Exercise 22: Surface Hydrologic Analysis

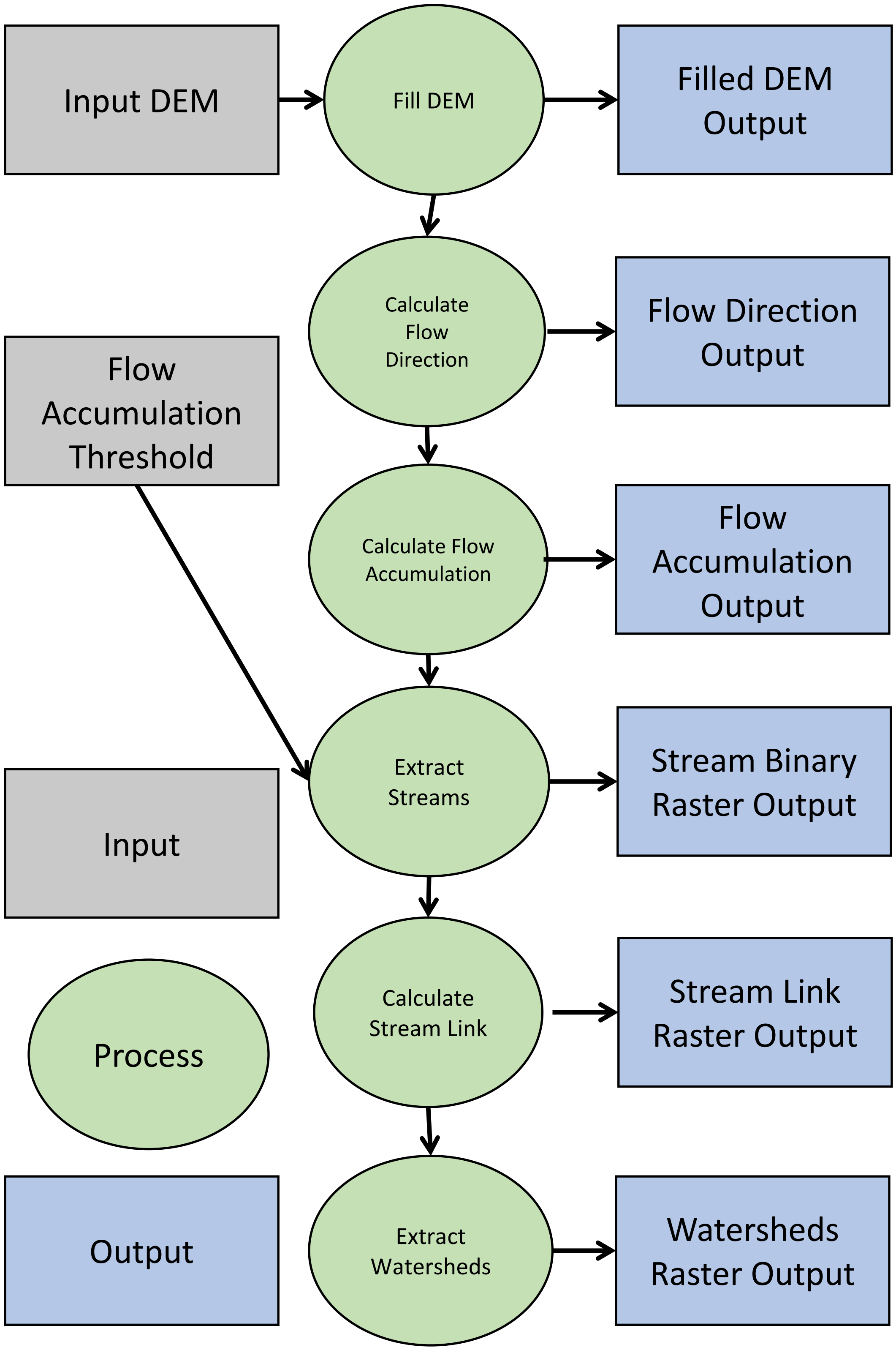
ArcGIS Pro provides tools for analyzing surface water and ground water flow. Here, we will focus on surface processes and introduce the hydrology tools available in the Spatial Analyst Toolbox. Our goal here will be to derive a variety of hydrologic surfaces and eventually derive watershed boundaries.

It should be noted that there are additional tools available for creating hydrologic outputs from digital elevation model (DEM) data. One example is TauDEM (http://hydrology.usu.edu/taudem/taudem5/index.html), which is available as an ArcGIS Pro extension.

Topics covered in this exercise include:

1. How to fill a DEM for hydrologic modeling.
2. How to create a flow direction grid.
3. How to create a flow accumulation grid.
4. How to produce a synthetic stream network.
5. How to create watershed boundaries.
6. How to calculate stream order.

The flow chart below describes the process undertaken to produce hydrologic derivatives from a DEM. This process assumes that water flows downhill and models this downhill motion using a DEM. First, you will need to create a filled DEM so that water can travel downhill without getting caught in a local depression. Note that sometimes this is not necessary, as the DEM may already be filled. Next, you will calculate flow direction and flow accumulation. Flow direction indicates which neighboring cell water will migrate to while flow accumulation counts the number of cells that will drain into a specific cell. Once you have the initial grids, you will need to set a flow accumulation threshold to define streams. In this lab we will use 200 acres. Using this binary "stream/not stream" distinction and the flow direction grid, you will determine stream linkages. Using the stream linkage and flow direction data, you finally produce watersheds as a raster and then convert them to polygons.


Input DEM
Fill DEM
Filled DEM Output
Calculate Flow Direction
Flow Direction Output
Flow Accumulation Threshold
Calculate Flow Accumulation
Flow Accumulation Output
Extract Streams
Stream Binary Raster Output
Input
Calculate Stream Link
Stream Link Raster Output
Process
Output
Extract Watersheds
Watersheds Raster Output

Before starting this lab, answer the following questions to make sure you have the required theoretical knowledge to work through this lab.

