14 Watershed Delineation

Introduction

The watershed is an area of land that serves as a catchment for water. From the watershed, the surface water then enters a common outlet in the form of either a body of water, such as a lake, stream, or wetland; or it infiltrate into the groundwater. It is simply an area that drains surface water from high elevation to low elevation. The watershed is a hydrologic unit that is used to be modeled as it is considered fundamental to hydrologic designs and it is used to aid in the study of the movement, distribution, and quality and quantity of water in an area. The watershed analysis is a technique essential in the management, conservation, and planning of the Earth's natural resources.

Traditionally, the watershed is created mannually from topographic maps by locating the water divide. In ArcGIS the watershed can be delineated using Spatial Analyst extension and the hydrology tools for watershed delineation.

There are many steps involved in creating the watershed boundary. The delineation of the watershed requires work with the raster DEM of a study area. If the raster DEM is not available and you have a point elevation, you can use one of the interpolation techniques such as IDW, GPI, or kriging in ArcGIS to convert the point elevation into DEM. The watershed can be created using DEM as it is considered the main source point to create a watershed model.

After obtaining the DEM, make sure that the raster is depression free. These topographic depressions are also called sinks. Depression is normal in nature, and could be generated during the interpolation process of DEM creation. Depression in DEM is when a very low elevation relative to neighboring cells is found and they prevent downslope DEM flow-path routing. These low elevation cells can be removed by increasing its cell value to the lowest overflow point. The table below shows that the cell in row 3 column 2 is a depression.

450	446	441	451	454
447	441	440	446	451
440	339	431	440	445
438	435	422	431	439
431	429	414	422	424

Therefore, to use the raster DEM in watershed delineation, the depressions should be removed using the Fill tool.

Electronic Supplementary Material: The online version of this chapter (https://doi.org/10.1007/978-3-319-61158-7_14) contains supplementary material, which is available to authorized users.

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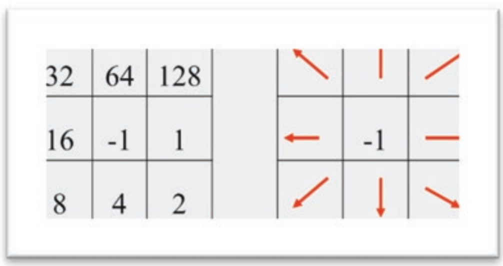
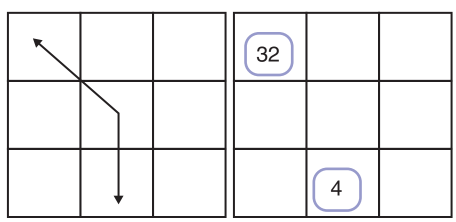
Flow Direction

The next step is to create a raster grid containing the information about flow directions. The Flow Direction tool resides in the hydrology tool. Flow Direction tool is used to find drainage networks and drainage divides and it is determined by the elevation of surrounding cells in the DEM. The water can flow only into one cell and the GIS model assumes no sinks. If this does not happen in the output grid, this means that the raster DEM has sinks. Flow direction is critical in the hydrologic modeling process because it determines the direction of flow for each cell in the land topography. The raster grid that created by the Flow Direction tool is based on the D8 flow algorithm. The D8 algorithm is the method for performing the flow path analysis for the application of watershed delineation. The method will assign a cell's flow direction to one of its eight surrounding cell that has the steepest gradient. D8 has disadvantages and can be replaced by D∞. Flow direction function is that for each 3 × 3 cell neighborhood, the grid processor stops at the center cell and determines which neighboring cell is lowest. Depending on the direction of flow, the output grid will have a cell value at the center cell. The values for each direction from the center are 1, 2, 4, 8, 16, 32, 64, and 128. For example, if the direction of steepest drop was to the left of the current processing cell, its flow direction would be coded as 16. The figure below shows the output grid cell values with the center cell, as determined by this matrix:



If a cell flows northwest, then in the output grid, the cell in its location will have a value of 32 and if a cell flows southward, then the value will be 4 (figure below)



Flow Accumulation

The next step in creating the watershed is to run the Flow Accumulation function, which is an important step to create the drainage network and measure the area of a watershed that contributes runoff to a given cell. Therefore, it is a necessity to determine the ultimate flow path based on the direction of flow of every cell on the topography grid. Flow accumulation selects cells with the greatest accumulated flow, which will assist in creating a network of high-flow cells. These high-flow cells should be situated on stream channels and at valley bottoms. Cells that have high accumulation values, higher than "**1**" correspond to stream flow and cells having an accumulation value of "0" correspond to ridgelines. Once flow accumulation is calculated, it is customary to identify those cells with high flow. Higher-flow cells will have a larger value and the user can select any threshold number (i.e. >500), which should be close to network obtained from the traditional method.

