Geographic Information Systems in Water Resources
Watershed and Stream Network Delineation Exercise

CUAHSI Virtual University, 2019
David Tarboton

Purpose

TauDEM (Terrain Analysis Using Digital Elevation Models) is a set of Digital Elevation Model (DEM) tools for the extraction and analysis of hydrologic information from topography as represented by a DEM. This is software developed at Utah State University (USU) for hydrologic digital elevation model analysis and watershed delineation and may be obtained from http://hydrology.usu.edu/taudem/taudem5/.

The purpose of this exercise is to introduce Hydrologic Terrain Analysis in ArcGIS using the TauDEM toolbox and to guide you through the initial steps of installing TauDEM loading data and running some of the more important functions required to delineate a stream network and watershed. This is a simplified version of tutorials given in the TauDEM documentation. Refer to the TauDEM documentation if you want to learn about other TauDEM functions (http://hydrology.usu.edu/taudem/taudem5/documentation.html).

There is considerable similarity between TauDEM and some of the functionality in ArcGIS, though TauDEM does provide some enhanced capability that is used here. If you want to see how to do something similar using ArcGIS tools refer to the GIS in Water Resources class presented in 2018 with David Maidment http://hydrology.usu.edu/dtarb/giswr/2018/. Specifically, classes 9-12 cover this content. If you have trouble with TauDEM, which may occur if you do not have permissions to install software on the computer you are using, then instead of the exercise below, do Exercise 4 from this 2018 class.

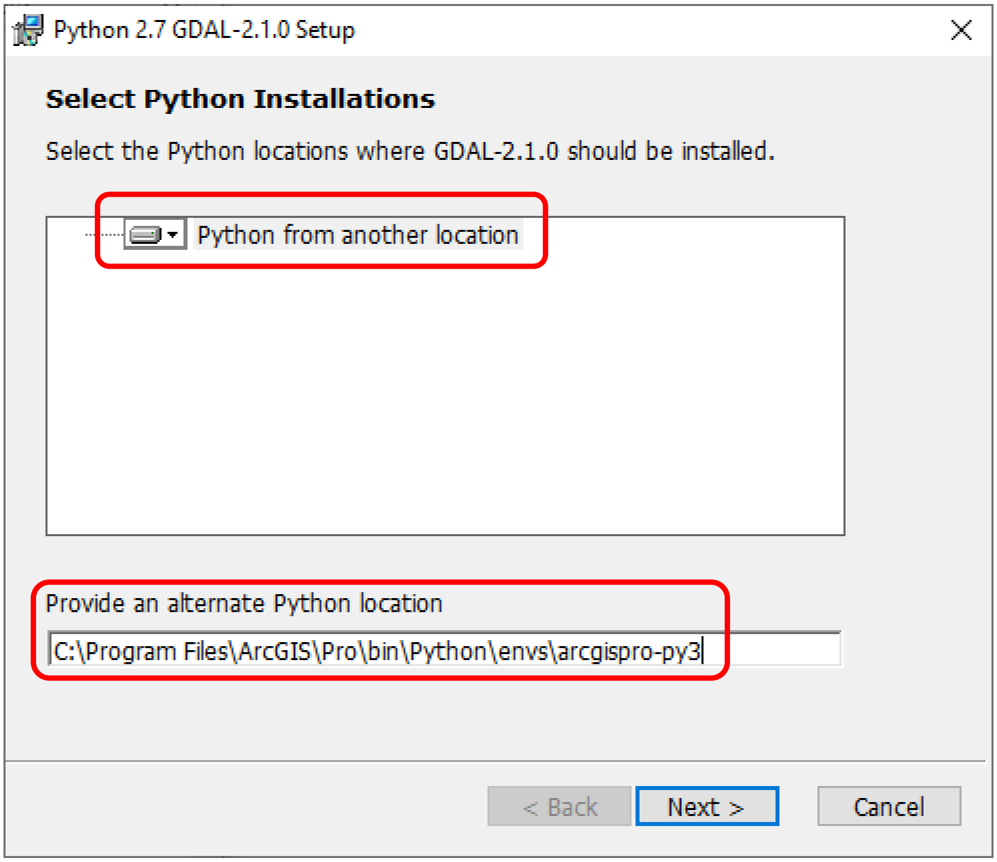
Learning objectives

- Identify and properly execute the sequence of TauDEM tools required to delineate streams, catchments and watersheds from a DEM.
- Evaluate and interpret drainage area and stream length properties from Terrain Analysis results.
- Develop a map of topographic wetness index for the Logan River Watershed.
- Develop a map of height above nearest drainage for the Logan River Watershed.

Install TauDEM

Download and install the TauDEM software following the instructions at http://hydrology.usu.edu/taudem/taudem5/downloads.html. You will need administrator rights on the computer to do the installation. Use TauDEM 5.3.7 Complete Windows Installer, the top link in the Downloads page.

When prompted to Select Python Installations, choose



This is the version of Python distributed with ArcGIS.

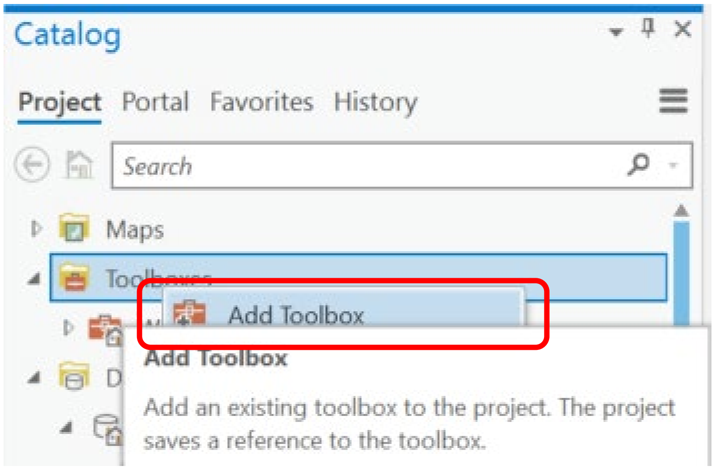
(I think it also works if you do not identify a Python location and just click Next. The Python location is only used for Terrain Stability functions which we will not use).

The TauDEM setup package will install a number of dependency components. Installation should be a matter of agreeing and saying yes to the default prompts during the install.