Question 1. Explain why it is necessary to fill a DEM before creating hydrologic derivatives. (5 Points)

Question 2. Explain the difference between a flow direction and a flow accumulation grid. (5 Points)

Question 3. Explain some of the assumptions when trying to predict stream discharge using flow accumulation values. What are some other important variables that are not included in this model? (5 Points)

Question 4. The flow accumulation at a certain cell is 3000. This raster has a resolution of 30 m by 30 m. Find the flow accumulation in square meters at this pixel. Show your work. (5 Points)

Question 5. For the data presented in Question 4, calculate the flow accumulation in acres. Show your work. (5 Points)

Question 6. For a stream with a measured discharge of 120 cfs at the outlet, the flow accumulation value at the stream outlet is 3000. Using the ratio method, estimate the discharge in cfs for a stream with a flow accumulation value of 4500 at the outlet. Show your work. (5 Points)

Question 7. List some examples of assumptions and difficulties associated with the ratio method for predicting stream discharge from flow accumulation data. (5 Points)

Step 1. Open a Map Project

First, we need to download and open the **Exercise_22.aprx** file.

- Download the **Exercise_22** data from https://www.wvview.org/. All lab materials are available on the course webpage and linked to the exercise. You will need to extract the compressed files and save it to the location of your choosing.
- Open ArcGIS Pro. This can be done by navigating to All Apps followed by the ArcGIS Folder. Within the ArcGIS Folder, select ArcGIS Pro. Note that you can also use a Task Bar or Desktop shortcut if they are available on your machine.
- After ArcGIS Pro launches, select “Open another project.”

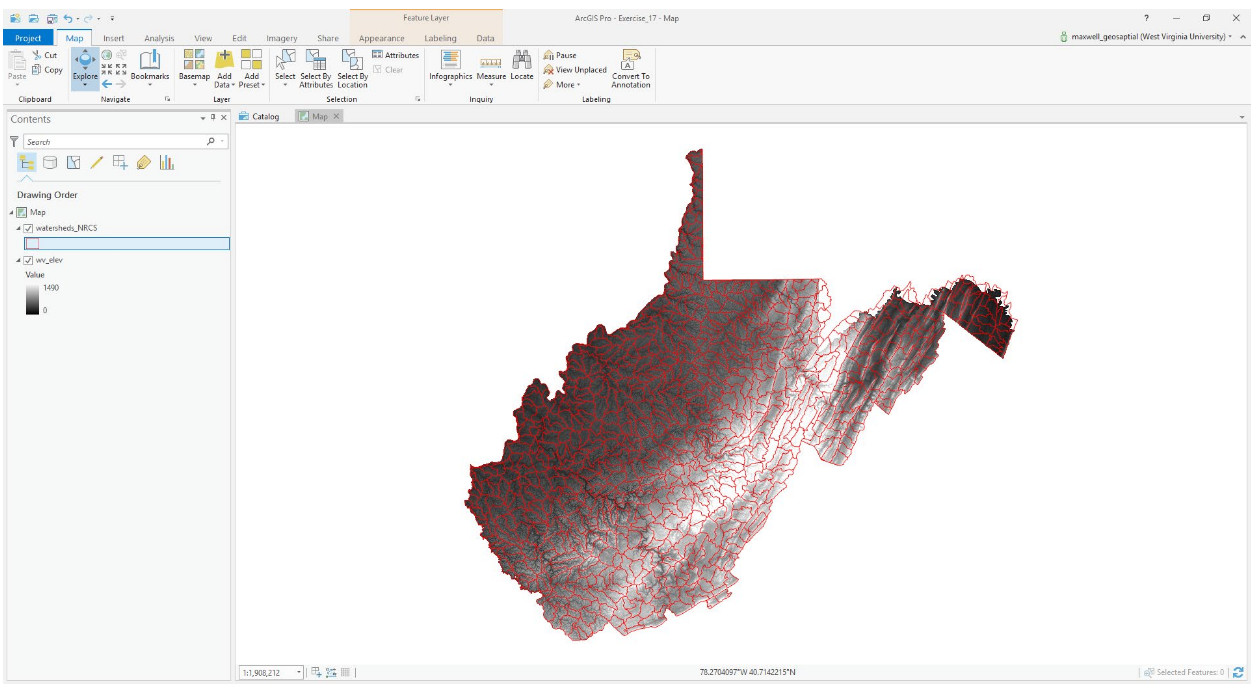
- Navigate to the directory that houses the material for this course. The project files are in the **Exercise_22** folder where it was saved on your local machine.
- Select **Exercise_22.aprx**. Click OK to open the project.
- If necessary, navigate to the WV map.

Note: If you would prefer, you can also just click on the **Exercise_22.aprx** file within the uncompressed folder directly to launch ArcGIS Pro.

This project contains a single map that contains two data layers.

watersheds_NRCS: polygon watershed extents.

wv_elev: digital elevation model (DEM) in meters for entire state of West Virginia.



Step 2. Set Environment Settings

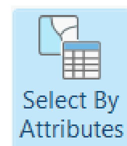
- Navigate to the Analysis Tab then select Environments in the Geoprocessing Area.
- Change the Current Workspace and the Scratch Workspace to the **Exercise_17.gdb** geodatabase in the **Exercise_22**

folder. This will cause all the outputs to automatically be saved to this location.
- Click Okay to accept these settings.

