WATERSHED DELINEATION MANUAL

Hydrological Modeling Using the Variable Infiltration Capacity Model (VIC) to Support Streamflow Monitoring in the Rufiji and Wami Ruvu Basins

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Requirements:

Software: ArcGIS Desktop 10.x

Data: Digital Elevation Model (DEM) - raster
pour point data - shapefile

Watershed Delineation

Watershed also referred to as river catchment or river basin is physically delineated by the area upstream from a specific outlet point. There are manual techniques of watershed delineation using a paper or digital delineation in a GIS environment. This document will outline the steps in delineating watersheds in ESRI's ArcGIS Desktop **10.X**. To successfully accomplish the task in this manual, you require a Digital Elevation Model (DEM) and point data/shapefile of delineation point. This manual assumes you have access to the required software, data and basic knowledge of GIS (ArcGIS software).

Definition of terms

Digital Elevation Models (DEM) are a gridded digital representation of terrain surface, with each pixel value corresponding to a height above a datum.

Work environment- the locations/folders where data is stored during geoprocessing. This includes geodatabases and folders.

Materials

For this exercise, you are provided with the following material;

- DEM to cover the station(s) of Interest – Raster format (Source: https://earthexplorer.usgs.gov/)
- Outlet/Pourpoint Location– RGS Wami river at Dakawa (**shapefile**) (Source: ???)

Step 1: Set up your working environment

In this step, you will set-up a working directory that will be used throughout the delineation process.

1. Start ArcMap and create a new map document and select a blank document. Save the map document using the **save as** option in the file menu into your preferred directory/folder.

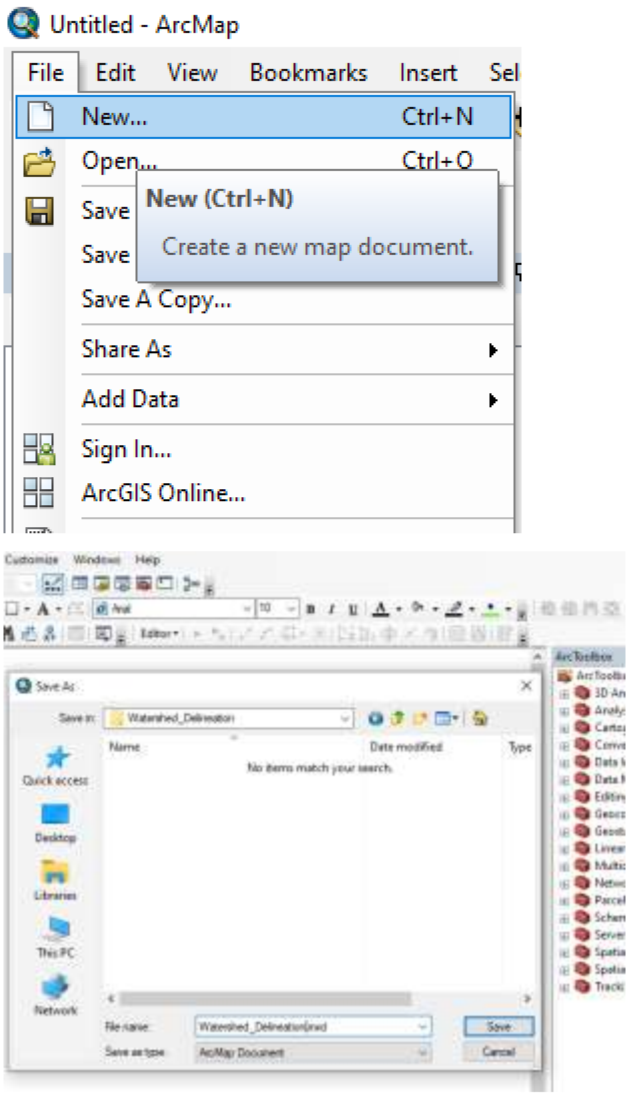


Figure 1: Creating a new project in ESRI ArcMap

2. Add DEM data and a delineation point file into ArcMap using the add button .
3. Create a file Geodatabase that will store your results in your preferred directory. Use the Catalogue pane in ArcMap to navigate to your preferred directory and Create a file geodatabase. Rename the geodatabase to preferred name. Right click on the geodatabase and select make default geodatabase.

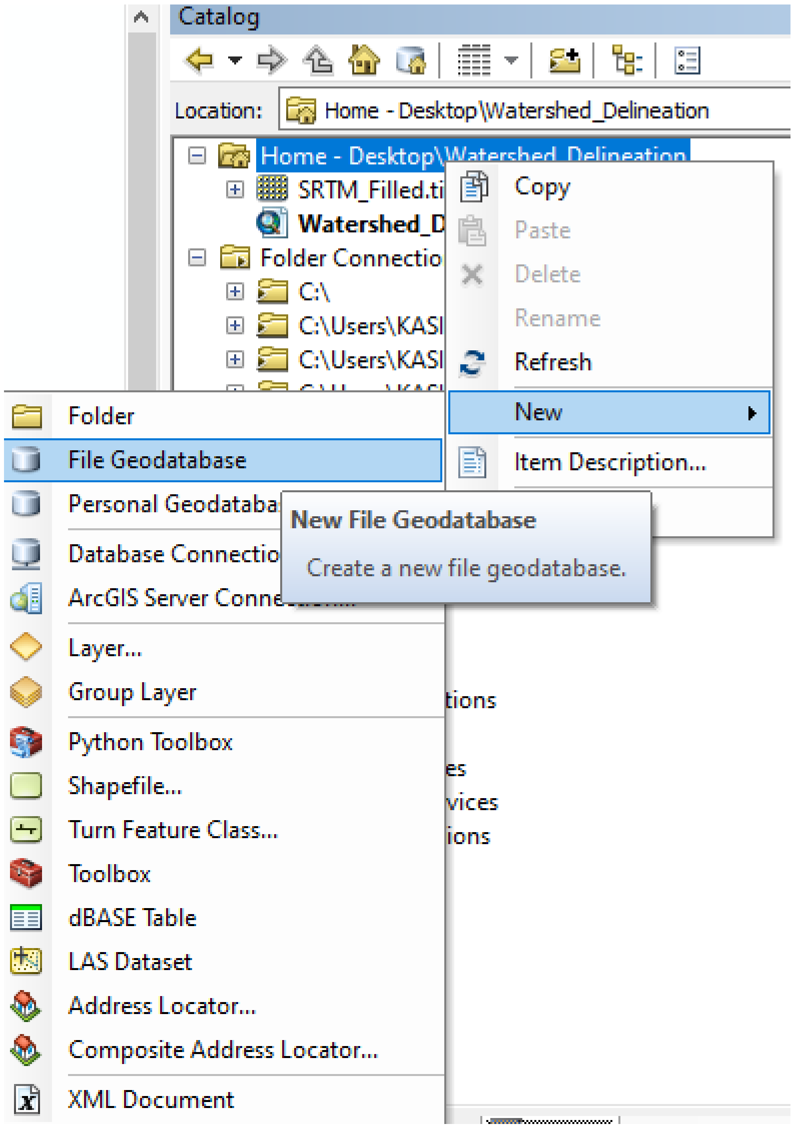


Figure 2: Creating a file Geodatabase

4. Browse to the Geoprocessing > Environment. And under *workspace* confirm that the *current workspace* and *scratch workspace* have been set to your recently created geodatabase. More information on geodatabase can be found [here].

