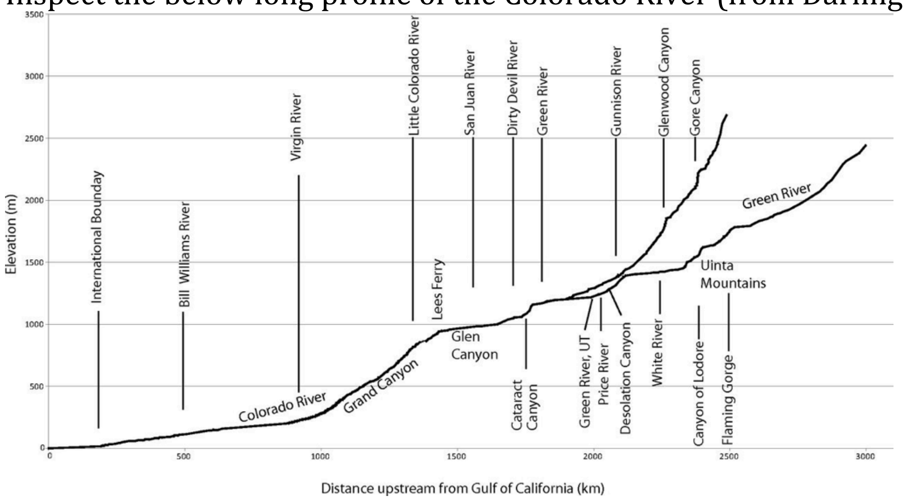
Earth and Planetary Surface Processes
Winter 2019 - Lab 3. River channel long profiles.
Hinds 440, 11a-noon

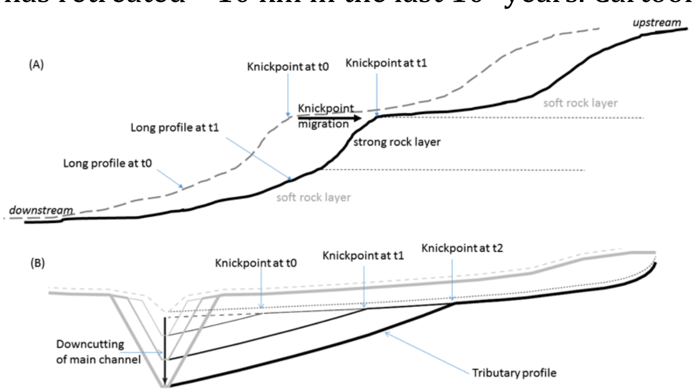
Grades are not assigned for lab, but attendance is required.
If you are unable to make a lab, email kite@uchicago.edu to set up an alternate time.
Portions of this lab draw on the WILSIM tutorials written by Wei Luo (NIU) and Jon Pelletier (Arizona).

The age of the Grand Canyon of the Colorado is uncertain. Both large ages (>30 Ma) and recent (post-6 Ma) incision of the Grand Canyon have been proposed. In this lab we will quantitatively explore the recent formation hypothesis.

Inspect the below long profile of the Colorado River (from Darling et al., Geosphere, 2012).



Notice that the Grand Canyon is a knickpoint (a "local" steepening, although local in the context of the Colorado River means <500 km long) on the long profile. Fluvial erosion in bedrock rivers tends to cause knickpoints to migrate upstream over time. This is because shear stress is greater in the steep zone, so erosion is faster at the knickpoint. An extreme example of knickpoint migration is Niagara Falls, which has retreated ~10 km in the last 10^4 years. Cartoon examples of knickpoint migration:



In the “young Grand Canyon” hypothesis, the knickpoint that is currently eroding the Grand Canyon is created by a tectonic event. This event is hypothesized to be an increase in the rate of slip on the Grand Wash Fault, which marks the W end of the Grand Canyon, at ~6 Ma:

