LiDAR Workshop

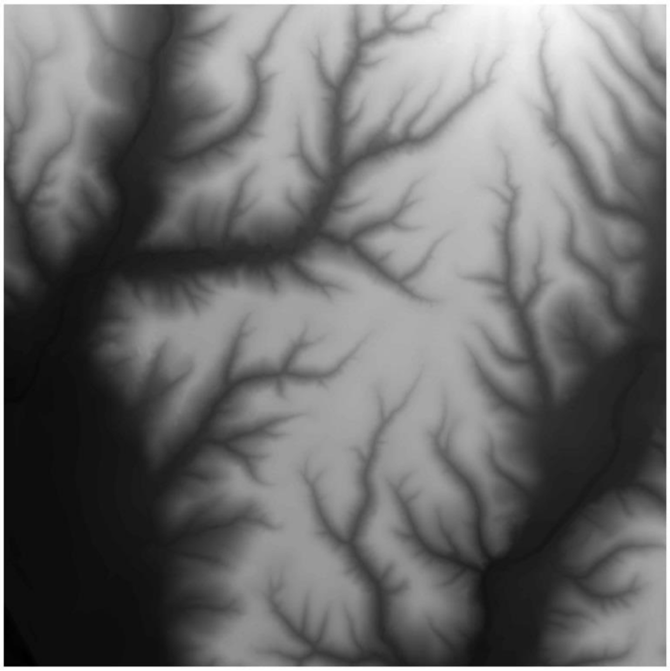
Ex #3: Watershed Analysis

1. Introduction

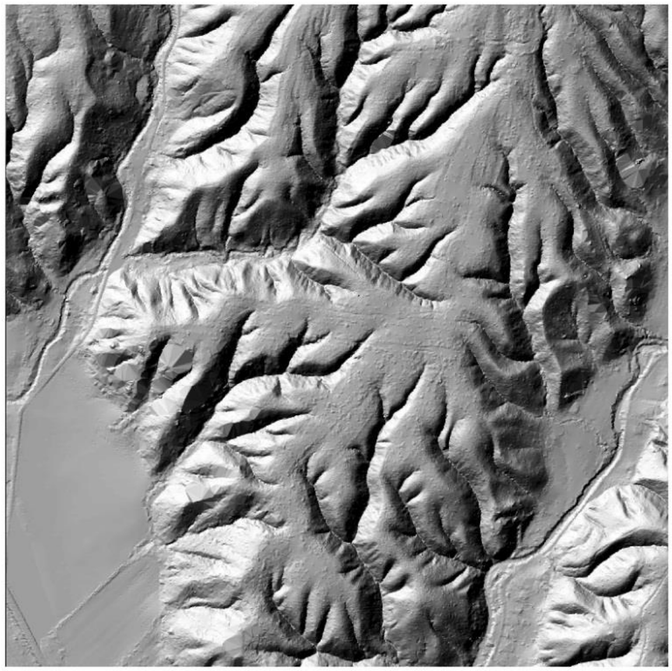
The shape of a terrain determines the movement of water across the terrain surface. A raster Digital Elevation Model contains sufficient information for delineating drainage basins, extracting stream network, and deriving other hydrologic properties within a watershed. Watersheds tend to function ecologically as single, uniform regions. Ecologists, hydrologists, engineers, pollution and flood control experts often need to perform watershed analysis for their own applications. This lab aims to introduce the GIS-based watershed analysis techniques with ArcGIS.

2. Data Sets

A digital elevation model "**s1475420**" created from LiDAR is provided for Cincinnati, Ohio in ArcInfo grid format under the directory **\Ex3\.** Its coordinate system is NAD_1983_HARN_StatePlane_Ohio_South_FIPS_3402_Feet with 2.5 m resolution.