Stream Link

After the stream network is established from flow accumulation, each stream section of the stream raster is assigned a unique value e.g. 1, 2, 3, etc. The intersection of the streams is like nodes and the stream section is the arc.

To delineate a watershed, you need to select an outlet cell (Pour Point), which is the lowest point in the watershed, where all flow is directed. The Pour Point also can be any feature such as a gauge station, dam, sampling location, confluence of a tributary with a main stream or any point of interest in the study area. The Pour Point could be a raster or vector. To obtain the watershed, the Pour Point should coincide with the flow path of high flow accumulation values in the flow accumulation raster. Finally, you can use the Watershed tool to extract the whole watershed polygons for the Pour Points, or a single watershed for a specific stream or tributary. At the end, you can convert your raster watershed to vector so that you can integrate it and align it nicely with the rest of your digital data.

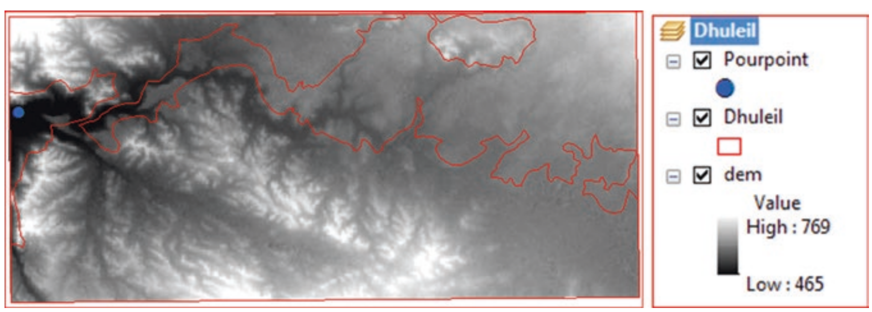
Scenario 1: You are a geologist working for WAJ and one of your duties is to delineate the catchment area of the Dhuleil-Halabat region. This catchment is going to be used as an input function to estimate the recharge amount to the groundwater resources in the area.

Your duty is to do the following:

1. Delineate the watershed based on the whole region.
2. Delineate the watershed based on a single point (Pour Point)
3. Convert the watershed raster into vector
4. Calculate the area of the watershed and amount of groundwater recharge

Required Files: **DEM, Dhuleil.shp,** and **Pourpoint.shp**

1. Launch ArcMap and rename the Layers data frame "Dhuleil"
2. Add Data, browse to \\Ch14\Data folder and integrate **Dhuleil.shp**, **Pourpoint.shp**, and **DEM**
3. Make the symbol of **Dhuleil.shp** hollow and the outline color red
4. Symbolize **Pourpoint.shp** (circle 2, size 12, and blue color)



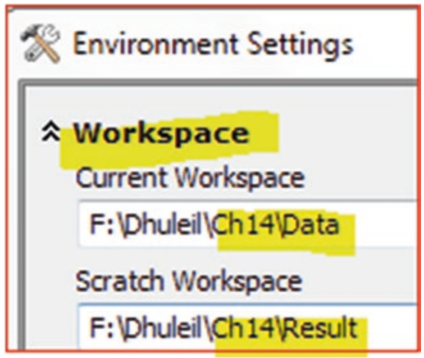
Delineate the Watershed

Delineating the watershed requires different steps:

