Stream Network and Watershed Delineation using Spatial Analyst Hydrology Tools

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Objective

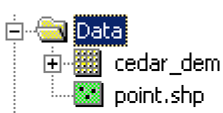
The purpose of this exercise to learn how to delineate stream network and watersheds from a digital elevation model (DEM) using the Spatial Analyst Hydrology Tools in ArcGIS.

Learning Outcomes

1) Filling sinks in a DEM
2) D8 pour point method for assigning flow direction
3) Meaning and role of stream network critical source area (CSA) threshold
4) Difference between watershed versus sub-watershed in ArcGIS
5) Computing drainage density and stream order of a river network

Input Data

Input Data needed for this exercise is provided in lab3.zip folder on Blackboard. The data are also available at: ftp://ftp.ecn.purdue.edu/vmerwade/download/data/lab3.zip. Copy the file on your working drive/folder, and unzip it. The ArcCatalog view of the data folder is shown below:

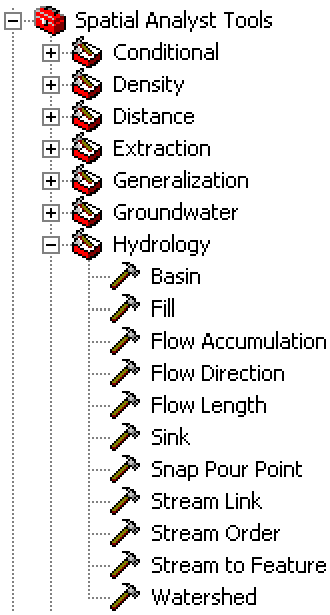


cedar_dem is a 30 DEM obtained from USGS. The second dataset, *points.shp*, is a shapefile containing points for which sub-watersheds will be delineated in this tutorial. Both *cedar_dem* and *point.shp* are already assigned a projected coordinate system (NAD_1983_UTM_16).

Note: It is very critical to assign and use consistent coordinate system for all the datasets used in delineating watersheds by using any pre-processing tool.

Getting Started

Open *ArcMap* and save it as *lab3.mxd*. All spatial analyst tools that are used for delineating stream network and watershed boundaries are available in *ArcToolbox*. If *ArcToolbox* is not activated within the map document, **click** on the *ArcToolbox* button to access the tools. Hydrology tools can be found by selecting *Spatial Analyst Tools*→*Hydrology* within *ArcToolbox* as shown below:

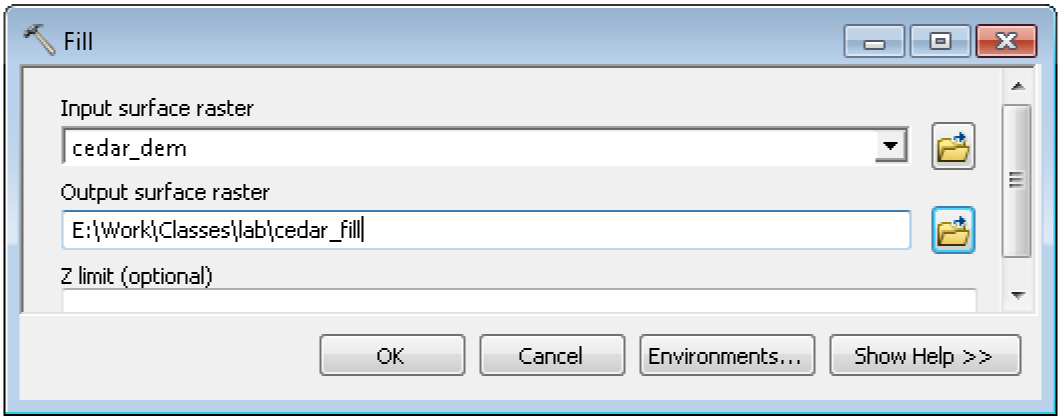


Now **add** *cedar_dem* to the map document. This is the only dataset you will need to get started with the process. Note the lowest and highest elevation in this dataset. Open the properties of this dataset to look at the cell size, projection and the pixel type. We will add other datasets later in the tutorial. Before using any tool in ArcToolbox, go ahead and disable the background processing by going to Geoprocessing→Geoprocessing options..

Filling Sinks

The Fill function fills the sinks in a grid. If cells with higher elevation surround any cell in a DEM, the flow gets trapped in that cell and cannot go downstream. The Fill function modifies the elevation values to eliminate this problem.

Double click on the *Fill* tool. Provide *cedar_dem* as the input surface raster, and **save** the output raster as *cedar_fill* in your working directory. The main function of this tool is to remove imperfections in the DEM to enable the flow move downstream. However, if there are natural sinks in the data (e.g, 10m deep lake), you can use the “Z limit” to retain these natural sinks. For example, if you specify Z limit as 6m, the program will not fill any sinks that are deeper than 6m. The default is to fill all sinks (do not provide any input for Z limit). **Click** *OK*.

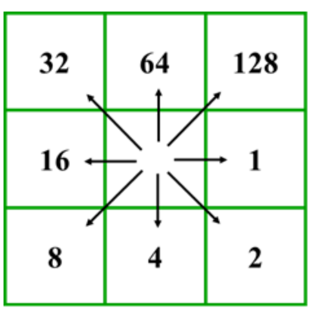


After the process is complete a filled DEM (*cedar_fill*) will be added to the map document. Again, note the highest and lowest elevation in this dataset.

