Watershed and Drainage Delineation by Pour Point in ArcMap 10

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In this tutorial, you will learn how to delineate the boundary of a stream gage's drainage area (watershed polygon) based on a Digital Elevation Model (DEM) and optionally how to delineate the drainage network (lines) within the watershed. You will use the same the stream gage data point and DEM that you used in *Tutorial 1 - ArcGIS Basics for Water Resources Mapping*. (S:\Tutorials\Tufts\Tutorial Data\Watershed Delineation by Pour Point)

Note: if your area is fairly flat, the watershed area delineation will not be accurate.

Section 1 - Preparing your base map for watershed delineation

1. Before you begin, create a new folder called *ProcessedData* in your *HydroGIS* project folder.
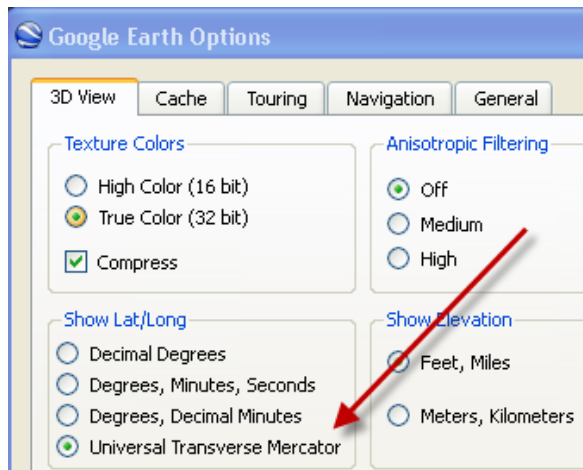
2. Start ArcMap with a new map.

3. Start a new ArcMap session with the following layers:

    a. The flowlines upstream from your gaging station (HCDN_tributaries.shp from *Tutorial 1*)

    b. Your stream gage point (Station_xxxx.shp *from Tutorial 1*) – this will be your reference for your pour point

    c. NED_xxxx (your DEM) for your subbasin (from *Tutorial 1*)

4. It is also useful for context to add the *Shaded Relief* from ArcGIS Online (to do this, click on **File – Add Data – Add Basemap – Terrain** and then display the Shaded Relief layer).

5. Save your map file (**File-Save**) to your project folder – call it *Watershed Delineation Base Map.mxd*

Section 2 - Projecting your GIS data into the UTM Coordinate System

Before proceeding with watershed delineation or any other kind of hydrological analysis, your data sets need to be in a projected coordinate system in which the horizontal units of the xy coordinates are the same as the vertical elevation units of your DEM. Your DEM elevation values are in meters. But the horizontal units of your DEM are in spherical degrees, and the DEM data set is NOT projected – it is still in spherical coordinates. So we need to *project* our DEM into a coordinate system in which the horizontal units of the xy coordinates are in meters, not degrees. One coordinate system that fits our needs is called UTM NAD 83 (for Universal Transverse Mercator, based on the North American Datum of 1983). The UTM system divides the world up into 60 zones, and you need to know which **zone** your stream gage is in. There are several ways to find this out – use *ONE* of the following:

- Look at the **map** of *UTM Zones for the United States* at the end of this tutorial.

- Use **Google Earth**

a. In Google Earth, Under *Tools-Options* go to the *3D View tab* and set *Show Lat/Long* to *Universal Transverse Mercator*:
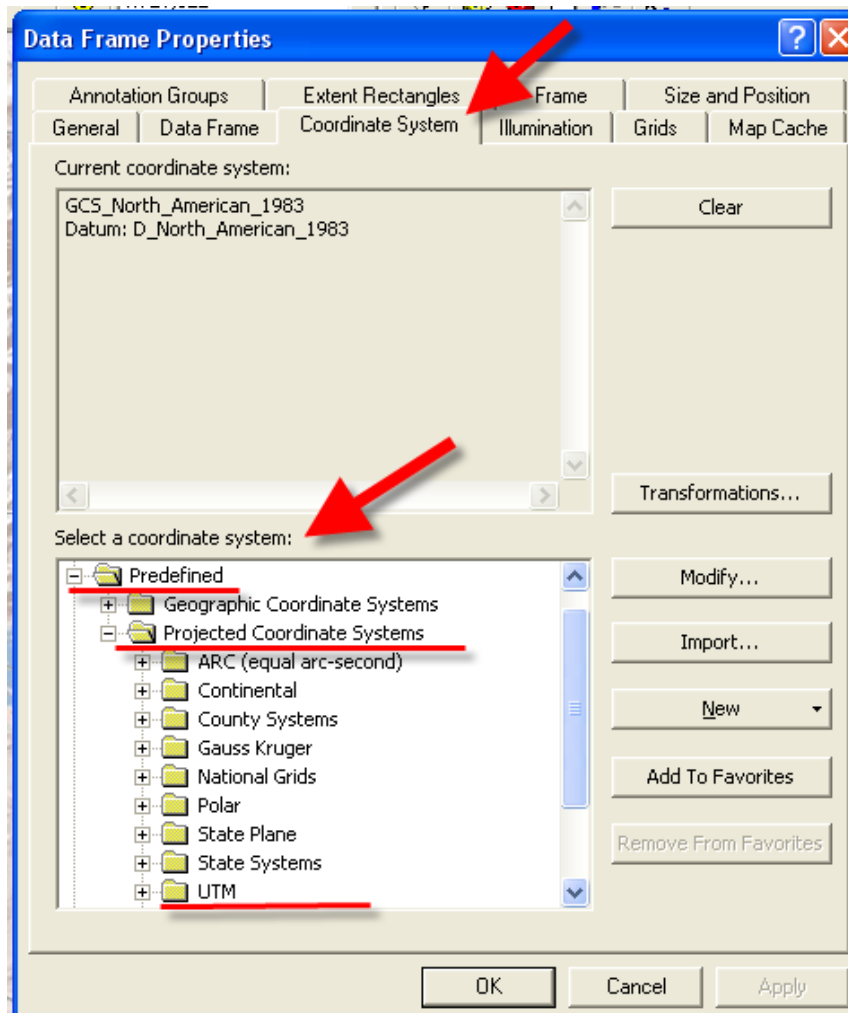