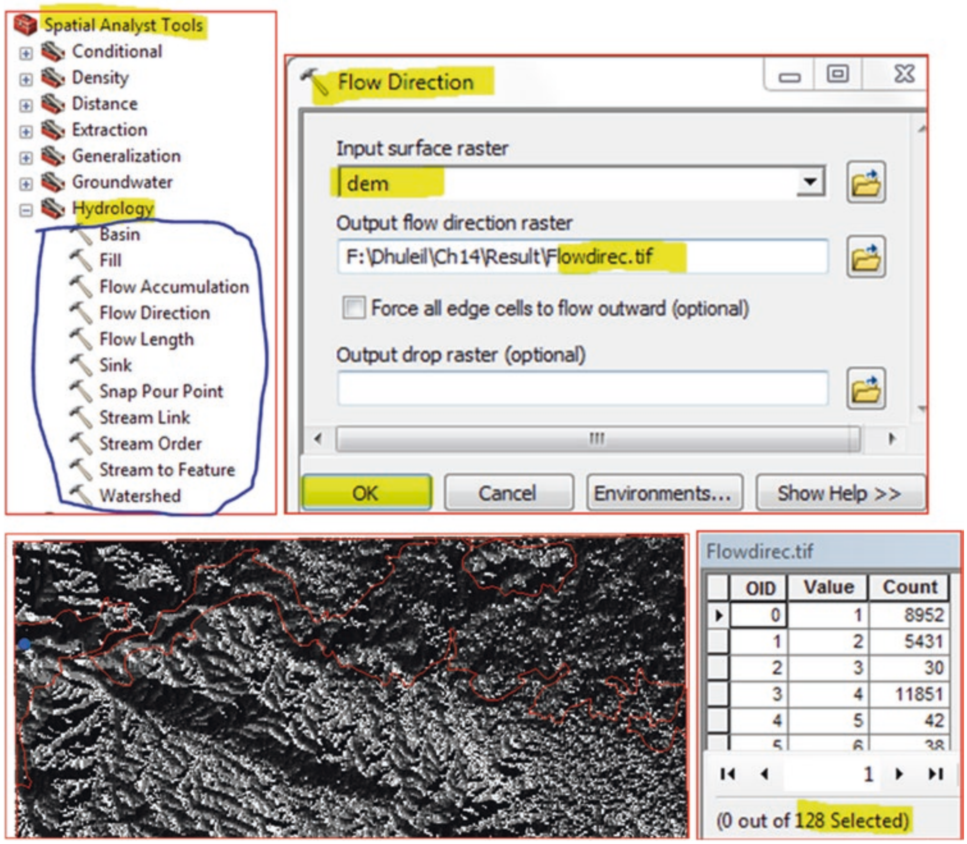
Step 1: Run the Flow Direction Tool

This step is very important to run in order to create a raster grid containing the information about flow directions and identify any depressions in the raster DEM. The DEM raster file will be used for performing the task

5. Launch ArcToolbox/Set Environment
6. Current Workspace: \\Ch14\Data
7. Scratch Workspace: \\Result
8. OK



9. Spatial Analyst Tools/Hydrology/Flow Direction
   a. Input surface raster: **dem**
   b. Output flow direction raster: **Flowdirec.tif**
10. Ok

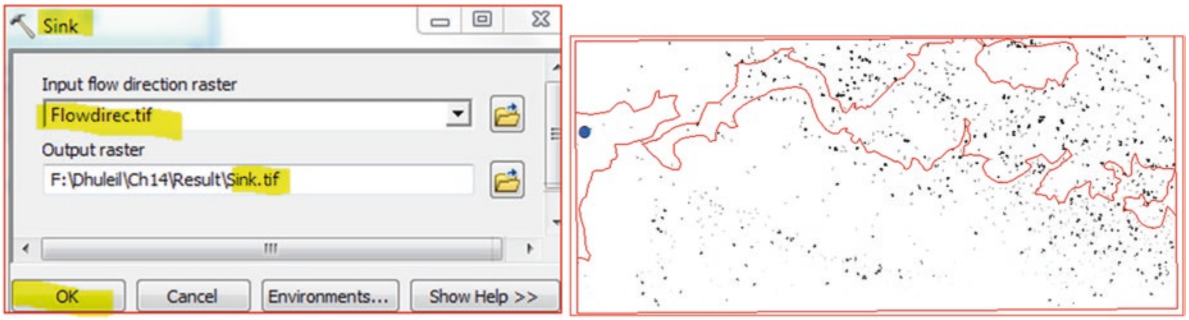


Result: The output raster is an integer and contains 128 records. The grid has no information about the flow directions, but has recognized that the **DEM** contains sinks.