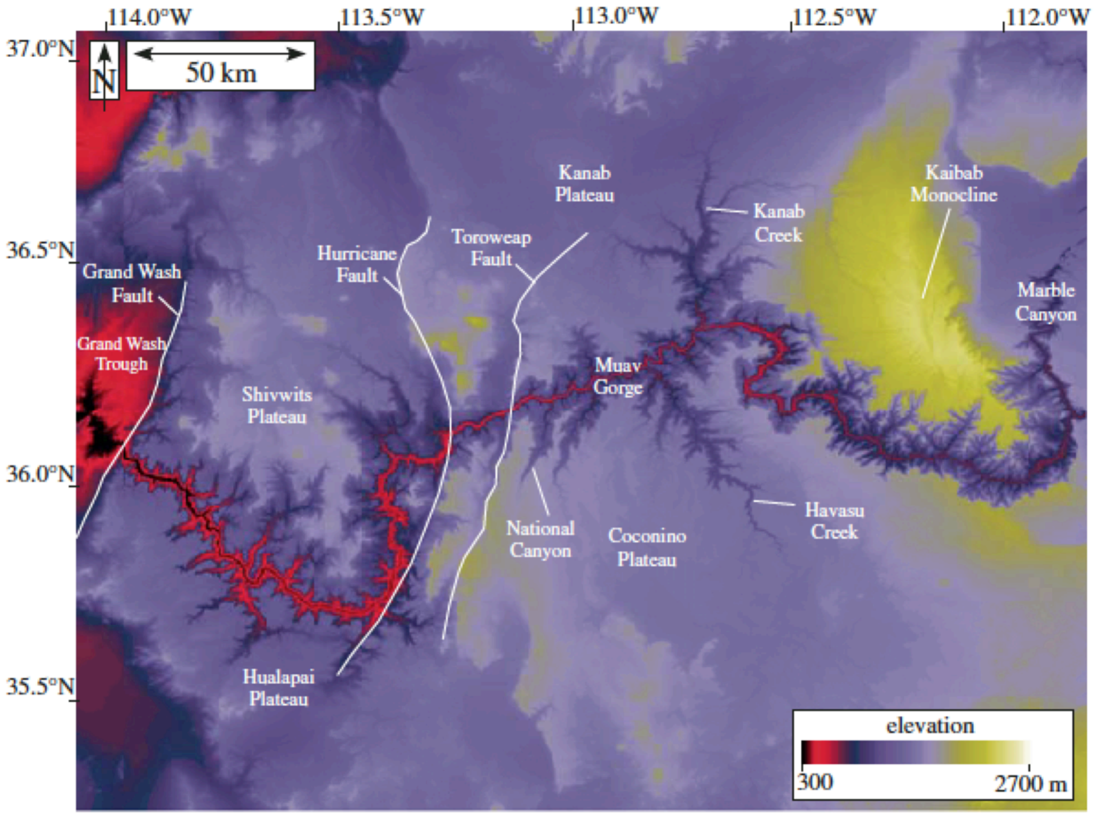
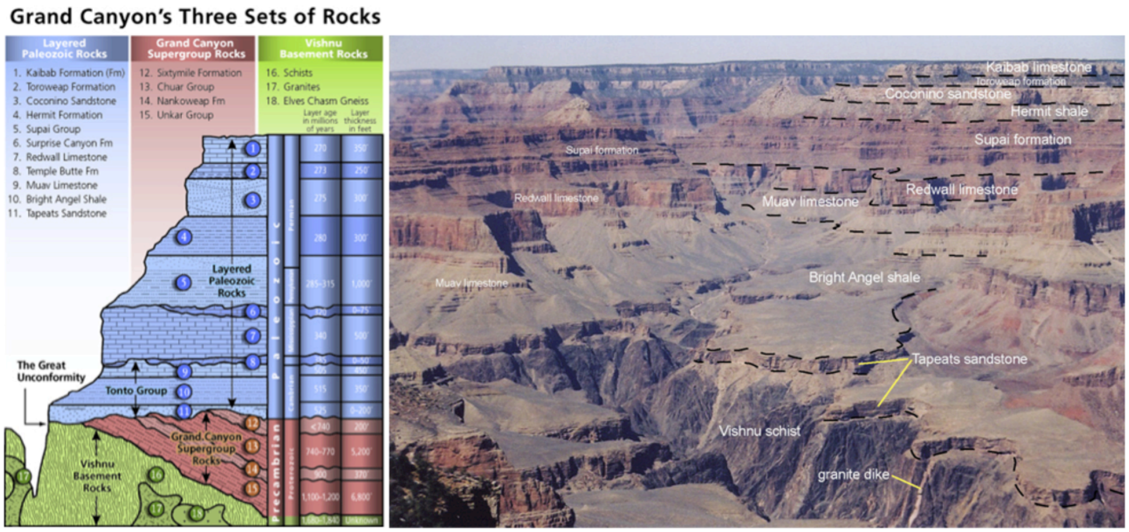


Figure 1. Color map of the topography of the Grand Canyon region, showing the location of major geomorphic and structural features.

(from Pelletier, 2010). Read the “Model description” section of Pelletier’s 2010 paper (http://geosci.uchicago.edu/~kite/doc/Pelletier_2010.pdf) , up to but **not including** equation 4.

Strong rocks form cliffs, and weak rocks form benches.



Images from National Park Service (left) and U. Arizona geology department (right)

Now we will run a model based on Pelletier 2010.

If you are using a Stereopticon machine, then Wilsim should be preinstalled; do a search for files with the name "wilsim," then run Wilsim. If you are using your own machine, download and run WILSIM-Grand Canyon (http://serc.carleton.edu/landform/start.html). The code may prompt you to install the latest version of Java; you can skip this step.

