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Hydrology tools in ArcGIS

Before you begin, think about where you will be storing all the GIS files that you will be downloading and creating in this exercise. You can create a working folder on the Usertemp drive on the MIT Libraries computer you are using. Create a working folder in a place that makes sense to you if you are using your laptop.

The tools we will be using today to create a watershed are all described well in the ArcGIS Hydrology Tools Concepts help:

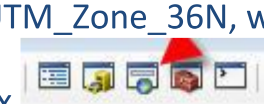
http://resources.arcgis.com/en/help/main/10.1/index.html#/Understanding_drainage_systems/009z0000005m000000/

We will use a Digital Elevation Model covering the area west of Mount Elgon in Uganda.

Add DEM (it is a mosaic of 4 panels downloaded from the NASA website called Reverb|ECHO. http://reverb.echo.nasa.gov/reverb/#utf8=%E2%9C%93&spatial_map=satellite&spatial_type=rectangle)

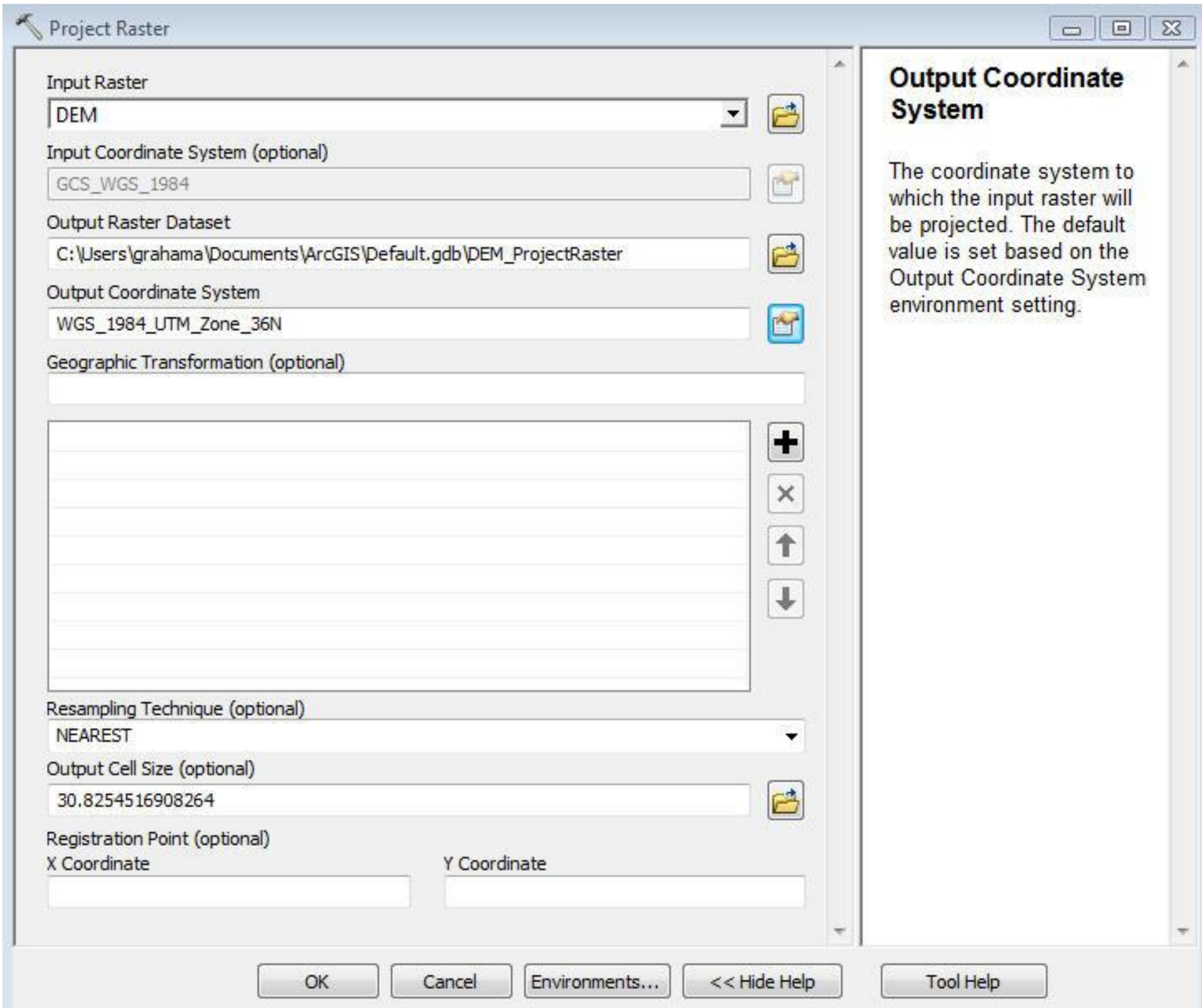
Before you work with a DEM it should be projected so that your calculations will be as accurate as possible.

Right click on the file name in the table of contents, and click on properties. Then click on the Source tab. Scroll down to see that the data has a defined datum: WGS84.

To create a file that will preserve areas, we will project this file into the Projected Coordinate System: WGS_1984_UTM_Zone_36N, which is the projection for this data. Open the search box  and search for “Project Raster.” Double click on Project Raster to open the tool’s form.

Fill in the form with DEM as the input raster, call the output raster dataset DEM_ProjectRaster, and for the output coordinate system, navigate to through the Projected Coordinate System folder into the UTM folder > World > WGS 1984 > Northern Hemisphere, scroll to WGS_1984_UTM_Zone_36N.

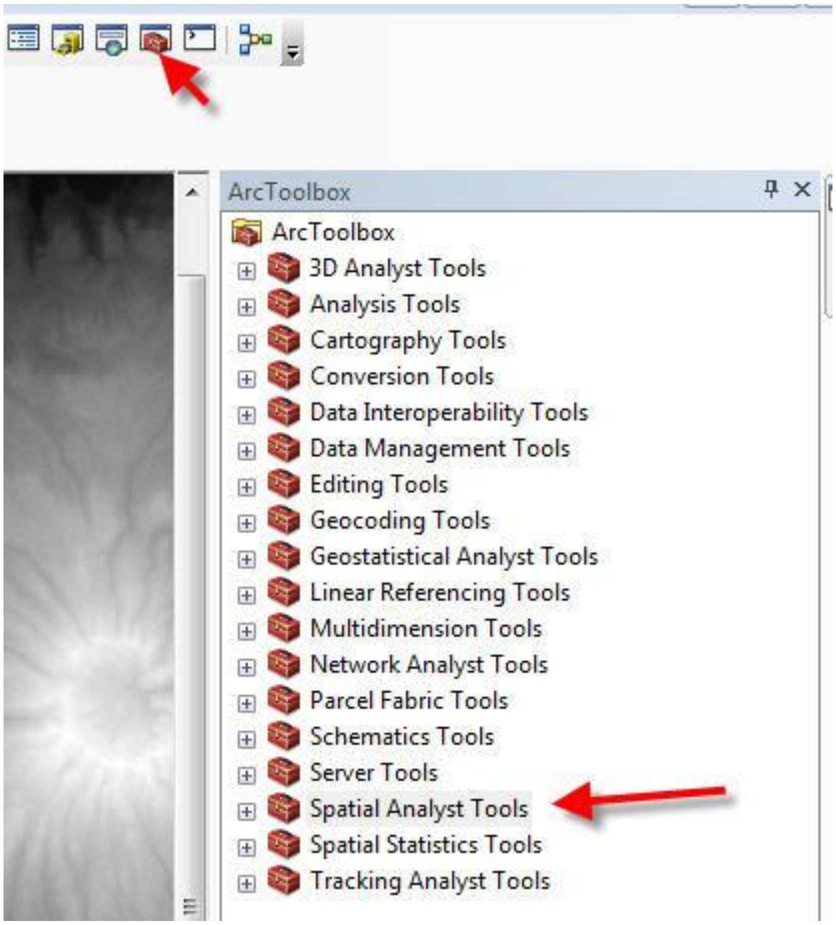
Your tool should look like this:



Click OK. It will take a minute or two, but when the projection is completed, you will get a message, and your projected file "DEM_ProjectRaster" will be added to the table of contents. This is the file you will use to perform your hydrologic analysis.