Step 2: Identify the Locations of the SINK (Sink Tool)

1. Spatial Analyst Tools/Hydrology/Sink
2. Input flow direction raster: **Flowdirec.tif**

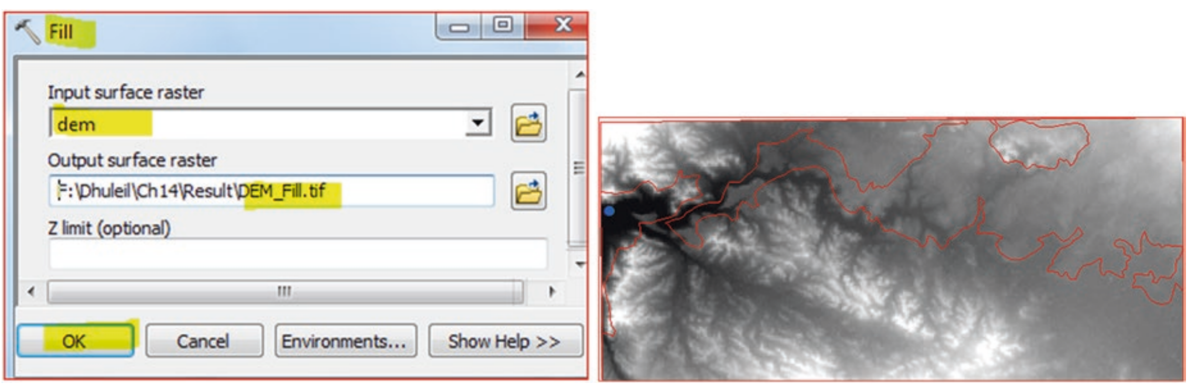
3. Output raster: **Sink.tif**
4. Ok



Comments: The output grid shows that the DEM of Dhuleil has 927 **sinks**. A sink is a depression or raster cell surrounded by higher elevation values. Some sinks are actually in nature and some are deficiencies in the DEM. After knowing the number of sinks, we have to fill them using the "Fill tool" on the original DEM raster.

Step 3: Run the Fill Tool

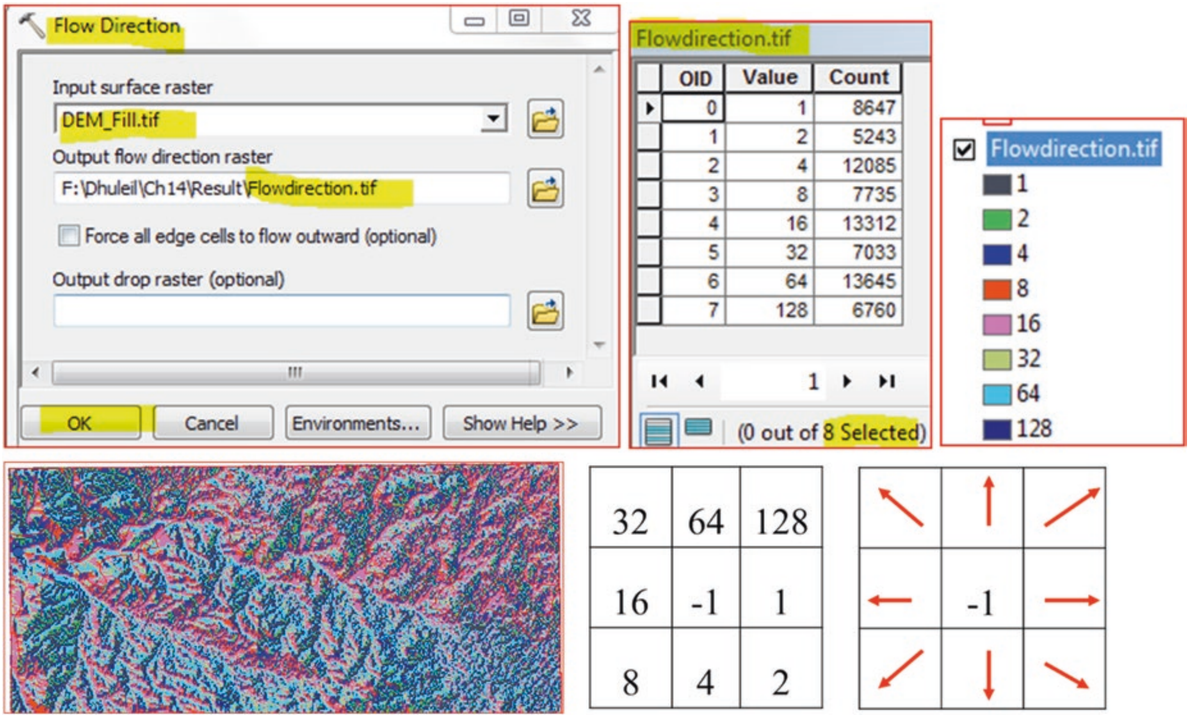
5. Spatial Analyst Tools/Hydrology/Fill
   a. Input surface raster: **dem**
   b. Output surface raster: \\Result\ DEM_Fill.tif
6. OK



Result: Now the **DEM_Fill.tif** is a DEM free of any SINKS.

