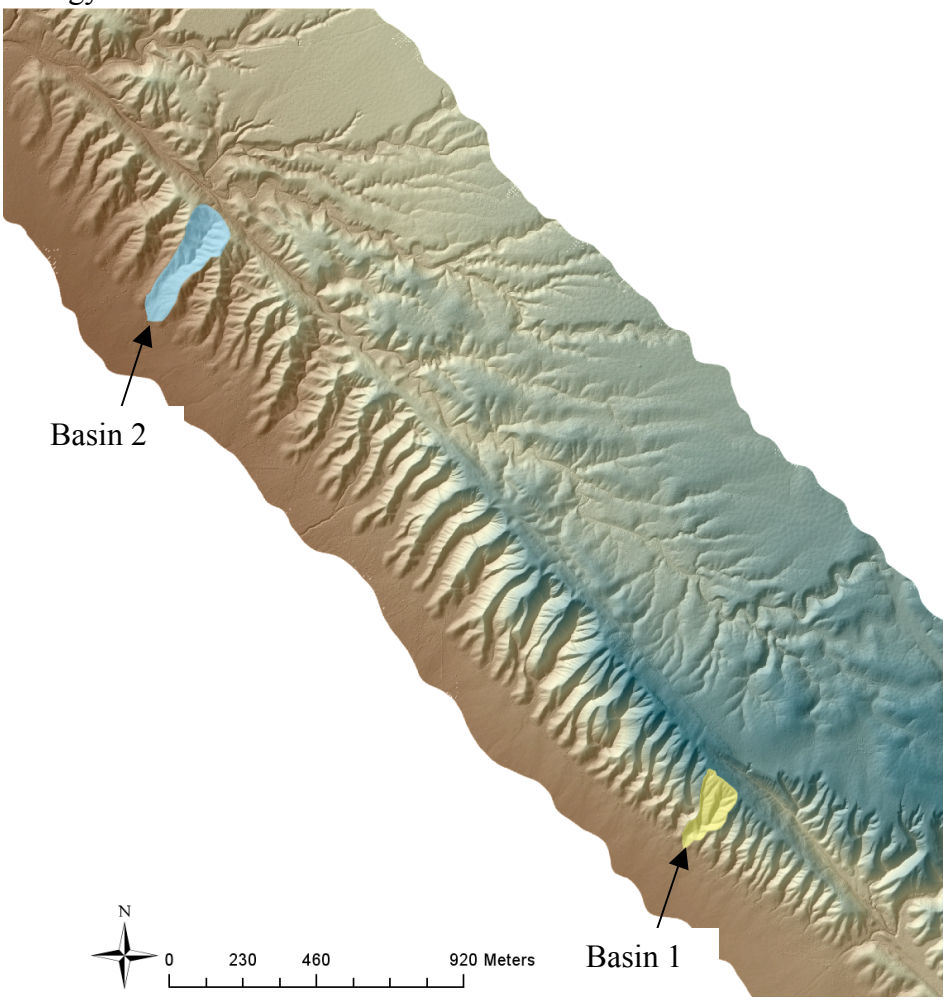
Exercise 8: Simple landscape morphometry and stream network delineation

Introduction

This exercise covers sample activities for extracting quantitative information about the landscape from DEMs in ArcMap. Topics include topographic slope comparisons and stream network delineation and visualization. Portions of this exercise are derived from a similar one by Roman Dibiase (ASU; http://cws.unavco.org:8080/cws/learn/uscs/2008/2008Lidar/handouts/).