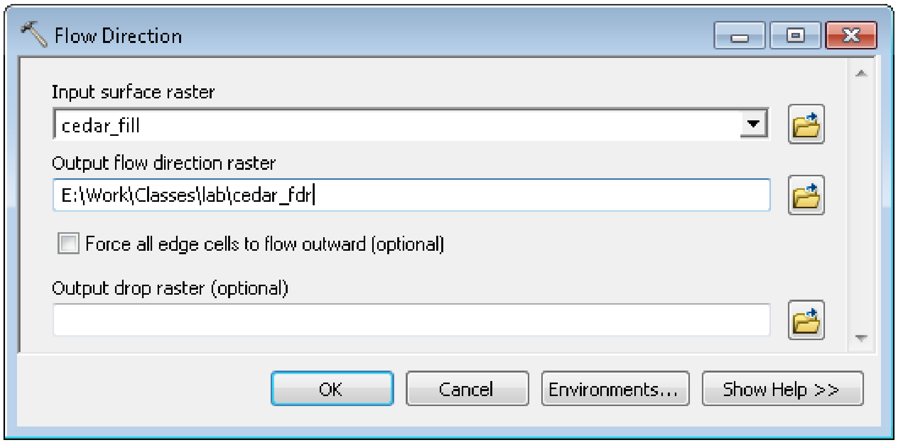
Q1. How has the high/low values of the filled DEM changed? Why?

Flow Direction

This function computes the flow direction for a given grid. The value in any given cell of the flow direction grid indicates the direction of the steepest descent from that cell to one of its neighboring cells using the eight direction pour point (D8) method. In the D8 method, the steepest descent for each cell is computed by looking at the slope between the target cell and its 9 neighbors. A flow direction number is given to each cell depending on the location of the neighboring cell that produces the steepest slope as shown below. For example, if the steepest slope from the central cell is towards south, the central cell will get a value of 4.



Double click on *Flow Direction* tool. **Select** *cedar_fill* as the input surface raster, and name the output raster as *cedar_fdr*. The optional output drop raster will produce a raster that shows the ratio in percent between the maximum drop in the elevation from each cell towards the direction of the flow and the flow length between the adjacent cells. We do not need the drop raster so leave this input empty. The other option of forcing all the edge cells to flow outward is also not needed for this exercise so leave that option unchecked. **Click** *OK*.



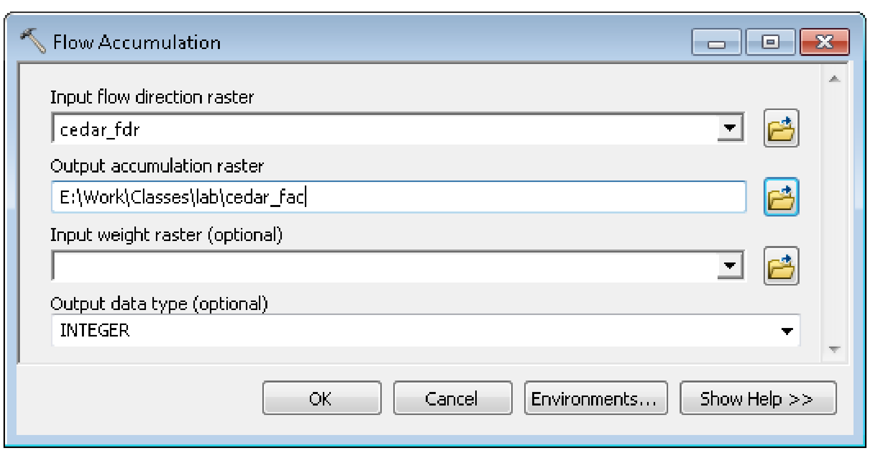
After the process is complete, a flow direction grid with cells having one of the eight flow direction values (1,2,4,8,16,32,64,128) will be added to the map document. **Save** the map document. Look at the properties of cedar_fdr.

Q2. <u>What is the pixel type for the flow direction raster? Why?</u>

Flow Accumulation

The Flow Accumulation function uses the flow direction grid to compute the accumulated number of cells that are draining to any particular cell in the DEM. **Double click** on *Flow Accumulation* tool. **Select** *cedar_fdr* as the input flow direction raster, and save the output flow accumulation raster as *cedar_fac*. Leave the default options for input weight raster as null, and change the output data type to <u>INTEGER</u>. **Click** *OK*.

<u>Q3. What is the maximum flow accumulation in the cedar_dem dataset?</u>



After the process is complete, a flow accumulation grid will be added to the map document. You will clearly see a stream network in this output, and if you check the pixel value (by using the identifier tool), the values along the cells that appear to form a stream network will have much higher values compared to the surrounding cells. If you do not see the network clearly, zoom-in until you see the network. **Save** the map document.