There are a few simplifications in this code relative to the Pelletier 2010 model.
Comments on the code:

- The initial topography is set to be a muted version of the modern topography (with the Grand Canyon infilled) to ensure that the simulated Grand Canyon looks similar to the modern Grand Canyon. This is a reasonable assumption, but unproven.
- Tectonic motion on the Hurricane and Toroweap faults (up to 600m vertical) is neglected.
- The model resolution is 720 meters per pixel.
- For drawing cross-sections, a good place to cut across the Grand Canyon is the location of the Kaibab Monocline.
- A rock erodibility factor of 0.1 kyr^{-1} generates erosion at a rate equal to 0.1 meter per thousand years, for a fluvial channel of slope equal to 1 (45°) and drainage area equal to 1 square kilometer.
- The model has a strong layer located 400 m below the canyon rim, representing the Redwall Limestone. Increasing the "hard/soft contrast" decreases the erosional resistance of soft layers.
- Cliff retreat rate is constant for all layers. Data (from packrat middens) suggest the Redwall Limestone retreats at a rate of 0.5 mm/yr (Cole and Mayer, Geology, 1982).
- The default parameter values (when you close and reopen the simulation) are set to roughly reproduce the real Grand Canyon.
- The cross-sectional profile can be drawn anywhere on the map by clicking in "Draw" mode.

Erodibility of different layers within the near-horizontal sedimentary layers of the Grand Canyon is inferred from the relative steepness of the side-canyons crossing those layers (Pelletier 2010). These are the results:

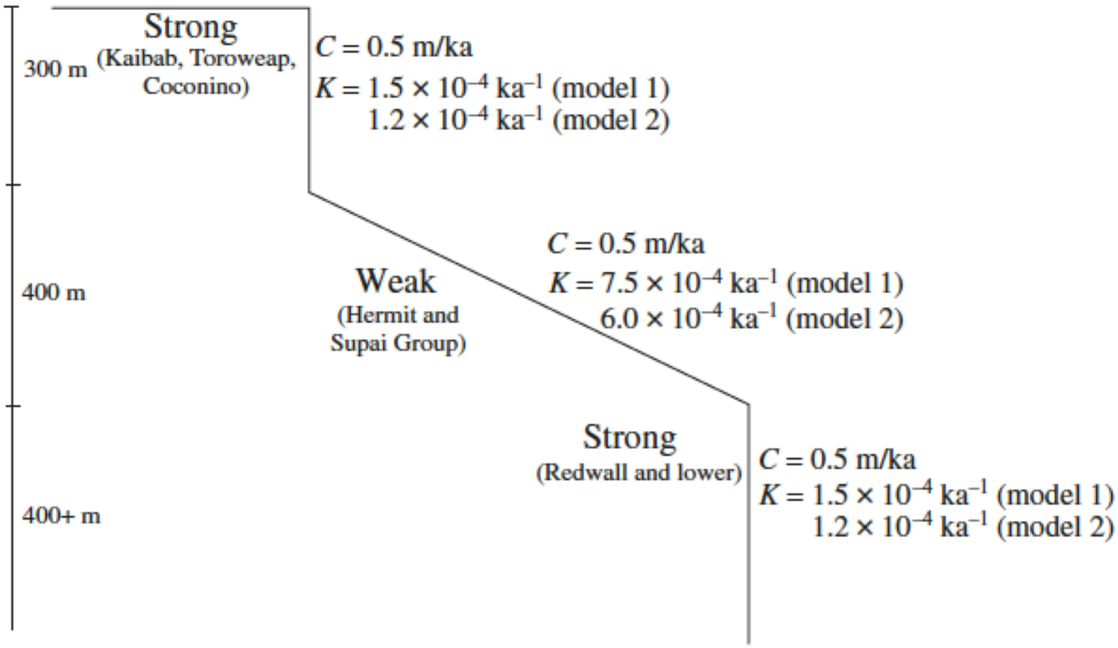


Figure 6. Schematic diagram illustrating the spatial variability of bedrock erodibilities and cliff retreat rates in the model. The coefficient of bedrock channel erodibility, K, is a function of the depth of incision into the rim surface, $h_{rs} - h$. If $h_{rs} - h < 300$ m, the value of K is a relatively high 1.5×10^{-4} ka^{-1} (model 1), corresponding to the strong units of the Kaibab through Coconino units. If $300 < h - h_{rs} < 700$ m, the value of K is a relatively high 7.5×10^{-4} ka^{-1}, corresponding to the weak units of the Hermit Shale and Supai Group. Finally, if $h - h_{rs} > 700$ m, $K = 1.5 \times 10^{-4}$ ka^{-1}, corresponding to the strong units of the Redwall Limestone and lower units. In model 2 (i.e., no erosion assumed prior to 6 Ma, the values of K are 1.2×10^{-4} ka^{-1} and 6.0×10^{-4} ka^{-1} for the strong and weak units of the Grand Canyon, respectively.