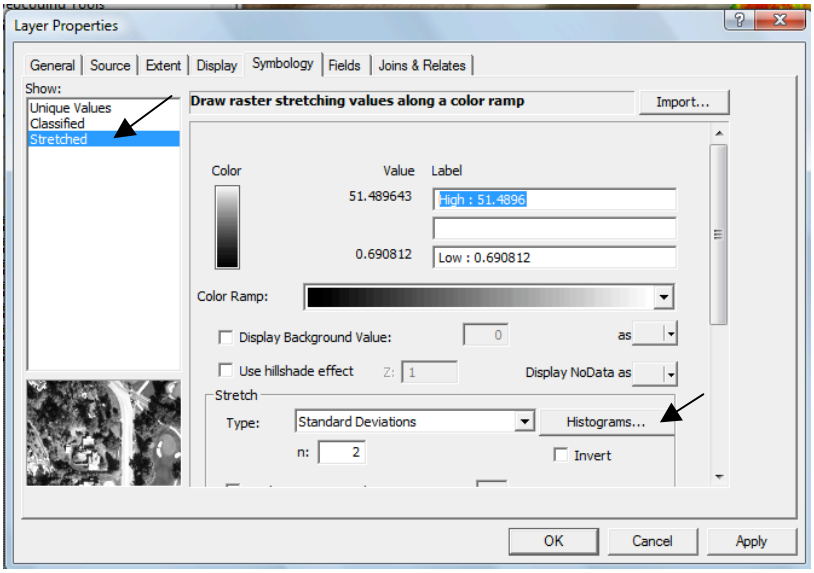
Sample data

For a simple demonstration, I have computed a 1 m DEM with a 1 m search radius using the IDW method for a portion of the B4 LiDAR dataset in http://www.opentopography.org. The study area is the Dragon's Back pressure ridge along the southwest side of the San Andreas Fault in the Carrizo Plain (Hilley and Arrowsmith, 2008). The landscape along the pressure ridge shows a progressive development in which Basin 1 is in the active uplift zone, whereas Basin 2 has been carried away from the uplift zone with continued landscape response. Our morphometric investigations will focus on the associated change in the drainage basin structure under conditions of uniform lithology.

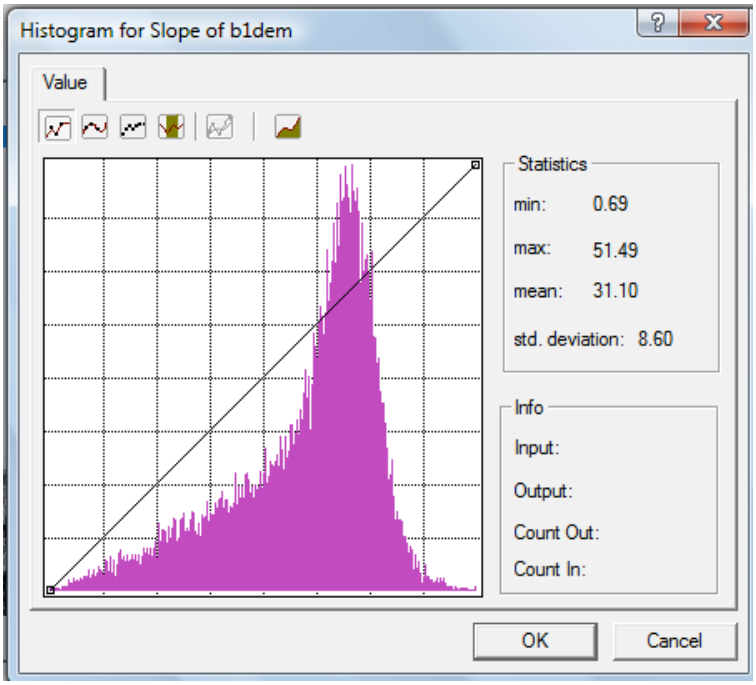


Slope distribution

Compute the slope distributions for Basin 1 and Basin 2 (Spatial Analyst->Surface Analysis->Slope). Right click on the slope grids->properties->Symbology tab. Show Stretched, and click on the histograms…



Here is the Basin 1 slope distribution. What are the slopes at the mode and how do they compare to the mean?



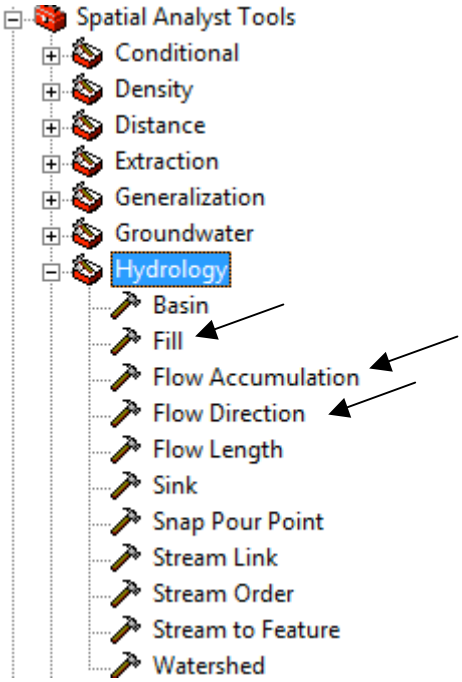
How do the slope distributions vary? How might you explain the variation in slope distribution in terms of the hypothesized change from active uplift to steady degradation?