Hydrology Toolbox

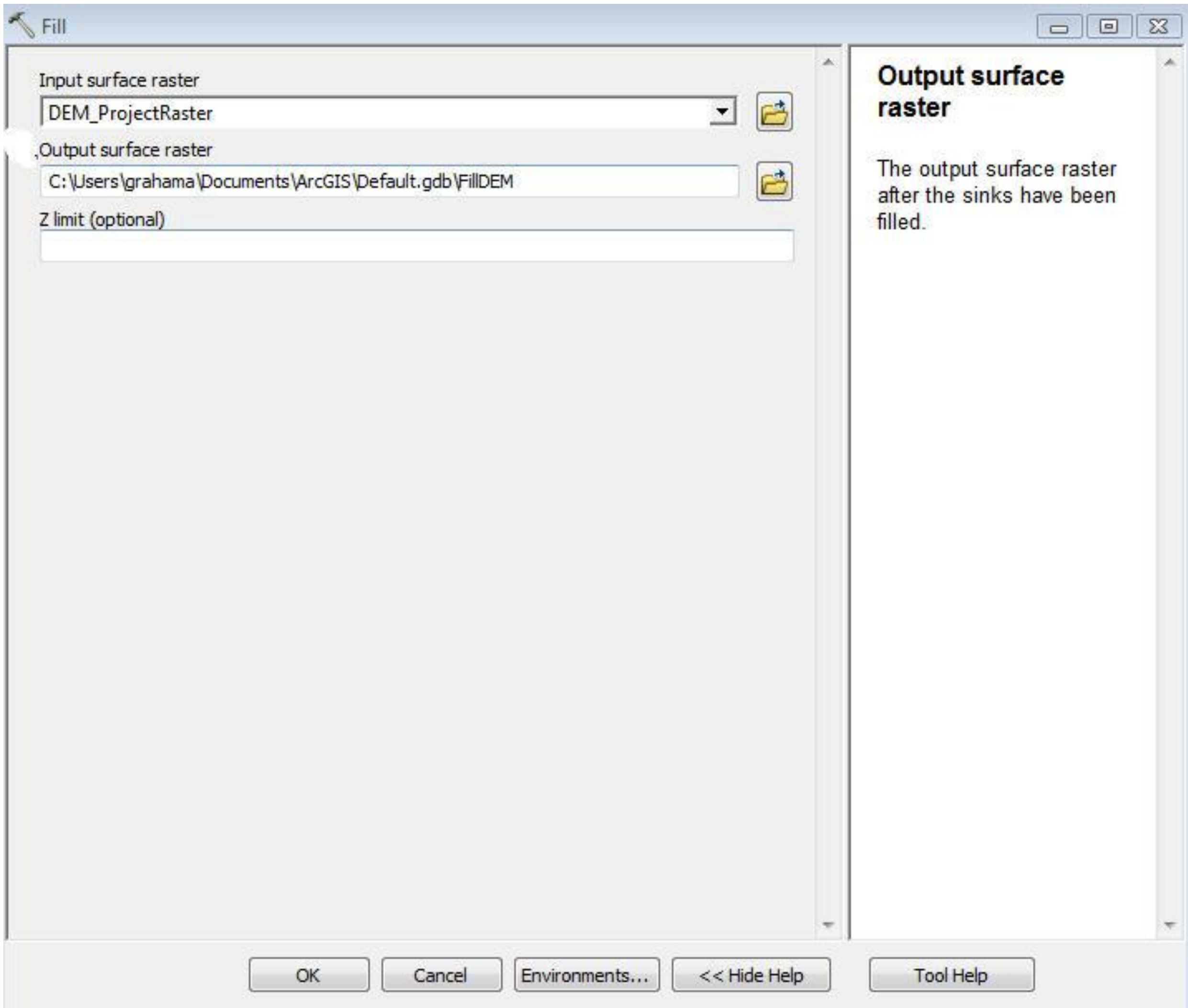
Open ArcToolbox by clicking on the icon with a red toolbox in it. Then open Spatial Analyst Tools, and finally, open the Hydrology toolset.



Fill

Sinkholes occur naturally in certain types of landscapes, such as karst (limestone) where the rock is soluble. Outside of these areas you will find sinks in your DEM data which are simple errors in the data, due to a typo, a place where the scale of the data does not adequately represent an existing drainage channel, or some other source. Generally, hydrology tools in GIS do not deal easily with sinks, whether natural or an error in the data. You will need to remove the sinks before you look at flow direction and flow accumulation.

Open the Fill tool in the Spatial Analyst toolbox. You should see this form:

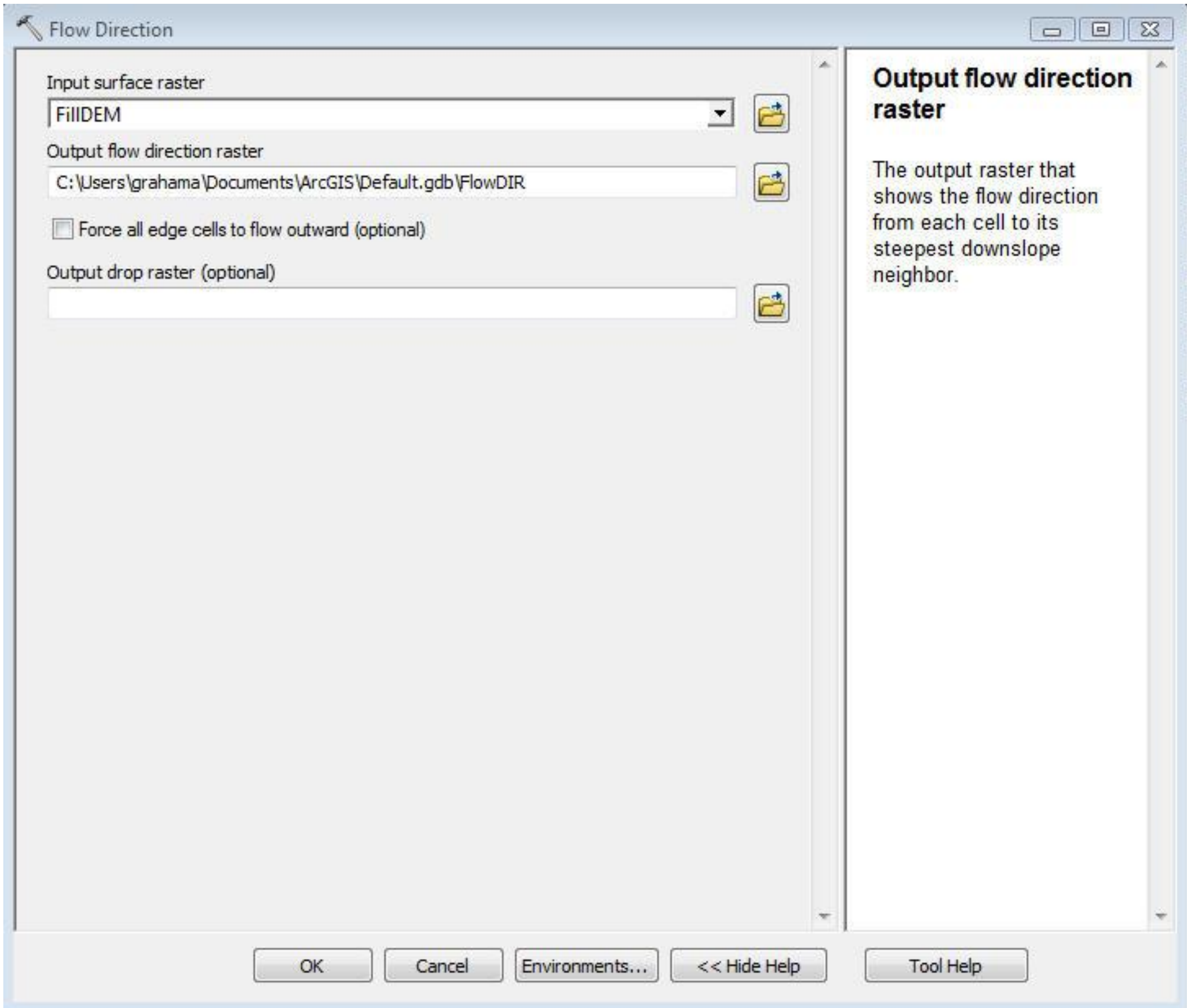


Call your new DEM "fillDEM" and click OK. The new DEM should not be visibly different from the previous version.