Questions.

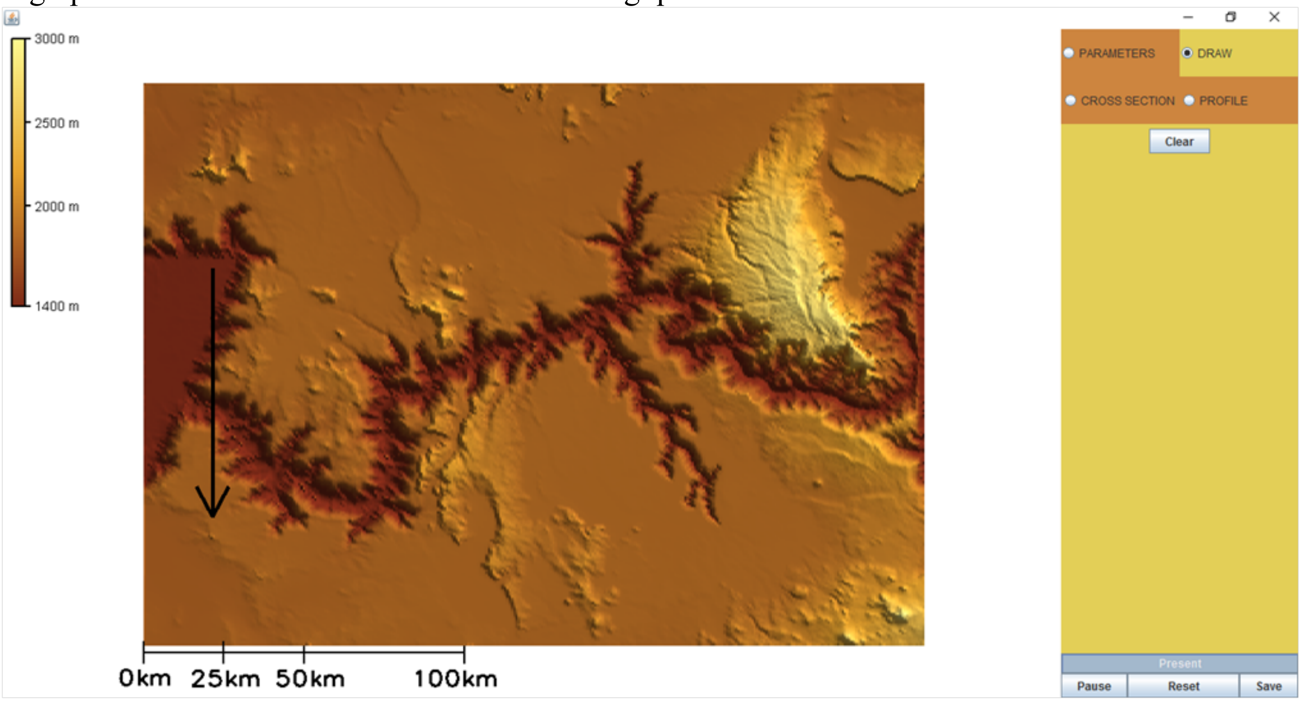
With default parameters set, what is the knickpoint retreat rate in cm/yr?

Double the rock erodibility. Run the model. Use the ‘profile’ and ‘cross section’ tools to summarize the (quantitative) differences in canyon width, canyon depth, length of the main canyon, and length of tributaries between this scenario and the default-parameters scenario. You may have to re-run the model to build up cross-sections in different regions of interest. Explain your answers.

Reset the rock erodibility to default parameters. Run the model. Now change the subsidence rate to 0.9 m/kyr. Use the ‘profile’ and ‘cross section’ tools to summarize the (quantitative) differences in canyon width, canyon depth, length of the main canyon, and length of tributaries between this scenario and the default-parameters scenario. Explain your answers.

Intepreting cross-sections.

The following page shows cross-sectional graphs of the Grand Canyon from four pairs of simulations. In each simulation, **one** variable was changed from the default value (shown in the left image) to its maximum possible value in WILSIM-GC (shown in the right image). The **subsidence rate**, **rock erodibility**, **hard/soft contrast**, and **cliff retreat rate** are the ***only*** variables used in the below scenarios. The image below shows where the cross-section line was drawn to create the images in scenarios A-D. Use the information from the image below and the graphs in each scenario to answer the following questions.