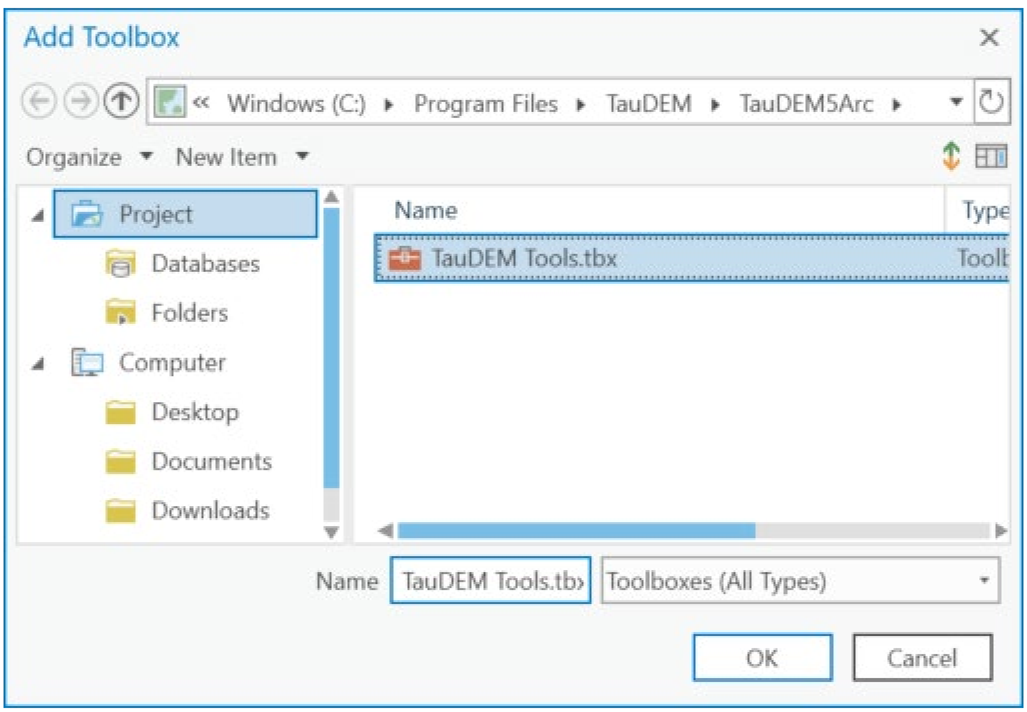
The TauDEM Toolbox for ArcGIS is by default installed in C:\Program Files\TauDEM\TauDEM5Arc. It does not appear in the Geoprocessing Pane in ArcGIS. Instead it needs to be added as a Project Toolbox.

1. Open ArcGIS Pro and create a new map project. I used the folder C:\Users\dtarb\Documents\ArcGISWork\WatershedDelineationExercise to hold this project. You should pick a similar location to keep track of where your work is.

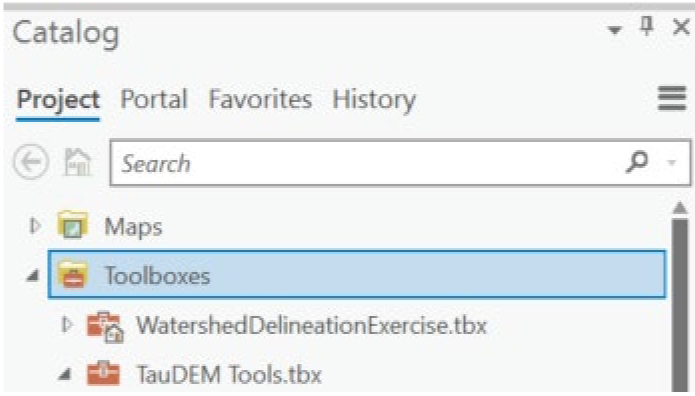
2. In the Catalog Pane Project Tab Right Click on Toolboxes and select Add Toolbox



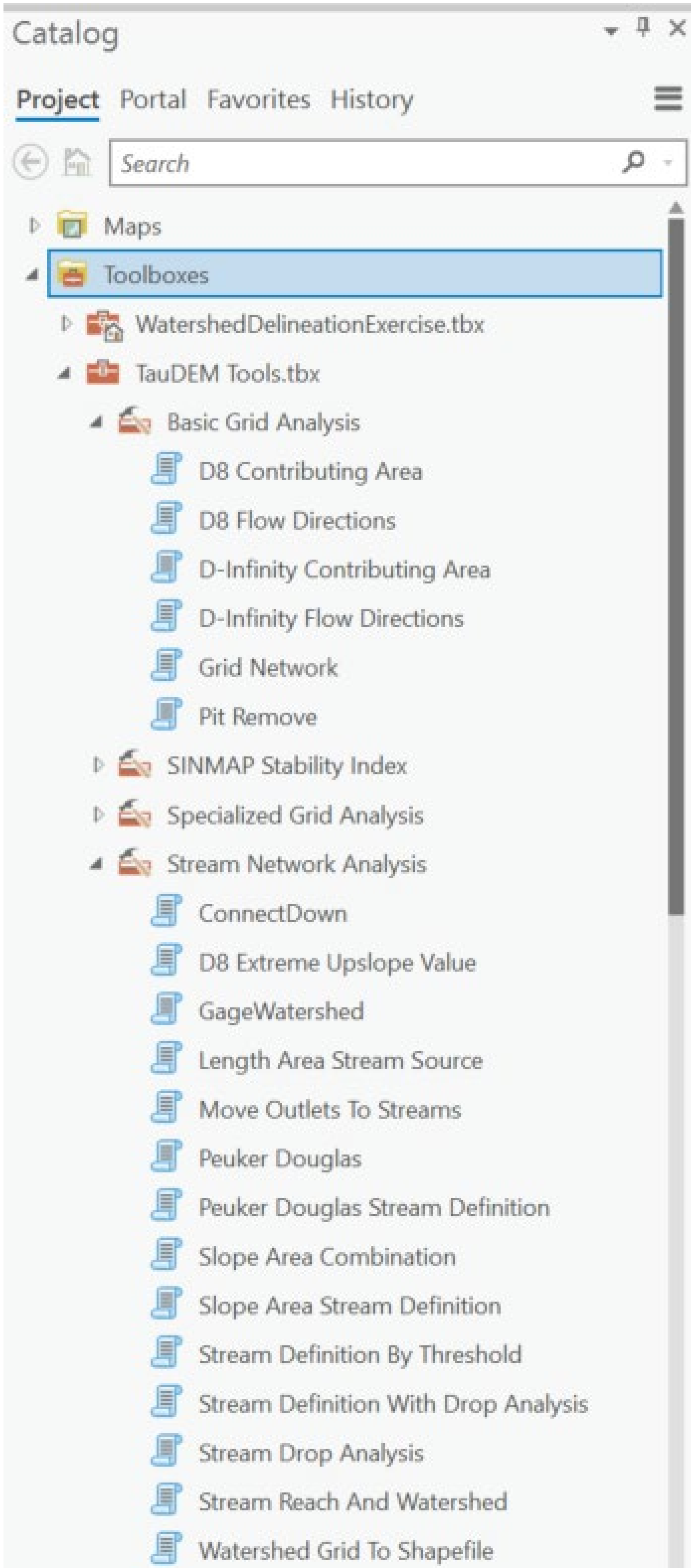
Browse to and Click on TauDEM Tools in C:\Program Files\TauDEM\TauDEM5Arc (by default)



You should now have TauDEM Tools available in the Toolboxes for your project.