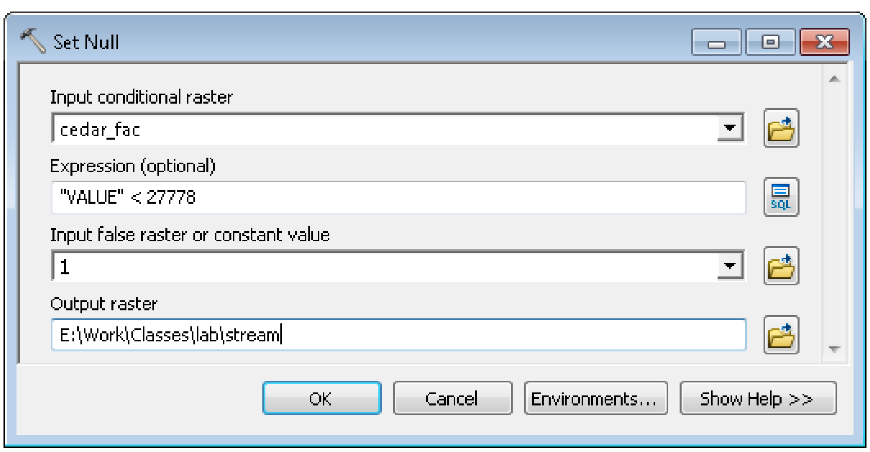
Right click on cedar_fac layer, and see if you can open the attribute table. If you are not able to see the attribute table, then we need to build one. To build an attribute table for an integer raster, you can use the ArcToolbox. **Click** on *Data Management Tools→Raster→Raster Properties→Build Raster Attribute Table*. While building the table, leave the option overwrite box **unchecked**, and **click** *OK*. Once this is done, you will now be able to see the attribute table.

<u>Q4. What information is contained in a raster attribute table? How is this table different than the attribute tables for vector features (points, lines and polygons)?</u> (Hint: think of the mandatory fields, what information is stored in raster attribute table)

Stream Network

Because the flow accumulation gives the number of cells (or area) that drain to a particular cell, it can be used to define a stream. It is assumed that a stream is formed when a certain area (threshold) drains to a point. This threshold can be defined by using the number of cells in the flow accumulation grid. If we assume an area of 25 km^2 as the threshold to create a stream, the number of cells corresponding to this threshold area is 27,778 (25000000/(30*30)). To create a raster, that will have stream cells corresponding to a threshold area of 25km^2, **select** *Spatial Analyst Tools→Conditional→Set Null*. Create a raster from *cedar_fac* such that it only includes cells that have pixel value greater than 27778 as shown below. This will create a calculation raster where all the cells with value greater than or equal to 27778 in *cedar_fac* will have a value of 1, and all other cells are set to *Null*. **Save** the output raster as *stream* in your working directory. **Click** *OK*.

<u>Q5. What will be the equivalent threshold area in km^2 if you want to use 50,000 cells?</u>

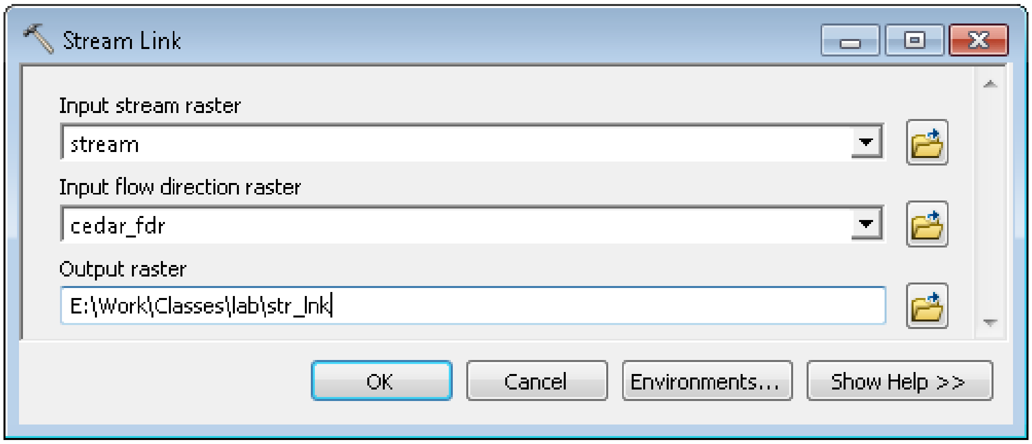


Save the map document.

(Note: This step can also be accomplished using the Con tool under Spatial Analyst Tools→Conditional)

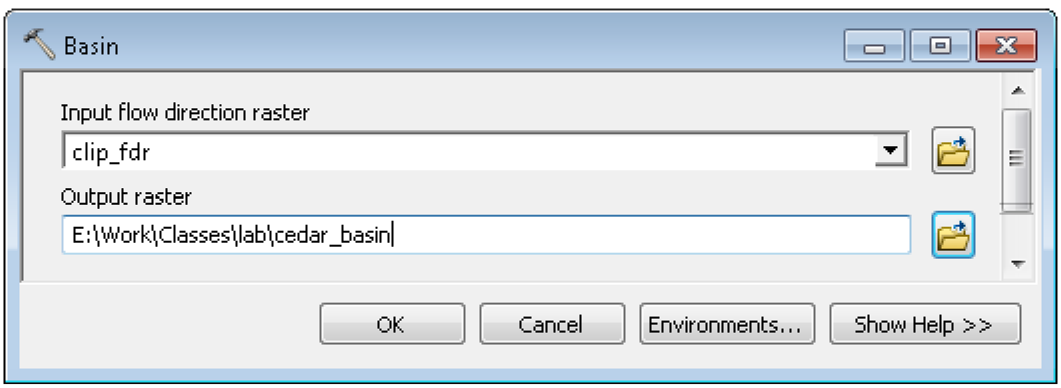
Stream Link

This tool assigns a unique number to each link (or segement) in the stream raster. **Double click** on *Stream Link*. Provide *stream* as the input stream raster, *cedar_fdr* as the flow direction raster, and name the output raster as *str_link*.