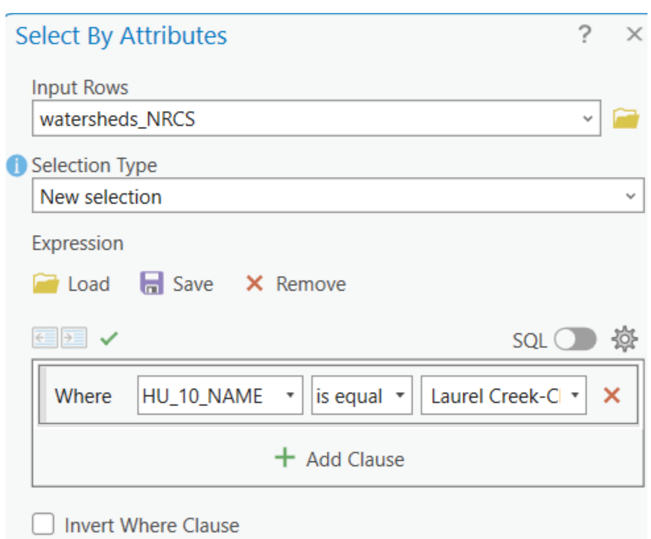
Step 3. Extracting Required Data

You have been provided with watershed boundaries for the entire state and a DEM for the entire state. However, you will perform an analysis for only Laurel Creek-Cherry Run. So, you will start by extracting these watersheds. You will then use this boundary to extract the DEM data.

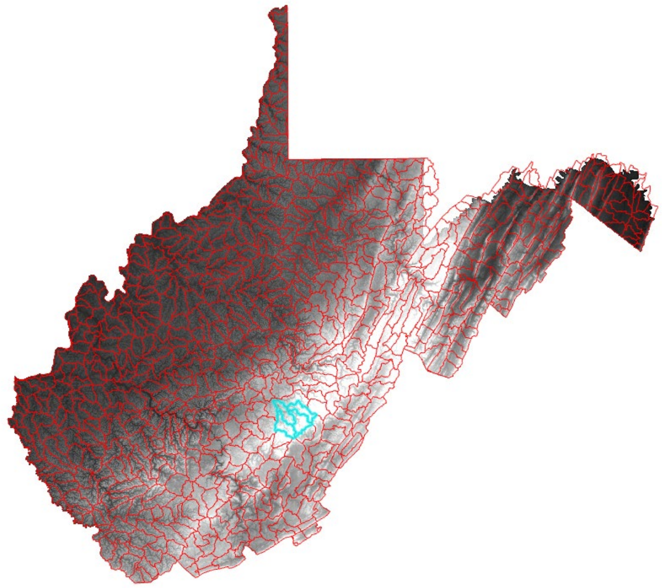
First, you will use the Select by Attribute Tool to select the required watersheds.



- Navigate to the Map Tab and Select By Attribute from the Selection area. This will open the **Select by Attributes Tool**.
- Set the Layer Name or Table View to the **watersheds_NRCS** layer.
- Make sure the Selection type is set to "New selection."
- Select Add Clause to add a new clause.
- Set the Field to "HUC_10_NAME."
- Set the operator to "is equal to."
- Set the value equal to "Laural Creek-Cherry Run" (you can get this from the available list).
- Add the clause.
- Click Run to execute the tool.



The watershed of interest should be selected.

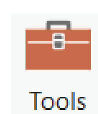


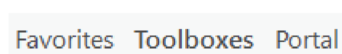
Although it is not necessary to do so, we will have you export the watersheds.

- Right-click on the **watersheds_NRCS** layer in the Contents Pane.
- Select Data followed by Export Features. This will open the **Copy Features Tool**.
- Name the Output Feature Class **watershed_extact** and save it to the **Exercise_22.gdb** geodatabase in the **Exercise_22** folder. The layer should automatically be added to your map.

You will now use the new watershed boundaries to extract out the DEM. You will do this using the **Extract by Mask Tool**.

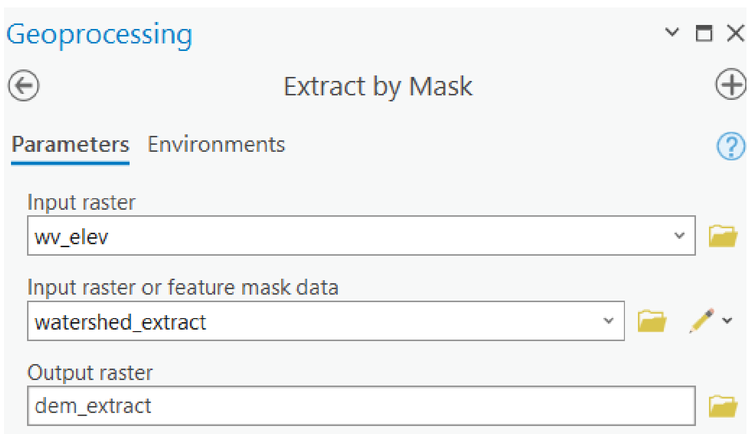
- In the Analysis Tab, select Tools from the Geoprocessing Area. This should open the Geoprocessing Pane.
- In the Geoprocessing Pane, navigate to the Toolboxes.





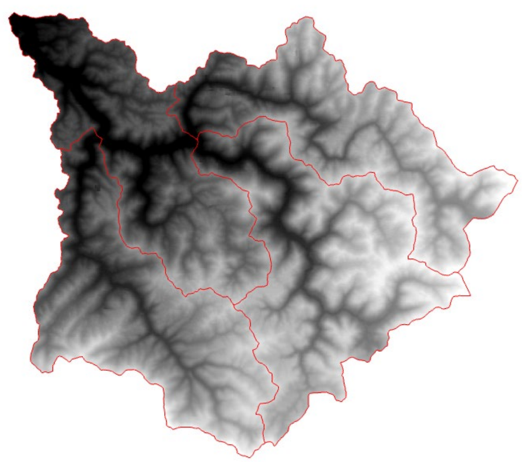
Note: We will not provide these directions for accessing other tools. We will just tell you where to find them within ArcToolbox.

- Navigate to Spatial Analyst Tools followed by the Extraction sub toolbox.
- Click on the **Extract by Mask Tool**.
- Set the Input Raster to the **wv_elev** layer.
- Set the Input Raster or Feature Mask Data to the **watershed_extract** layer.
- Name the output **dem_extract** and save it to the **Exercise_22.gdb** geodatabase in the **Exercise_22** folder. It should save here automatically since this was defined in the environments.
- Click Run to execute the tool. The output should automatically be added to your map.



You have now extracted the required DEM data.