b. In the Google Earth "Fly To" search box, enter the lat/long coordinates of your stream gage (or just zoom into the area if you know where it is). At the bottom of the view you will see coordinate information – the first number (**19** below) is the *UTM Zone number*:

- If you are in the Tufts GIS Lab, you can add the **UTM Grid.lyr** from the *M:\World\ESRIDataMaps93*\Vector\ folder. When the UTM Grid appears, you should see the *Zone Number* labeled somewhere in the center of your map

- If you are working at a different Tufts computer lab, click on the *Connect to Folder* icon, and enter \\rstore2\gis$\datasets. This will connect you with the M drive in the GIS lab. Add the **UTM Grid.lyr** as described above.
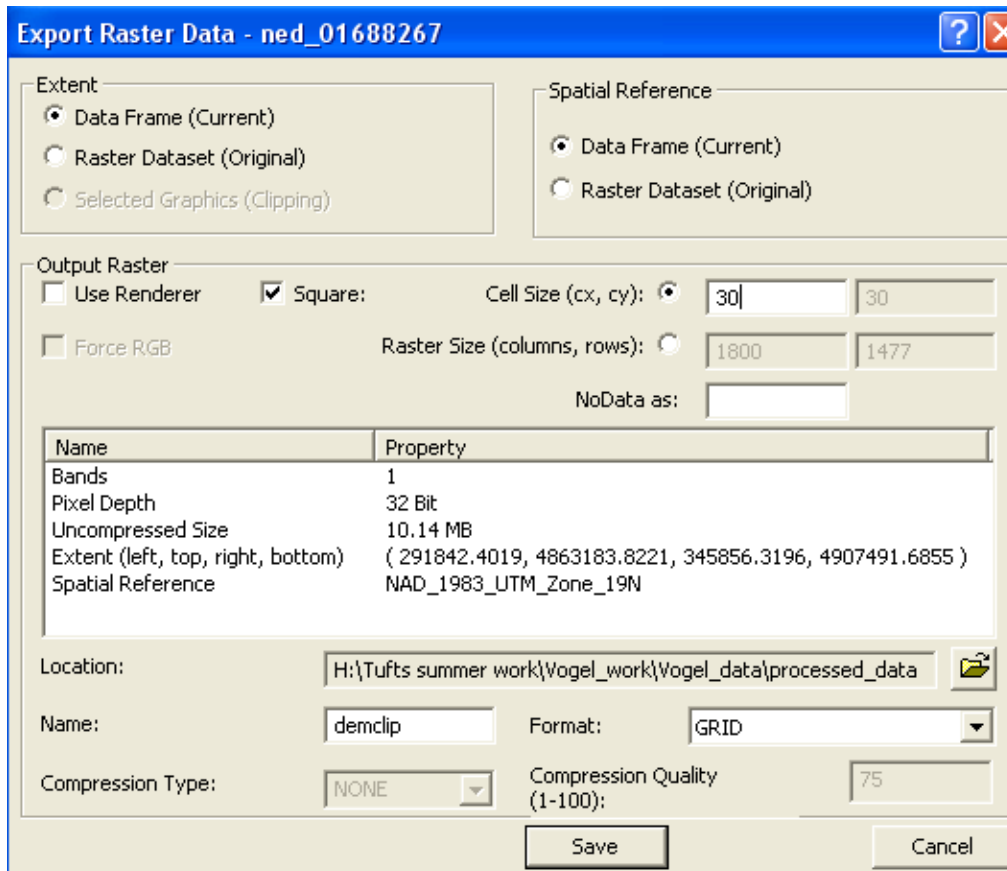
6. Now that you know the **UTM Zone** number for your stream gage area, you are going to change the coordinate system of your current map (called your *Data Frame*) to this UTM zone number – this DOES NOT change the coordinate systems of the individual data sets – just the DATA FRAME containing those data sets:

   a. Click on **View – Data Frame Properties**

   b. Go to the *Coordinate System Tab* and under *Select a Coordinate System*, choose *Predefined- Projected Coordinate Systems – UTM – NAD 1983* and from there click on your stream gage's UTM zone (e.g., 19N) and click OK (*note that all UTM Zones NORTH of the equator are labeled N!*):

   c. Click **YES** to proceed when warned about the coordinate system being different from some of your data layers – we're going to fix that now!

   d. If you previously added UTM Grid layer, remove it now.

   e. Save your map file (**File-Save**)

7. In order to reduce computing times and file sizes we are only going to project the portion of the DEM that we will be performing the watershed delineation on. Zoom to your HCDN_tributaries layer and then zoom out slightly so that you know you will be displaying the entire tributary watershed in your view window.