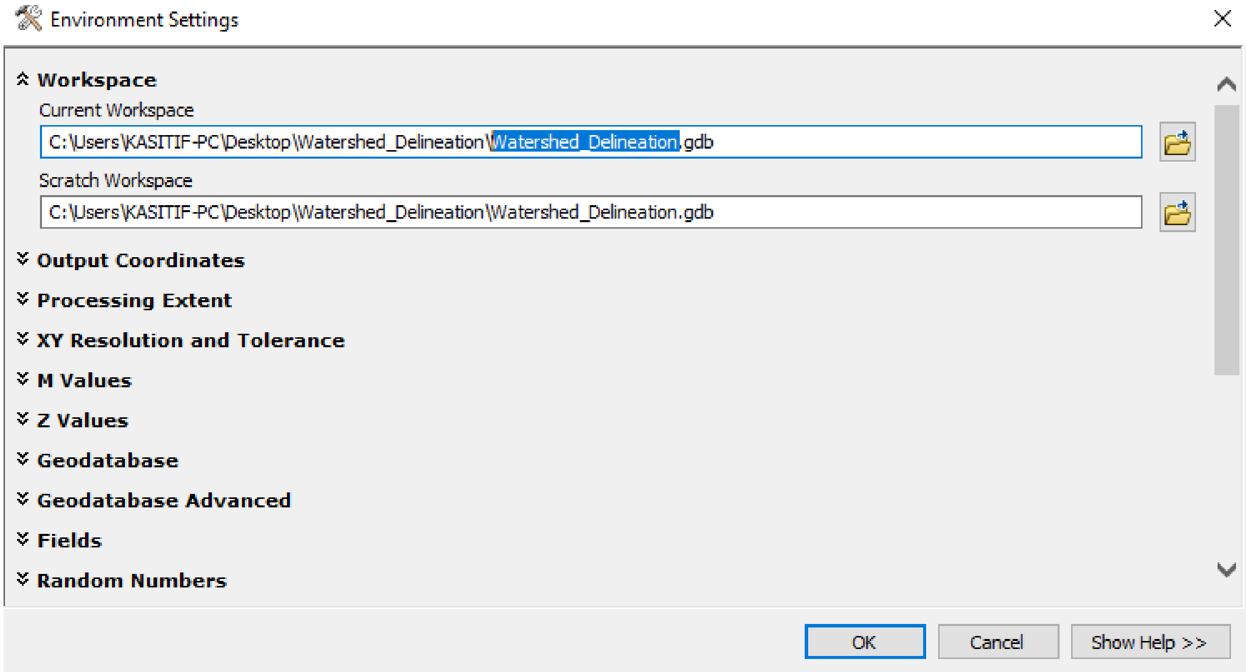


Figure 3: Setting up working environment

5. Set the default output cell resolution for the environment under Environment Settings > Raster Analysis and use the drop-down menu to set the cell size 'same as DEM' layer. Click Ok to accept changes.

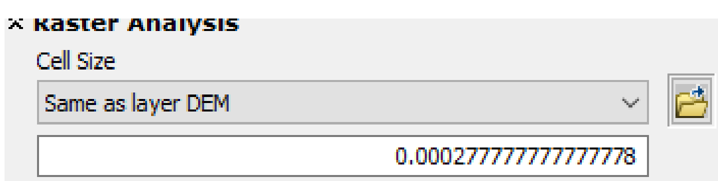
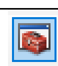


Figure 4: Setting up the output resolution

Note: if necessary, enable the Spatial Analyst Extension (*Customize> Extension > Spatial Analyst*).

6. Open the ArcToolbox  from the main menu and expand the spatial Analysis tools > Hydrology toolbox to view the contents.

7. Save your Map document (***File*** > ***save***)

Step 2: Filling the DEM

To create a depression less DEM, the *fill* tool in the hydrology toolbox is used. This tool removes any imperfections on the DEM (Sinks). A **sink** is a cell that has no associated drainage value. The drainage values are values that indicate the direction of flow of water from a cell and these values are assigned during the process of creating flow direction.

1. Double click on the fill tool to open the dialogue box. Enter the following parameters: Set the DEM as the *Input Surface Raster.* If necessary, set *Output Raster* to your working directory and give a descriptive name. Accept other defaults and click *Ok* (i.e. leave z limit blank).

> **Note***: Depending on the processing power of your computer, this process might take some time.*

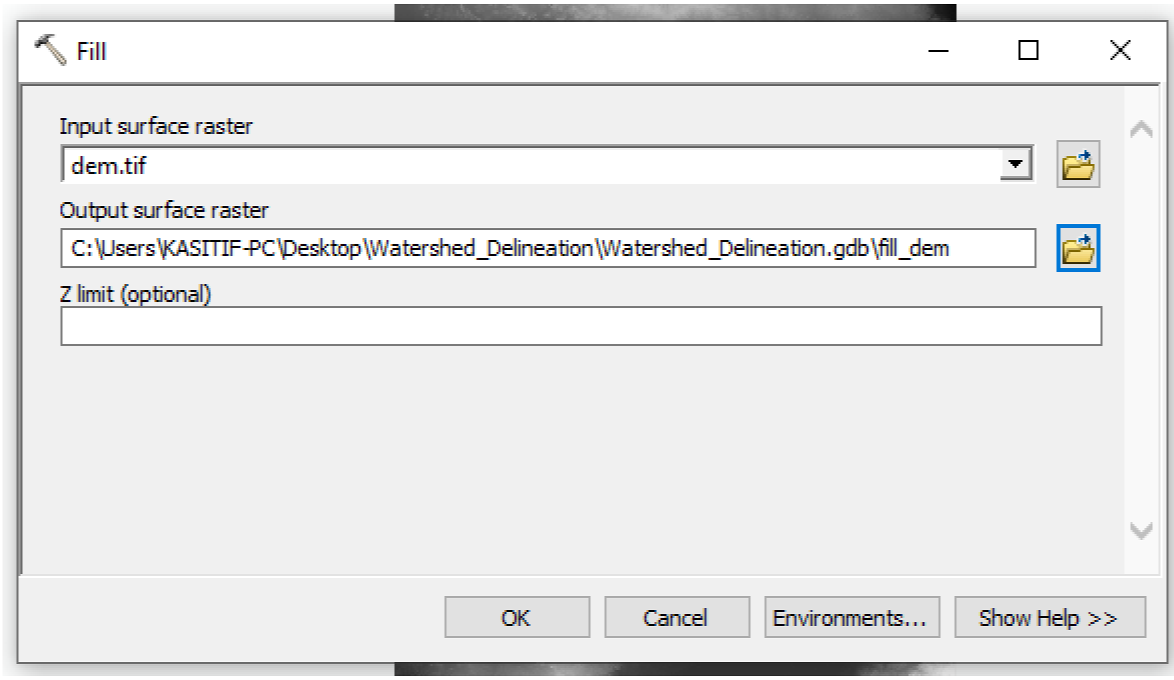


Figure 5: Filling Sinks in a DEM

If the process is successful, a filled/sink filled DEM is automatically added to the map.