Catalog
Project
Portal
Favorites
History
Search
Maps
Toolboxes
WatershedDelineationExercise.tbx
TauDEM Tools.tbx

Expand to see the various tools available.



3. Save your project.

Data

The USGS NWIS website for the Logan River:
http://waterdata.usgs.gov/nwis/inventory?agency_code=USGS&site_no=10109000 gives the following information about the Logan River Stream Site.

USGS 10109000 LOGAN RIVER ABOVE STATE DAM, NEAR LOGAN, UT

Available data for this site SUMMARY OF ALL AVAILABLE DATA GO

Stream Site

DESCRIPTION:
Latitude 41°44'36", Longitude 111°46'55" NAD27
Cache County, Utah, Hydrologic Unit 16010203
Drainage area: 214 square miles
Datum of gage: 4,680.00 feet above NGVD29.

Note the Latitude, Longitude and geographic coordinate system (NAD27). Note also the drainage Area.

Compute the latitude and longitude in decimal degrees for the Logan River stream gage in an Excel Spreadsheet and save it as a .csv file (LoganGage.csv). Retain at least 5 significant figures of precision in LatDD and LongDD.

	A	B	C	D	E	F	G	H	I
1	SiteID	LatDeg	LatMin	LatSec	LongDeg	LongMin	LongSec	LatDD	LongDD
2	10109000	41	44	36	111	46	55	41.74333	-111.78194

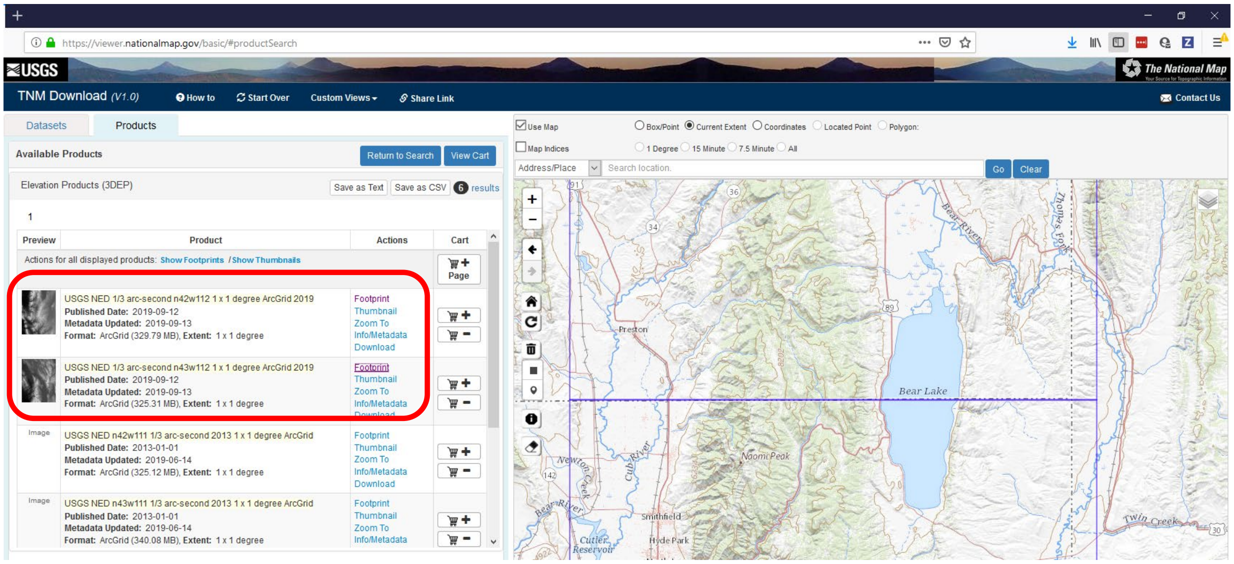
Digital Elevation Model Data

Go to the national map viewer https://viewer.nationalmap.gov/basic/ Elevation Products (3DEP)

If you examine availability you will see that while there is some 1/9 arc second and 1 meter DEM data available for the Logan River, it is not for the entire basin. Thus we will work with 1/3 arc-second data. This is nominally 10 m resolution.

Search for data available in the Logan River Basin area and download the following products

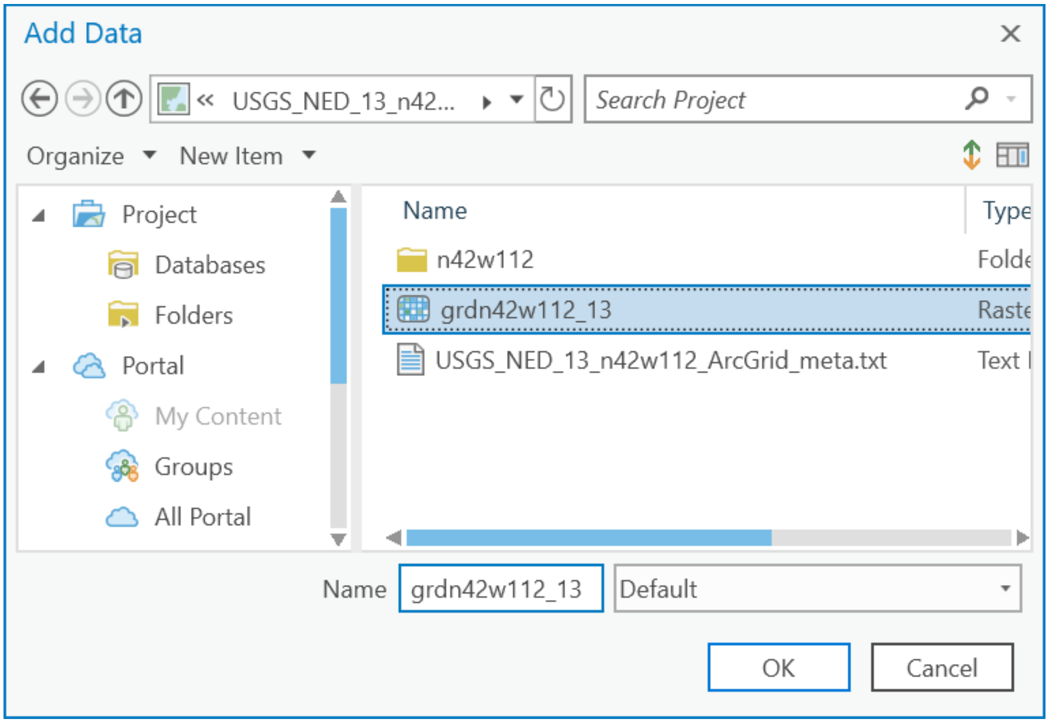
- USGS_NED_13_n43w112_ArcGrid.zip
- USGS_NED_13_n42w112_ArcGrid.zip