8. Right-click on the DEM data layer and choose **Data – Export Data**. Carefully follow the screen shot below for guidance. You want to export just the extent of the DEM that fills your Data Frame, and you want the spatial reference (coordinate system) to be the same as the Data Frame (UTM NAD83). The 1-arc second DEM you are using has square cells equal to 30 meters to a side. Use the *folder icon* (📂) to set the save *location* to your project folder (*ProcessedData*), but don't try to name the file through the *Select Workspace* dialog. Instead, use the *Name* field and name exported file **DemClip**. Finally, change the raster format to GRID – again, see the example below:

9. Click **Save**

10. Add the exported data file to the map when prompted

11. Save your mapfile (**File-Save**)

Section 3 - Delineating a Watershed – Overview of Steps

ArcGIS can delineate the total area flowing into a given outlet, also called a pour point, based on a *digital elevation model*. In this analysis, the pour point will be your stream gage, and you will delineate the watershed upstream of your stream gage. Recall that a digital elevation model is an array of evenly spaced grid cells, and that the value of each cell is the estimated elevation of that cell. ArcGIS can compute from the DEM the direction of flow down a slope and how many cells "flow into" each cell (called flow accumulation). Here is a quick overview of the steps for delineating a watershed in ArcGIS – we have detailed directions later. Note that you should carefully review the ArcGIS Help for this topic – you can find it in the software under *Help – ArcGIS Desktop Help – Extensions – Spatial Analyst – Analysis Concepts – Hydrologic Analysis*, or online starting here (in both cases, each step has its own detailed section): http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#//009z0000005m000000.htm

The *USGS Hydrosheds Project* (http://hydrosheds.cr.usgs.gov/) is another good source for understanding this process, and discusses more complex technical issues than we cover here.

Conceptual overview of watershed delineation:

1. **Flow Direction:** Based on your clipped DEM (*DemClip*) – this will compute for every cell the direction that water would flow through it. The value of the cell is a number representing a cardinal direction as shown here:

Direction coding

The output data set is *FlowDirxx*

2. **Sink**: This step uses your *Flow Direction* grid to identify sinks in your DEM. These are areas surrounded by higher areas, so that there is no external drainage. Sometimes sinks are real, but often DEMs have erroneous sinks. Regardless of whether they are real or not, for the watershed
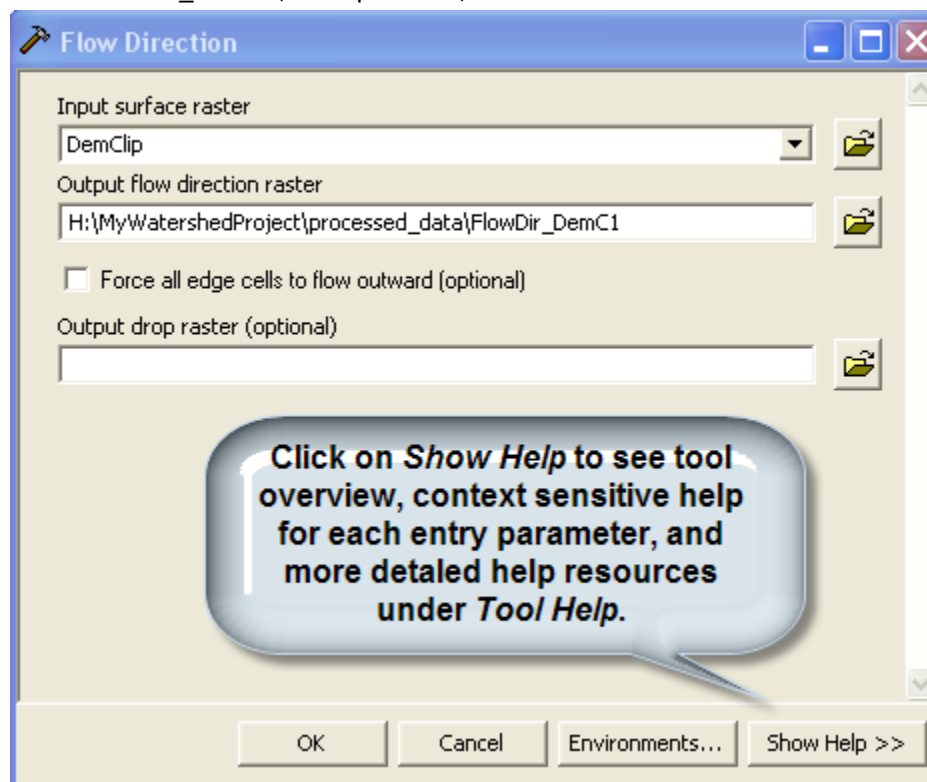
delineation process to work, we need a "depressionless DEM," i.e., a DEM with no sinks. The Output data set is *Sink_FlowDirxx*.