Step 3: Creating a flow Direction

A flow direction grid assigns a value to each cell to indicate the direction of flow – that is, the direction that water will flow from that particular cell based on the underlying topography of the landscape. This is a crucial step in hydrological modeling, as the direction of flow will determine the ultimate destination of the water flowing across the surface of the land. Flow direction grids are created using the *Flow Direction* tool. For every 3x3 cell neighborhood, the grid processor finds the lowest neighboring cell from the Centre. Each number in the matrix below corresponds to a flow direction – that is, if the centre cell flows due north, its value will be 64; if it flows northeast, its value will be 128, etc. These numbers have no numeric meaning – they are simply codes that define a specific directional value, and are determined using the elevation values from the underlying DEM.

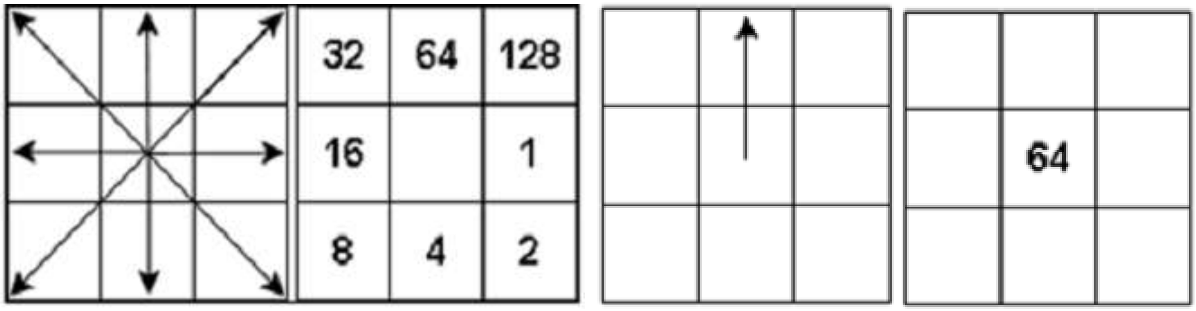


Figure 6: Flow direction matrix

- Double click the *Flow direction* tool to open the dialog and input the following parameters. Set the *Input Surface Raster* to be the Filled DEM/sink filled dem from step 2, set the *Output Flow Direction* raster as your working directory if necessary, as below.