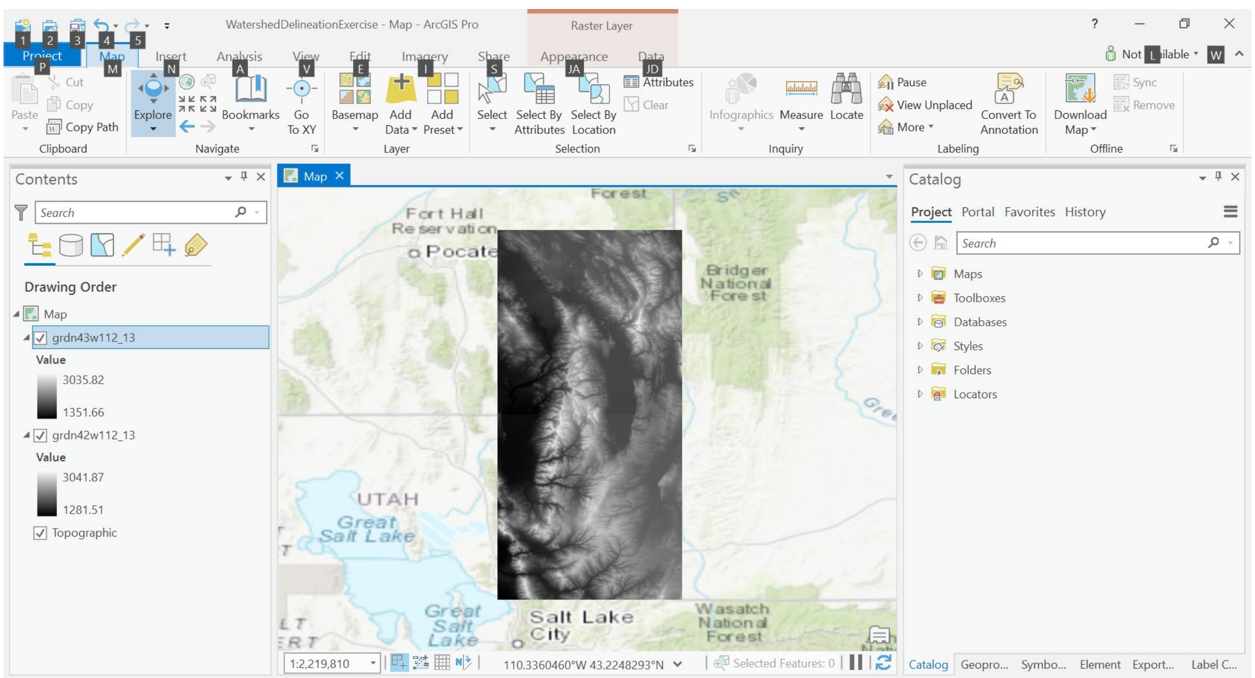
Preparing the data

In this section we combine the two DEM raster grids into a single raster using the ArcGIS "mosaic" function. We then clip the DEM to the extent of a 1 km buffer around the Logan River Basin extracted in Exercise 3. This reduces it to a manageable size so that the functions run quickly. This step is strictly not necessary. You could do all this work with the entire DEM downloaded. However to save time and obtain results more quickly while learning it is instructive to work with a smaller grid. We also create an outlet shapefile at the location of the Logan River stream gage.

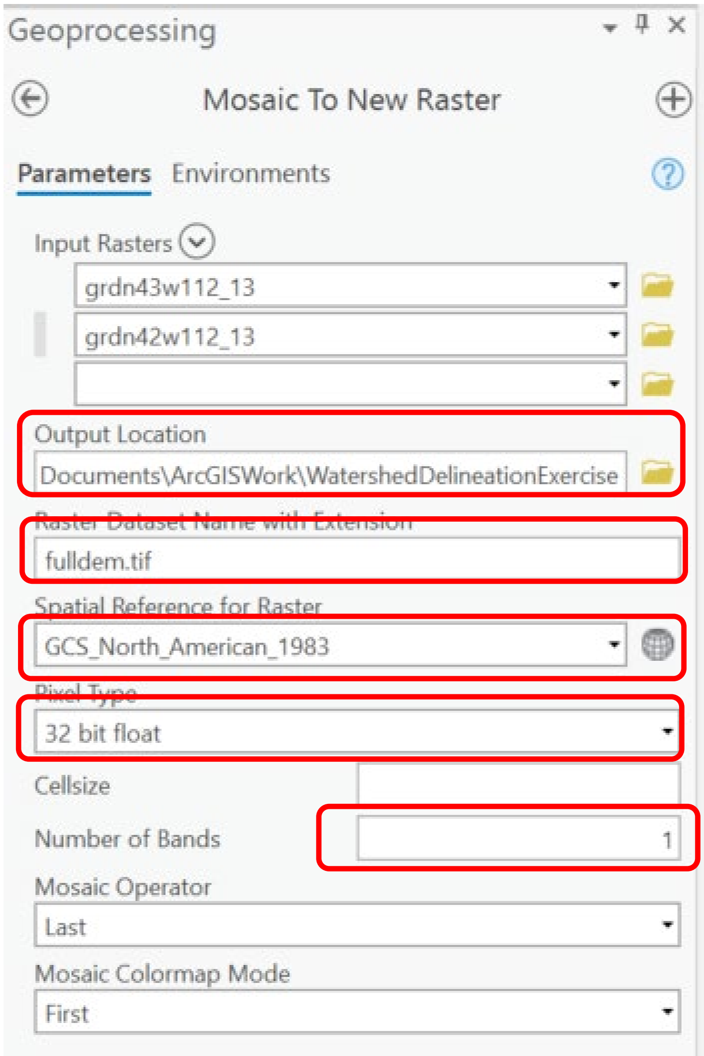
1. Open your ArcGIS Pro project if necessary.
2. Unzip the two files USGS_NED_13_n43w112_ArcGrid.zip, USGS_NED_13_n42w112_ArcGrid.zip, into separate folders in this folder. It is best to unzip these files into folders as they have similarly named content (an info folder) and you want to avoid name clashes and possible overwriting.
3. Use the  **Add Data** tool to and add the grids grdn42w112_13 and grdn43w_112_13 to your map.