3. **Fill**: This step will fill the sinks of your DEM (*DemClip*). Note that doing this correctly requires care and an iterative process which we don't detail in this tutorial. Instead, we will do a basic *Fill* command. The result of this step will be a depressionless DEM (*Fill_Demxx*) which will in turn be the basis of the rest of the process

4. **A new Flow Direction** based on the Filled (depressionless) DEM. The result will be *FlowDir_Fillxx*

5. **Flow Accumulation** based on your new corrected (filled) *Flow Direction* grid: This step calculates for each cell in your filled DEM array, the number of cells flowing into it). Areas of higher values are where water collects and drains. Areas of very high values are likely perennial streams or rivers, areas with lower values may be intermittent streams. The Flow Accumulation grid will allow the software to determine the area draining to any specified point on the DEM (i.e., your stream gage). The output grid is *FlowAccxx*

6. **Snap Pour Point:** Your stream gage point may not fall directly over the correct raster cell (all GIS data have inherent positional error). Since a stream gage is by definition next to a stream, we know that the Pour Point representing the gage should be coincident with the stream. The Snap Pour Point command snaps your stream gage point to the nearest area of high flow accumulation within a distance you specify. Your output grid will be *SnapPour*

7. **Watershed**: This command performs the watershed delineation based on your snapped stream gage pour point (*SnapPour*).

Section 4 - Delineating the Watershed of your Stream Gage – Detailed Instructions
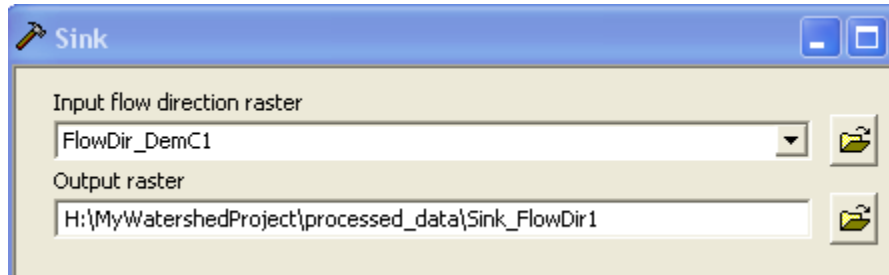
Follow the process steps using tools in *ArcToolbox – Spatial Analyst Tools – Hydrology* DEMCLIP is your initial base:

1. Initialize the *Spatial Analyst Extension* (*Tools – Extensions –* checkmark *Spatial Analyst*)

2. Open **ArcToolbox** ( ) to the *Spatial Analyst Tools – Hydrology* section

3. You will go through the tools in turn

   a. **Flow Direction** – for this initial process, set the *Input Surface Raster* to *DemClip*. For Output flow direction raster, navigate to your *ProcessedData* folder, and call the new raster FlowDir_DemC1, then press OK, as show below:
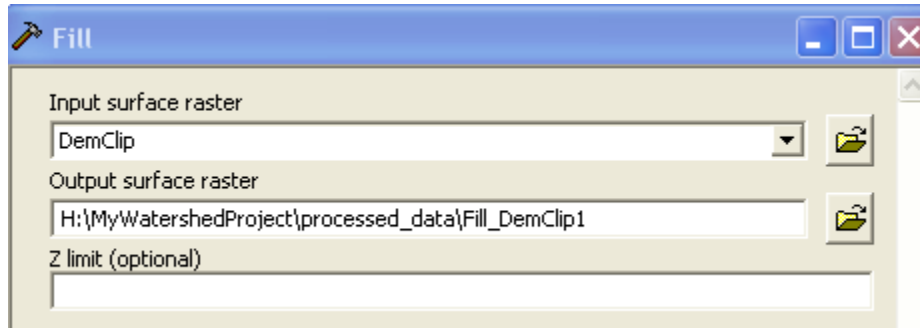
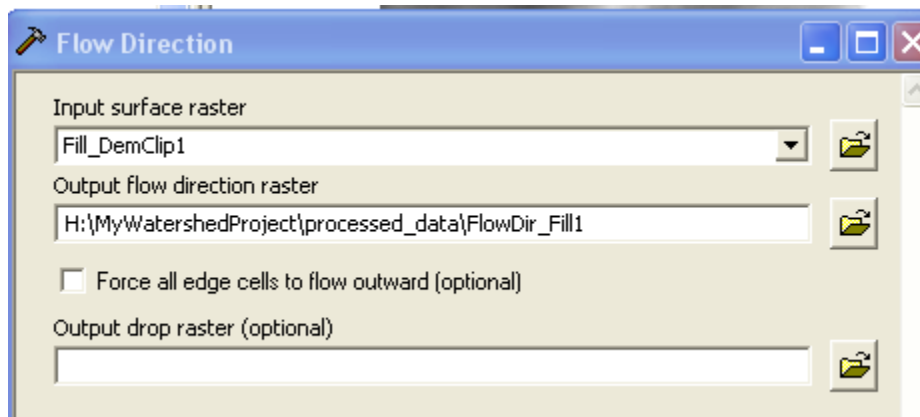b. **Sink** – The flow direction grid is the input:

Examine the Sinks raster you have created. In a more detailed analysis, you would constrain the depth to which sinks are filled to eliminate small sinks due to errors in the DEM, but not actual basins. This process is iterative and very time consuming, and so will not be covered in this tutorial, but you can read about it on the ESRI online help or the *USGS Hydrosheds Project* (http://hydrosheds.cr.usgs.gov/).
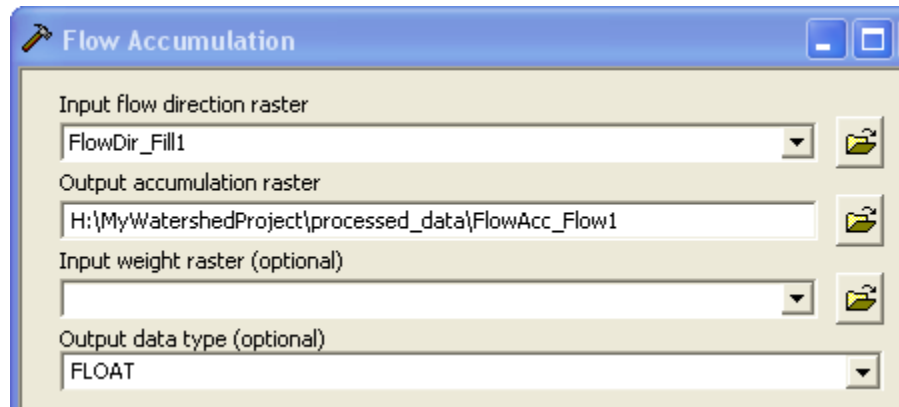
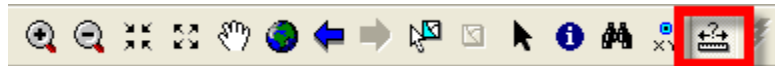c. **Fill**

d. **Flow Direction based on the filled DEM** -
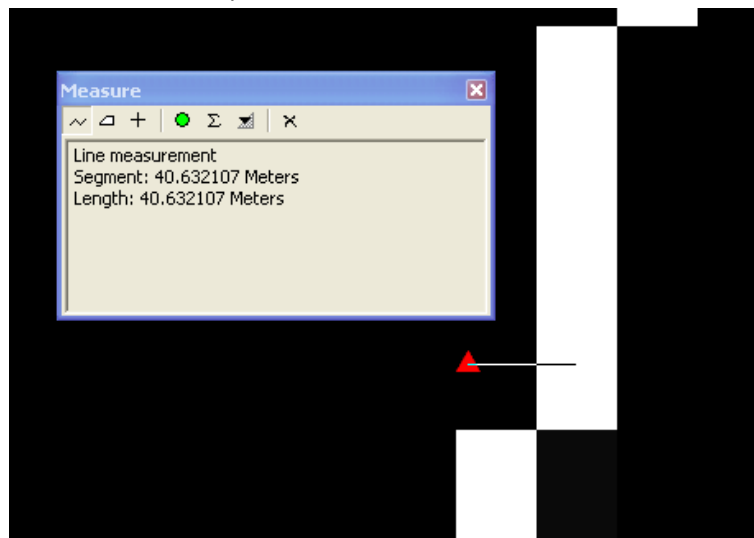
e. **Flow Accumulation** (may take a long time) -