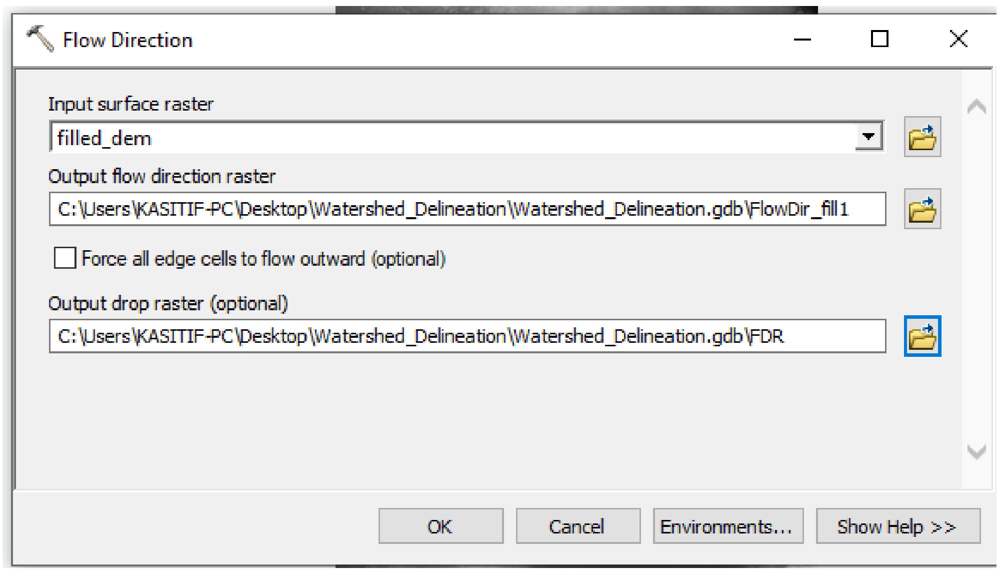


Figure 7: flow direction input options

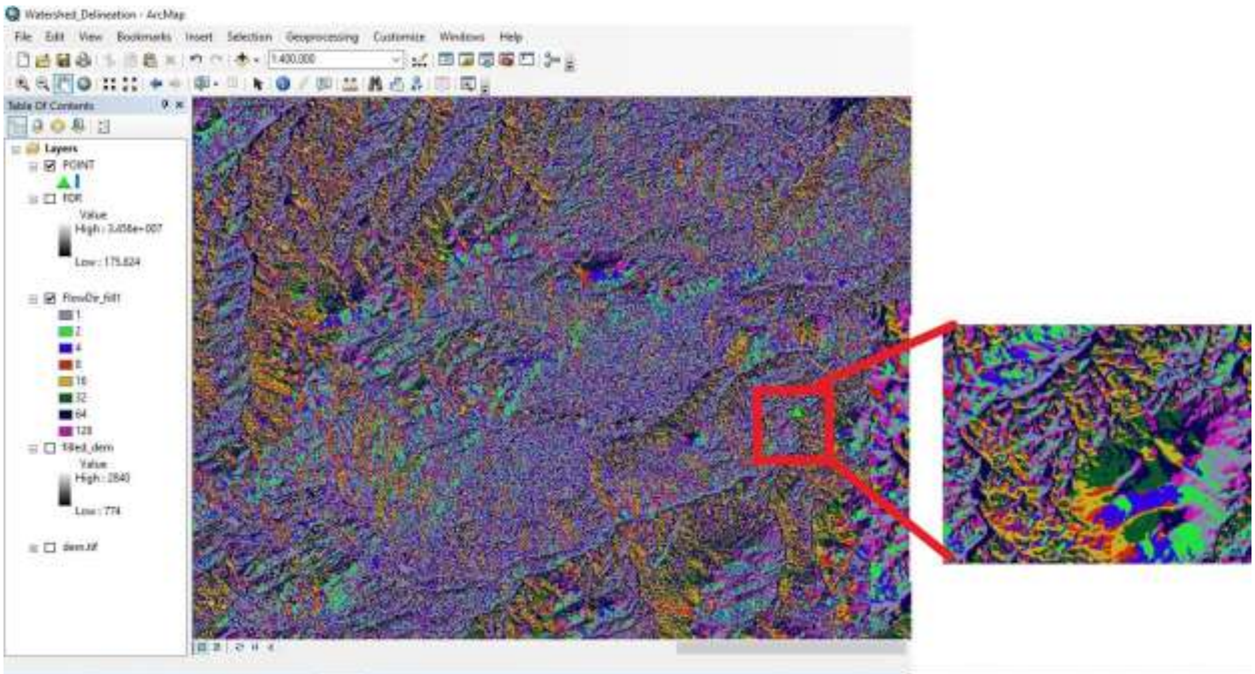


Figure 8: output of the flow direction raster tool indicating flow directions within the data

Step 4: Creating a flow Accumulation Grid

This step calculates the flow into each cell by identifying upstream cells. Flow accumulation value is determined by the number of upstream cells based on the topography. To run this tool, double click on the *Flow accumulation* tool to open the dialogue box.

- Set the input flow direction raster to the flow direction grid from step 3.
- Set your output flow accumulation raster to your working directory and name appropriately. Accept other defaults and click **Ok.**

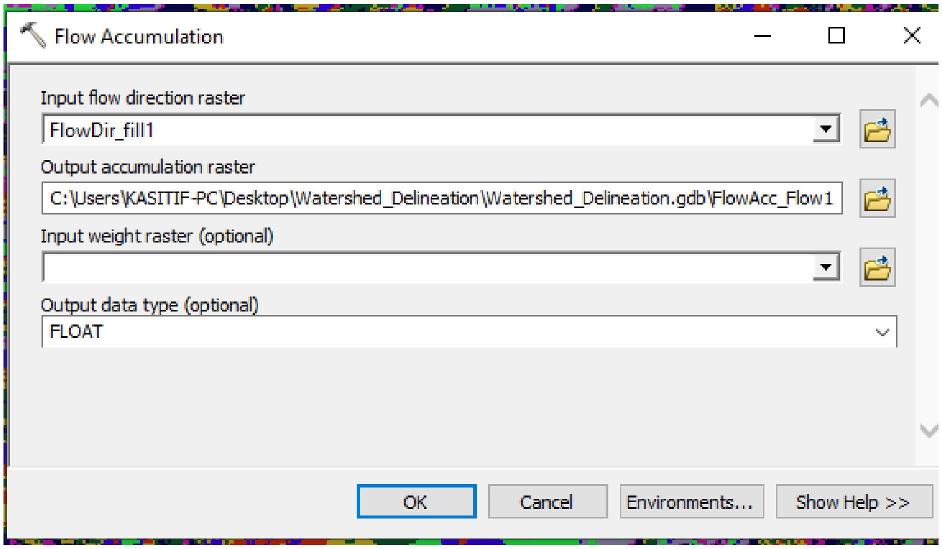


Figure 9: flow accumulation input parameters

If the tool runs successfully, a flow accumulation raster will be added to the map. Change the symbology to help in visualization since cells appear dark.

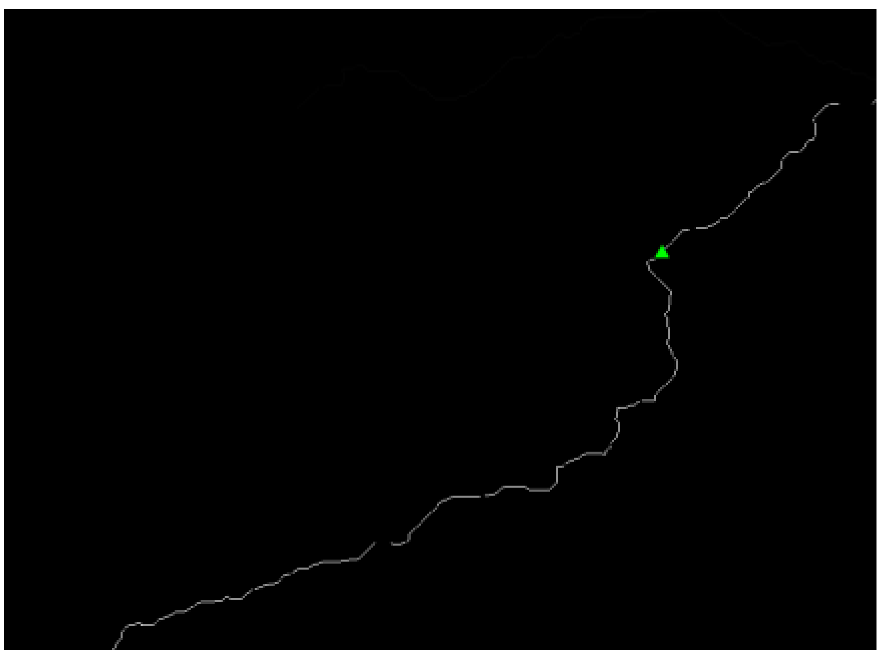


Figure 10: sample flow accumulation output

Right click on the layer and select *properties* > *symbology*, highlight ***classified*** in the left pane and set the classes to 2 and set the values as below.