Digital elevation model **s1475420**



Hill shading image of DEM **s1475420**

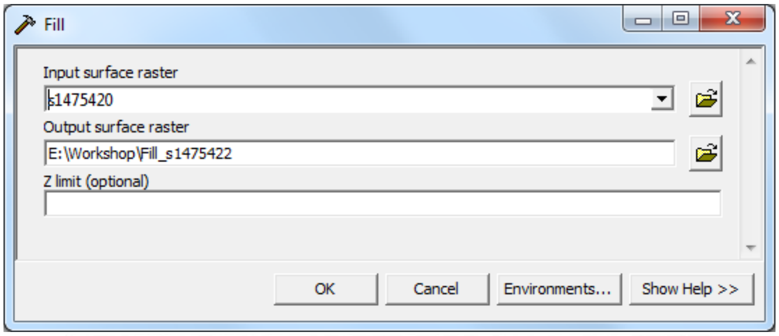
3. Requirements and Instructions

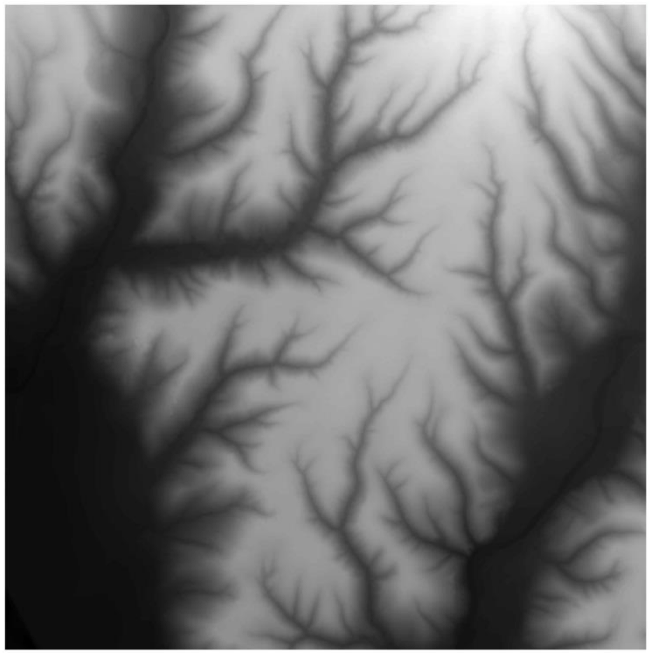
1) Create a Depressionless DEM by Filling Sinks

A sink (also known as a depression or a pit) is a cell or set of spatially connected cells whose flow direction cannot be assigned to one of the eight valid values in a flow direction grid. This can occur when all neighboring cells are higher than the processing cell, or when two cells flow into each other creating a two-cell loop. Although some of these may be natural, particularly in glacial or Karst areas, many sinks are imperfections in the DEM. As water cannot "flow" from a pit cell to its adjacent cells, a pit cell has an undefined flow direction. Sinks should be filled to ensure proper delineation of basins and streams. If the sinks are not filled, a derived drainage network may be discontinuous. To avoid the problem caused by unwanted pits, DEMs need to be pre-processed to identify and remove the spurious sinks (pits) for developing a DEM free of sinks for the calculation of flow direction.

Following are the steps used to create a depressionless DEM with ArcGIS:

- Open ArcMap and add digital elevation model "**s1475420**" to the default workspace.
- In "**Windows**" Menu, Click "**ArcToolbox"**
- Go to "**Spatial Analyst Tools->Hydrology->Fill**" to start "**Fill"** function.
- Specify the input and ouput rasters for the program. Click Ok and the output raster will be loaded automatically.