Basin

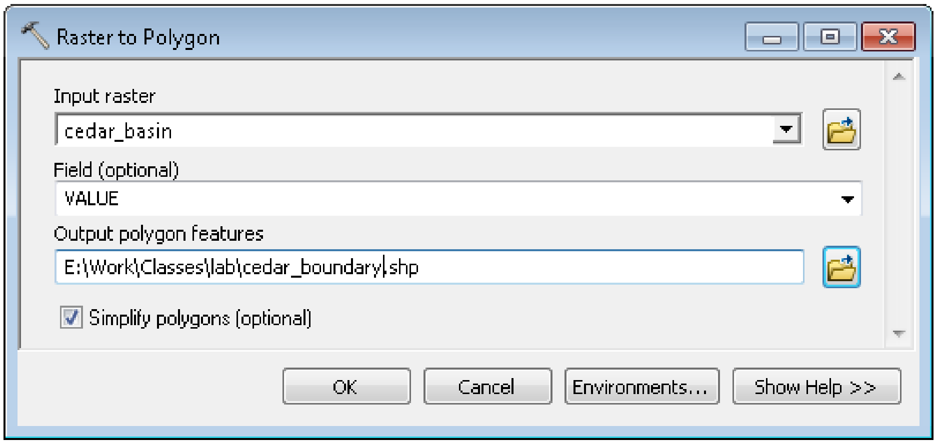
This tool uses the flow direction grid to find all sets of connected cells that belong to the same drainage basin, and assigns a unique number to all the cells within that basin. **Double click** on Basin. Provide *cedar_fdr* as the input flow direction raster, and name the output raster as *cedar_basin* as shown below. **Click** *OK*.



After the process is complete, *cedar_basin* raster will be added to the map document. Change the symbology of this layer to a different color ramp to see each basin distinctly. Although you will see a big drainage basin that gives the drainage boundary for cedar creek output, there are some small drainage areas that do not drain to the cedar outlet.

Creating Basin Boundary Polygons

We can use the basins raster to get polygons as boundaries for all the basins. **Select** *Conversion Tools→From Raster→Raster to polygon*. **Provide** *cedar_basin* as the input raster, **choose** output geometry type as polygon, and save the output as *cedar_boundary.shp* in your working directory as shown below. **Click** *OK*.

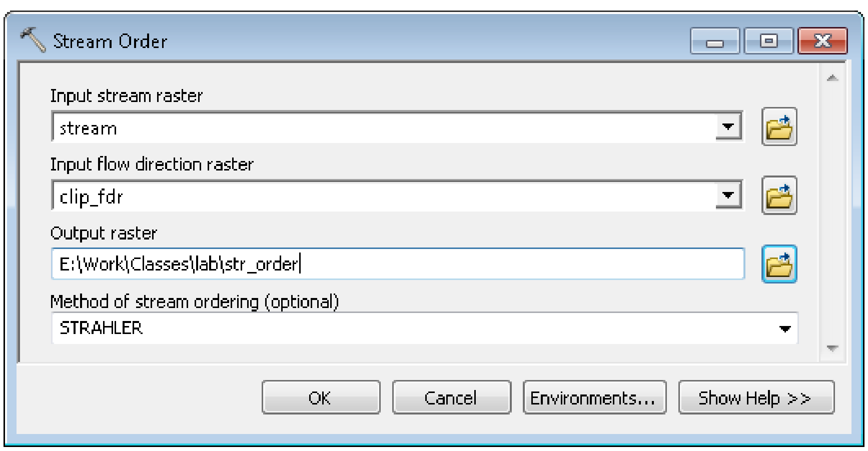


After the process is complete, *cedar_boundary* shapefile will be added to the map document. This shapefile will contain multiple polygons, with each polygon representing a watershed that is draining to an outlet.

Q6. What is the area (in square kilometers) of the biggest basin among all the basin polygons in the dataset? (Hint: explore the measure tool in ArcMap, also learn how to calculate geometry (length or area) for a field in attribute table)

Stream Order

This tool creates stream order for the stream network. **Double click** on stream order. Provide *stream* as the input for stream raster, *cedar_fdr* as the input for flow direction raster and name the output raster as *str_order* as shown below. Two methods are available for estimating stream order. Choose anyone you like (Strahler in this case), and **click** *OK*.

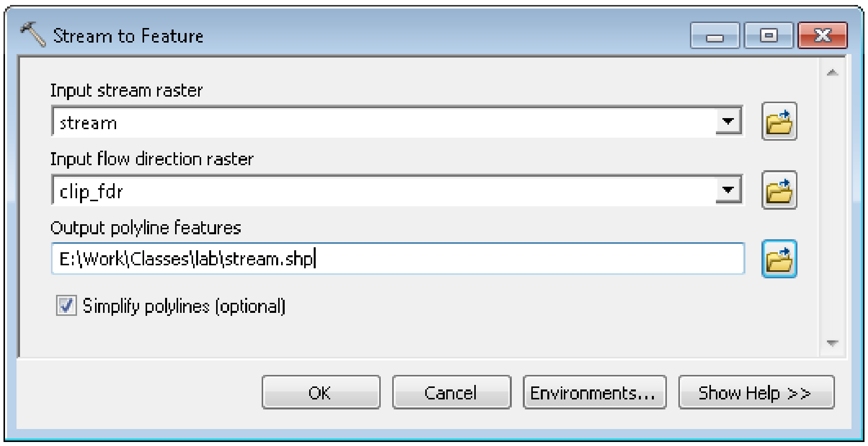


After the process is complete, str_order will be added to the map document.

Q7. What is the stream order of the biggest watershed in the dataset?

Stream to Feature

This tool converts stream raster to a polyline feature class or shapefile. Provide *stream* as the input for stream raster, *cedar_fdr* as input for the flow direction raster and **save** the output as *stream.shp* in your working directory. **Click** *OK*.



