n$)? Describe the qualitative differences observed with differing values of n . Repeat for a decrease in rock uplift rate to 0.5 mm/yr at time $t = 0$ and address the same set of questions. From your observations of the *pattern* of response, how would you expect the observed response times to compare with those predicted by the equations given in Whipple (2001)? [For extra credit you could calculate the response times predicted by that analysis]. If inconsistent, explain why.