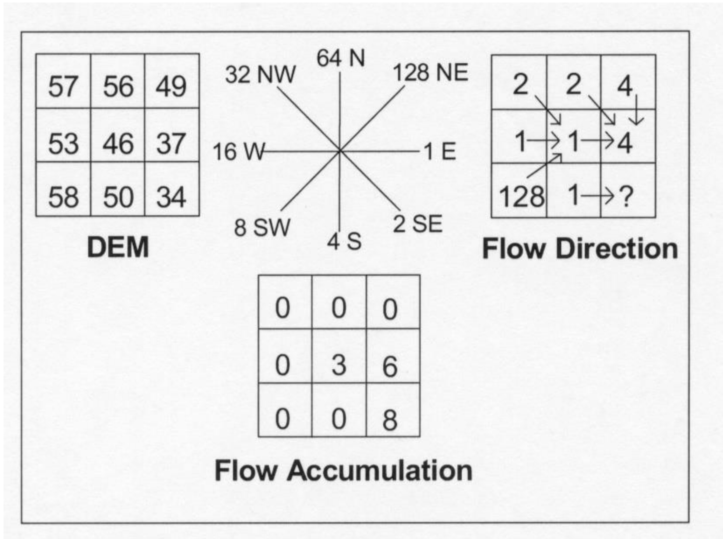




Depressionless DEM

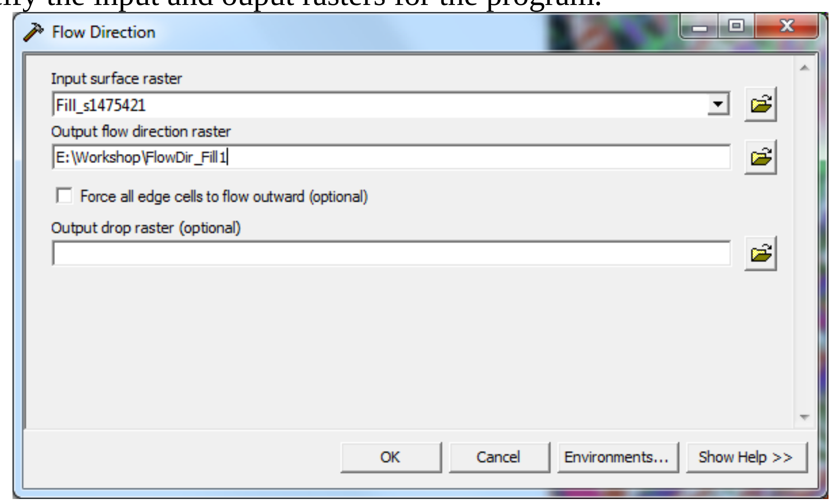
2) Create a Flow Direction Grid based on the Depressionless DEM

Water is assumed to flow across a surface in the steepest descent. Namely, the aspect at each cell determines the direction of water flow. Determining the direction of the steepest descent for each terrain cell is the key to the DEM-based watershed analysis. In the ArcGIS implementation, the direction of water flow at each cell is simply determined by comparing the elevation value of the central processing cell with the elevations of 8 immediate neighbor cells. Eight possible flow directions (the Queen's move directions) are assumed for the central cell as shown in the following diagram. The coding scheme is: East = 1, Southeast=2, South=4, Southwest=8, West=16, Northwest=32, North=64, and Northeast=128. If a cell has the same change in z value in multiple directions and that cell is part of a sink, the flow direction is referred to as undefined. Since the spurious sinks of the raw DEM have been filled, each cell in the depressionless DEM **"Fill_s1475420"** should assume an integer direction value in the set {1, 2, 4, 8, 16, 32, 64, 128}.