Flow Direction

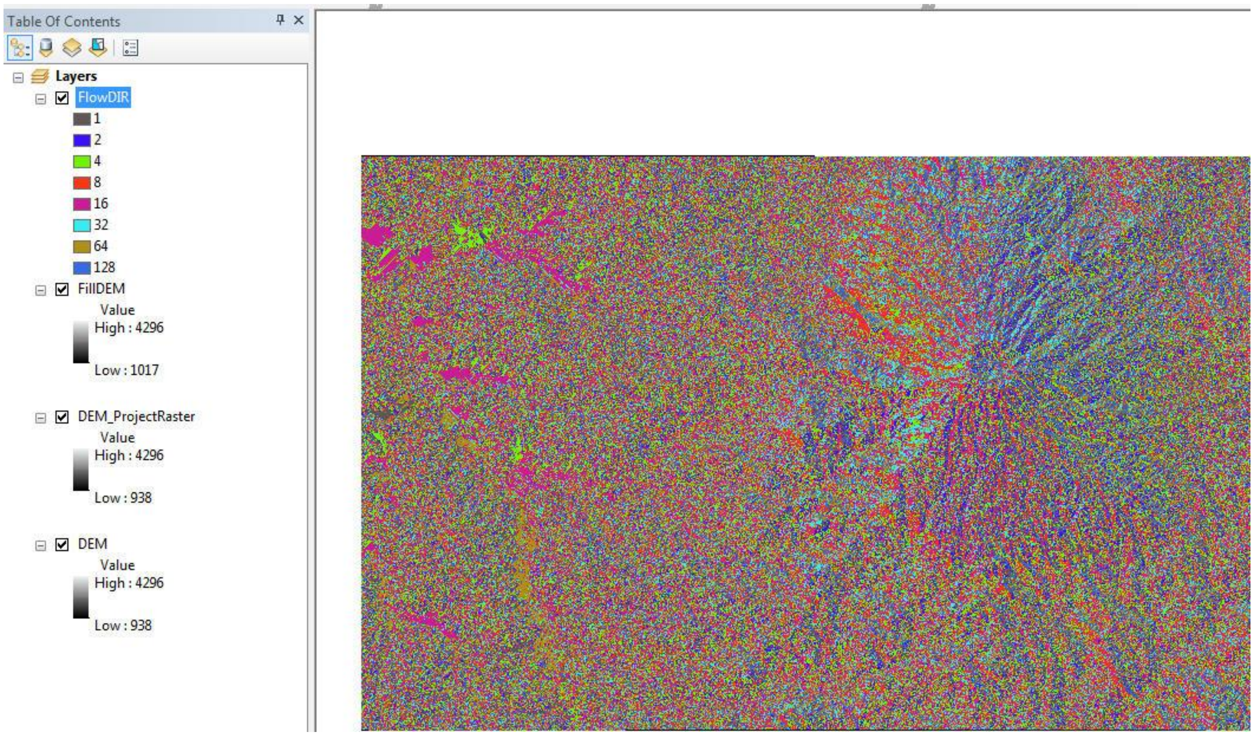
Next you will create a flow direction grid. Use the corrected (filled) DEM and save the resulting grid to the same folder as above.

Find the Flow Direction tool and start it. You should see this form:



Be sure to use the filled DEM (with no sinks) as the input and "flowDIR" as the output.

Your map should look something like this:



While the numbers are not intuitive, the map should be somewhat easy to read. The areas of each value represent areas of similar aspect. The purply-pink in this map represents land that slopes to the west (value 16 from our chart above). Your colors may be different. Other colors have similar meanings.

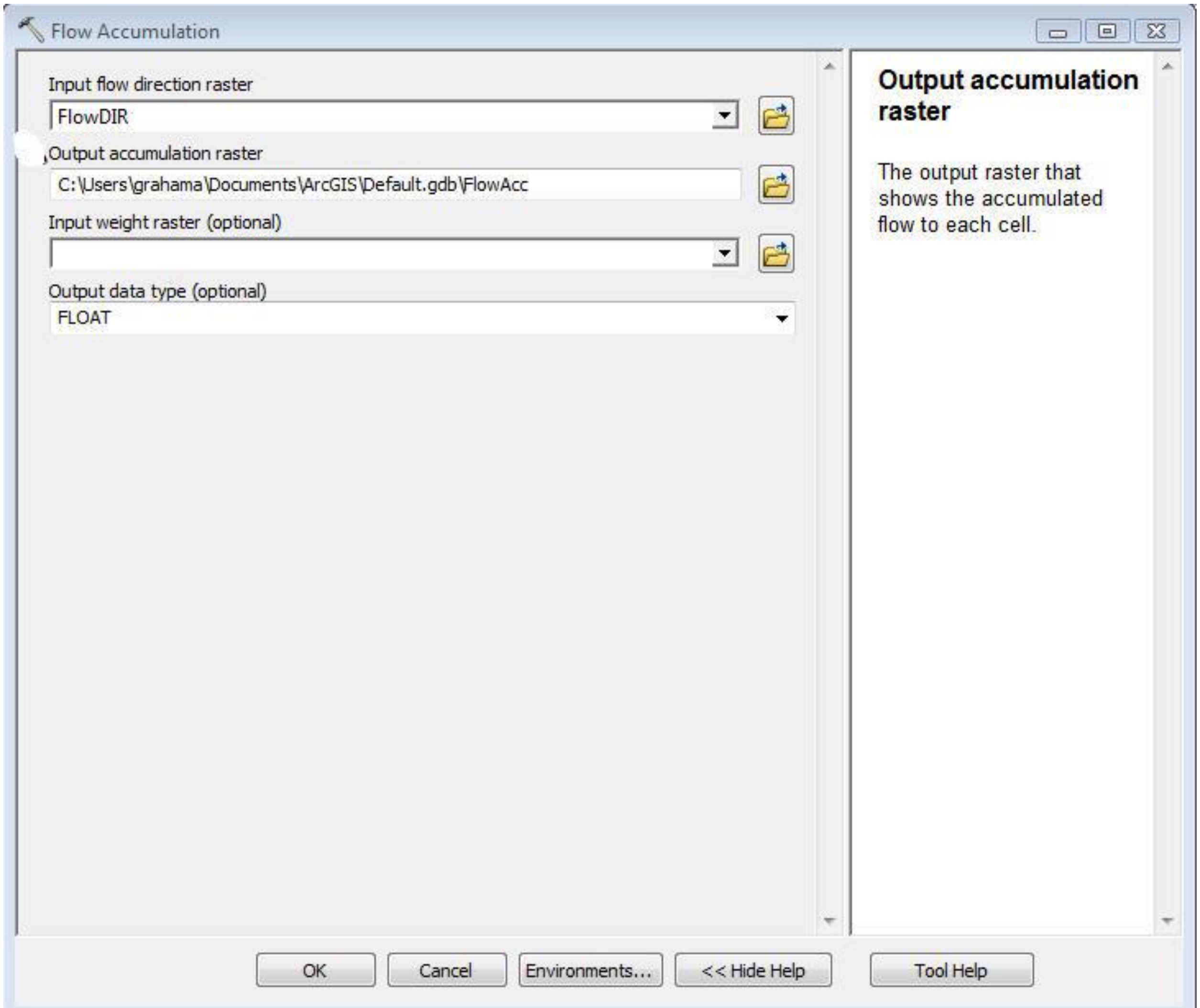
32	64	128
16	**CELL**	1
8	4	2

This illustration shows how the values are set. If the flow of water would flow to the east, the value for the cell would be 1, to the southeast, the value would be 2, etc. This is the required format of data for input for creating flow accumulation grids.