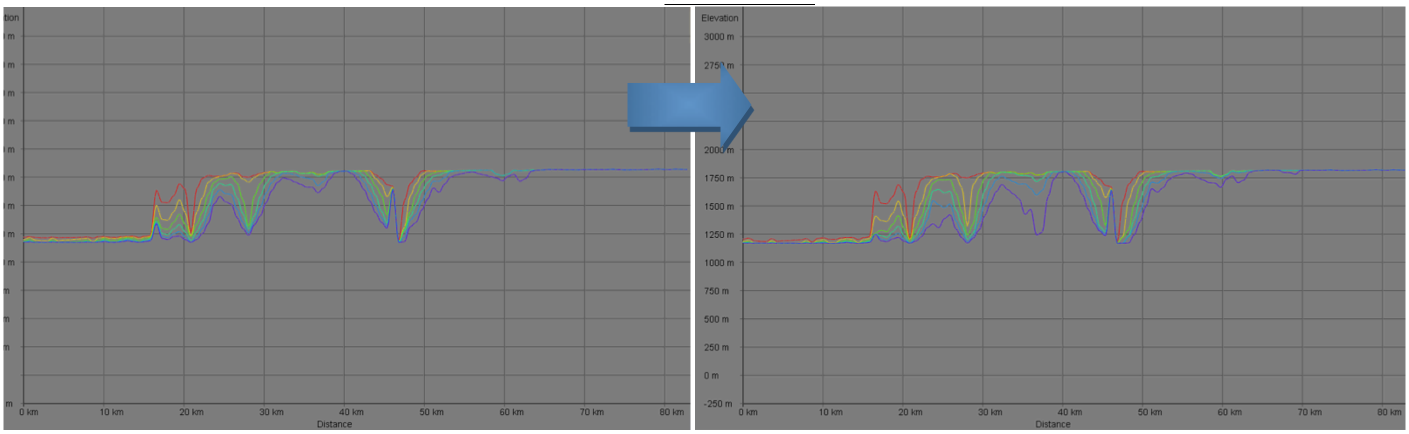


Describe the changes you see in each scenario (A-D) below. The following image displays where the cross-section line was drawn to obtain the graphs in scenarios A-D. Use this information to determine which variable was changed. What characteristics do you see in each image (on the right) that led you to suggest that variable has changed? Now run several simulations by changing **one** variable to its maximum value in each simulation (with the rest of the variables set to their default values) and compare the simulation results to the cross-section graphs below. Were your educated guesses correct?

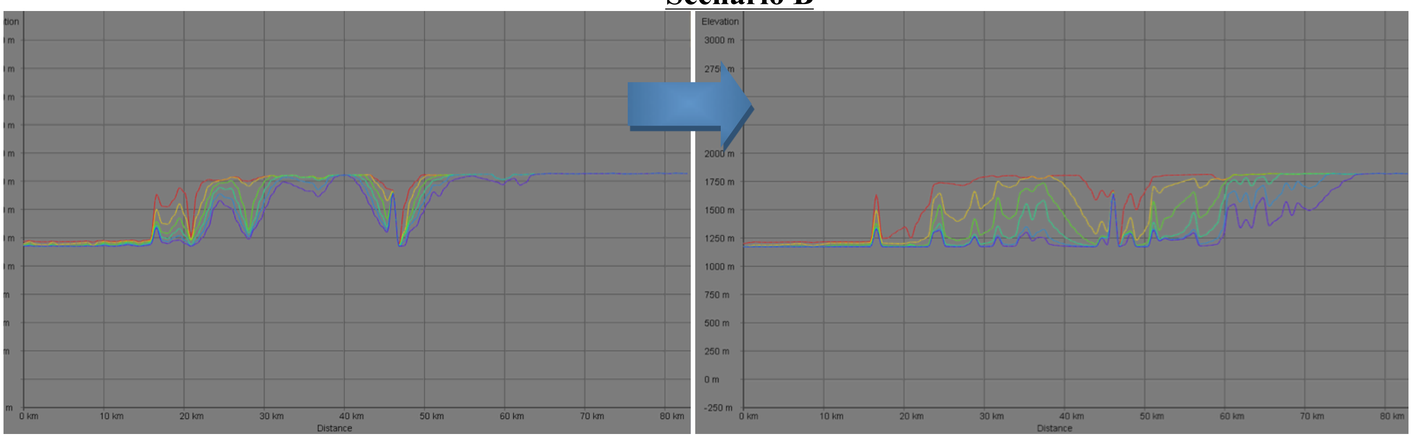
Simulated Cross-Sections

---5.0 Myr Ago ---4.0 Myr Ago ---3.0 Myr Ago ---2.0 Myr Ago ---1.0 Myr Ago ---Present