Stream network delineation

The stream network provides the fundamental structure of the landscape. The threshold between the drainage network and the adjacent hillslopes (over which flow is not sufficiently concentrated) is the fundamental landscape transition. LiDAR data derived DEMs permit us to represent the landforms and associated transitions at the appropriate fine scale.

Spatial Analyst Tools-Hydrology

Much of this work can be streamlined by writing simple Python scripts, or by using the command line window in ArcMap. For more information on this, you may read through the ESRI online help guide:
http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=An_overview_of_writing_geoprocessing_scripts

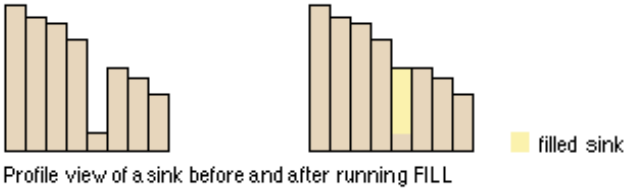


Creating the flow accumulation grid (drainage network)

Now we will go through how to create a flow accumulation grid, which forms the basis for extracting the stream network. This process has three steps: first, we need to fill in any pits or sinks in the DEM, then we calculate the direction of steepest descent for each cell, and finally, we count up the number of cells that flow into each cell.

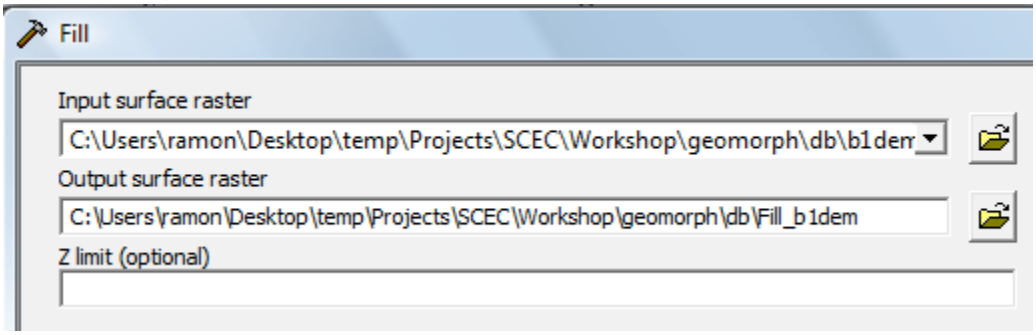
The Fill command

A drop of rain falling anywhere in the DEM must be able to follow a downhill path all the way to the edge of the DEM. In order to do this, the Fill command adds elevation to local lows in the DEM until they 'spill' over. This is an iterative process, and is computationally expensive; some DEMs may take minutes to hours to fill. We can map out the pit depth by subtracting the original DEM from the filled DEM using the raster calculator in the spatial analyst toolbar. This can be helpful for assessing DEM quality.



Profile view of a sink before and after running FILL

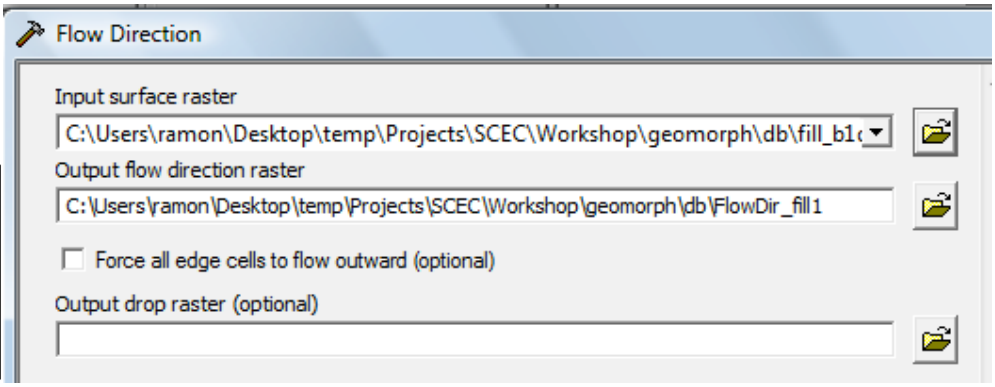
(from ESRI website)