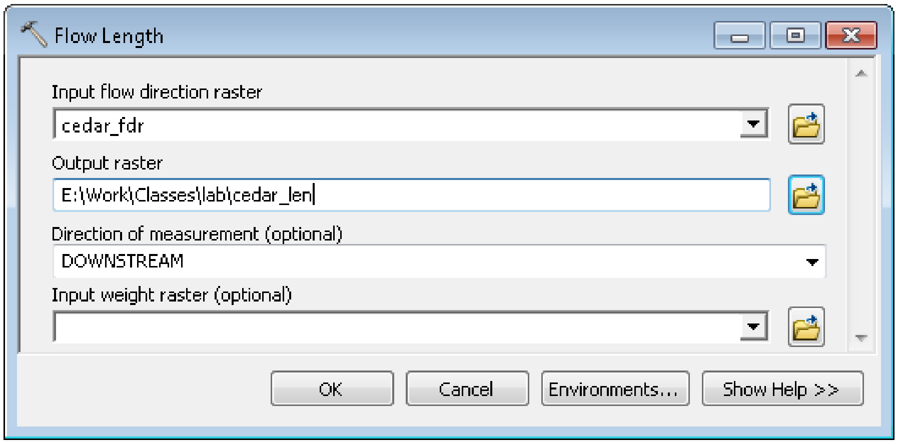
After the process is complete, a shapefile named stream will be added to the map document. **Save** the map document. You can use this tool to create features from other stream related rasters such as stream order and stream link.

Q8 How many streamline features are created? How did you find out?

Q9. What is the total length of all streams? How did you find out?

Flow Length

This tool uses the flow direction to compute the flow distance or length from each cell to the most downstream or upstream cell in the DEM. **Double click** on *Flow Length*. Provide *cedar_fdr* as the input flow direction raster and **save** the output as *cedar_len* in your working directory as show below. Use downstream to compute the flow length to the watershed outlet. **Click** *OK*.

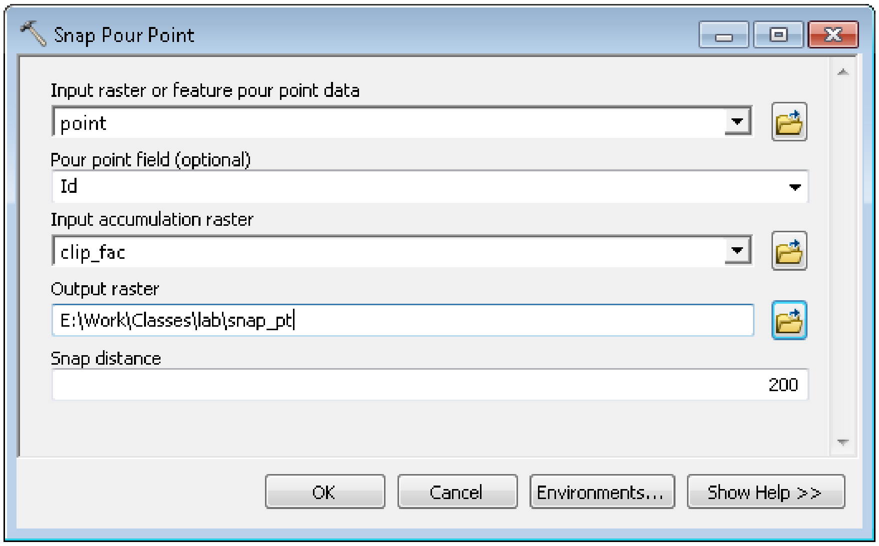


After the process is complete, *cedar_len* will be added to the map document.

<u>Q10. What is the maximum distance any water drop will travel in the given dataset?</u>

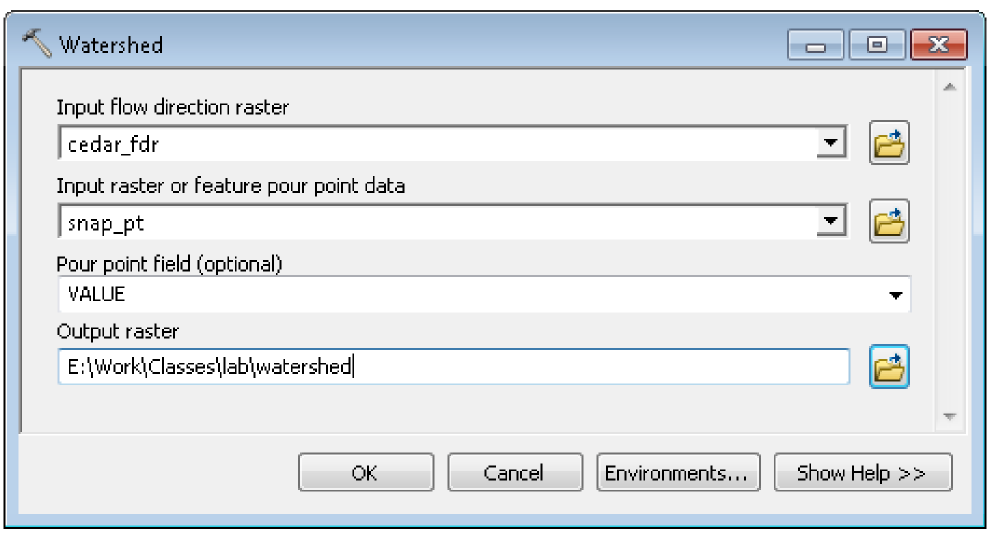
Delineating Watersheds and Sub-watersheds