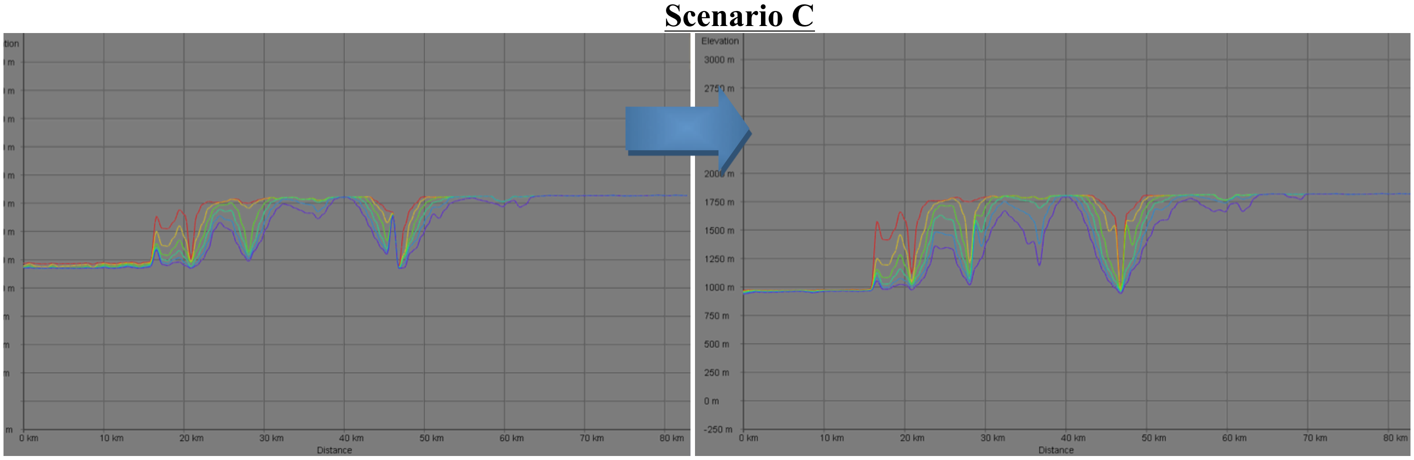
Scenario A



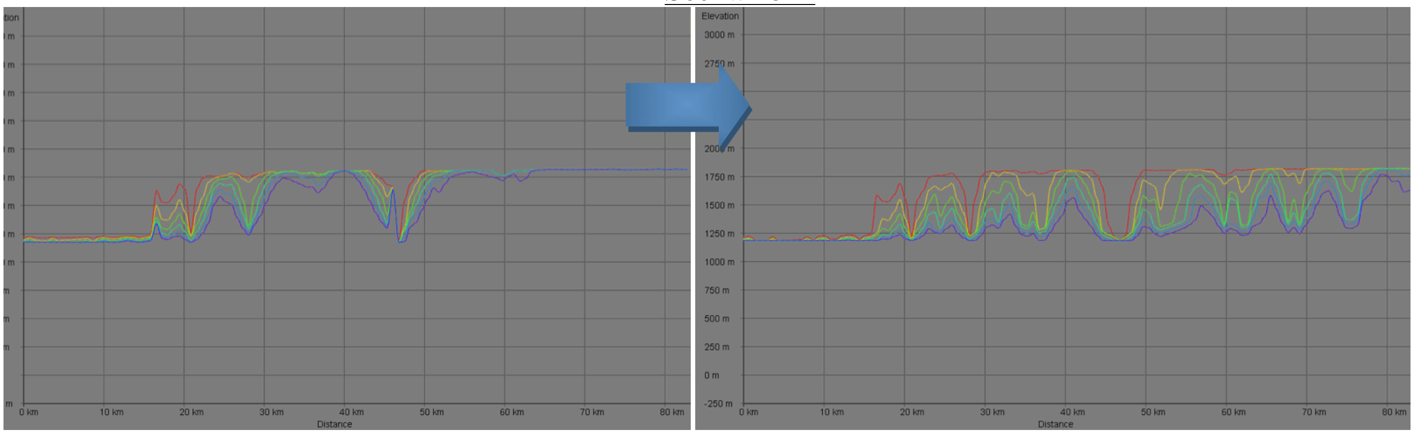
Scenario B



Scenario C



<u>Scenario D</u>



Interpreting (Simulated) Long Profiles

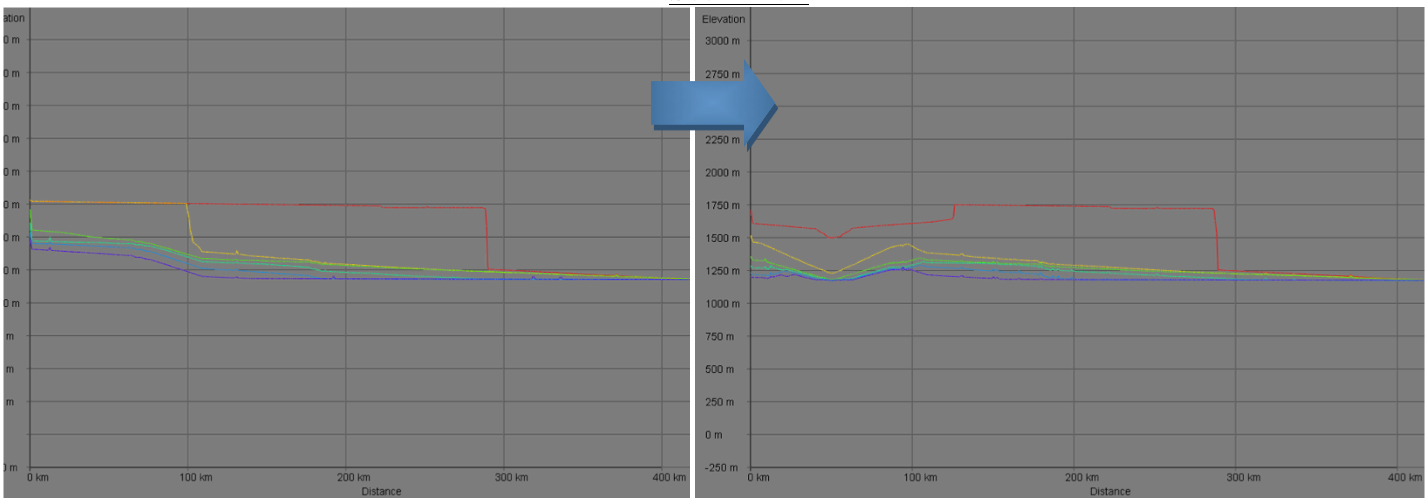
The following page shows long profile graphs of the Grand Canyon from four pairs of simulations. In each simulation, **one** variable was changed from the default value (shown in the left image) to its maximum possible value in WILSIM-GC (shown in the right image). The **subsidence rate**, **rock erodibility**, **hard/soft contrast**, and **cliff retreat rate** are the ***only*** variables used in the below scenarios.