f. **Snap Pour Point**

Before proceeding, you need to measure how far your stream gage is from an area of high accumulation on your Flow Accumulation grid. It is likely that your stream gage is on top of or near an area shaded white, indicating high flow accumulation.
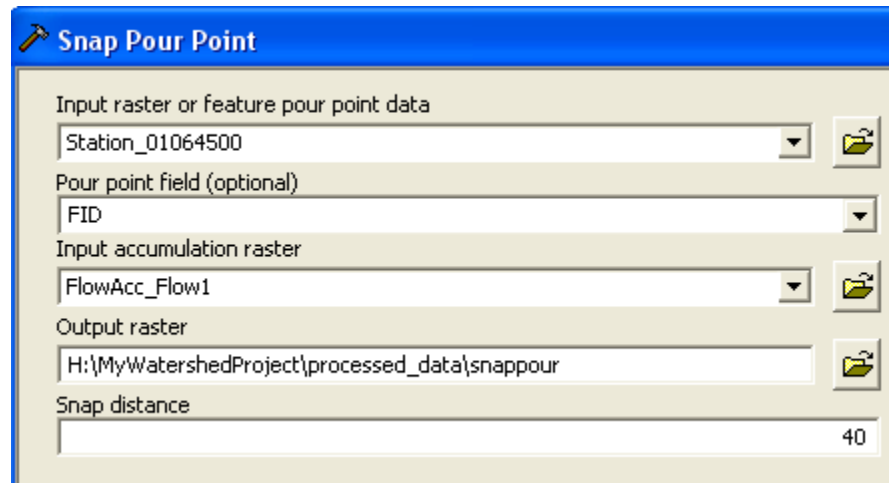
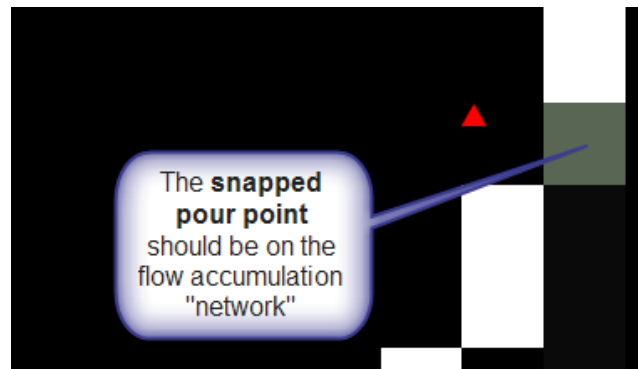 i. Zoom into your stream gage on ArcMap and click on the Measure Tool:

  ii. Measure the distance between your stream gage point and the center point of the nearest high value flow accumulation cell. In the example below, the distance is about 40 meters to each of the nearest cells – round this up a bit to make sure the Snap will work:
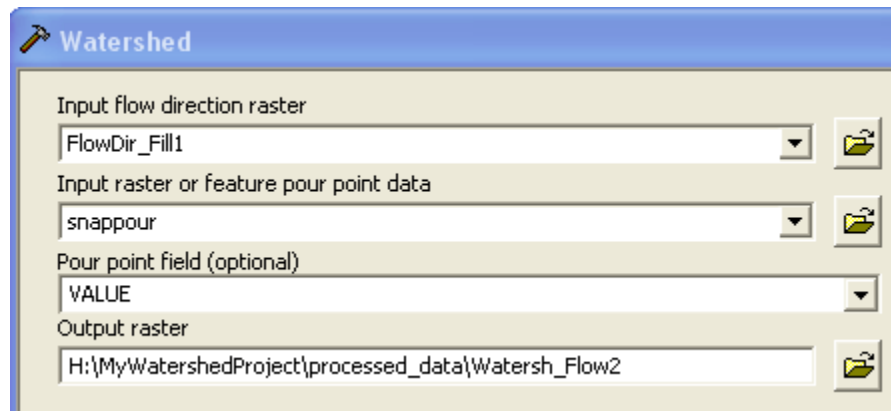

  iii. Activate the **Snap Pour Point** tool in ArcToolbox with specifications similar to what you see below, using the distance you measured plus a little extra as your *Snap Distance*. Make sure to call the output raster, *SnapPour*:
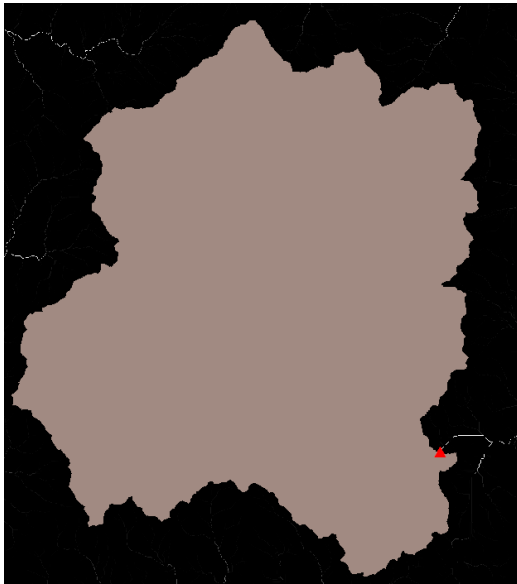
iv. Make sure the result is a single cell directly on top of a high accumulation area (colored white) and near your stream gage, as you see here:

The **snapped pour point** should be on the flow accumulation "network"
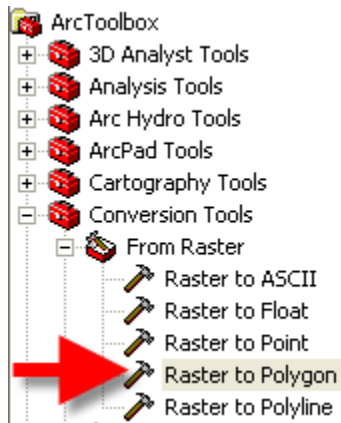
g. **Watershed**:
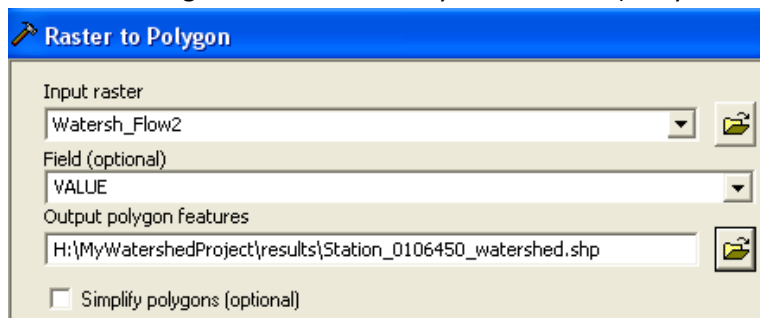
Your results should look something like this:

If you think your result is correct, you can convert this raster data set to a GIS vector polygon (shapefile) so that you can have it permanently for mapping. To do this:

1. in ArcToolbox choose **Conversion Tools – From Raster – Raster to Polygon**

2. Fill in the dialog box similar to what you see below (use your Watersh_Flow data set):
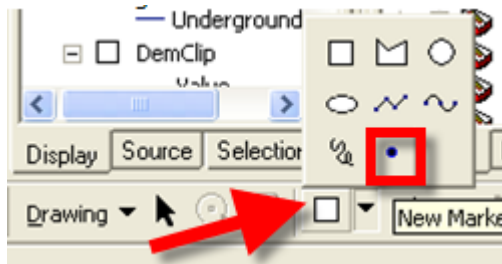
3. For mapping purposes, you may make the new polygon hollow (no fill) with a thicker outline using the Symbology properties

Didn't work properly?

If your watershed delineation did not work properly (e.g., it did not cover the entire area of your tributary streams), you may have re-do the *Snap Pour Point* command. If it still doesn't work, examine your flow accumulation network to see where you think the most logical place is for snapping your stream gage is, then place a graphic point at that location using the **Draw Toolbar**:

Then still with the Draw Toolbar, choose *Drawing – Convert Graphics to Feature*. This will create a new GIS data set (shape file) of this point. Use the *Data Frame's coordinate system* and call the output shape file *Adjusted Stream Gage*. Then start at step F above, using this adjusted gage point as the input data set.

How does the boundary of your delineated boundary compare with the upstream NHD flow network?

This delineation process is not foolproof! Some watersheds have flat areas that are ambiguous to the flow direction calculator. In most cases you can assume that the NHD flow network has been checked and is correct. Be sure to note on your submittal if this has occurred.

Section 5 - What to turn in

Create a well-designed map in ArcMap showing the watershed area of your stream gage point with appropriate context information (towns, roads, water bodies).

Section 6 – Optional: Delineating the drainage network for your area

The following section is optional. You have been using the NHD flow lines for your stream network. The NHD flow lines are based on 1:24,000 USGS maps. But sometimes it is useful to generate a more detailed drainage network or you may be working in an area of the world for which there are not digital stream GIS data files. In this section of the tutorial you will learn how to delineate a drainage network from a DEM. Note that if your area is fairly flat, the drainage network delineation will not be accurate.

*Look at ArcGIS 10 Help - Spatial Analyst – Analysis Concepts – Hydrologic Analysis Identifying Stream Networks - *http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#//009z0000005v000000.htm

This process requires your Flow Accumulation raster from Section 4. The basic conceptual process is to reclassify all cells that meet a certain accumulated flow threshhold to be 1, and all other cells to be no data. To do this you can apply a conditional statement to your Flow Accumulation raster in which all cells with a value greater than a threshold number (e.g., 100) are reclassified to be 1, and all other cells receive a "no data" value.
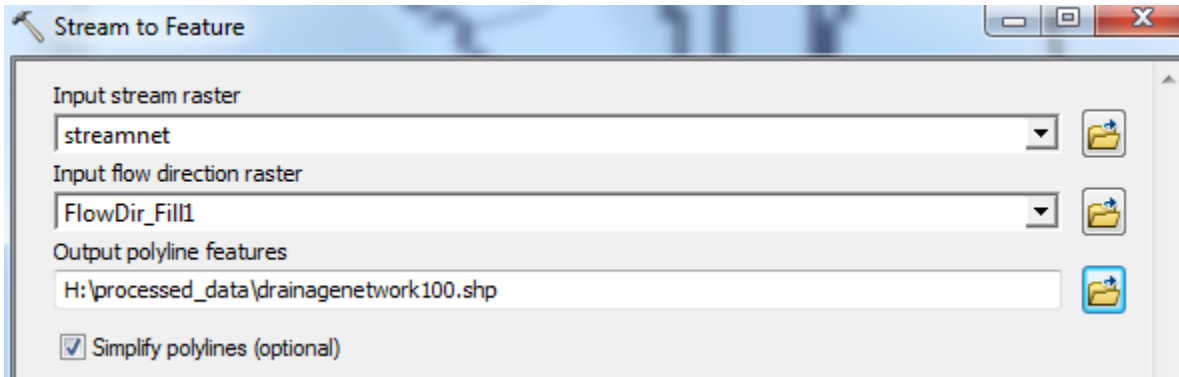
1. Go to **Spatial Analyst Tools – Map Algebra – Raster Calculator**.