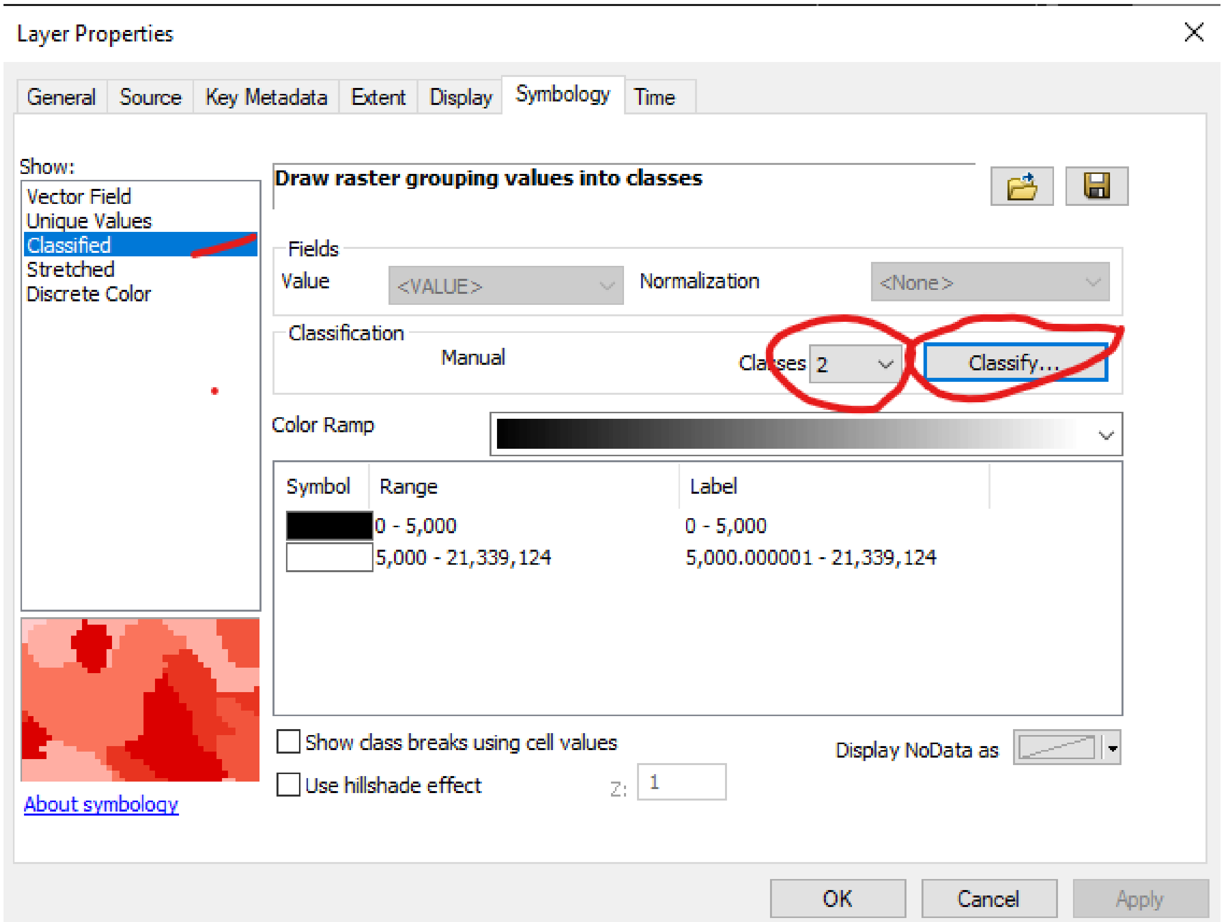


Figure 11: visualization option for the flow accumulation

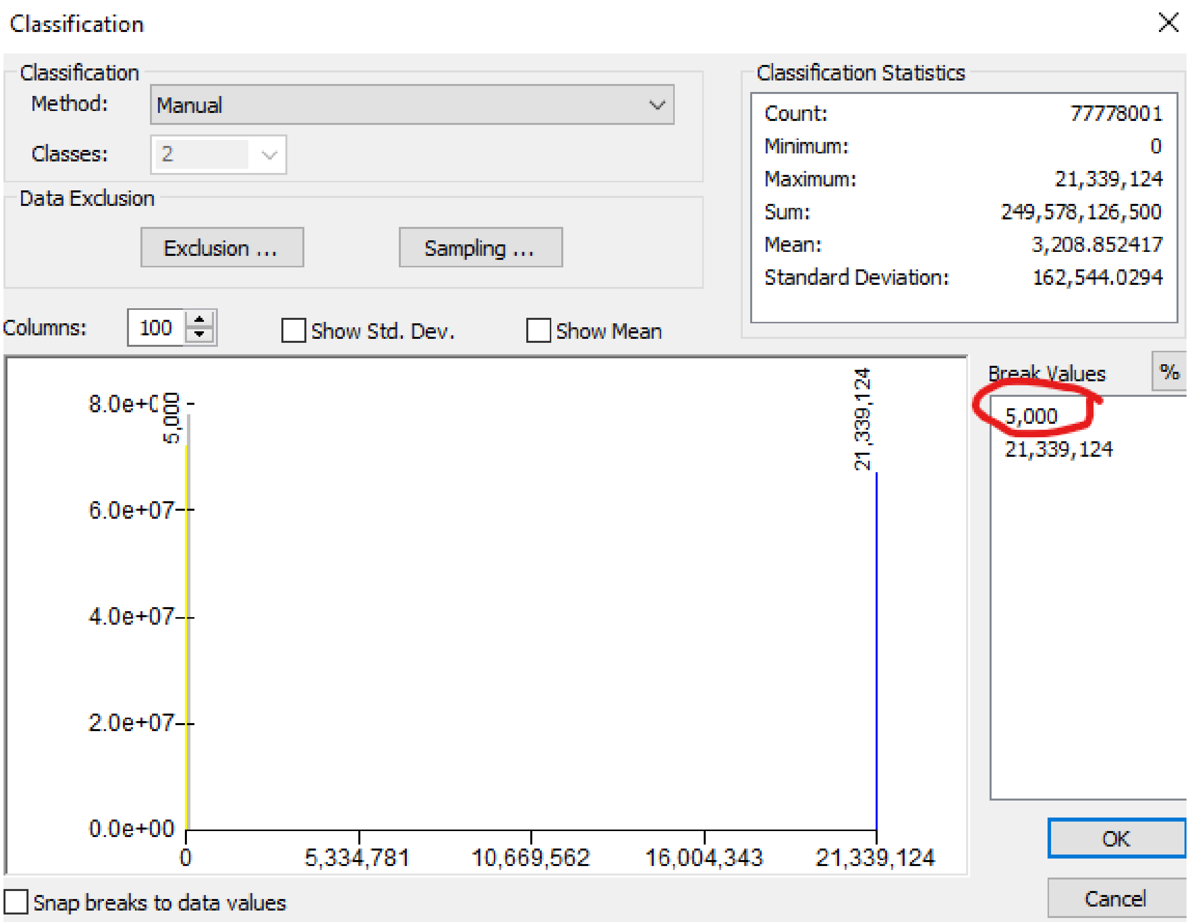


Figure 12: classification options and lower-class limit

The symbology option update should result into a similar output as the figure 13.