- At this time, we would suggest turning off the **watersheds_NRCS** and **wv_elev** layers and zooming to the extent of the new data layers.

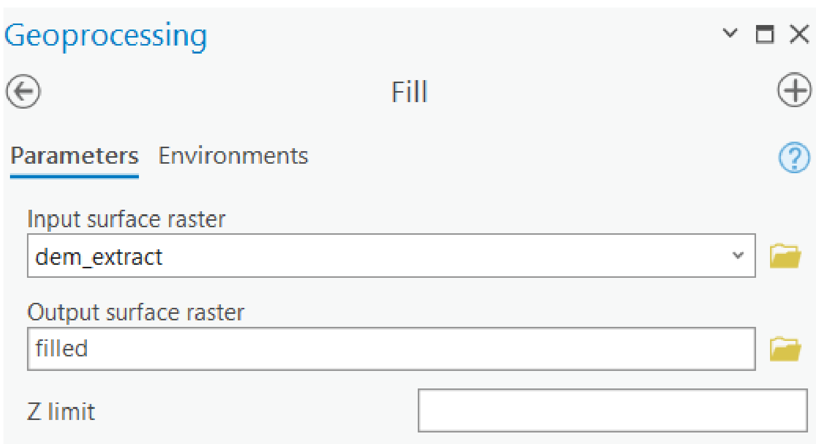


Note: In this example you had to extract a portion of a DEM. However, it is often necessary to merge multiple DEMs together. This can be accomplished with the **Mosaic To New Raster Tool** available in the Data Management Toolbox.

Step 4. Fill DEM

We will start our analysis by filling in the DEM. Note that this is not always necessary since some DEMs have already been filled or are hydrologically corrected. This operation can take some time to complete on a large DEM.

- Navigate to Spatial Analyst Tools followed by the Hydrology sub toolbox.
- Click on the **Fill Tool**.
- Set the Input Surface Raster to the **dem_extracted** layer.
- Name the Output Surface Raster **filled**.
- You do not need to change any of the other settings.
- Click Run to execute the tool. The output should automatically be added to your map.

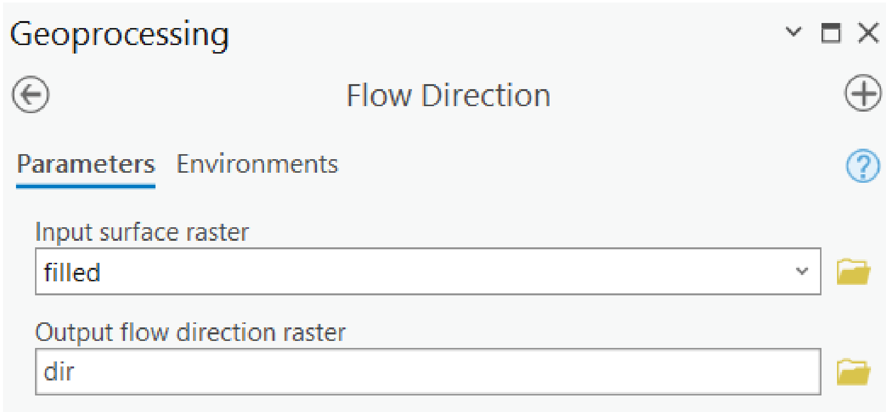


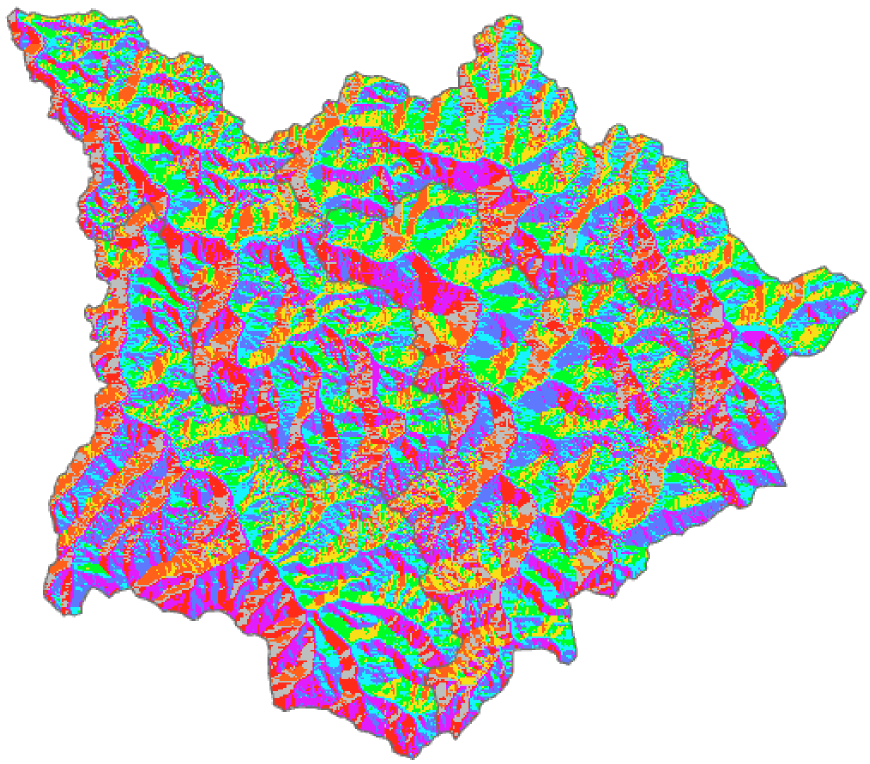
Question 8. Explain the purpose of the Z limit option. (4 Points)

Step 5. Create a Flow Direction Grid

The next step is to create a flow direction grid from the filled DEM.

- Navigate to Spatial Analyst Tools followed by the Hydrology sub toolbox.
- Click on the **Flow Direction Tool**.
- Set the Input Surface Raster to the **filled** layer.
- Name the Output Flow Direction Raster **dir**.
- You do not need to change any of the other settings.
- Click Run to execute the tool. The output should automatically be added to your map.