Step 4: Run the Flow Direction tool

7. Spatial Analyst Tools/Hydrology/Flow Direction
   a. Input surface raster: **DEM_Fill.tif**
   b. Output flow direction raster: \\Result\Flowdirection.tif
8. Ok



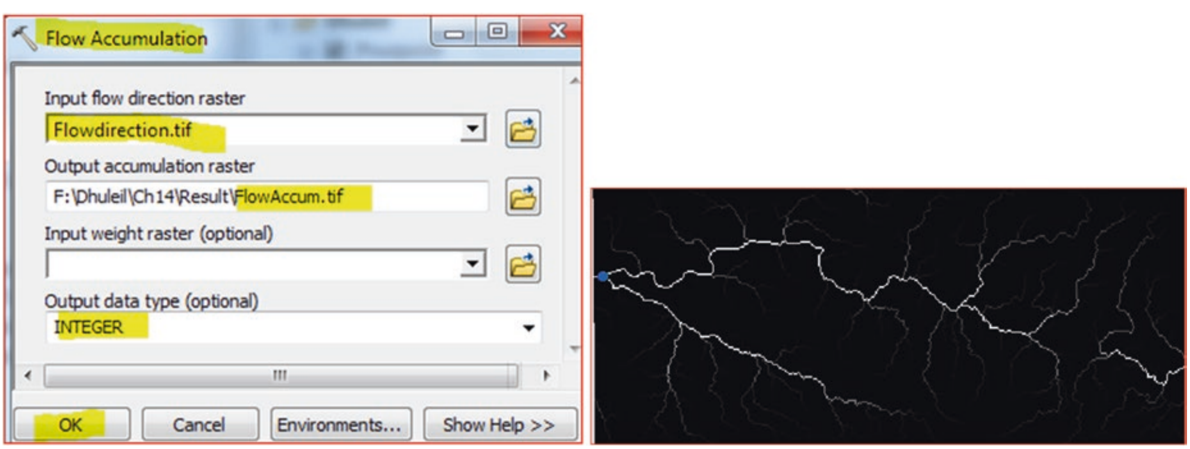
Result: The output Flowdirection.tif raster is an integer raster with the attribute table of eight records.

Comments: The values 64 and 16 have the highest frequency, which means the direction of the surface flow is north and west.

Step 5: Create a Flow Accumulation Raster

This step is important as it will tabulate for each cell the number of upstream cells that will flow into it and the tabulation will be based on the flow direction raster. This step will derive two values; "**0**" and "**1**".

9. Spatial Analyst Tools/Hydrology/Flow Accumulation
   a. Input flow direction raster: **flowdirection.tif**
   b. Output accumulation raster: \\Result\flowAccum.tif
   c. Output Data Type: INTEGER
10. Ok



Question: What is the range of cell value in **flowAccum.tif**?

Step 6: Create Source Raster to Delineate Watershed

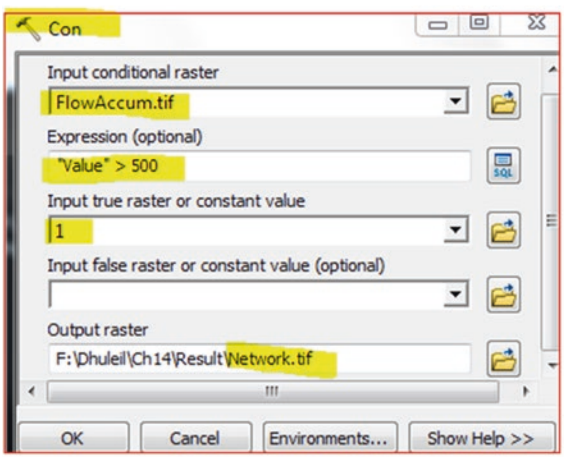
The flow accumulation raster will help in deriving the stream network. The stream derivation is based on threshold cell values, which could be 100, 500, or more cells. The 500 cells means that each cell has a minimum 500 cells contributing to them. The difference between the 500 cells and the 100 cells is the 500 cells will generate less dense stream networks, while the 100 cells will generate denser streams.