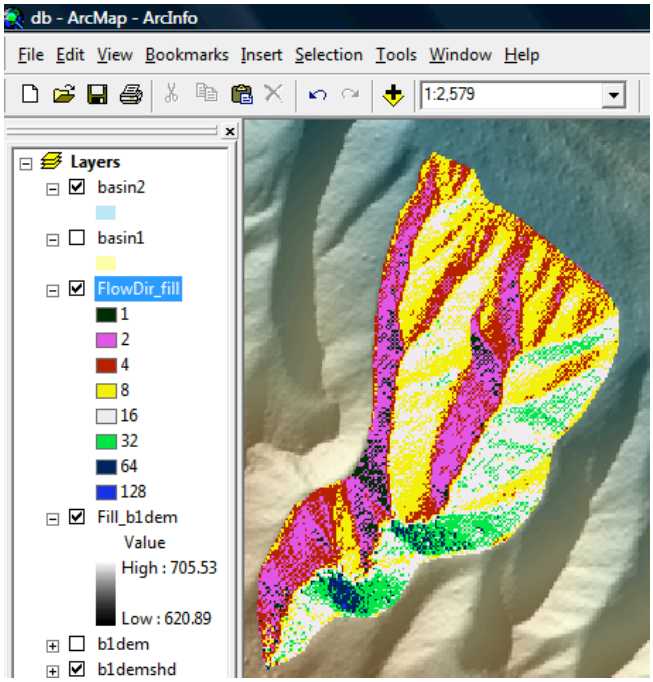


The Flow Direction command

Now that we have a 'filled' DEM, we can determine a flow direction for each cell. There are many different ways to distribute flow from a cell, but the simplest is the D8 algorithm, which is used by Spatial Analyst. At each cell, a number is assigned based on the direction of the lowest elevation neighbor (steepest descent), as shown below, such that if the elevation is lowest to the left, the output flow direction will be 16.