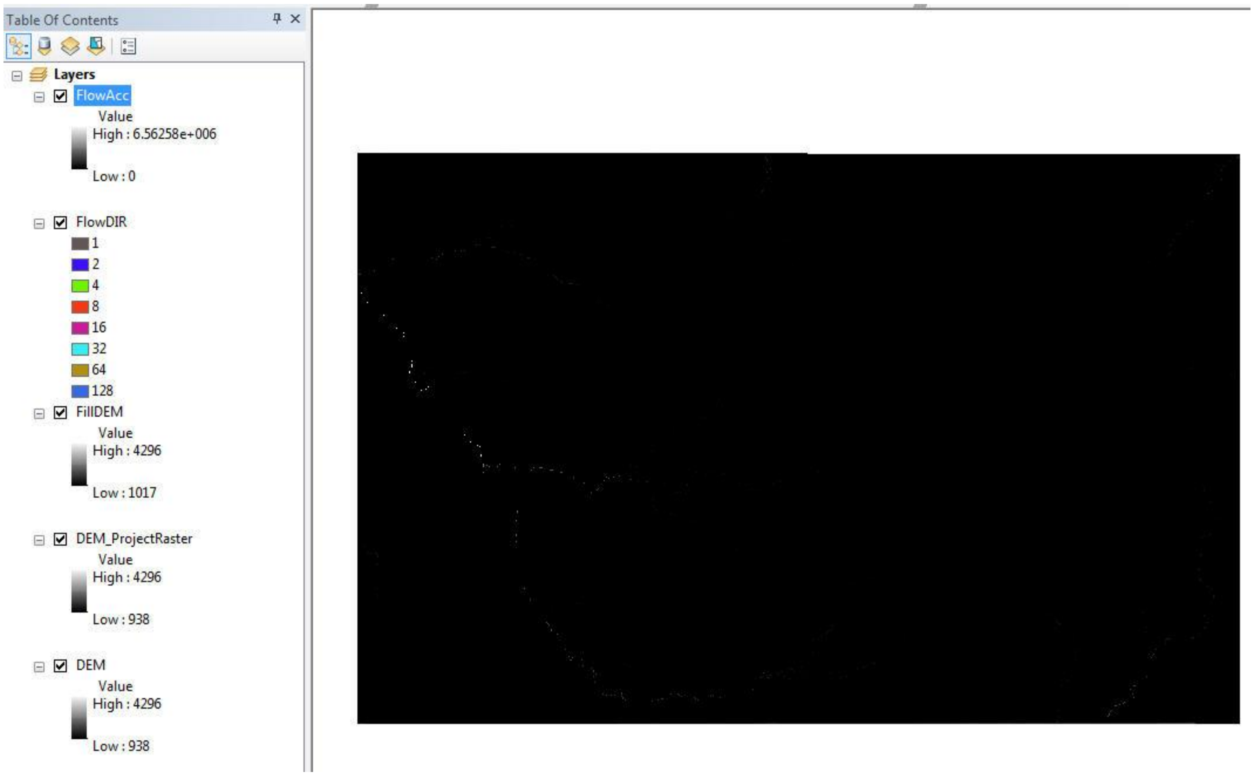
You don't analyze this layer directly but instead use other layers, such as the Flow Accumulation layer.

Flow Accumulation

Flow accumulation gives you the total area (number of cells times the area of each cell) that is upslope and/or upstream of any given cell. Cells that lie on drainage networks have substantially higher values than cells on hill slopes. The Flow Accumulation tool form looks like this:



The resulting map will be a little difficult to interpret, and it will look like this.

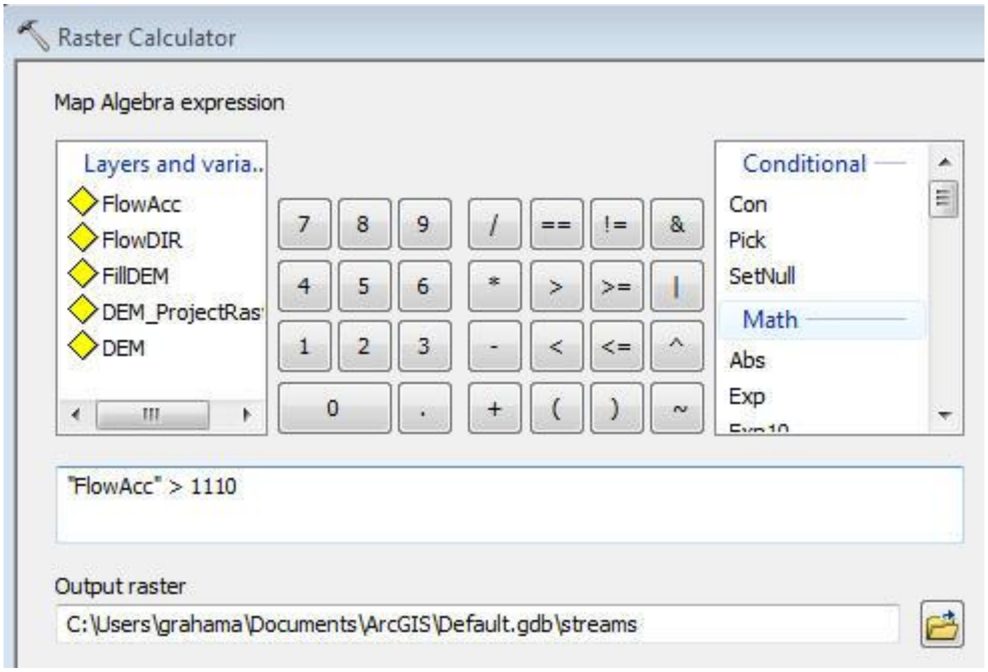


The streams are highlighted because the default symbols are from black (small area contributing to runoff) to white (large area contributing to runoff) but the numbers of cells that are represented are large while your screen has limited pixels. This causes screen moirés which make the lines look disconnected. If you zoom in, you should see the stream channels intact and hopefully make the data easier to interpret.

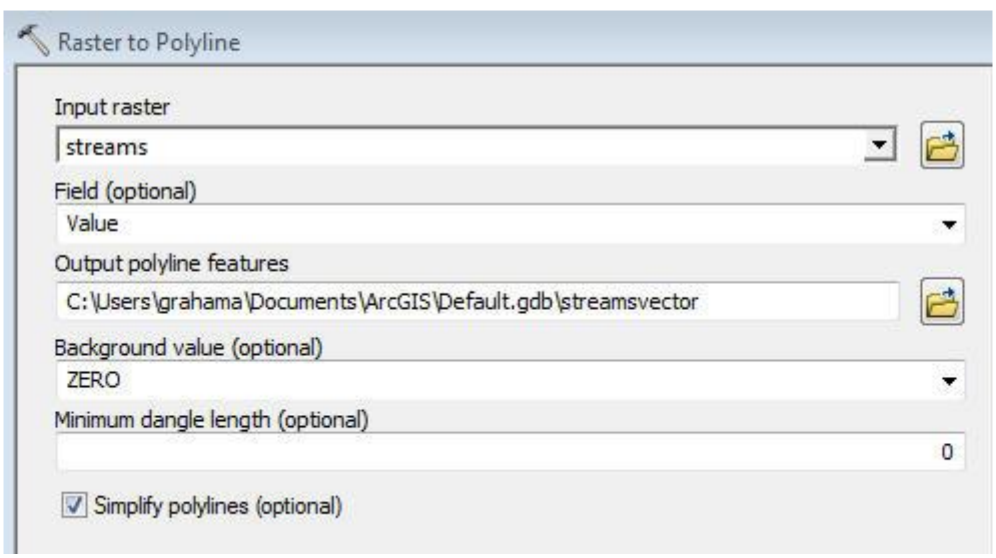
Stream Threshold

Stream threshold values are used to determine the actual stream channels. This value is highly dependent surface vegetation, rainfall amounts, and soil and/or rock type. Let's try a value of 0.3 kilometers, or approximately 1110 cells in an approximately 30 meter DEM, as a test approximation for this area. You can run various test values in terrain that you know well to empirically test this value. To find the streams using this threshold value, find the Raster Calculator in the