If you have not done already, add the point shapefile from your working directory to the map document. The DEM that you have used contains the cedar creek watershed and surrounding areas. In order to delineate the cedar creek watershed, add the point shapefile in your map document. Watersheds are delineated by defining a point on a stream so it is important that the points you use to delineate a watershed must intersect with the stream line. Now zoom to each point to see if they fall on the stream cell. If not, find out how far each point is from its stream. You will see that one point is closer to the stream and other point is little too far off. We will create a new dataset and pull these points to align with the stream by using the Snap Pour Point tool. **Double click** on Snap Pour Point. Use the point shapefile as input for the feature pour point data, leave the default *Id* field unchanged for pour point field (although this field is optional, it is important to specify this field and make sure that each point has a unique ID), use *cedar_fac* as input for the flow accumulation raster and name the output raster as *snap_pt*. Use a snap distance of 200m (this may change for different datasets and resolutions). This distance is decided based on how far your points are from the stream. Click on the Environments, and make sure that the extent (under processing extent) is set to cedar_dem, and the mask under raster analysis is also set to cedar_dem). **Click** *OK*.

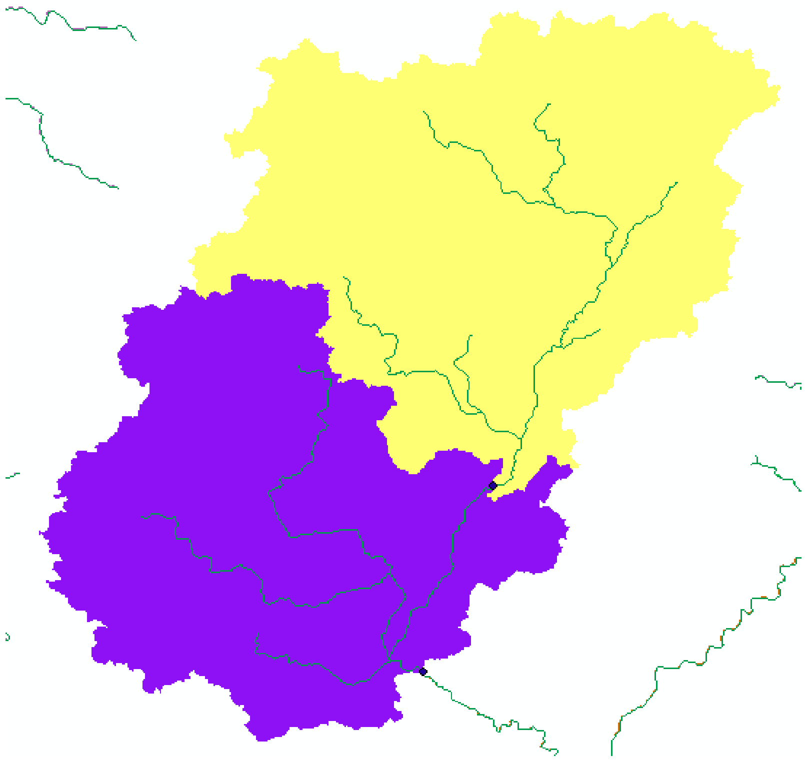


After the process is complete, a raster named *snap_pt* will be added to the map document. **Zoom-in** to the points to make sure that they align with the stream or flow accumulation grid.

Next, **double click** on *Watershed*. Use *cedar_fdr* as input for flow direction, *snap_pt* for input pour point raster, leave the default pour point field unchanged, and name the output raster as watershed. **Click** *OK*.

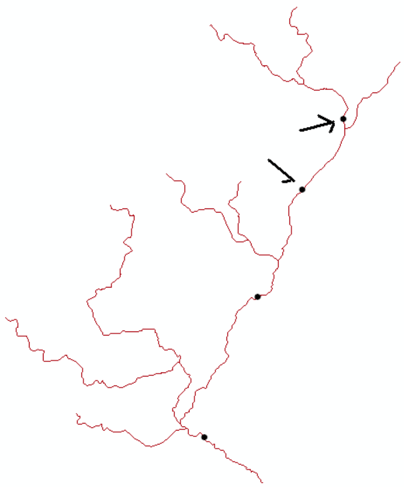


After the process is successfully completed, you should get a raster showing watersheds at these two points as shown below. If for some reason, you do not see any delineation or if the watershed size is too small, run the tool again, but make sure you set the processing extent correctly by going to Environments→Processing Extent in the tool options.



OK, you are done using all spatial analyst tools for hydrology in ArcMap!

Q11. Add two more points to the point feature class (shown by arrows below, you can add these points at approximate locations along the stream lines shown below), and recreate sub-watersheds using the Watershed tool. What is the area of these four sub-watersheds in km^2? (Note: Think about the role of Id field you used earlier before running the watershed tool).



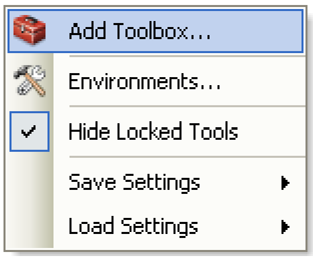
Q12. How many rasters and vector datasets did you create until now? How are these files stored in your working folder? How is the format of the vector files different than the vector data you created in lab1 for storing gauge points and time series? What is the format of the raster outputs?