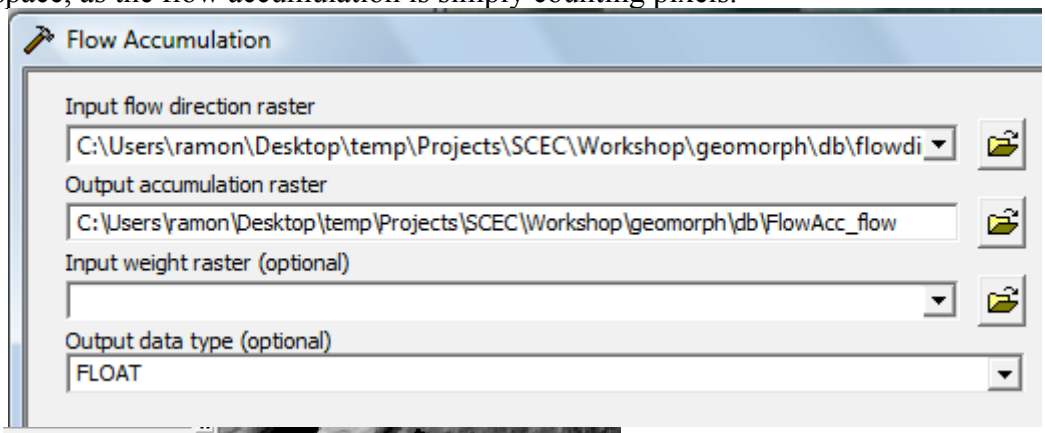
32	64	128
16		1
8	4	2

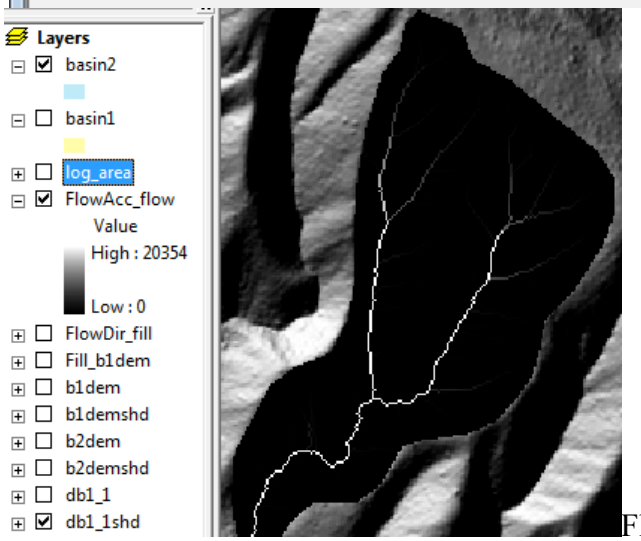




The Flow Accumulation command

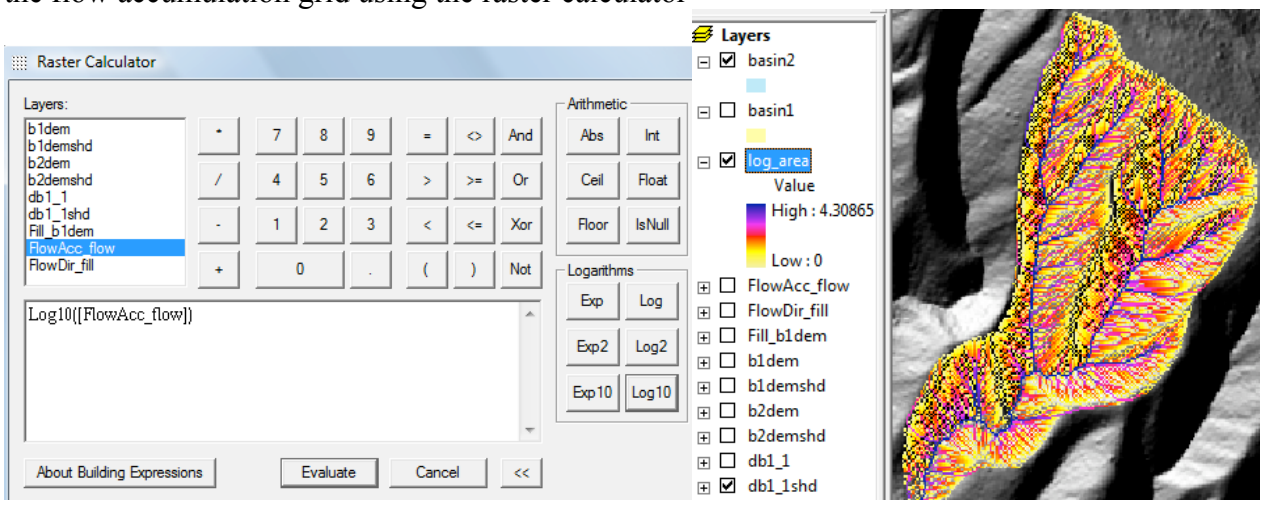
Now we will calculate the flow accumulation for each cell, which tells us how many cells are 'upstream' of a given cell. The output is analogous to the upstream drainage area of each cell, and you can convert from flow accumulation to drainage area by multiplying the accumulation in cells by the square of the cell size. This command, like the fill command, is recursive, and can take a long time to run for large grids. It can be helpful to specify the output type as INTEGER in order to save space, as the flow accumulation is simply counting pixels.





Flow accumulation grid (basin 1)

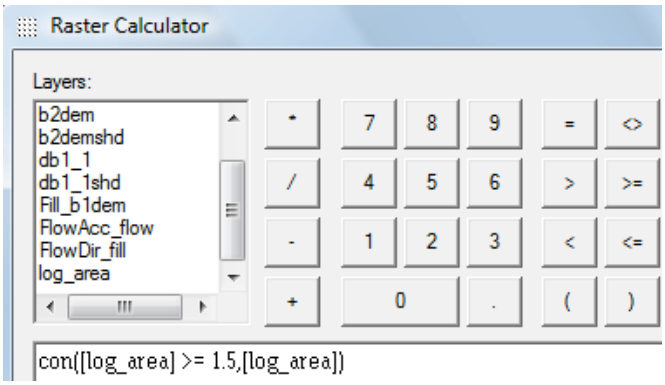
To better see the drainage network, given the large range of contributing areas, take the **log10** of the flow accumulation grid using the raster calculator



Where does the drainage network begin?

Looking at the computed flow accumulation, and the hillshades, where does it look like the landscape transitions from smooth hillslopes to convergent geometry of the drainage network? What drainage area is that? It looks like about 10^1 or maybe $10^{1.5}$ m^2 (~30 m^2) for basin 1. Use the CON command in spatial analyst to pull out the drainage network:

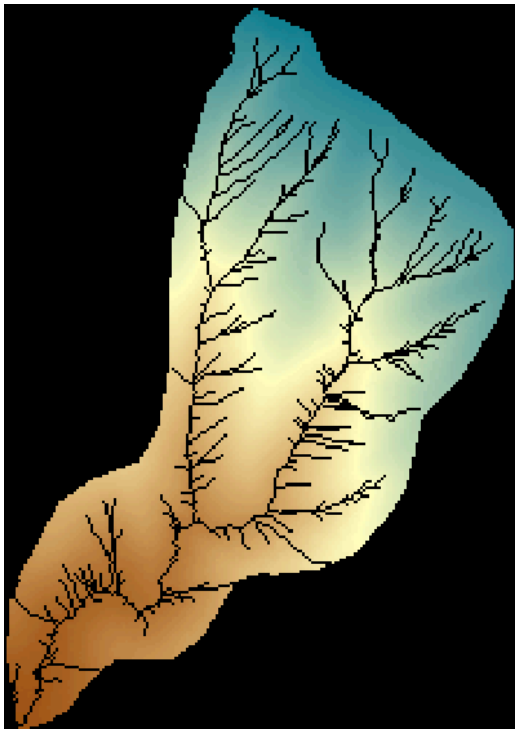
```
con([log_area] >= 1.5,[log_area]).
```



Make the resulting calculation permanent and give it a good color ramp.

Now that you have the drainage network defined, extract the hillslopes using CON command again: `con(IsNull([drainage1]),[b1dem])`.

Drainage network (>$10^{1.5}$ m^2)

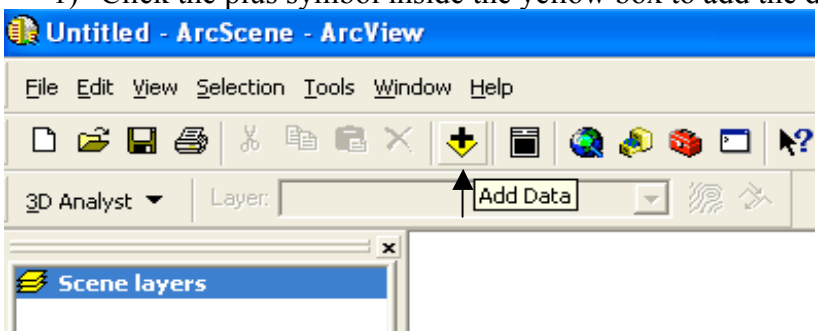


Hillslopes

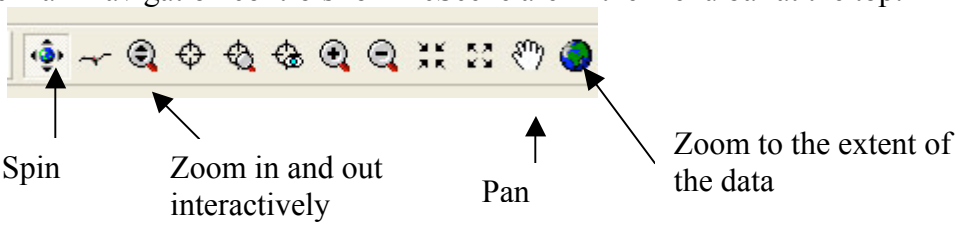
Visualizing the drainage network in ArcScene

ArcScene is a useful part of the ArcGIS software suite which provides 2.5D visualization.

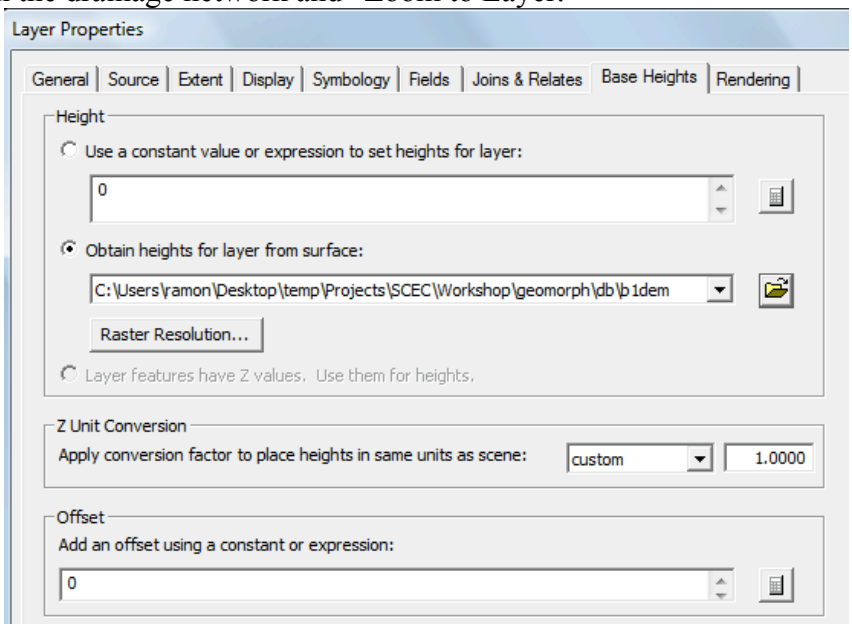
1) Click the plus symbol inside the yellow box to add the drainage network grid:

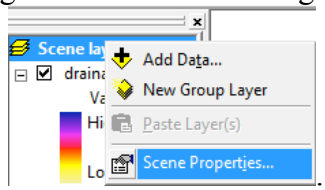


The main navigation controls for ArcScene are in the menu bar at the top:



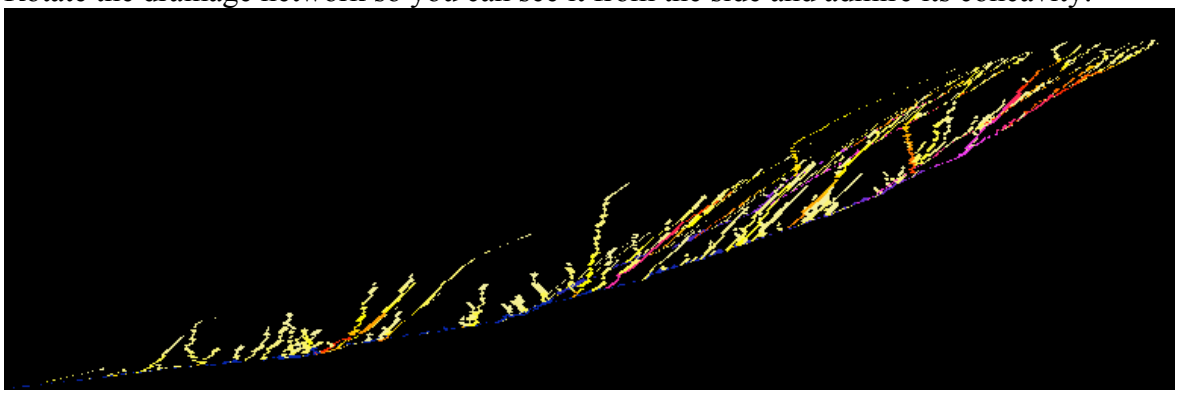
Right click on the drainage network grid in the Table of Contents and select properties and the Base Heights tab. Click on the Obtain heights for layer from surface: and navigate to find the DEM from which the drainage network was computed and push apply. You may need to right click on the drainage network and "Zoom to Layer."



2) Change the drainage network color ramp. Change the scene color background by right clicking on the Scene on the Table of Contents. 

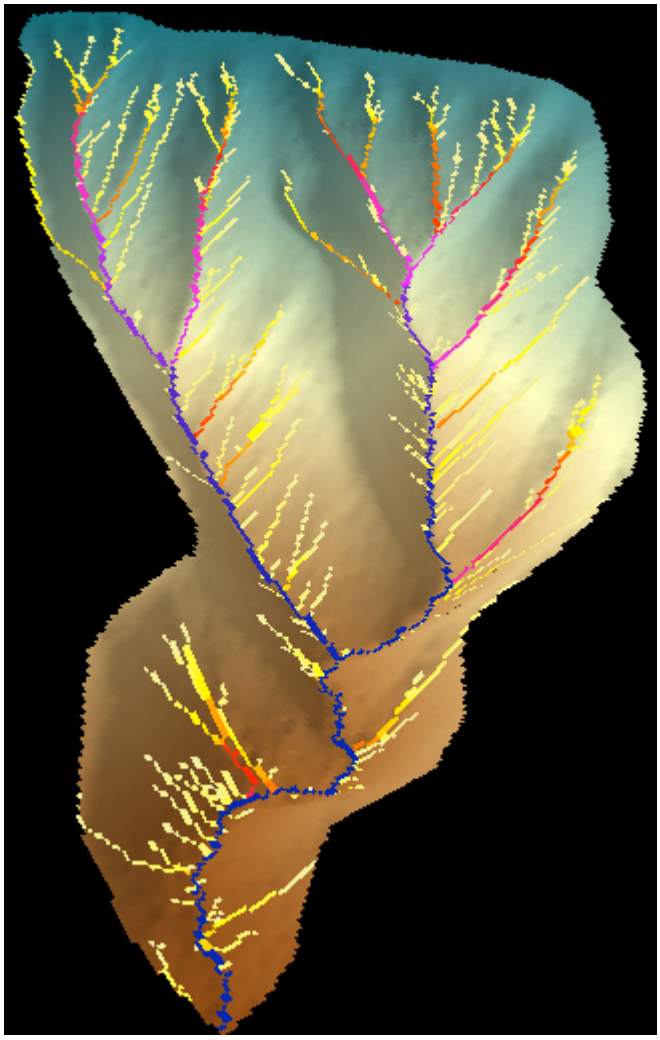
. Make the Background color black.