Describe the changes you see in each scenario (A-D) below. Use this information to determine which variable was changed. What characteristics do you see in each image (on the right) that led you to suggest that variable has changed? Now run several simulations by changing **one** variable to its maximum value in each simulation (with the rest of the variables set to their default values) and compare the simulation results to the profile graphs below. Were your educated guesses correct?

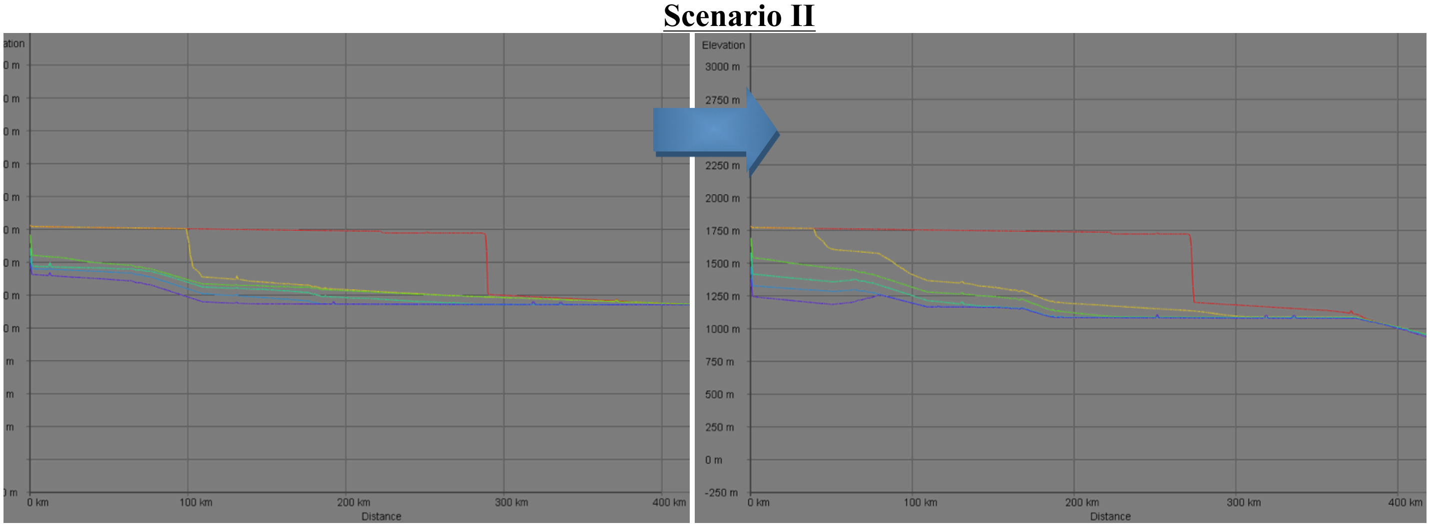
Simulated Profiles

---5.0 Myr Ago ---4.0 Myr Ago ---3.0 Myr Ago ---2.0 Myr Ago ---1.0 Myr Ago ---Present