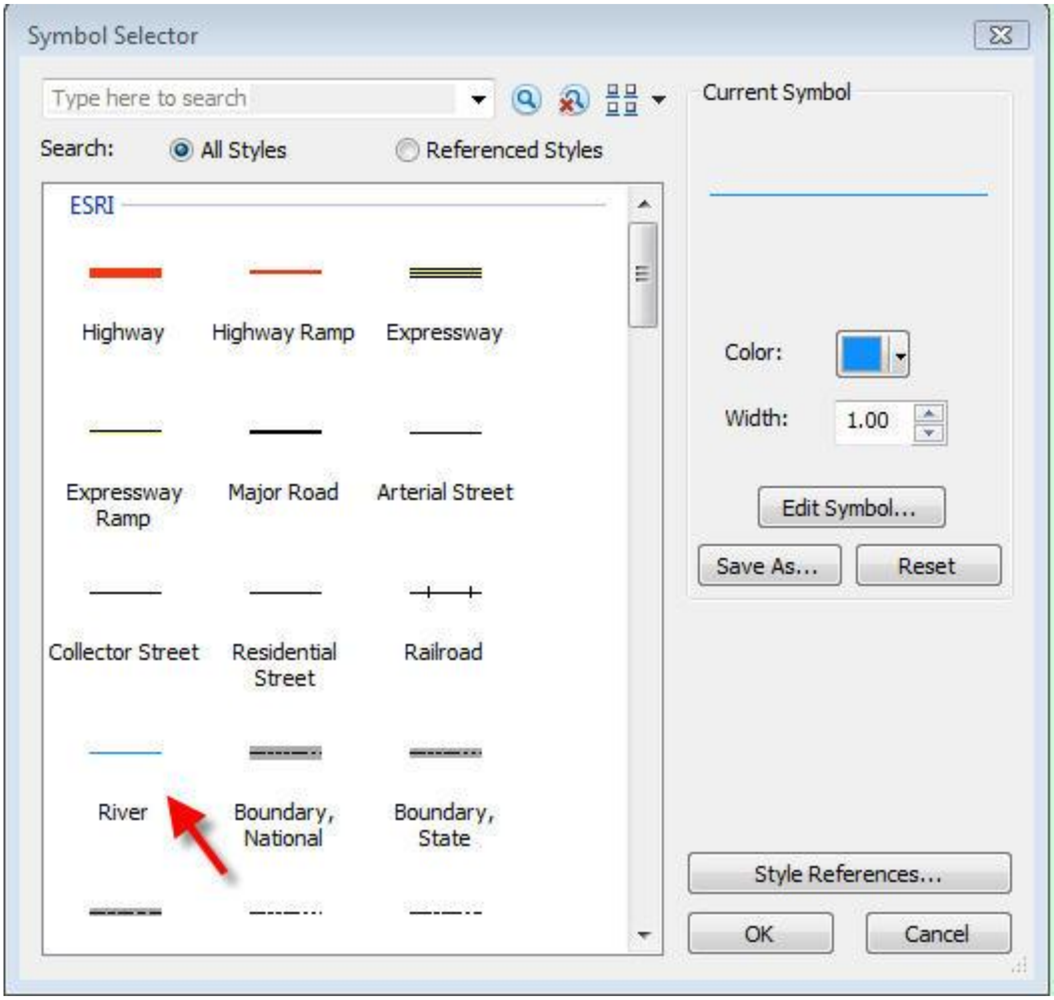
Spatial Analyst toolbox under Map Algebra. You should see this form (fill in as below):



The output of this operation should be called streams. Now convert this cell based data to vector format to make it easier to symbolize you data. Find the Conversion Tools in the Toolbox and find Raster to the Polyline conversion tool:

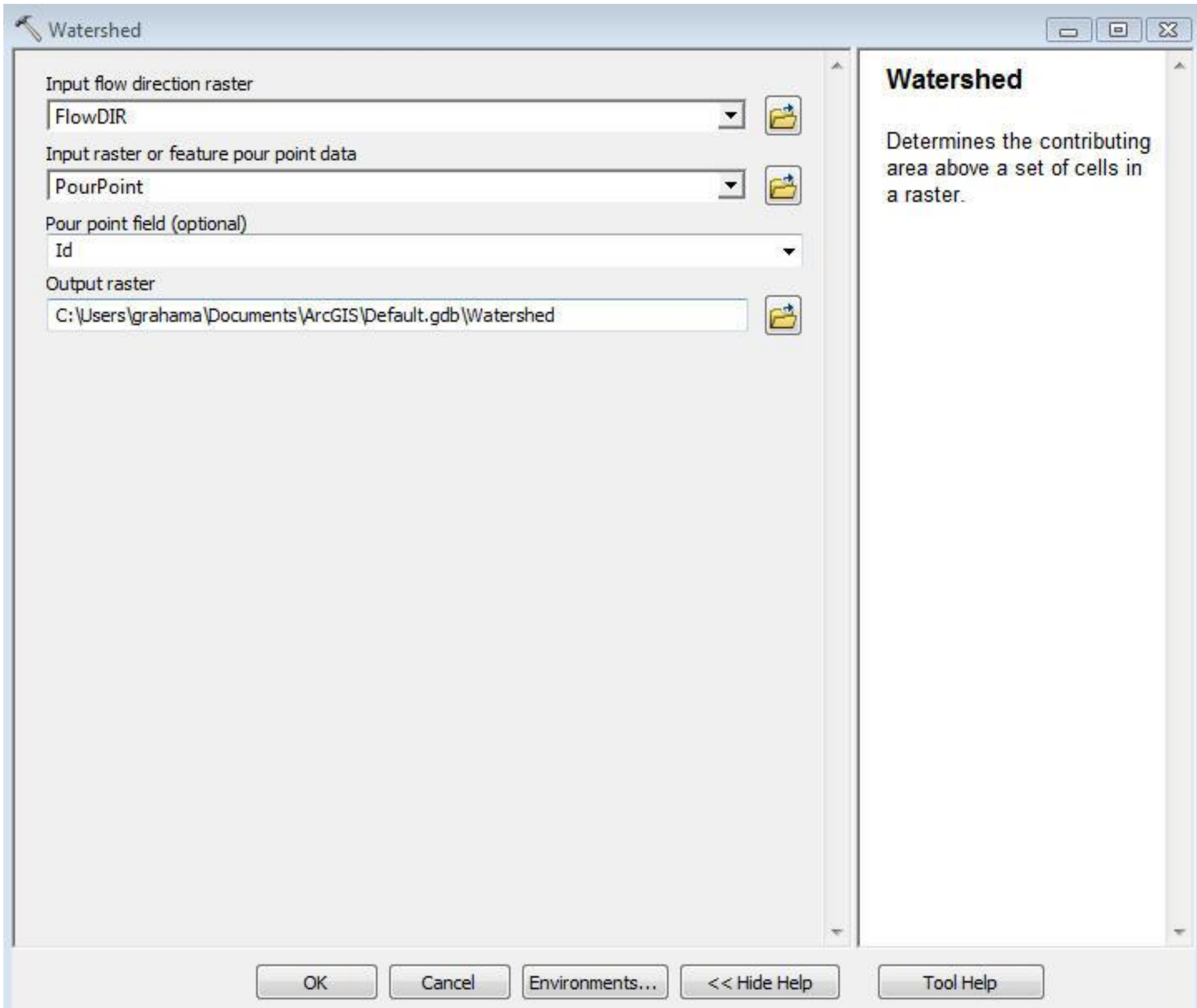


Once you have this new layer, change the symbology as below by double clicking on its line color in the table of contents:

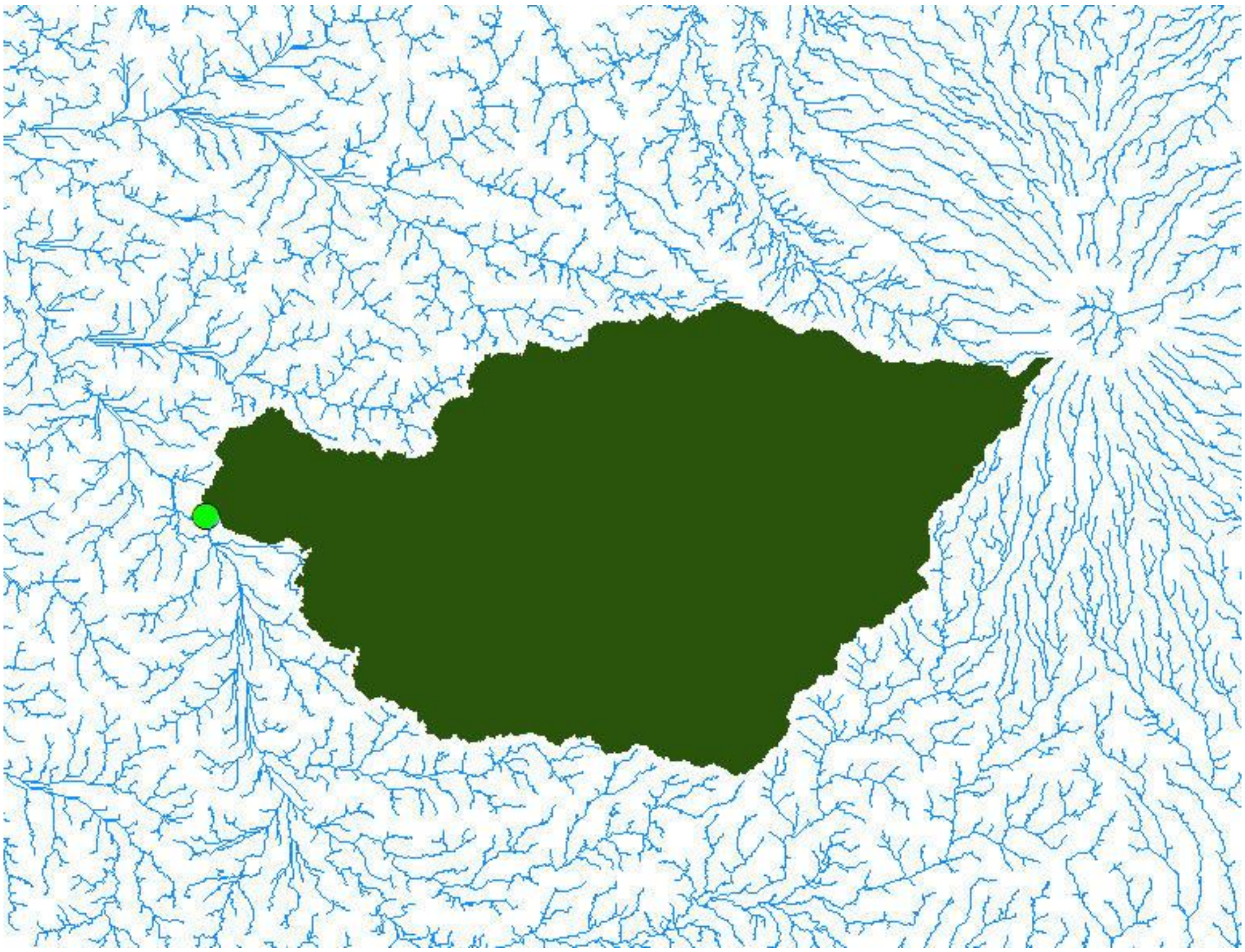


Deriving the watershed

A watershed is the upslope area that contributes flow to a common outlet. The outlet, or pour point, is the point on the surface at which water flows out of an area. It is the lowest point along the boundary of a watershed. A pour point called PourPoint1 was created for this exercise. Add it from the data folder. Use the watershed tool in the Hydrology Section of the Spatial Analyst tools in the Toolbox area. You should see something like this – Use FlowDIR as the input raster:


Watershed
Input flow direction raster
FlowDIR
Input raster or feature pour point data
PourPoint
Pour point field (optional)
Id
Output raster
C:\Users\grahama\Documents\ArcGIS\Default.gdb\Watershed
Watershed
Determines the contributing area above a set of cells in a raster.
OK
Cancel
Environments...
<< Hide Help
Tool Help

Your result should look like this:



More Hydro Tools: Flow Length

As part of the Hydro extension in ArcGIS, we have used the Flow Direction and Flow Accumulation tools. The Flow Direction tool creates a new grid that contains the direction that each of the cells in the grid flows into. The Flow Accumulation tool creates a new grid that contains the number of cells that contribute runoff to a cell in the grid. Now we will work with a tool available in the Raster Calculator, called the Flow Length command. It creates a grid, called the Flow Length Grid, which indicates the length, in distance units, from each cell in the grid to the outlet (which may be the edge of the grid), following the path the water would take. This lab uses the Flow Direction and Flow Accumulation grids to create a

Flow Length grid. In the older (ArcView) version, this command was available as a tool on the Hydro menu, but in ArcGIS, it is only available as a raster calculator command.

Like the Flow Accumulation grid, the Flow Length grid is created from the Flow Direction grid, not from the DEM. You use weights to determine distance and travel time. The travel time will vary based on whether the water is in a channel or running down slope. This is a simple version of a runoff model. A more complex model would account for underground flow and surface properties that affect the speed of the water over different slopes values and land uses and land covers. We will simply calculate flow time from where rain falls to an outlet in the DEM.

Questions you need to ask before starting:

1. What questions do you want to answer?
    1. How much water will pass through a given point on a stream in each of the first four hours of a rain storm?
2. What data do you need to find the answers?
    1. You will need a 30 meter cell size Digital Elevation Model, with sinks filled
3. How do you process the data to find the answers you are looking for?
    1. There will be a number of steps, all in ArcGIS:
        - Create the Flow Direction grid
        - Create the Flow Accumulation grid
        - Create a grid that contains only cells that you consider as being part of a drainage channel.
        - Create a weight grid that has two travel times, one for channel flow, one for overland flow.
        - Create a Flow Length grid from the Flow Direction grid and the weight grid you already created.
        - Slice the Flow Length grid in hourly segments for the first 4 hours.
        - Look at the table and find the total number of cells for each hourly segment and multiply by the cell size.

This gives a very basic version of a runoff model. What would you do if you wanted to implement this as an operational model? You would need to account for overland flow through different land uses and land covers, different soils (soil permeability - how much rain is percolates through the soil versus how much runs off), and changes in permeability over the course of a storm. Finally, you would need to calibrate the model for an individual storm and then test that calibration against other storms.

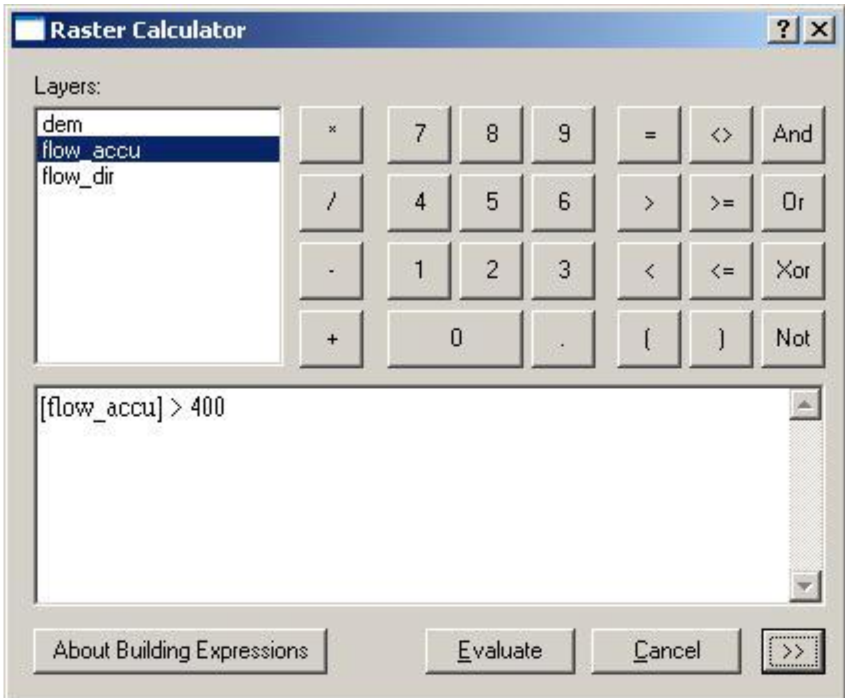
ArcGIS hints

You may end up with a lot of files clogging your drive space, so when you have finished, go back into ArcCatalog and delete all those datasets that you do not need anymore.