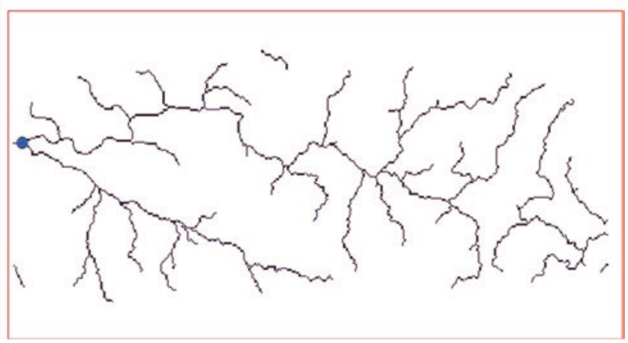
Source Raster

The source raster required two steps:

First Step: This step will allow you to select the cells in the flow accumulation raster that have more than 500 cells flowing into them.

11. Spatial Analyst Tools/Conditional/Con
    a. Input Conditional raster: FlowAcum.tif
    b. Expression (SQL) “Value” > 500
    c. Input true raster or constant value: 1
    d. Output raster: \\Result\Network.tif
12. OK

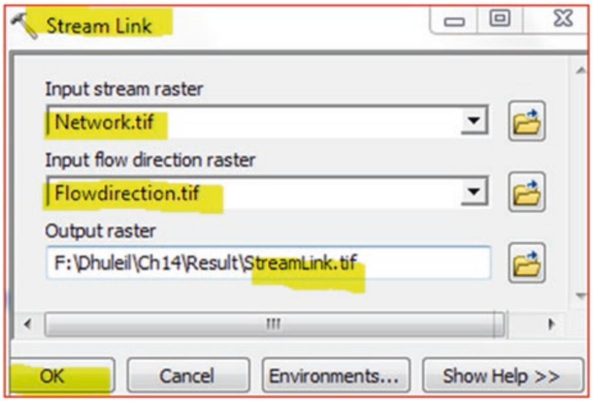




Result: The Network raster has only 1 record.

Second step: Assign a unique value to each section of the **Network** raster and its associated flow direction. In other words, make each segment where it intersects with another segment as a unique record.

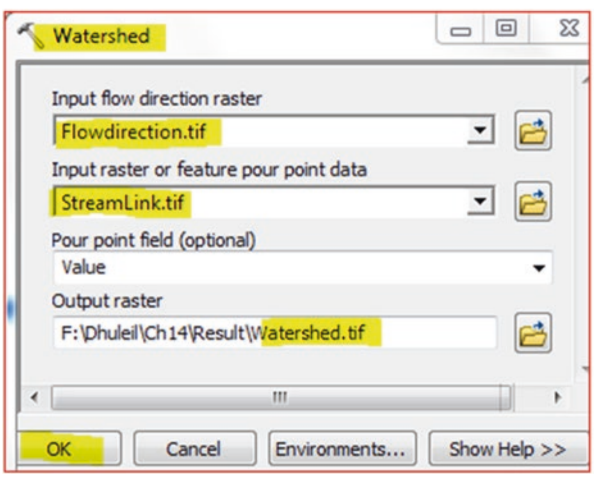
13. Spatial Analyst Tools/Hydrology/Stream Link
    a. Input stream raster: **Network.tif**
    b. Input flow direction raster: **flowdirection.tif**
    c. Output raster; \\Result\StreamLink.tif
14. Ok

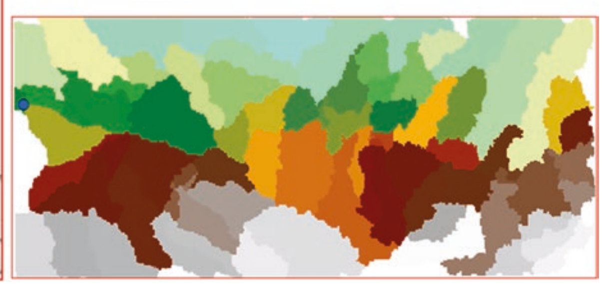


Result: The StreamLink raster has 82 segments and each stream segment is now an independent record and has a “Value” in the attribute table.