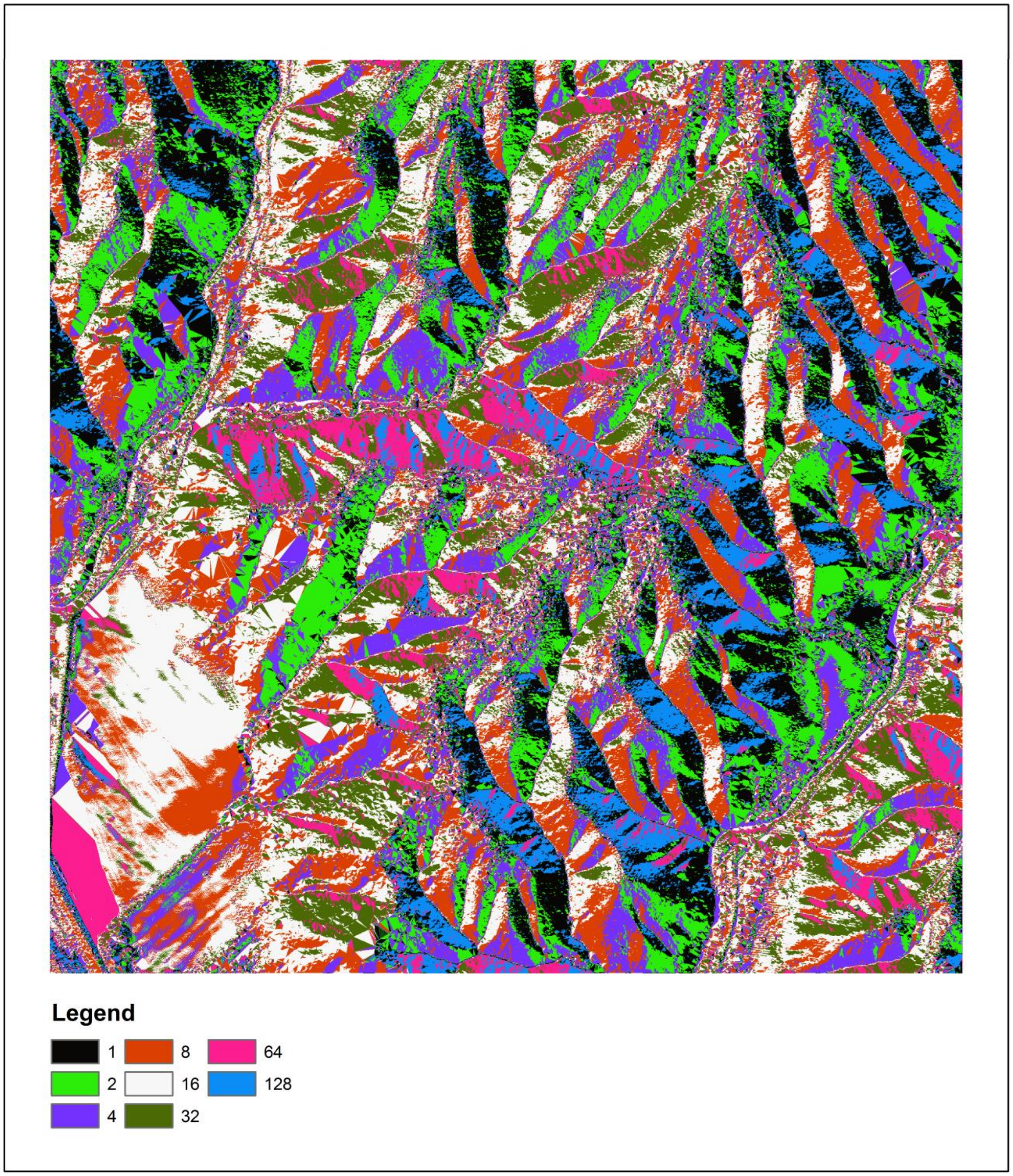


Following are the steps used to calculate flow directions with ArcGIS:

- Go to "**Spatial Analyst Tools->Hydrology->Flow Direction**" to start "**Flow Direction"** function.
- Specify the input and ouput rasters for the program.



- The output raster will be loaded automatically.

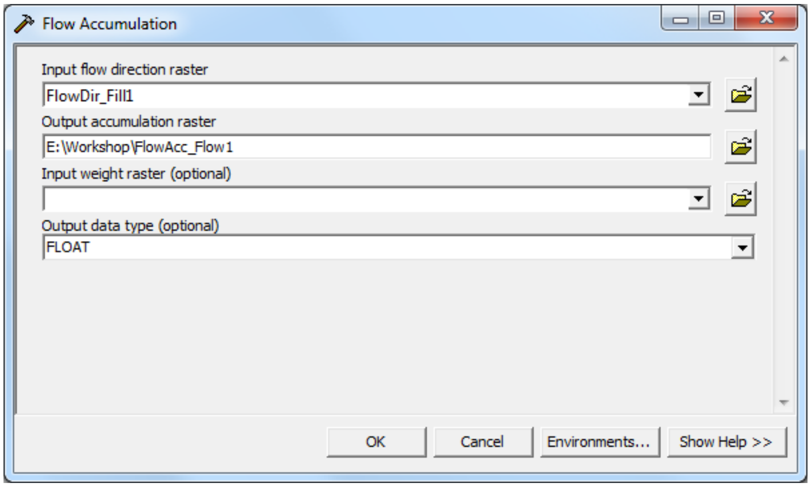


For a specified cell, you may use "**Create Steepest Path**" tool in 3D Analyst Extension to see how would the water flow from this cell.