Doing the work in ArcGIS

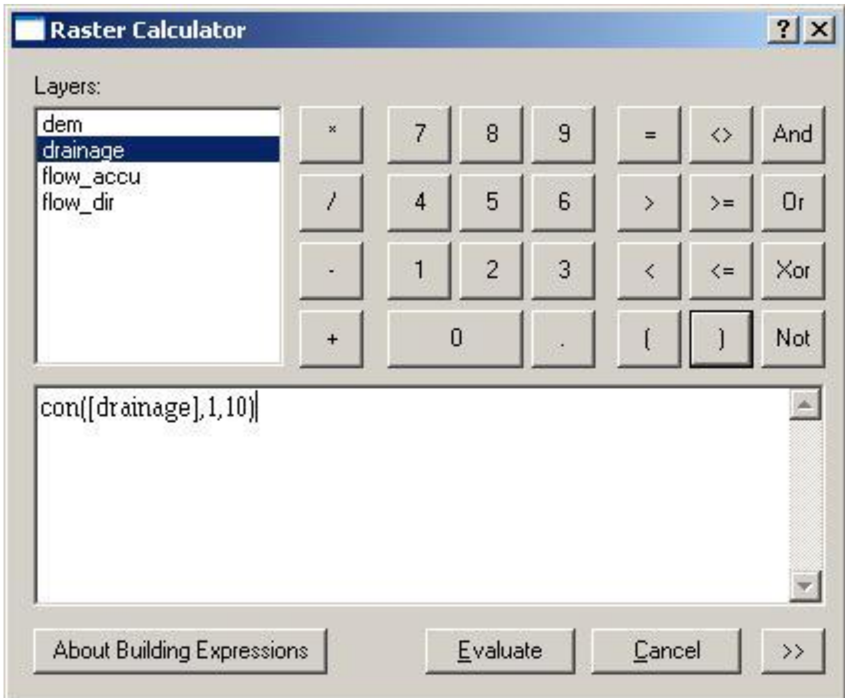
Use the filled version of the DEM that you just created.

Create the **drainage grid**. This should contain only the cells that have 400 or more cells contributing runoff them. To do this, go to the Spatial Analyst menu, click on Raster Calculator and make the selection **[flow_accu] > 400**



This will create a new grid called "Calculation#", which shows your drainage channels. Right-click on Calculation#, and select "Make Permanent.” Save it to your folder, with a name like "drainage". Change the name of the layer in your table of contents to match, and give it useful colors.

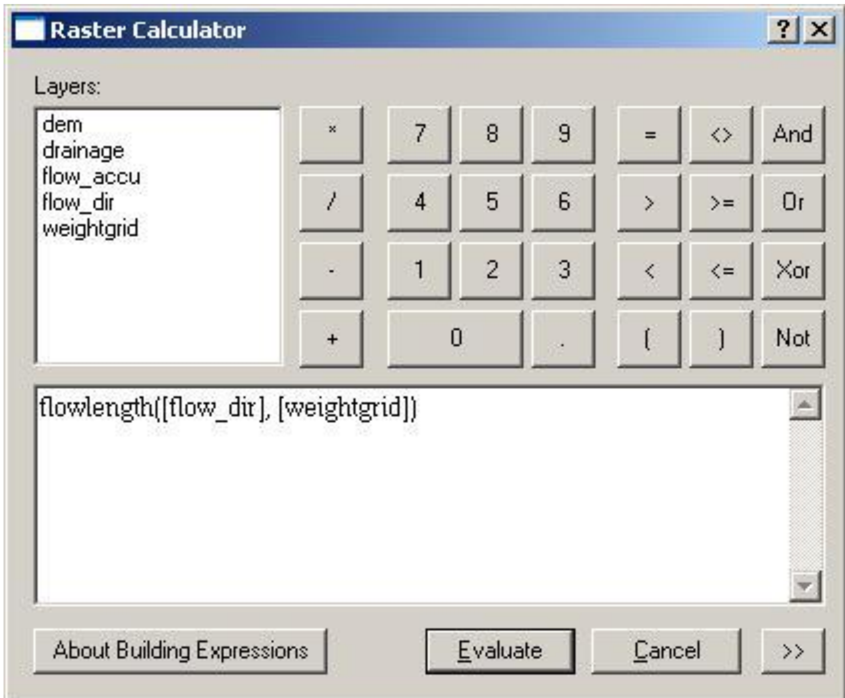
Now we want to create a Weight Grid that classifies the land as 10 and your drainage channels as 1, since flow moves much more easily through the channels than overland. To create the Weight Grid, use the Raster Calculator again, and run this command: **con([drainage],1,10)**. Be careful with syntax! The grid "drainage" is the grid that you created in the last step, which contains only cells that have 400 or more cells contributing to runoff.



What are these weights? They are time (in seconds) that the water takes per unit measure (meters in this case. They are the inverse of meters per second. So 1 represents 1 meter per second and 10 represents 1/10 or 0.1 meter per second. Or the numbers (1 and 10) represent the number of seconds that it takes water to traverse a cell in stream and overland respectively. These are examples and you would want to test these numbers empirically before creating a real runoff model.

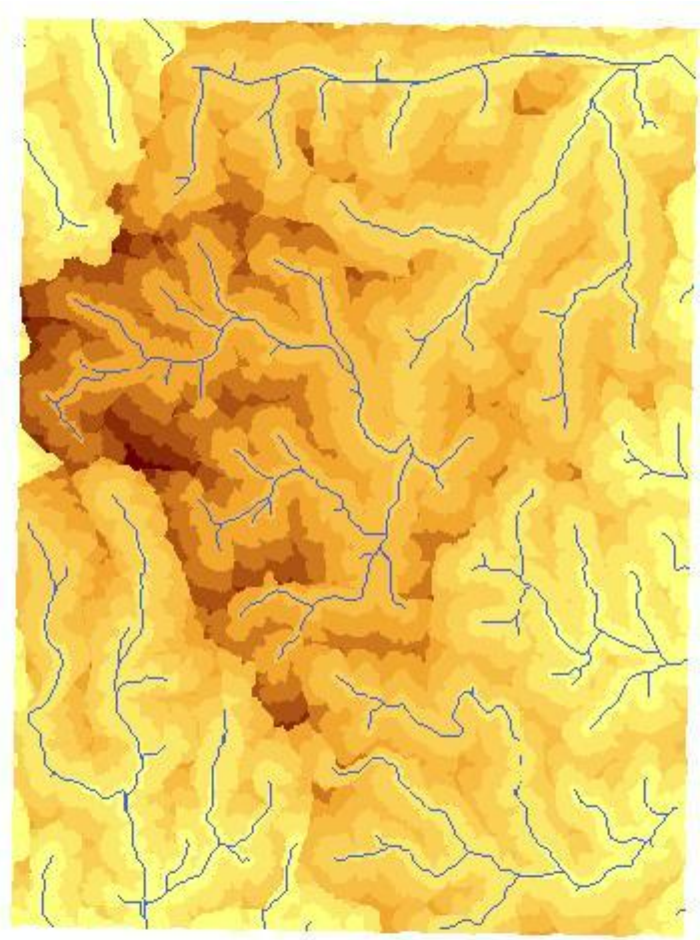
Make this layer permanent, renaming it "weightgrid" in both the filename and on your table of contents.

Now create the Flow Length grid. With the Raster Calculator run this command: **flowlength([flow_dir], [weightgrid])**. Again, remember to be careful with syntax and naming. In this case, the grid "weightgrid" is the grid that contains the weights, 1 and 10, and "flow_dir" is the grid that you create with the Flow Direction command.