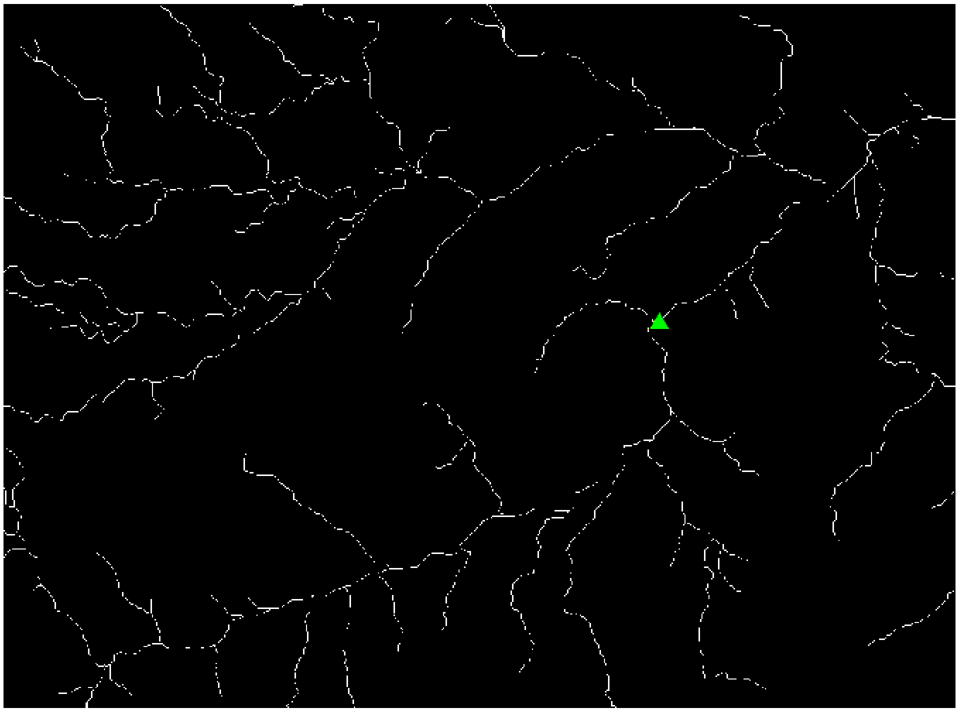


Figure 13: symbology results

Flow accumulations are important because they allow us to locate cells with high flow where streams and channels are to be expected. Each cell has an outlet point called a pour point that indicates the location where water would naturally flow out of the cell. Pour points must be located in cells with high cumulative flow or the delineated watersheds will cover very small areas.

Step 5: Creating Pour Points (Outlets)

Pour point location or placement is vital in watershed delineation. It should be located within an area of high flow accumulation because it will be used to calculate the total contributing water that flows to that selected point. Pour points can be a pre-existing shapefile of a gauge location or can be created manually. In this example we will explore an already existing shapefile. Load a gauge location file/pour point feature file and zoom in to the pour point to inspect the point location relative to the flow accumulation.

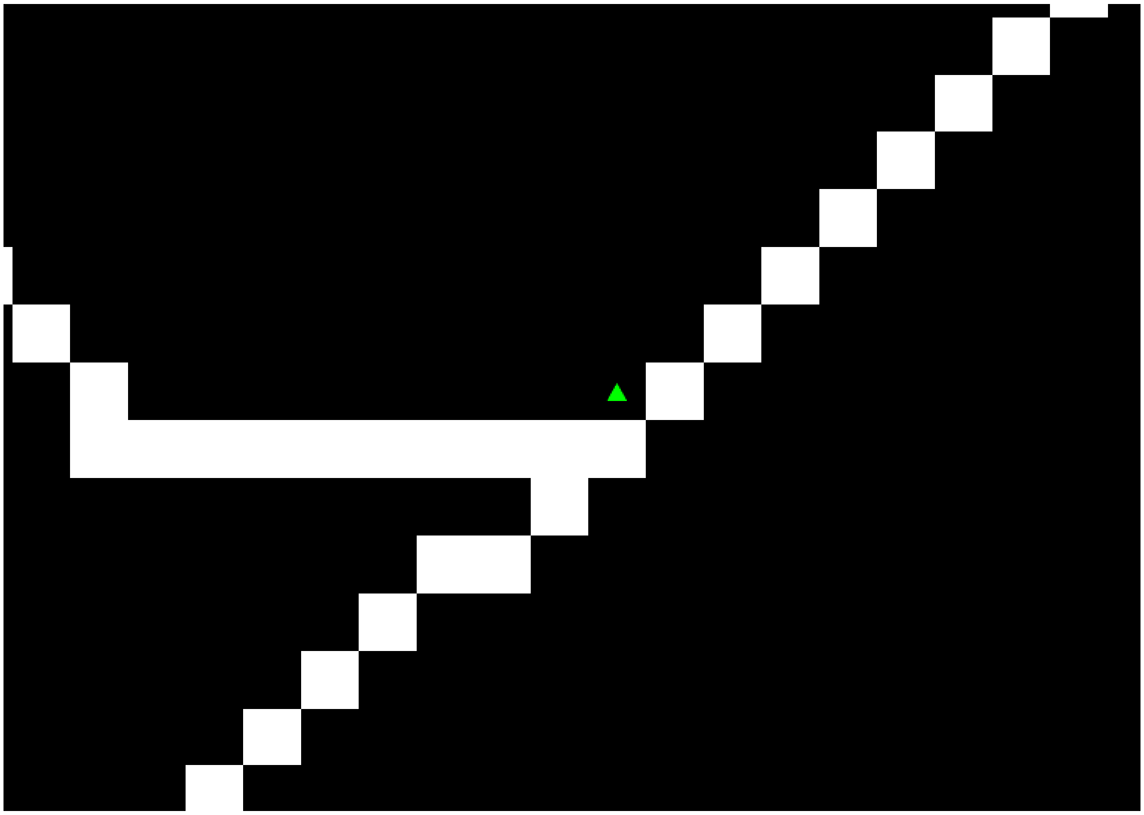
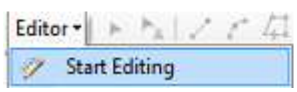


Figure 14: visualizing the location of the pour point vis a vis the flow accumulation

The pour point location may not coincide with the cells with high flow accumulation (as shown in the example fig. 14). In that case, ArcGISs' edit tool is used to manually correct the location.

Start the editor tool to edit the point and move it on to the flow accumulation path.



and select the point feature to edit. The tool shown in figure below to move your pour point.

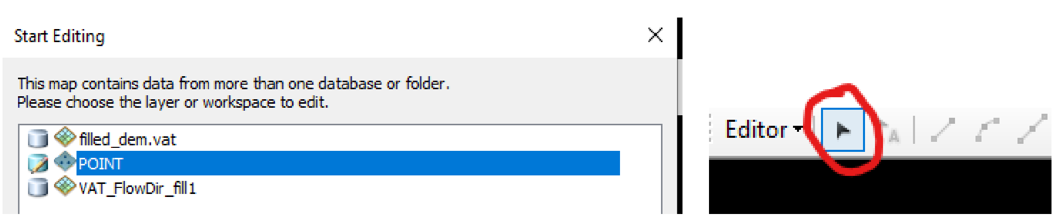


Figure 15: Editor tool start

After successful moving of the point, save your edits and stop the edit session.