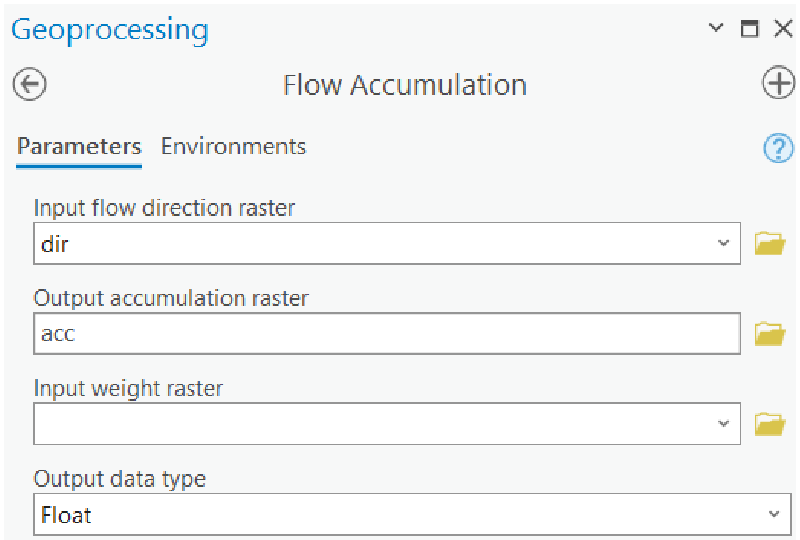


Step 6. Create a Flow Accumulation Grid

Next, you will create a flow accumulation grid from the flow direction surface.

- Navigate to Spatial Analyst Tools followed by the Hydrology sub toolbox.
- Click on the **Flow Accumulation Tool**.
- Set the Input Flow Direction Raster to the **dir** layer.

- Name the Output Flow Accumulation Raster **acc**.
- Make sure the Output Data Type is set to float.
- You do not need to change any of the other settings.
- Click Run to execute the tool. The output should automatically be added to your map.



Question 9. Explain the difference between a float and an integer output.

(4 Points)

Step 7. Extract Stream

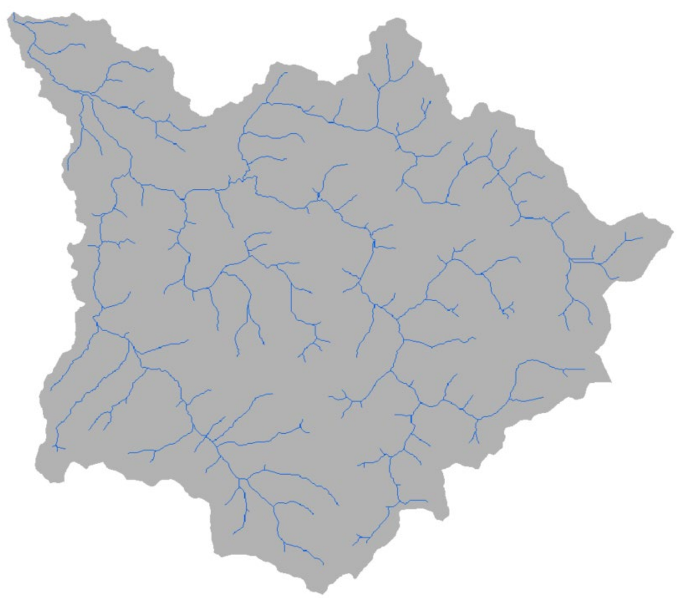
We will now extract streams using a threshold of 200 acres. The flow accumulation grid expresses a count of pixels. So, you will need to determine the number of pixels that are equivalent to 200 acres. Remember that the cell size of your flow accumulation grid is 30 x 30 meters.

Question 10. Calculate the number of pixels in your flow direction grid that would correspond to 200 acres. Show your work. (4 Points)

Once you have calculated the number of pixels, you will need to use the **Raster Calculator Tool** to select the raster cells that have a flow accumulation larger than this number.

Acc > Your Threshold

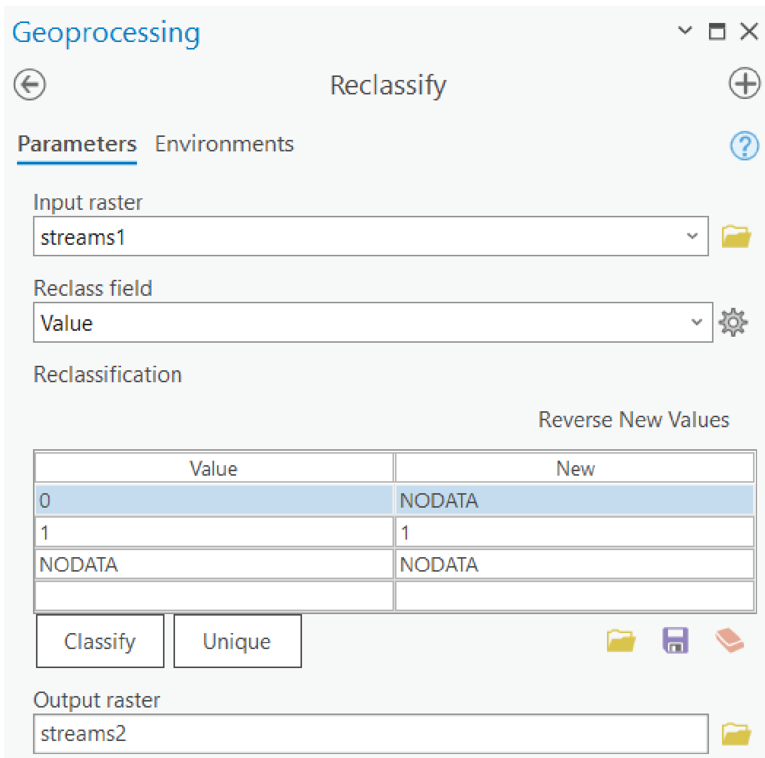
- Use the **Raster Calculator Tool** to obtain a binary grid of stream vs. not stream using your threshold value. Name the output **streams1**.