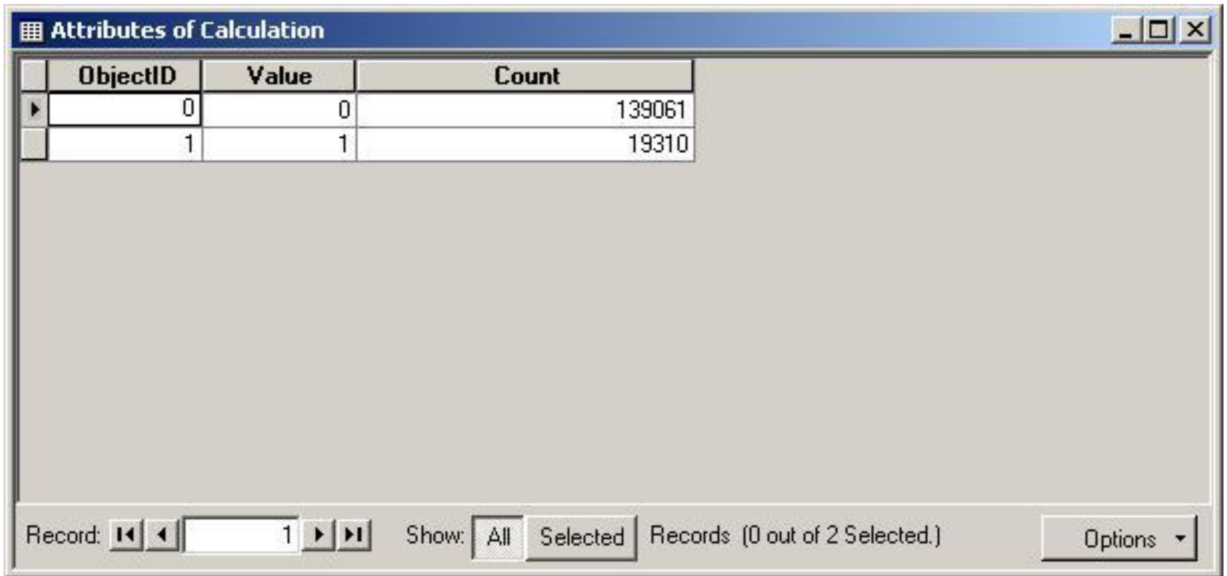
Your resulting map should look something like the one below. In this example, darker colors indicate longer travel times, though your symbology may be reversed, with lighter colors indicating longer travel times. To make your drainage channels visible on top, drag your "drainage" grid to the top of the list, and the non-channel areas (value=0) to "no color", leaving the drainage channels (value=1) visible.

Make your flow length grid permanent, and rename it "flow_length".

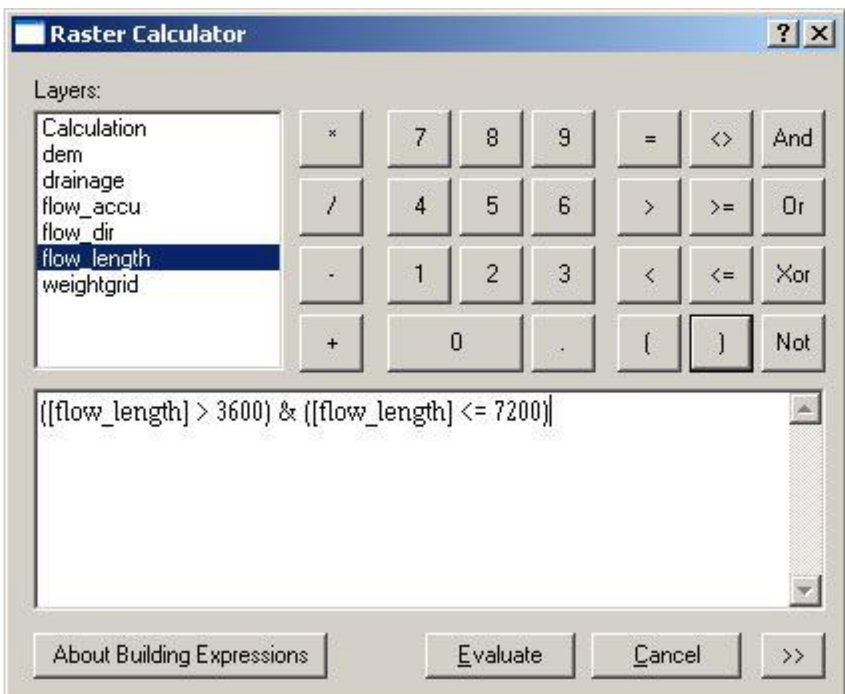


Now slice this grid (the Flow Length grid) for each hour of time (for a total of four hours), 1 to 3600 seconds, 3601 to 7200 seconds, 7201 to 10800 seconds, and 10800 to 14400 seconds. Use the Raster Calculator again to do four separate queries. For the first hour, your query should be this: **([flow_length] <= 3600)**. This assumes that "flow_length" is the grid that contains the Flow Lengths.

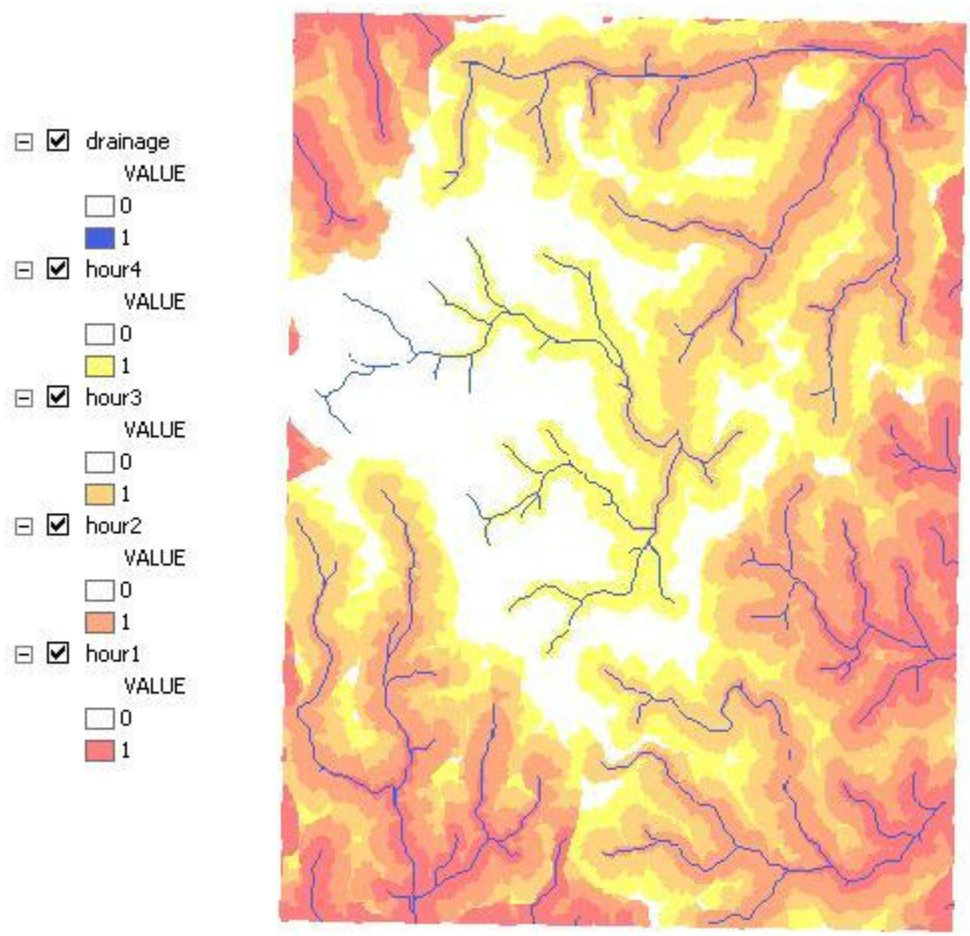
After each Query, open the Attribute table of the newly created grid. You should look at this and get the total area for the for the selected cells. Record the area and multiply by 900 (since each cell is 30 x 30 meters or 900 square meters) and divide by 1,000,000 to get the area in square kilometers. This is what the table for the first hour runoff looks like. The value of approximately 19,310 is the number of cells. The area in square meters is about 17,379,000 and the area in square kilometers is about 17.38.



Your query for the second hour should look like this: **([flow_length] > 3601) and ([flow_length] <= 7200)**.



Continue for the first 4 hours of flow. Rename each "hour1", "hour2", etc... Make the area not represented by the hour (value=0) "no color", so that only the area that drains within each hour shows.



Be sure to save your project, and check each data layer to make sure that it is not in a temporary folder where it will be deleted.