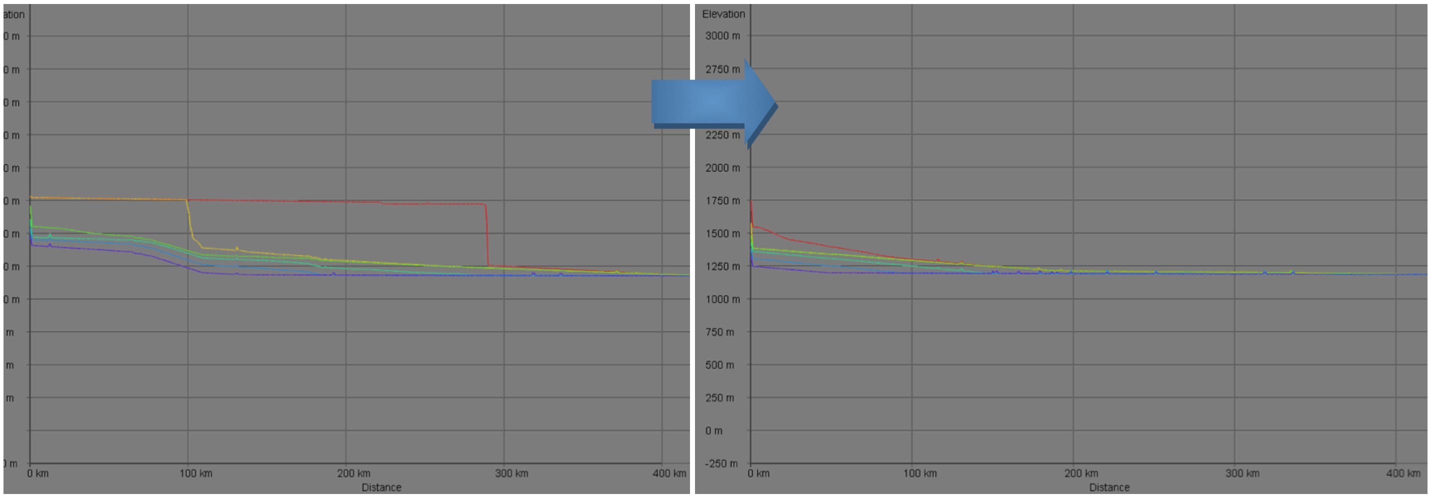
Scenario I



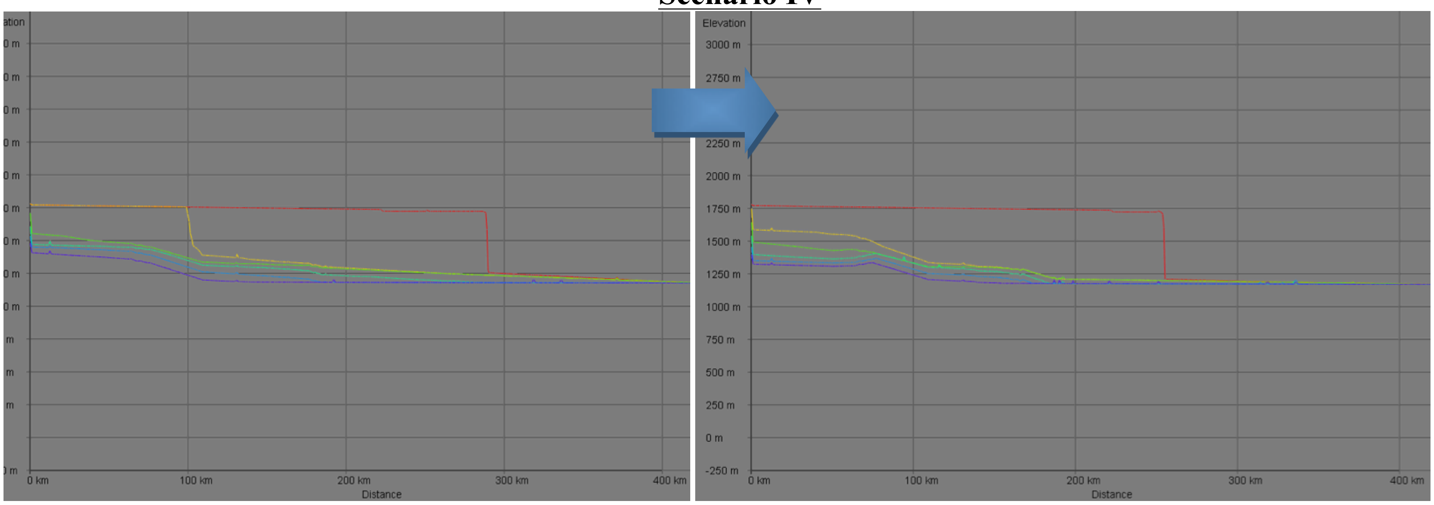
Scenario II



Scenario III



Scenario IV



If time remains:

Can you create a landscape similar to the Grand Canyon, using values significantly different than the default values of the model (i.e., by trading-off changes in multiple parameters such that the final form is similar)?