Your map should look like



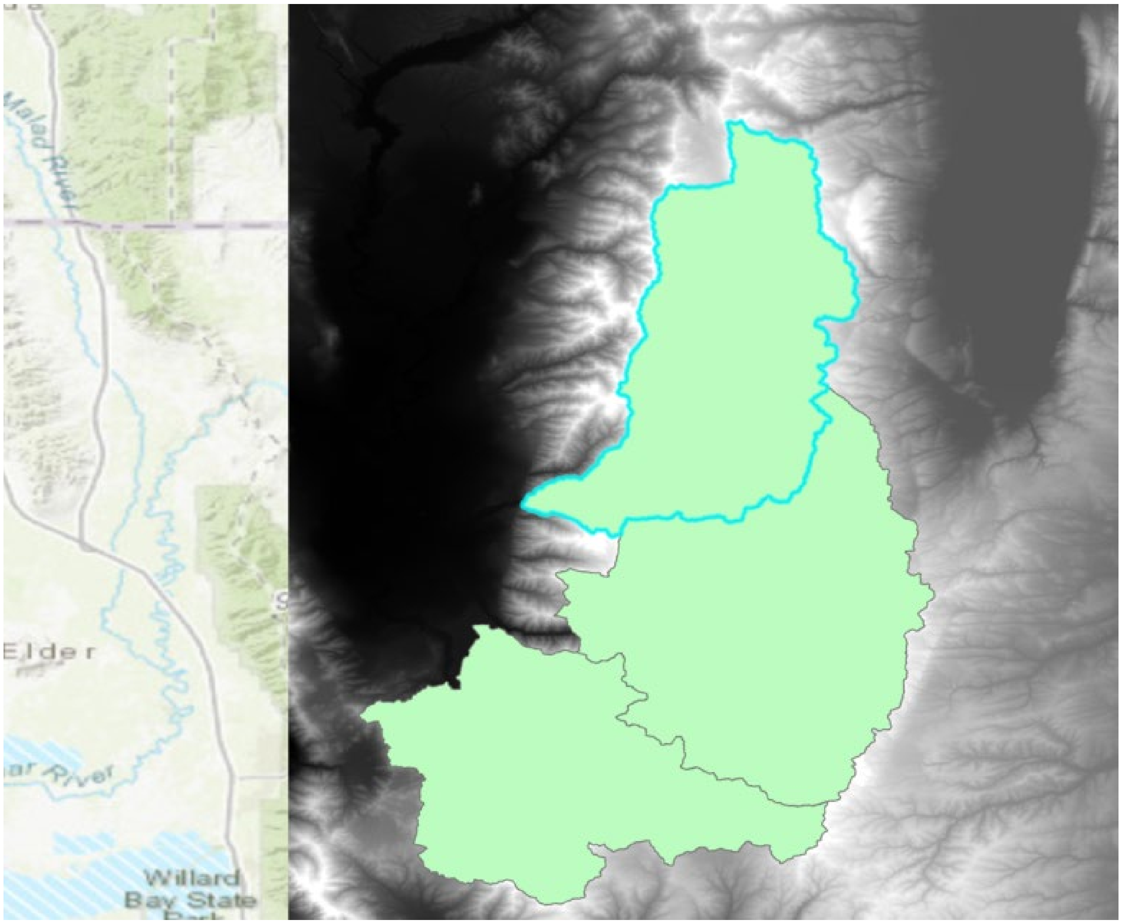
4. Locate the Mosaic to New Raster Geoprocessing tool and enter the settings below



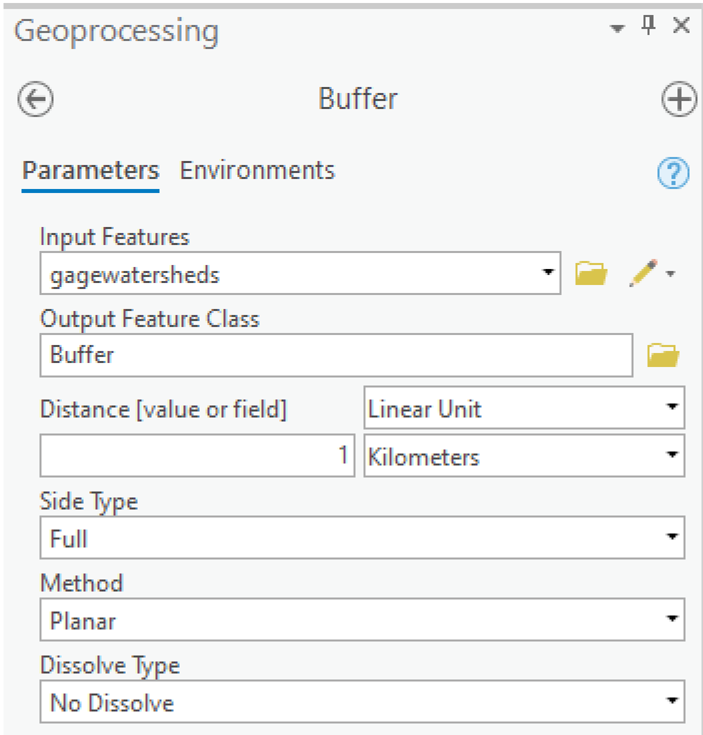
- The output location is a folder since this exercise will be done with files outside of a Geodatabase. TauDEM is not able to write results into a geodatabase.
- fulldem.tif has the extension .tif to make the tool output the result in GeoTIFF format, an open grid file format that is the default format used by TauDEM.
- The GCS_North_American_1983 spatial reference you can set by picking either of the input layers in the drop down. This is a Geographic (latitude and longitude coordinate system) with NAD83 datum. TauDEM can work with data in Geographic as well as projected coordinates.
- 32 bit float sets the data type of the output grid (fulldem.tif).
- There is just one Band. Rasters can hold multiple bands, but in most of our work a single band is used.

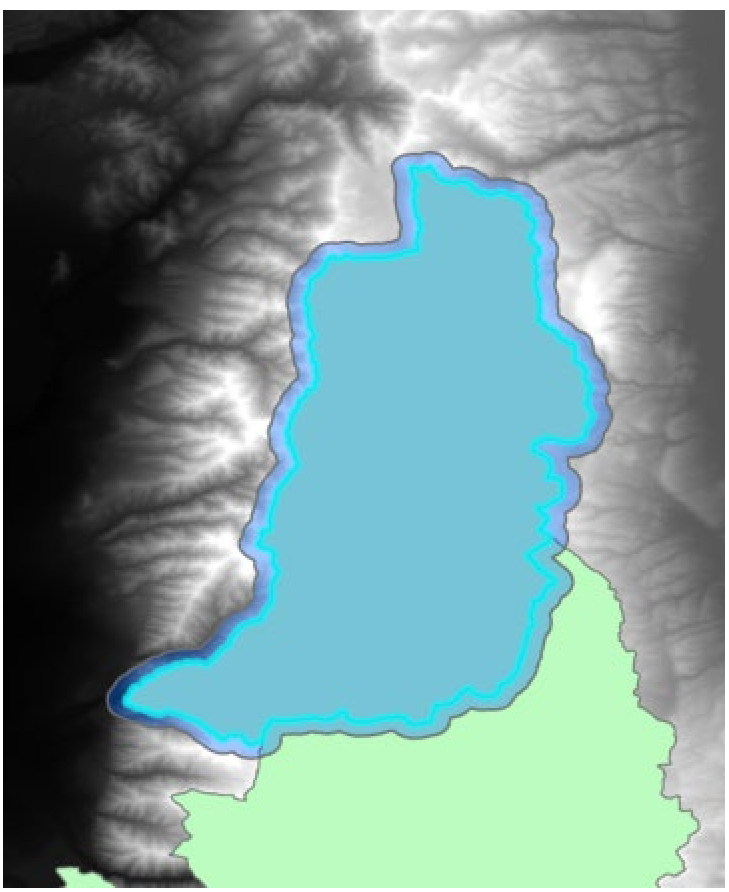
The result is a single DEM file that combines the two DEM grids downloaded. We will not need the original DEMs any more so they may be removed from the map.