Step 7: Delineate Watershed

15. ArcToolbox/Spatial Analyst Tools/Hydrology/Watershed
    a. Input flow direction raster: **flowdirection.tif**
    b. Input raster or feature pour point data: **StreamLink.tif**
    c. Output raster; \\Result\Watershed
16. Ok
17. D-click **Watershed /**Symbology**/** Color ramp /Elevation 1/OK





Result: Watershed is created.

Question: How many sub-basins are in the watershed?

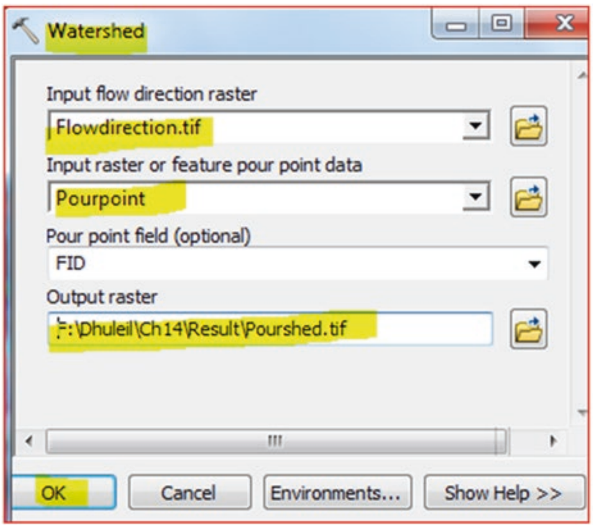
Point-Based Watershed

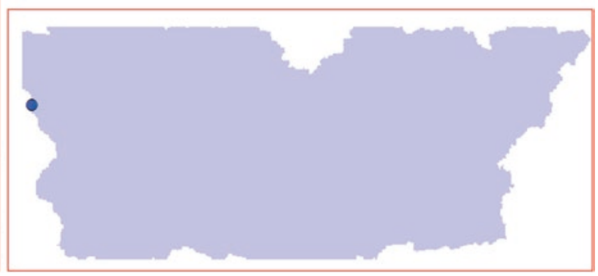
This approach allows the user to derive a watershed either for each stream or based on a point of interest such as any point of interest along the flow system.

Scenario 2: Your superior asked you to create only one watershed based on a point (Pourpoint.shp) and then calculate the total area of the watershed.

Run the watershed using **Pourpoint**

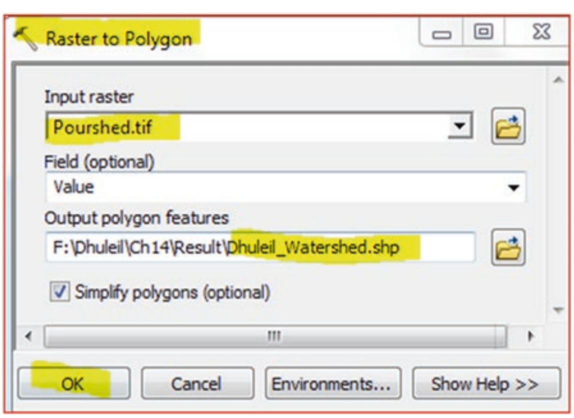
18. Insert Data Frame and rename it to **PourPoint**
19. Drag the **Flowdirection.tif**, and **Pourpoint.shp** from Dhuleil data frame
20. Spatial Analyst Tools/Hydrology/Watershed
21. Input flow direction raster: **Flowdirection.tif**
22. Input raster or feature pour point data: **Pourpoint**
23. Output raster: **Pourshed.tif**
24. OK
25. Change the color ramp of the **Pourshed.tif** into Blue Bright

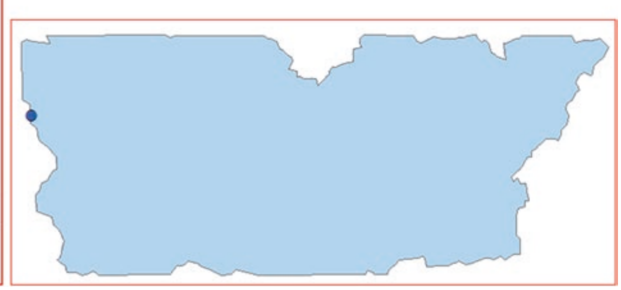




Convert Pourshed Raster to Vector

26. ArcToolbox/Conversion Tools/From Raster/Raster to Polygon
27. D-click Raster to Polygon
28. Input raster: Pourshed.tif
29. Output polygon features: \\Result\Dhuleil_Watershed.shp
30. Ok