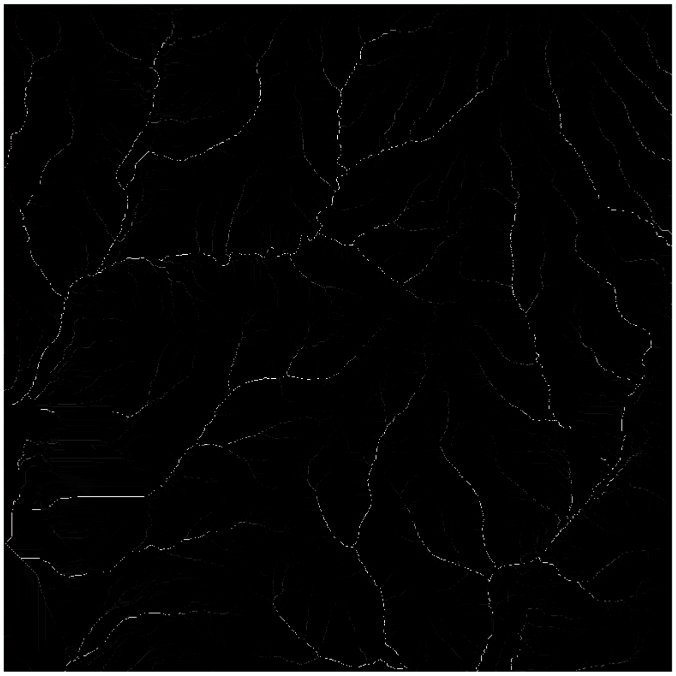
3) Create a Flow Accumulation Grid
Based on the flow direction grid, the number of upstream cells flowing into any given cell can be determined and accumulated. Start by setting all cells to zero. Then, process each

cell one by one. For each processing cell, add 1 to it, and also add 1 to all cells downstream of the processing cell by following the directions indicated in the direction grid. Sequential processing of all cells in the direction grid results in a flow accumulation grid. The value of a cell in the flow accumulation grid will be the number of cells that flow into that cell, which determine how much rain would flow into that cell. Cells with a flow accumulation of 0 are local topographic highs and can be used to identify ridges. Cells with high flow accumulation values are often located on the stream channels.
Following are the steps used to calculate flow directions with ArcGIS:

- Go to "**Spatial Analyst Tools->Hydrology->Flow Accumulation**" to start "**Flow Accumulation"** function.
- Specify the input flow directon raster and ouput accumulation raster for the program.



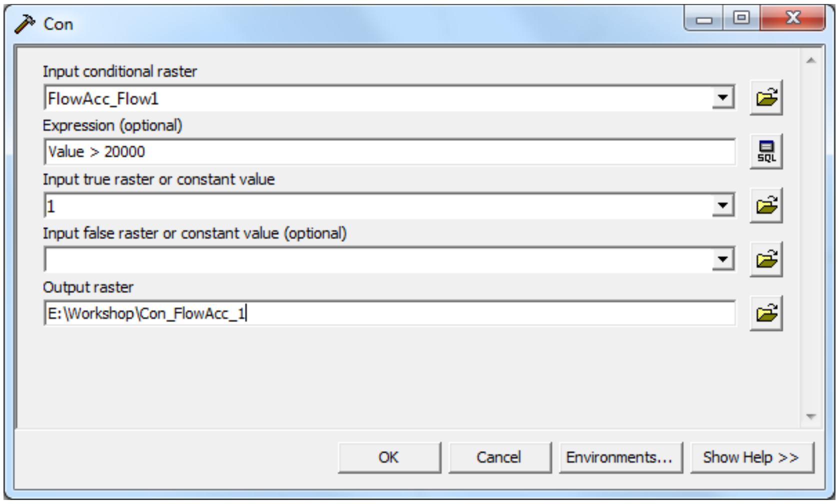
- The output raster will be loaded automatically.