5. Locate the GageWatersheds Feature Class from the Spatial Analysis Exercise done previously and add it to your map. Select the Logan River Watershed. This will be used to create a 1 km buffer to clip the large DEM (fulldem.tif) to a more manageable size.

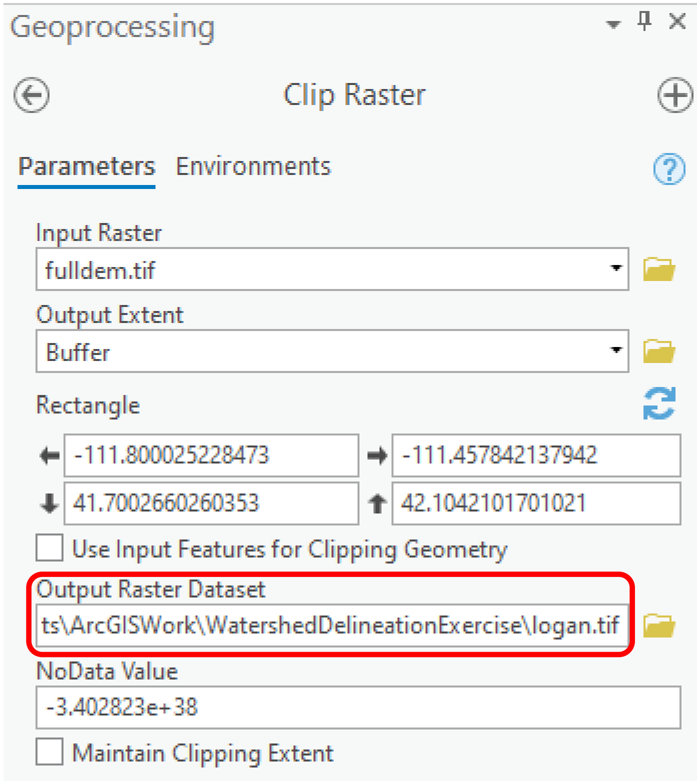


6. Open the Buffer Geoprocessing tool and create a 1 km buffer

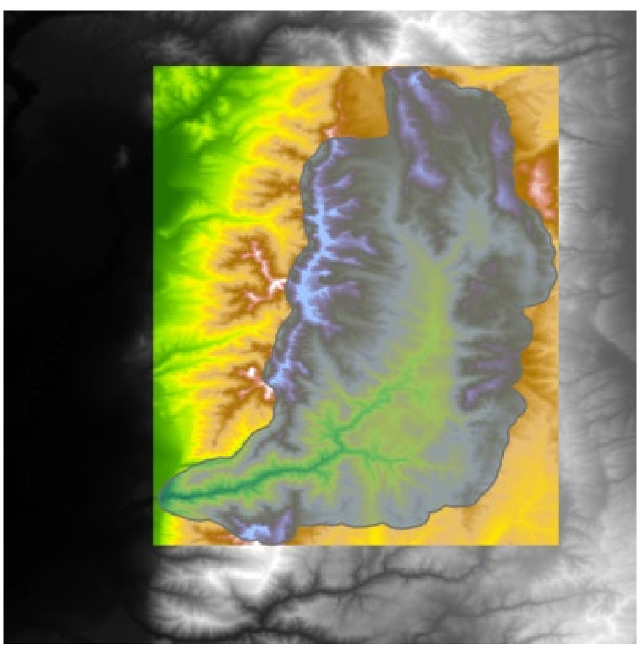




7. Open the Clip Raster Geoprocessing tool and clip fulldem.tif to the extent of this Buffer



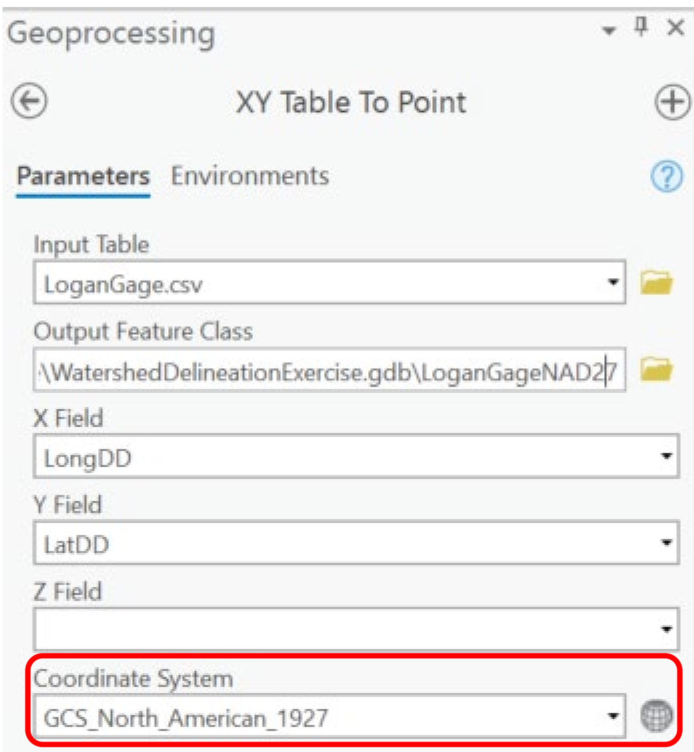
Note that the output file logan.tif should not go into a geodatabase. The .tif extension again results in this being written as a Geotiff file. You should obtain a DEM with smaller extent. I have symbolized this differently.



Open the Properties for logan.tif and fulldem.tif. Record the number of rows and columns in each. Also check the spatial reference and cell size of each. You should see that the cell size is given as 9.259×10^{-5}. The units on this are degrees (part of Spatial Reference). Refer back to slides 66 and 67 from lecture 1 where formulae were given for the calculation of N-S (meridian) and E-W (parallel) distances on the spherical earth approximation. Use these formulae and an assumed earth radius of 6370 km to compute the N-S and E-W cell size in meters for these DEMs, at a latitude of 42° N (a latitude near the center of this grid). You will need to be careful to convert angles to radians where appropriate (radians = degrees * π/180).

To turn in: The number of rows and columns in logan.tif and fulldem.tif. The name of the Geographic Coordinate System of these DEMS (this should be the same for both). The cell size in meters in the N-S and E-W direction corresponding to cell size in degrees from the Raster Information.