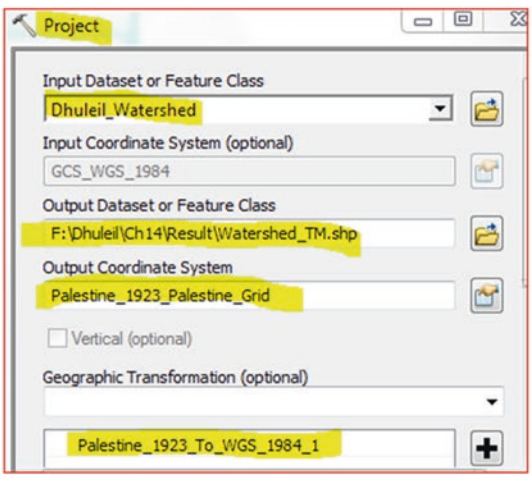


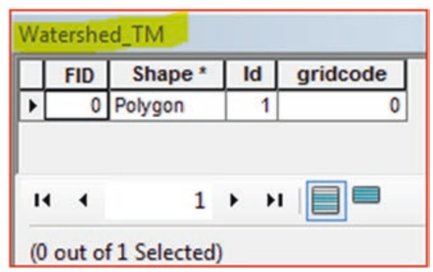


Calculate the Recharge amount of the Dhuleil_Watershed

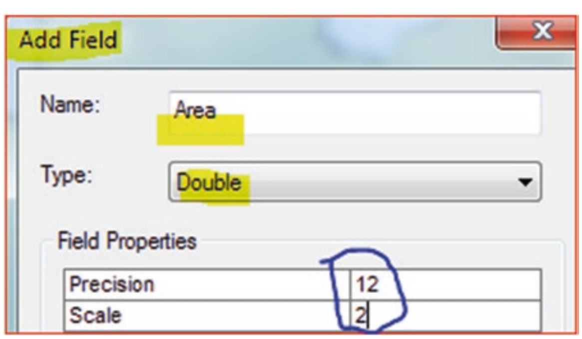
In order to calculate the Dhuleil_Watershed area, you have to project it into plane projection (Palestinian Grid)

31. ArcToolbox/Data Management Tool/ Projections and Transformations/Feature
32. D-click Project and fill as below
33. Input Dataset: Dhuleil_Watershed
34. Input Coordinate System: GCS_WGS_1984 (Default)
35. Output Dataset: \\Result\Watershed_TM.shp
36. Output Coordinate System: Browse\Projected Coordinate Systems\National Grid \Asia\Palestine 1923 Palestine Grid
37. OK
38. Geographic Transformation: Palestine_1923_T0_WGS_1984_1
39. OK



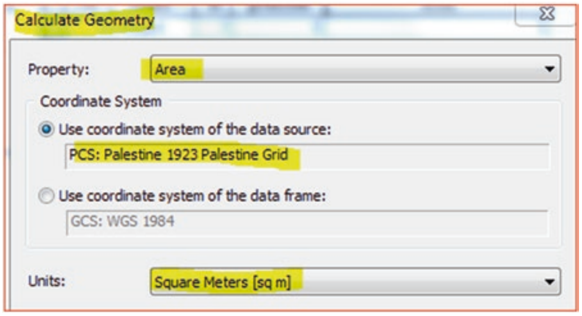


40. Open attribute table of Watershed_TM
41. Table Option/Add Field
42. Name: Area
43. Type: Double (Precision 12, Scale 2)
44. OK



45. R-click Area/Calculate Geometry/click Yes
46. Property: Area
47. Coordinate System: Palestine 1923 Palestine Grid
48. Units: Square Meters

49. OK



50. What is the total area?

Task: Calculate the recharge, if the amount of precipitation is 120 mm and the infiltration rate is 5%.
Hint:

1. Recharge = Area (m^2) × Infiltration Rate (120 × 0.05 mm)
2. Convert the mm into meter (1 mm = 0.001 m)