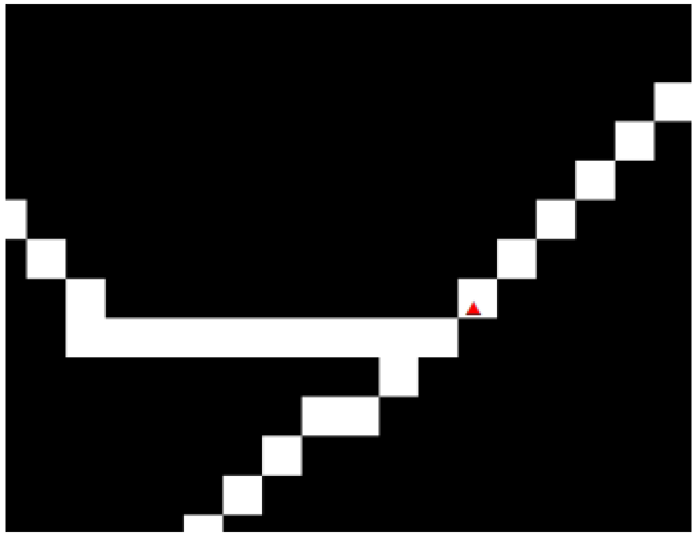


Figure 16: Result of editing the pour point

Step 6: Snap your pour point

This step accomplishes two tasks, snaps the point created in step 5 to the closest cell of high flow accumulation and converts the point to raster.

Double click on the *Snap Pour Point* tool to open the dialogue box and set the following parameters. Set *input Raster /pour point data* to the point created in step 5, *Pour Point field* to value or any unique id in the file, set the *Input Flow Accumulation Raster* as the output created in step 4 and finally set the Output Raster to your working directory assigning it a name. set the snap distance as 0. Click **Ok** to run the tool.

Note *that the snap distance is 0 because we corrected it by editing the file but this can be set to a different value to allow the tool to search within the radius given for cells with high flow accumulation.*

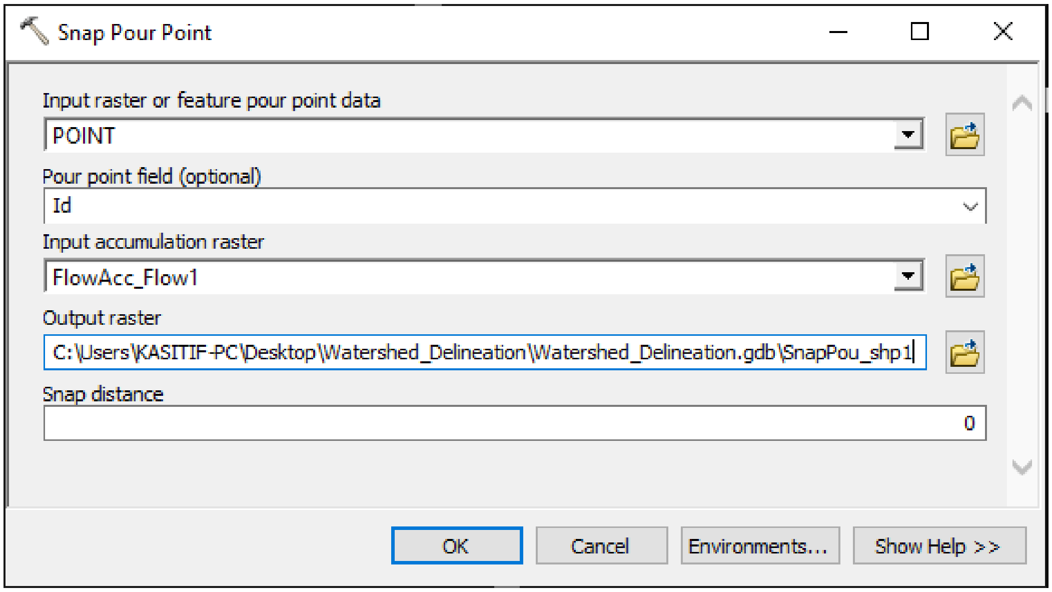


Figure 17: Snap raster tool parameters and options

If the tool runs successfully, a raster will be added to the map.

Step 7: Delineate watershed

Double click on the *watershed* tool to open the dialogue box and set the parameters as follows.

Input flow direction raster to the flow direction raster output from step 3, *input raster of feature pour point data* as the pour point feature from step 6, *pour point field* can be selected or left by default and set the output working directory with a name for the *output Raster.* Click Ok to run.

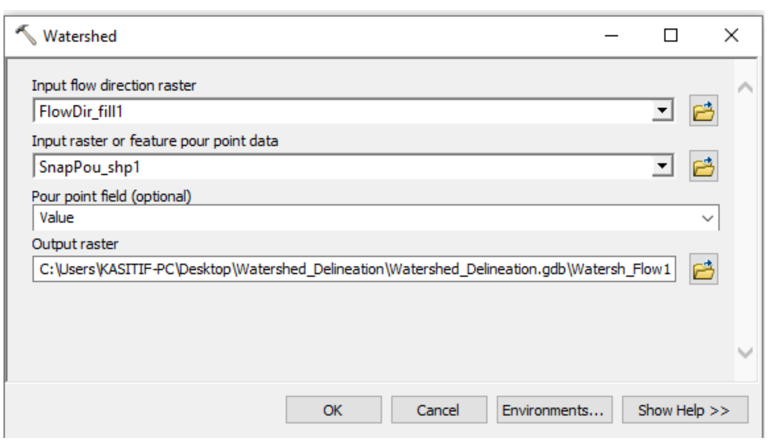


Figure 18: Watershed Delineation tool parameter

If the tool runs correctly, a watershed raster file will be added to the map.

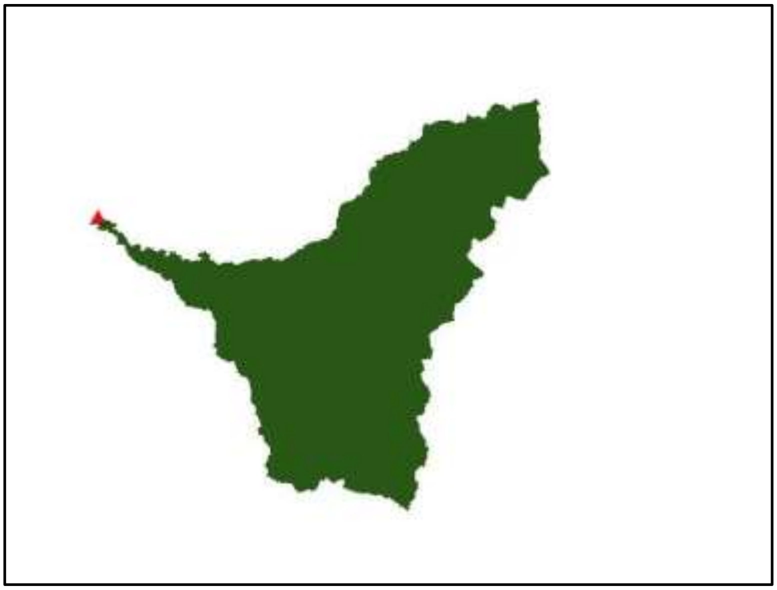


Figure 19: resulting watershed after successful delineation

Step 8: Converting the raster to shapefile

In this section you will convert the output raster from step 7 into a vector polygon file for different use. The Raster To polygon tool will be used for this task. Navigate to Arctoolbox > Conversion > From Raster and double click and set the parameters as follows.