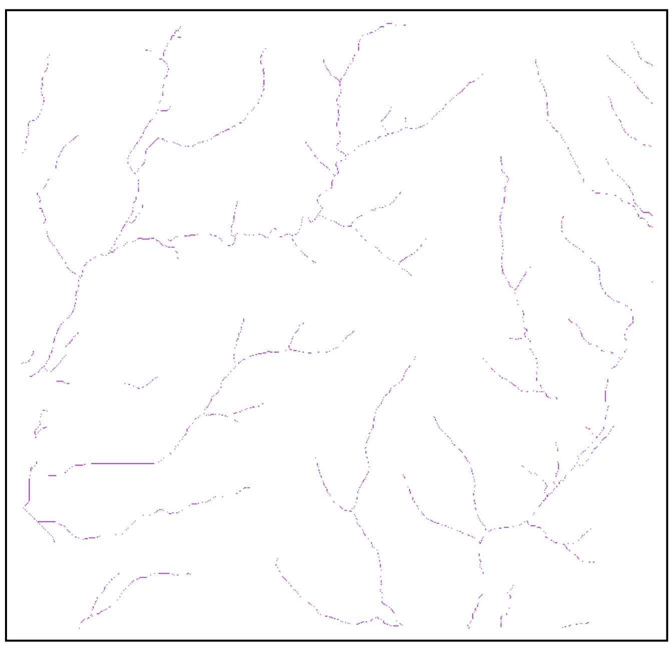


4) Extracting Stream Network

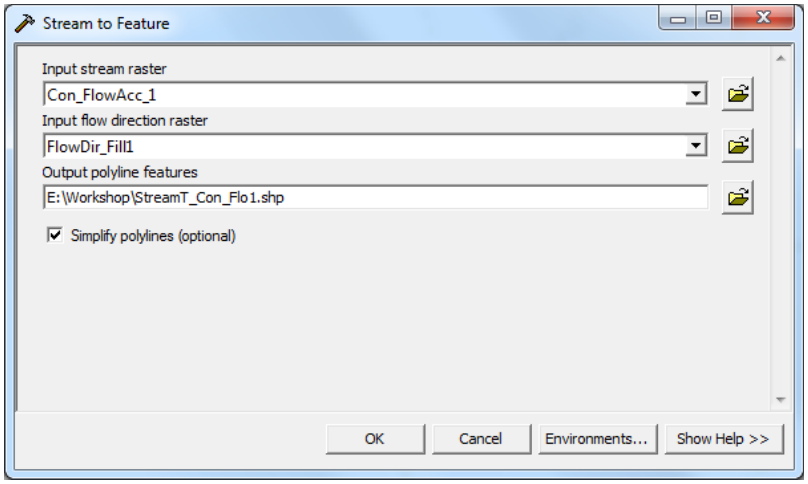
Since in natural drainage systems small quantities of water generally flow overland, not in channels, we only identify cells as stream channels when the volume of accumulated upstream water passing through a cell reaches some critical value. Classify all cells with flow accumulation greater than a user-specified threshold as cells belonging to a stream network. Some small tributaries may be deleted when the threshold is high. You can use trial and error method to identify an appropriate threshold for classifying river channels, with reference to some ancillary data such as aerial photographs.

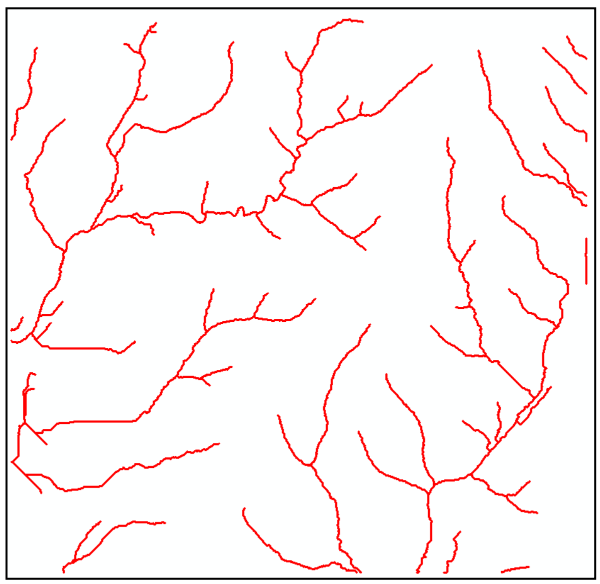
The **Conditional** function in the ArcToolbox can be used to extract stream network based on the flow accumulation grid. For example, you can start with a threshold of 20000 cells:

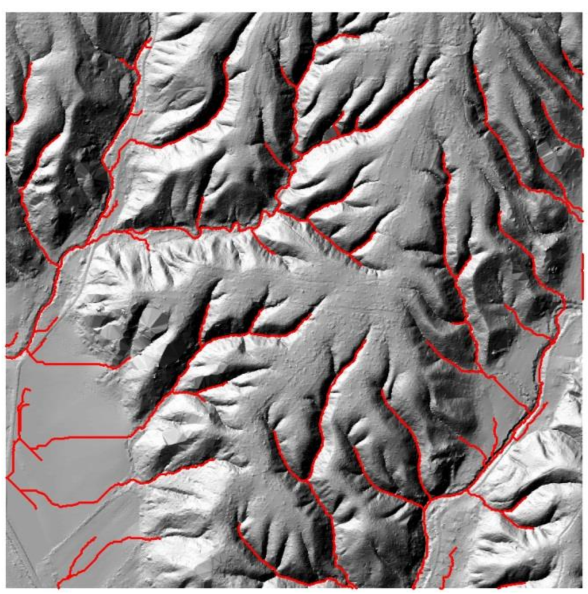




If a cell receives surface water run-off from more than 20000 upstream cells (20000x2.5x2.5=125000 m^2 area), it will be identified as a part of stream channel and assigned a value of 1. All other cells with a flow accumulation value less than 20000 will be classified as overland background cells and assigned NODATA (-9999). You may convert the raster representation of stream to shapefile using **StreamToFeature** tool.


Stream to Feature
Input stream raster
Con_FlowAcc_1
Input flow direction raster
FlowDir_Fill1
Output polyline features
E:\Workshop\StreamT_Con_Flo1.shp
Simplify polylines (optional)
OK
Cancel
Environments...
Show Help >>

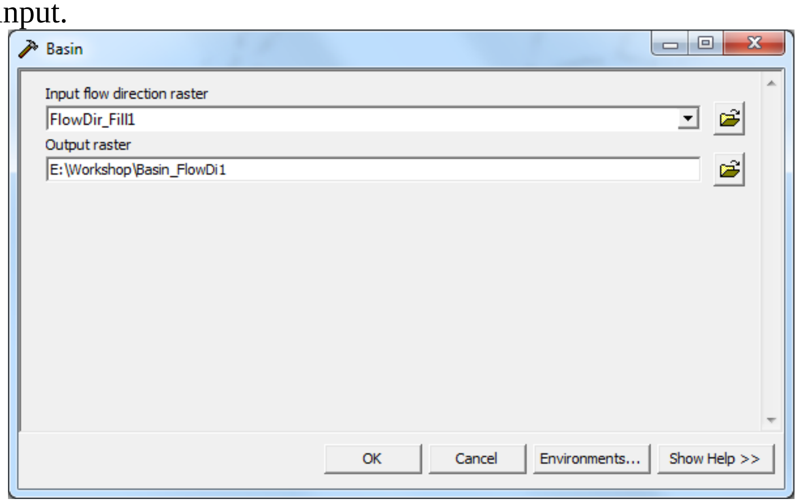




4.3 Delineating Drainage Basins

Drainage basin is also referred to as a watershed, catchment, or contributing area. A watershed of stream outlet (pour point) is defined as the upstream region within which all cells drain into the outlet cell (pour point). Two functions **Basin** and **Watershed** in ArcToolbox can be used to delineate the watersheds. The processing algorithm is to begin at a specified outlet cell. An outlet (pour point) is the point at which water flows out of an area. From a outlet cell, recursively label all cells that drain to it until the upstream limits of the basin are defined. The connected region formed by the labeled cells is a watershed. The boundary between two basins is referred to as a drainage divide or watershed boundary. A sub-watershed is simply part of a hierarchy implying that a given watershed is part of a larger watershed. Watershed boundaries are a key requirement for nearly all surface hydrologic modeling.

The **Basin** function delineates drainage basins within the study area by identifying ridge lines between basins. Basin function analyzes the flow-direction grid to find all sets of connected cells that belong to the same drainage basin. The drainage basins are created by locating the pour points at the edges of the study area (where water would pour out of the grid), as well as sinks, then identifying the contributing area above each pour point. This results in a grid of drainage basins. The function **Watershed** needs the specified pour points as the input.



You may want to vectorize the raster basins into Shapefile feature using **Raster to Polygon** function.