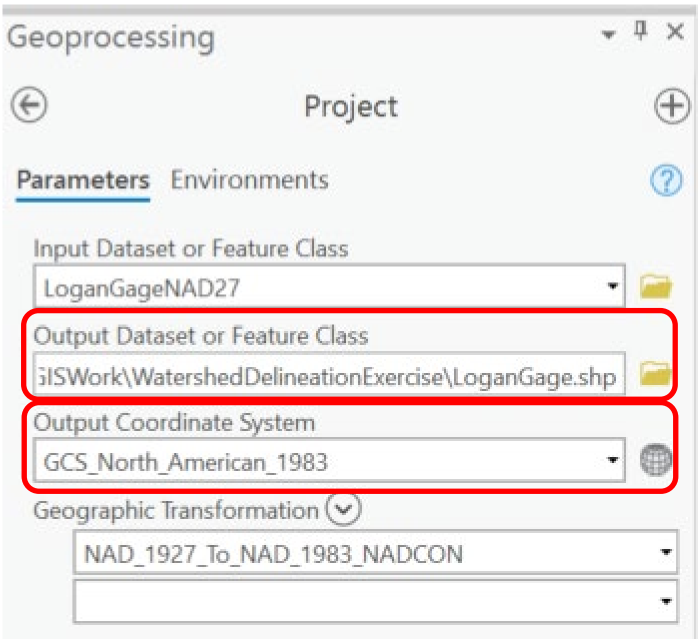
8. Add the LoganGage.csv file with outlet coordinates to the map. Right click to Display XY data and in the XY Table to Point Geoprocessing tool set the following parameters



Note that the Coordinate System is set to NAD 1927 because the USGS website indicates NAD27 for the latitude and longitude in the stream site information. The output feature class is named LoganGageNAD27 to identify this. Run this to obtain the LoganGageNAD27 feature class with a single point giving the location of the stream gage.

You will have noted above that the DEM uses the NAD 1983 coordinate system, therefore we will need to project this outlet for consistency with the DEM. Unlike ArcGIS, TauDEM does not do projection on the fly and requires all its data to be in the same coordinate system to work properly.

9. Open the Project Geoprocessing tool and set the following parameters.



Note that the output dataset is not placed in a Geodatabase, but instead is a Shapefile "LoganGage.shp" in the project folder. Again this is so that TauDEM can read it. TauDEM does not read the proprietary ESRI geodatabase files.

The output coordinate system was set to NAD 1983 from one of the DEM rasters. The resulting shapefile is in the same coordinate system as the DEM.

Remove all layers except Logan.tif DEM and LoganGage.shp from the map. Other layers will not be used in the next part of the exercise.

Coordinate system being used

TauDEM has the ability to work with Geographic coordinates and the above data has all been set up using the NAD 1983 Geographic Coordinate system. When a geographic coordinate system is used for display in ArcGIS the maps are distorted to be short and fat. You may choose to switch to something like UTM Zone 12 or another projected coordinate system for visualization. Map properties can be used to set the coordinate system of the map display.

Watershed Delineation

This activity will guide you through the hydrologic terrain analysis steps needed to delineate the Logan River Watershed and its subwatersheds. The steps are:

1. Fill Pits
2. Calculate D8 Flow Directions and Slope

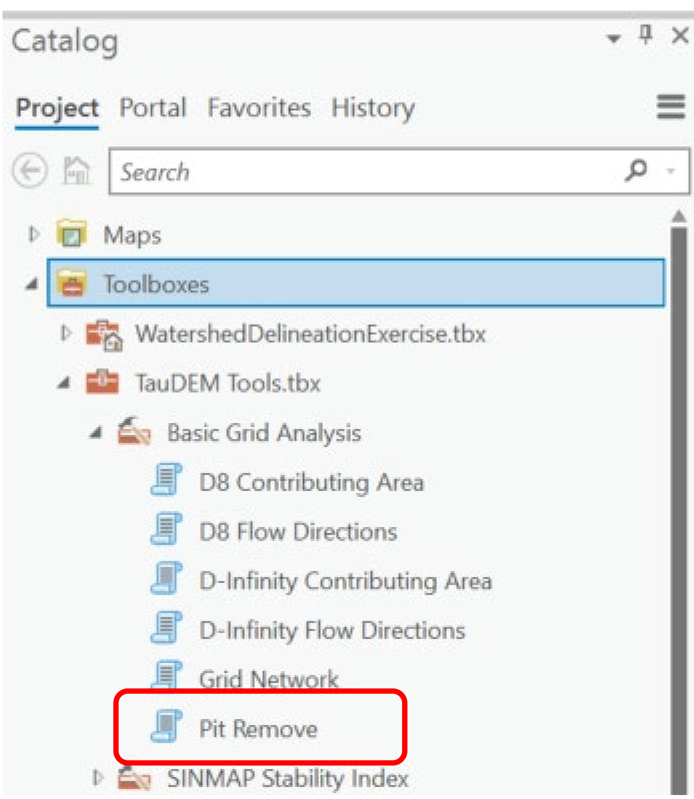
3. Calculate Contributing area. The resulting contributing area raster then allows you to identify the contributing area at each grid cell in the domain, a very useful quantity fundamental to much hydrologic analysis.
4. Define a preliminary stream raster
5. Adjust outlet to be located on preliminary stream raster
6. Re-compute contributing area upstream of outlet
7. Evaluate stream raster selecting the stream definition threshold objectively using Peuker Douglas approach with the constant stream drop test.
8. Calculate stream reaches and subwatersheds
9. Convert subwatersheds to polygons

The result will be a comprehensive set of information about the hydrology of this watershed all derived from the DEM that can serve as a starting point for subwatershed or semi-distributed hydrologic modeling. While doing this there will also be exploration of some of the results produced to help better understand what is produced by each of the tools used.

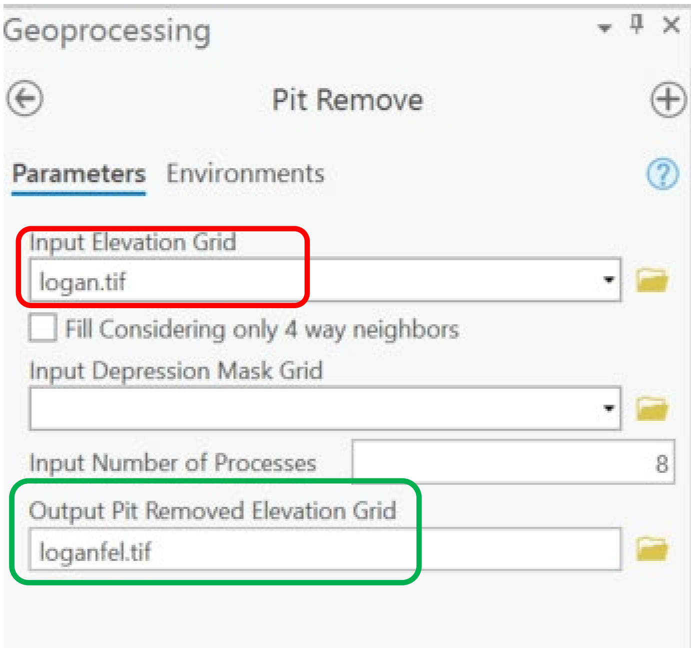
1. Pit Remove

This function fills the pits in a grid. If cells with higher elevation surround a cell, the water is trapped in that cell and cannot flow. The Pit Remove function modifies the elevation value to eliminate these problems.