This calculation will produce a binary raster in which 1 represents pixels that were selected as streams and 0 represents non-stream pixels. You will now need to reclassify the 0 pixels to NoData using the Reclassify Tool.

- Navigate to Spatial Analyst Tools followed by the Reclass sub toolbox.
- Click on the **Reclassify Tool**.
- Set the Input Raster to the **streams1** layer.

- Make sure the Reclass Field is set to "Value."
- In the New column in the table make sure the first column is set to NODATA, the middle to 1, and the last to NODATA. So, the stream cells will have a value (1) and all other cells will be NODATA. **Note:** Make sure to hit enter after changing a value or the table will convert back to the old value.
- Name the Output Raster **streams2**.
- You do not need to change any of the other settings.
- Click Run to execute the tool. The output should automatically be added to your map.

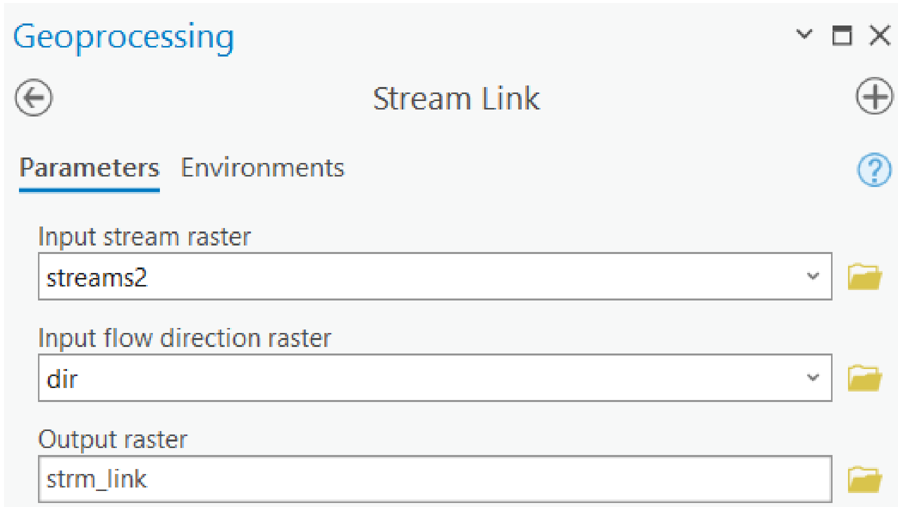


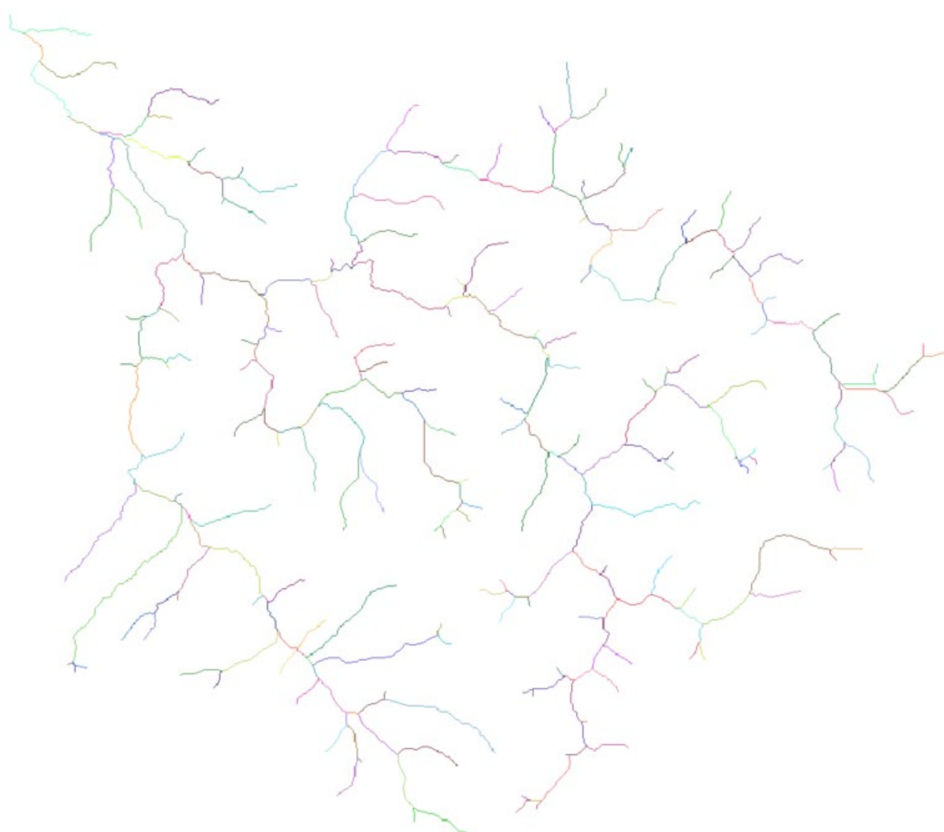
Step 8. Calculate Stream Link Grid

Before you can create watersheds, you will need to create a stream link grid that assigns a unique raster grid value to each stream segment.

- Navigate to Spatial Analyst Tools followed by the Hydrology sub toolbox.
- Click on the **Stream Link Tool**.
- Set the Input Stream Raster to the **streams2** layer.
- Set the Input Flow Direction Raster to the **dir** layer.
- Name the Output Raster **strm_link**.

- You do not need to change any of the other settings.
- Click Run to execute the tool. The output should automatically be added to your map.