Q13. You learned the use of all spatial analyst hydrology tools in ArcGIS. If you are given a DEM and a point, do you have to use all these tools or can you get delineate the watershed for the given point by using only a few tools? Write the names of the tools in the sequence that you will use in delineating the watershed. Draw the sequence/flow chart to show the input(s) and output(s) for each tool.

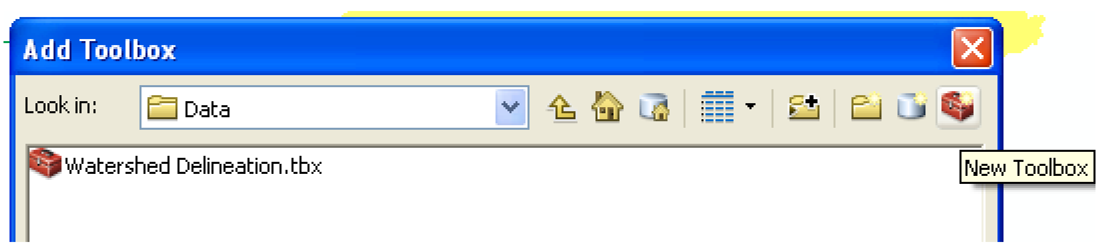
Creating a Model Builder Application

Hydrologists have to delineate lots of watersheds so it is a good idea to automate this process. Now that you know the sequential steps in delineating a watershed, you can automate this process by creating a model builder application.

In order to create a model builder application, first create an empty toolbox by **right-clicking** in the "white" space in ArcToolbox, and selecting Add Toolbox as shown below as shown below:

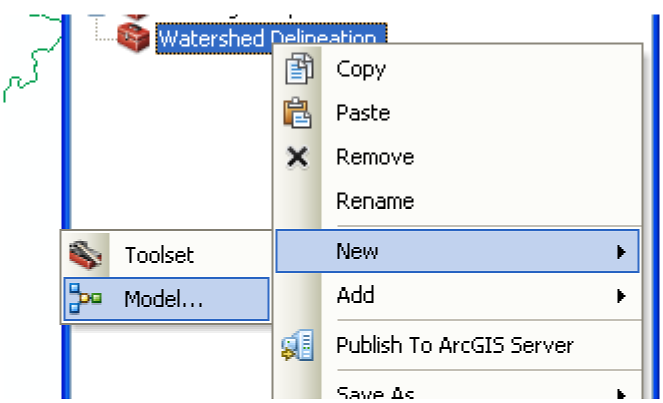


In the Add Toolbox window, press the tool box button on the top-right corner () to create a new toolbox with the name Watershed Delineation as shown below. **Click** *OK*.



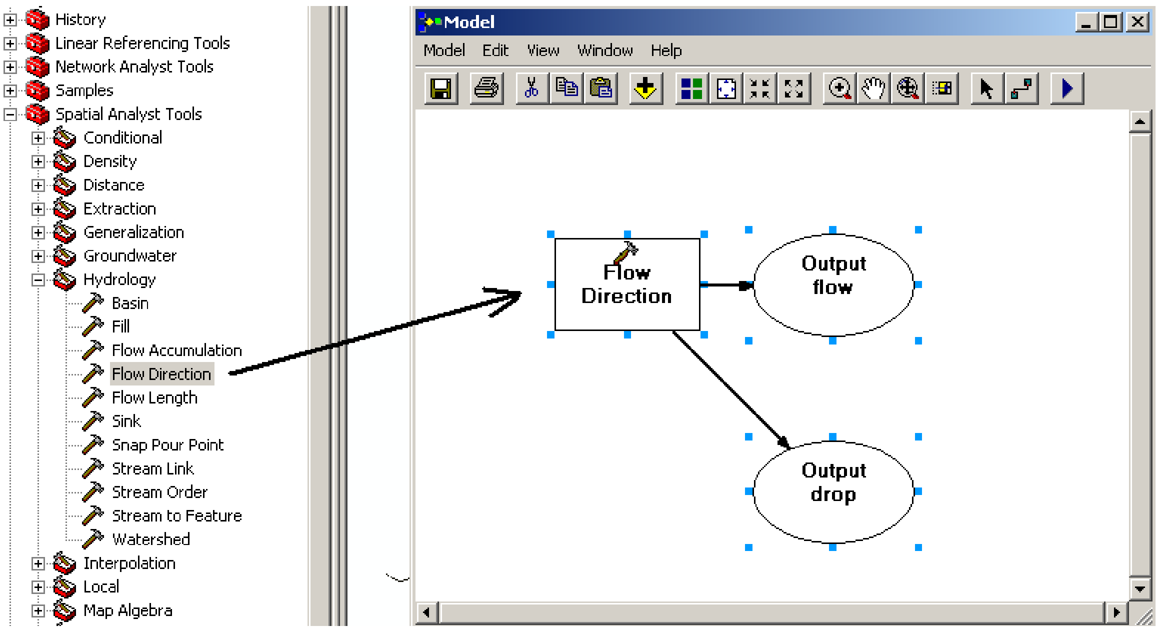
In ArcToolbox, **right-click** again on the white space to add the new *Watershed Delineation* toolbox.

Right-click on Watershed Delineation toolbox, and create a new Model as shown below.