Set the *input raster* to the watershed file created in step 7 and set the necessary output directory and file name under *Output polygon features* and accept all other defaults.

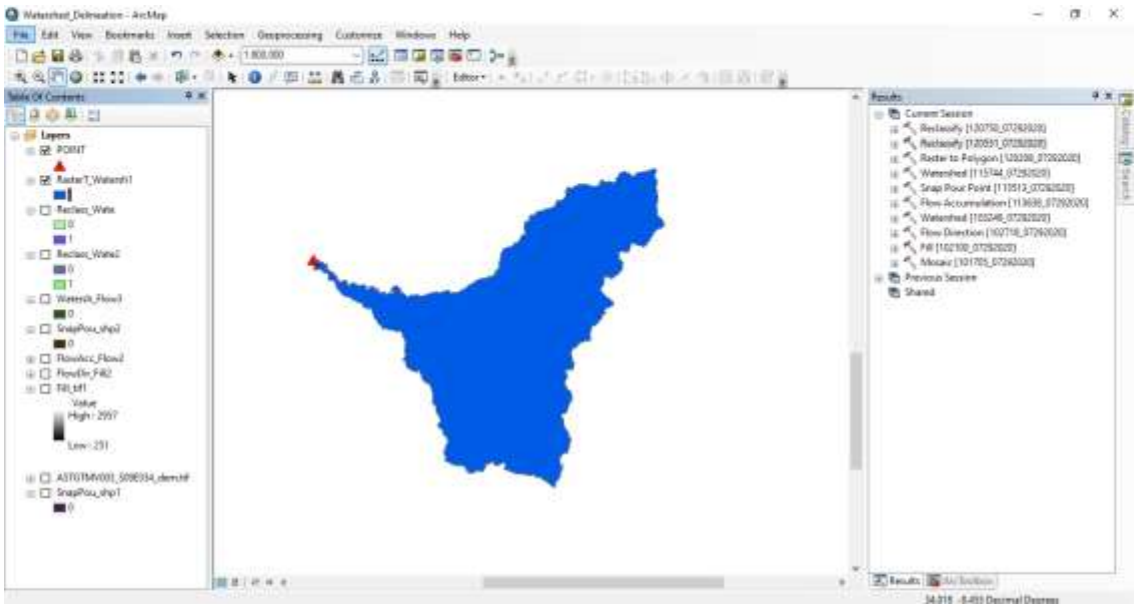
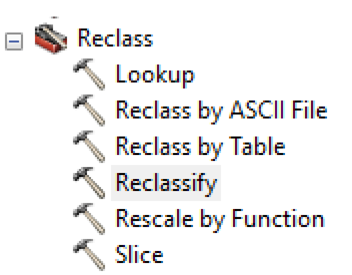


Figure 20: Shapefile output of the delineation

This completes the watershed delineation steps.

Step 9: Generating a gauge fraction file

To run the VIC hydrological model, one of the key inputs in generating discharge values at an outlet is a gauge fraction file. In this step, you create a gauge fraction file to the watershed which will be later used as input in routing discharge. In ArcMap, Right click the watershed raster from step 7 and select zoom to layer (automatic zoom to ensure that the map does not completely fit the window but leaves some margin on all sides).Under the spatial analyst tool menu in Arctoolbox, locate *Reclass* tool, expand it and select the *Reclassify* as shown below.



Double click to open the tool and input the following parameters.

Select the input raster as the watershed file from step 7, and *Reclass field* set to value. Use the classify option to select one classification class if necessary. Edit the new values tab as follows, old 0 values to new value of 1 and the NoData value to new value of 0. Set the appropriate name and output directory. Click Okay to Run.

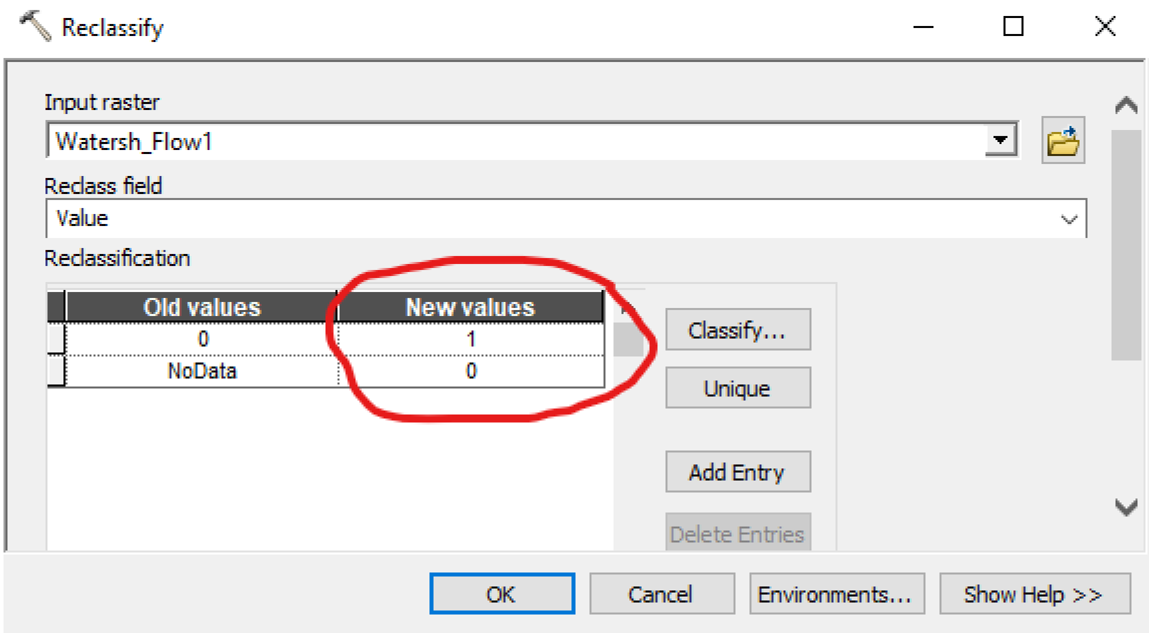


Figure 21: Reclassify tool and options

The resulting raster file is a gauge fraction file. This will be used as an input in routing.