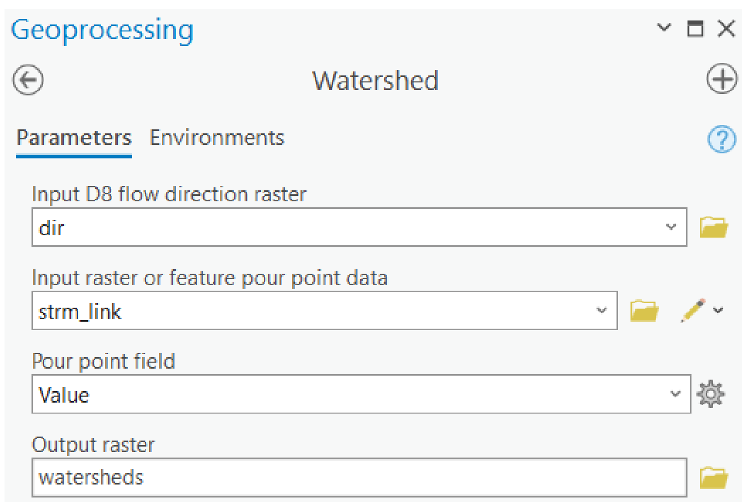


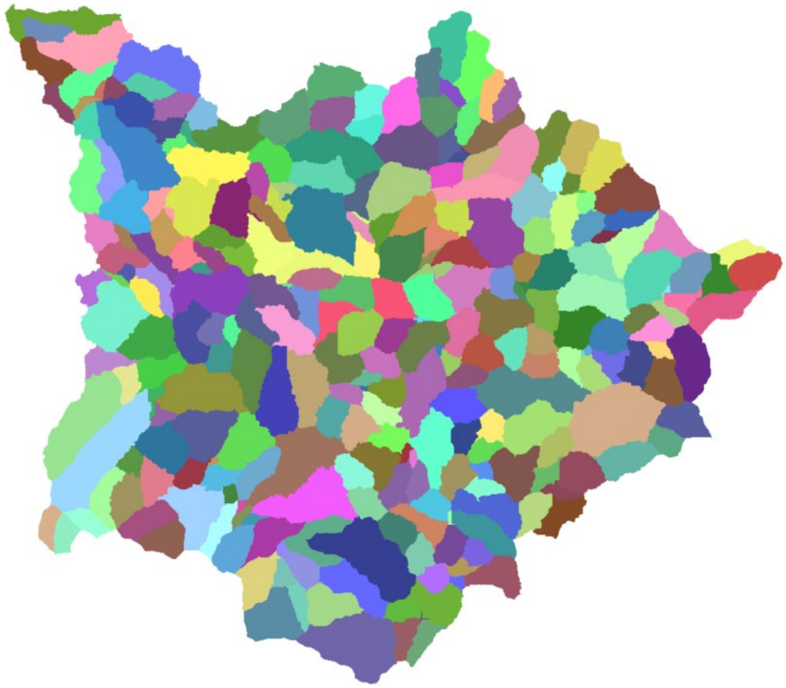


Step 9. Extract Watersheds

You can now create watershed boundaries using the raster grids created above.

- Navigate to Spatial Analyst Tools followed by the Hydrology sub toolbox.
- Click on the **Watershed Tool**.
- Set the Input Flow Direction Raster to the **dir** layer.
- Set the Input Raster or Feature Pour Point Data to the **strm_link** Layer.
- Make sure the Pour Point Field is set to "Value."
- Name the output **watersheds**.
- You do not need to change any of the other settings.
- Click Run to execute the tool. The output should automatically be added to your map.



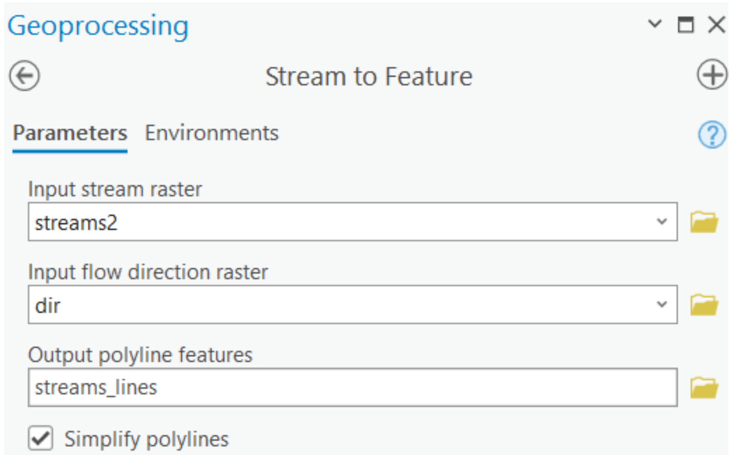


Note: If your map shows a black and white gradient, go to the symbology tab, and select Unique Values rather than Stretch for the method.

Step 10. Converting Results to Vector Features

You will now convert your streams to vector line features using the **Streams to Feature Tool**.

- Navigate to Spatial Analyst Tools followed by the Hydrology sub toolbox.
- Click on the **Stream to Features Tool**.
- Set the Input Stream Raster to the **streams2** layer.
- Set the Input Flow Direction Raster to the **dir** layer.
- Name the Output Polyline Features **streams_lines**.
- Check the Simplify Polylines option (This should be the default).
- Click Run to execute the tool. The output should automatically be added to your map.