Rotate the drainage network so you can see it from the side and admire its concavity:

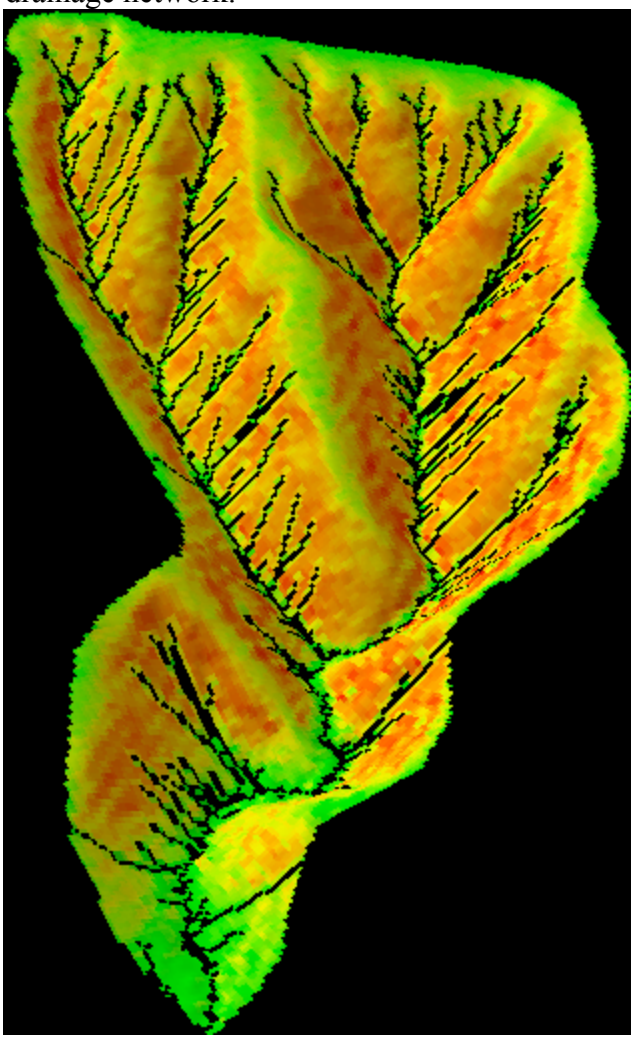


Do the same set of computations for Basin 2 and compare the two patterns. How does the map view and the concavity vary from the uplift zone to the degrading zone?

5) Add the hillslopes grid and use the DEM again as the base height.
6) Choose the **Rendering** tab. Click on the **Shade areal features relative to the scene's light position**. Also, slide the bar for **Quality enhancement for raster images** all the way to the right to **High**. You may get a warning about the memory resources that this may require, but go ahead and try it. Push **Ok**.



Go back to ArcMap and compute the SLOPE map from the hillslopes grid. Make it permanent and then load it into ArcScene as you did with the hillslopes. Color it with the green to orange color ramp. Turn off the drainage network.



Do the same with Basin 2. How does the slope distribution vary relative to the drainage network as you compare the active uplift zone and the degrading zone?

References and suggested reading

Hilley, G. E., and Arrowsmith J R., Geomorphic response to uplift along the Dragon's Back pressure ridge, Carrizo Plain, California, Geology, v. 36; no. 5; p. 367370; doi: 10.1130/G24517A.1, 2008.

Perron, T., Kirchner. J. W., & Dietrich, W. E., Formation of evenly spaced ridges and valleys, Nature, Vol 460|23 July 2009| doi:10.1038/nature08174.

Roering, J.J., (2008), How well can hillslope evolution models 'explain' topography? Simulating soil production and transport using high-resolution topographic data, Geological Society of America Bulletin, v. 120, p. 1248-1262.