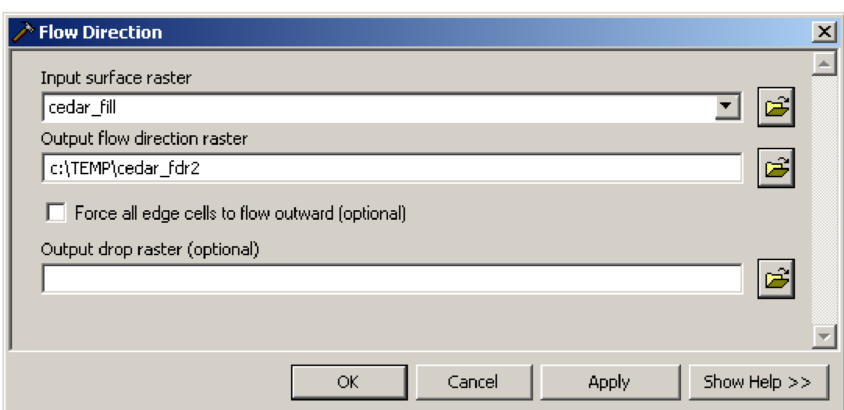


This will open the Model Builder interface in which you can create a workflow model by dragging tools from the *ArcToolbox*. Save the Model. Lets create a model that uses the filled DEM to create a flow direction raster.

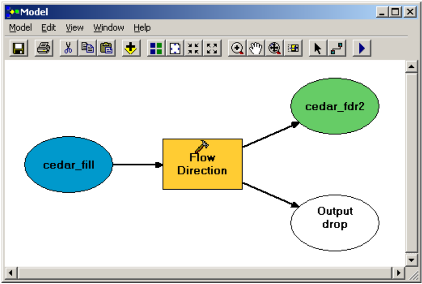
Drag the Flow Direction tool from ArcToobox in the Model interface to see the tool in the Model Builder interface as shown below.



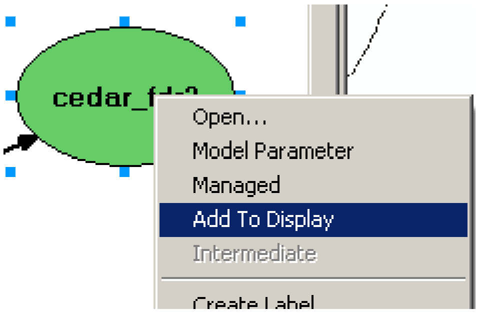
A rectangle (with the hammer) represents a tool, and an oval represents an input/output file. White colored box means that no input is provided to the tool. **Double click** on the *Flow Direction* rectangle to select *cedar_fill* as the input surface raster. Name the output flow direction raster as *cedar_fdr2* (we already have cedar_fdr), and **click** *OK* (no need to specify the optional drop raster).



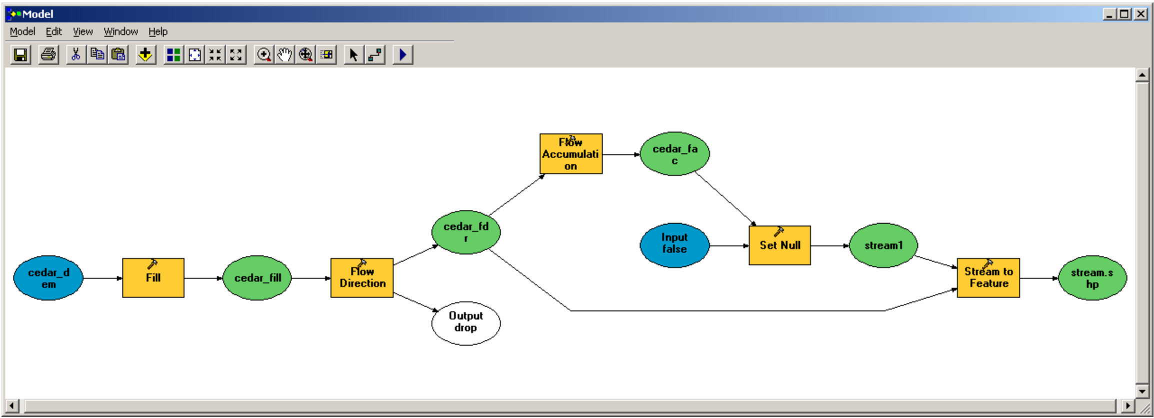
As soon as the input is provided, all the boxes (except the optional output drop) will change their color as shown below.



A toolbox is always yellow, a blue oval represents input to the model, and a green oval represents the output from the tool or the model. If you want, you can change these colors by right-clicking on them and selecting Display Properties. Similarly, you can make the model to add the final output or any intermediate outputs to the map document by right-clicking on the oval, and selecting Add to Display as shown below.



Save the model. You can expand the model to perform flow accumulation, and also the subsequent steps by dragging the tools from the ArcToolbox, and providing appropriate inputs. A workflow to start with DEM and get the stream network is shown below.



You can run the model by either pushing the run button  or going to Model→Run Entire Model. Ok, you are done!!

Homework #3 (Due on 01/29 by 5 pm in HAMP 1101G)

- Answers all the questions (Q1 – 13) included in the handout. For Q13, create a nice presentation quality map for Cedar Creek to show all the points and their boundaries using distinct color/shade.

- Create a model builder application to start from a DEM of Cedar Creek and end with a stream network (as a shapefile not raster). Use this model builder application to create stream network for Cedar creek by using the following threshold areas as a percentage of the total watershed area: 1%, 2%, 3%, 5%, 7.5% and 10%.

- Create a map of each stream network with proper legend and scale. Report the drainage density [in km^{-1}] corresponding to each stream network threshold. The equation for computing drainage density = total length of all the streams in a watershed / total area of the watershed. The unit for drainage density is [L^{-1}]