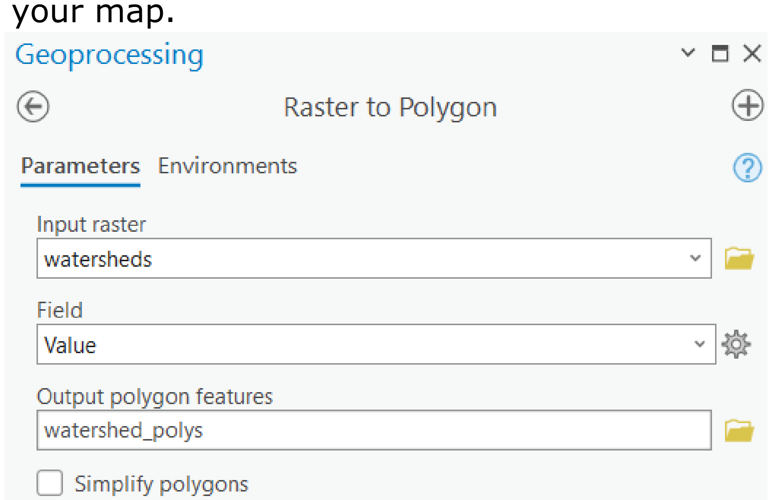


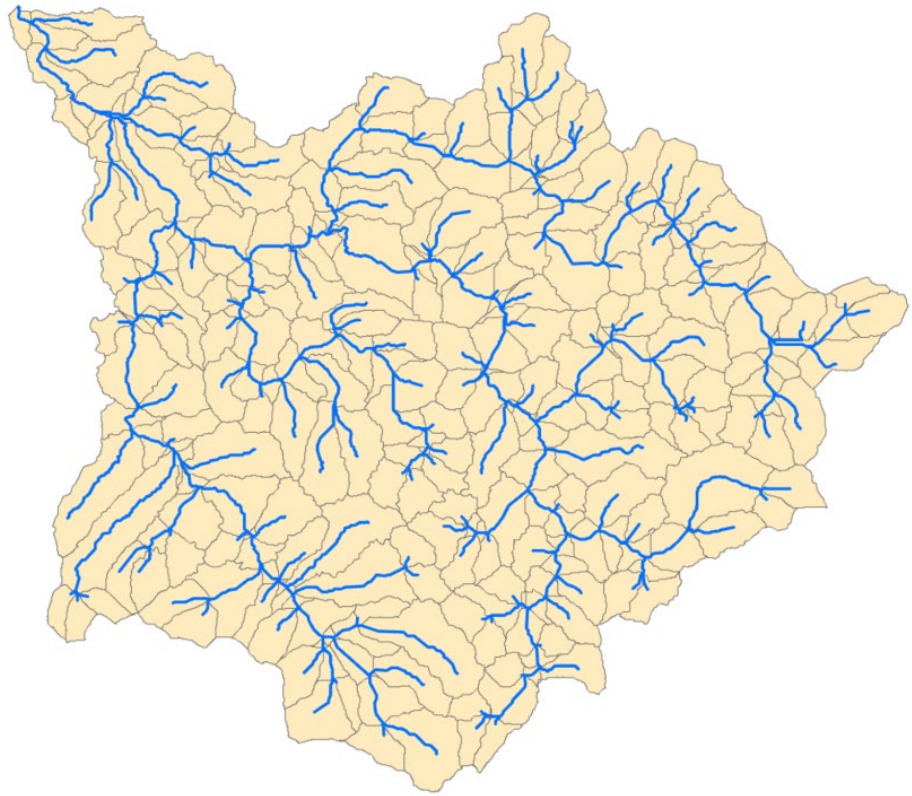
This should generate a line vector object. Note that the streams were smoothed or simplified since the Simplify Polylines options was selected.

Question 11. How many unique stream segments were created? (2 Points)

You will now convert your watershed raster to polygons using the **Raster to Polygon Tool**.

- ☐ Navigate to Conversion Tools followed by the From Raster sub toolbox.
- ☐ Click on the **Raster to Polygon Tool**.
- ☐ Set the Input Raster to the **watersheds** layer.
- ☐ Make sure the Field is set to "Value."
- ☐ Name the Output Polygon Features **watershed_polys**.
- ☐ Do **not** select Simplify Polygons (This should be the default).
- ☐ Click Run to execute the tool. The output should automatically be added to your map.



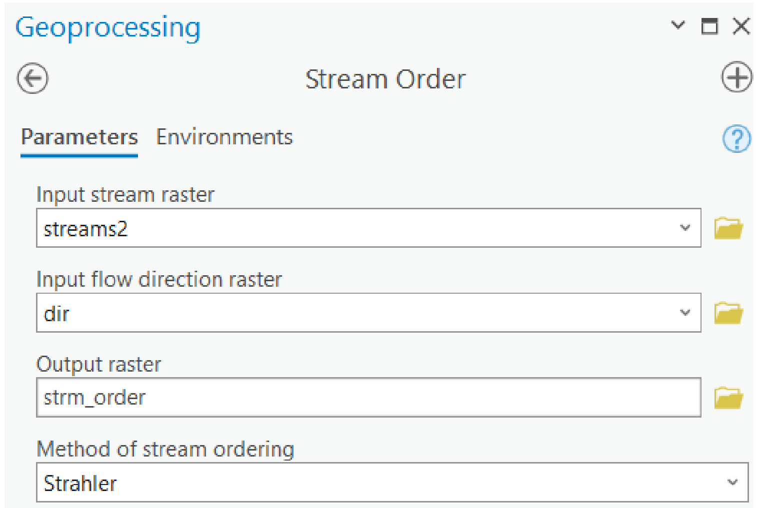


Question 12. How many unique watersheds were created? (2 Points)

Step 11. Calculate Stream Order

Lastly, you will calculate stream order using the Strahler method.

- Navigate to Spatial Analyst Tools followed by the Hydrology sub toolbox.
- Click on the **Stream Order Tool**.
- Set the Input Stream Raster to the **streams2** layer.
- Set the Input Flow Direction Raster to the **dir** layer.
- Name the output raster **strm_order**.
- Make sure the method is set to “Strahler.”
- Click Run to execute the tool. The output should automatically be added to your map.



Question 13. Using the attribute table for the stream order output, which stream order (1st, 2nd, 3rd, or 4th) had the largest number of stream pixels attributed to it? (2 Points)

Step 12. Create a Map

Deliverable 1 (15 Points)

Create a map that includes the following or meets the following criteria. Submit it as a PDF. This will be worth 15 Points.

1. A title and your name (1 Point)
2. A north arrow and scale bar (1 Point)
3. The watershed boundaries as polygons are shown as hollow polygons (1 Point)
4. The stream lines as vector lines are shown (1 Point)
5. A hillshade is generated from the DEM and is displayed beneath the watershed boundaries and stream lines (2 Points)
6. A legend showing only the stream lines and watershed boundaries (3 Points)
7. Space is used effectively (3 Points)
8. Overall neatness of map layout (3 Points)

END OF EXERCISE