2. Use the **Raster Calculator** to create a conditional statement
   Con("FlowAcc_Flow1" > 100, 1)
   - Name the new data set that will be produced streamnet. Note: Pay attention to spaces when writing your expression.

3. Zoom into it to see what it looks like – it is a detailed drainage network for the area covered by your Flow Accumulation grid.

Note that you can use a different threshold value. The value we used, 100, is arbitrary. Michael Wieczorek's *Flow-Based Method for Stream Generation in a GIS* (http://md.water.usgs.gov/posters/flowGIS/index.html) offers a more sound approach for specifying a threshold value using historical runoff data.

If you re-do this step with a different threshold value, you must change the output raster name – e.g., streamnet2, streamnet3, etc.

To create a vector drainage line data set from this raster file, you can use the **Stream to Feature** tool under *ArcToolbox – Spatial Analyst – Hydrology Tools*. Fill in the dialog box similar to what you see
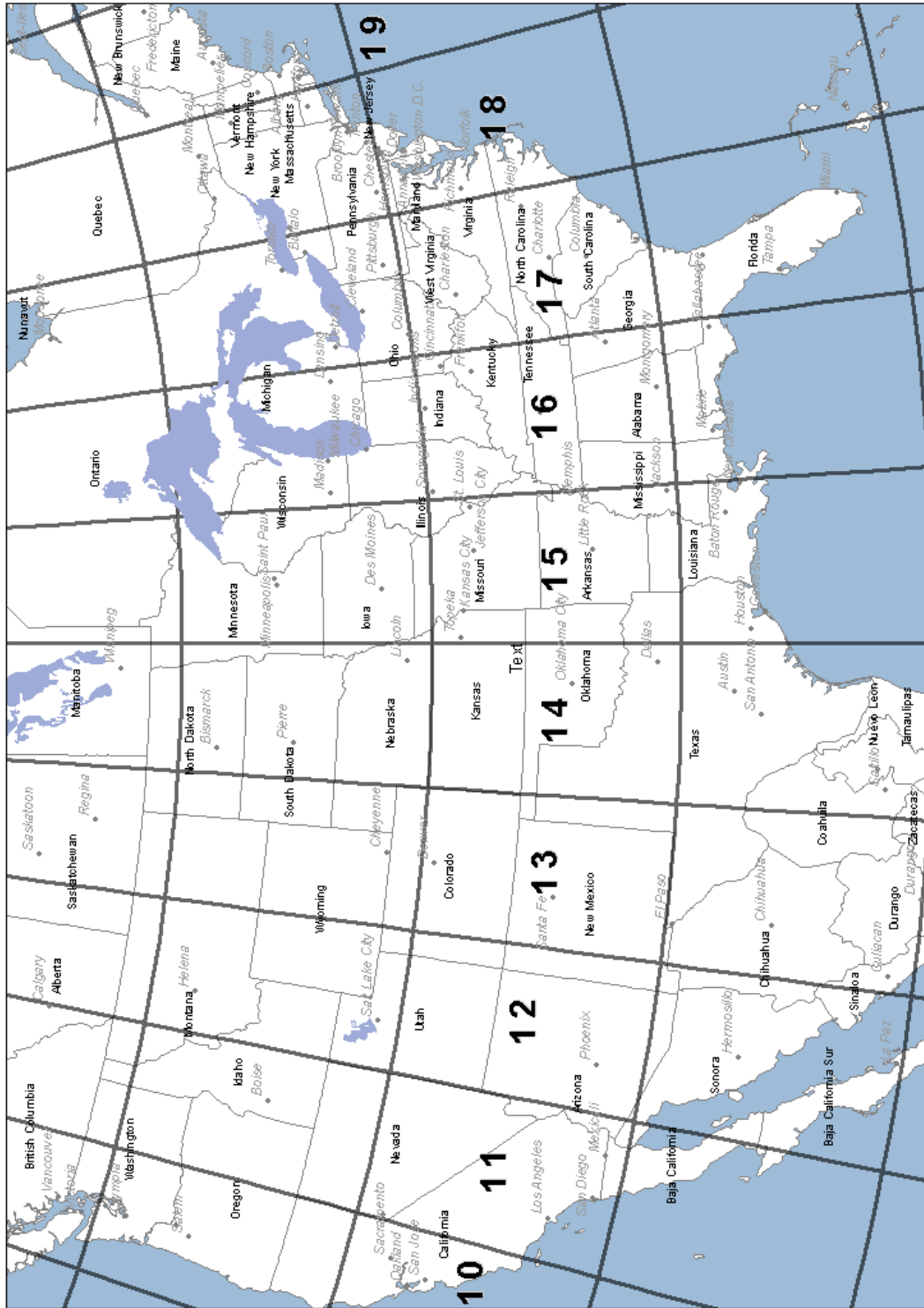
below (note we specified 100 in our data name to remind ourselves we used 100 as the accumulation threshold):

Online Resources:

For an online USGS application to create watersheds for selected states and download them as shapefiles, try **StreamStats** http://streamstats.usgs.gov/ssonline.html

UTM Zones for the United States

Note: All zones should be specified as North (e.g., Zone 14N)