In the TauDEM Tools.tbx toolbox (In Project Toolboxes) click on Pit Remove.



In the Geoprocessing Pit Remove tool select logan.tif for the Input Elevation Grid.



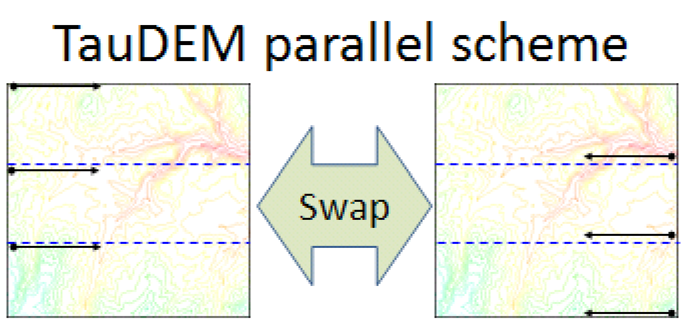
Note that the Output Pit Removed Elevation Grid is automatically filled, using the suffix “fel” for “filled elevation” appended to the original file name. You may adjust or leave the number of processes at 8.

Click Run.

The result loganfel.tif should be created and added to your map. This is the pit filled elevation grid.

The file suffixes used by TauDEM are described in http://hydrology.usu.edu/taudem/taudem5/help53/GridDefinitionsAndNamingConventions.htm. It is not required that you use these. You can use any names for the files you work with. But I have found that following these conventions is helpful in identifying what file is what. The tools automatically append them simplifying input.

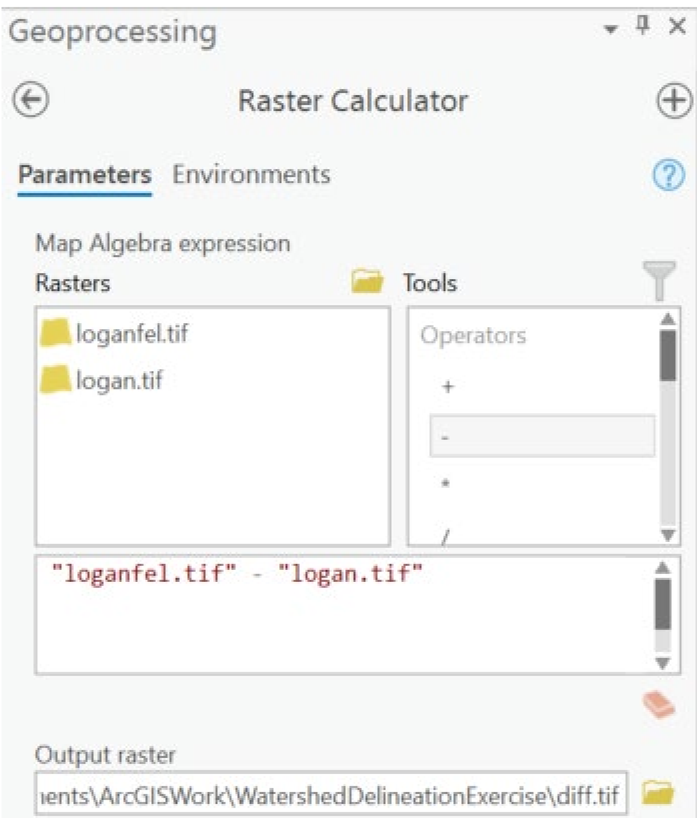
The parallel approach used by TauDEM is illustrated below.



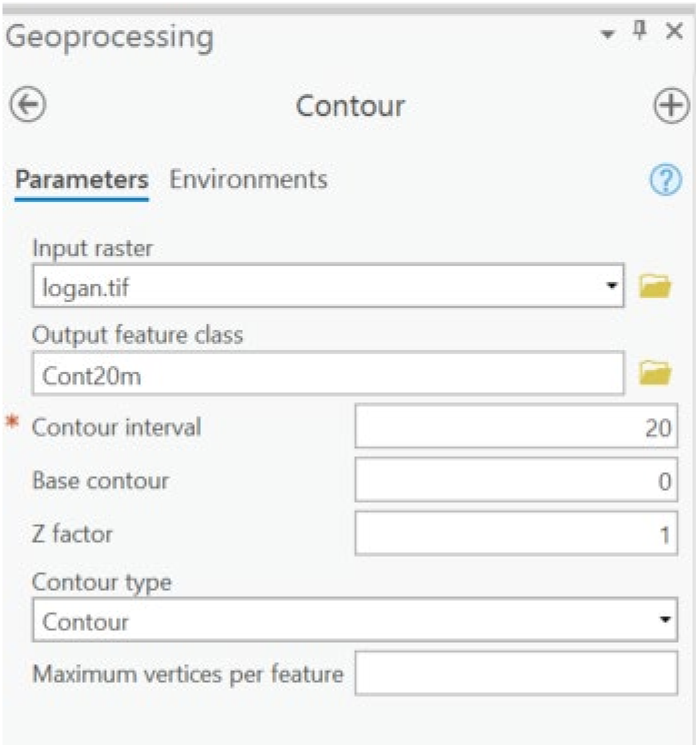
The domain is subdivided into row oriented partitions that are each processed independently by separate processes. When the algorithms reach a point where they can proceed no further within the partitions there is a swap step that exchanges information along the boundaries. The algorithms then proceed working within the partitions using new boundary information. This process is iterated until completion. The strategies for sharing information across boundaries and iterating are specific to each algorithm.

The number of processes does not have to be the same as the number of processors on your computer, although generally should be the same order of magnitude. The operating system (and MPI) takes care of time sharing between processes, so in cases where some processes are likely to be waiting for other processes to complete there may be a benefit in selecting more processes than physical processors on the computer. However then message passing across the borders is increased. For large datasets, some experimentation as to the number of processes that works best (fastest) is suggested. For this exercise the functions run quickly and the number of processes does not matter too much.

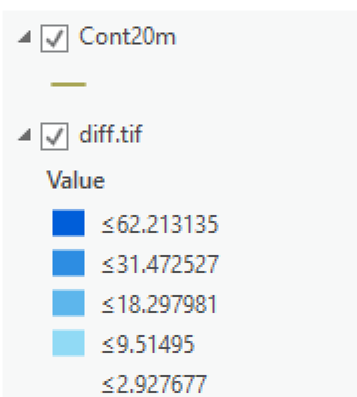
Let's examine the impact of Pit Remove on the DEM. Select **Spatial Analyst Tools → Map Algebra → Raster Calculator** and evaluate **loganfel.tif – logan.tif**.



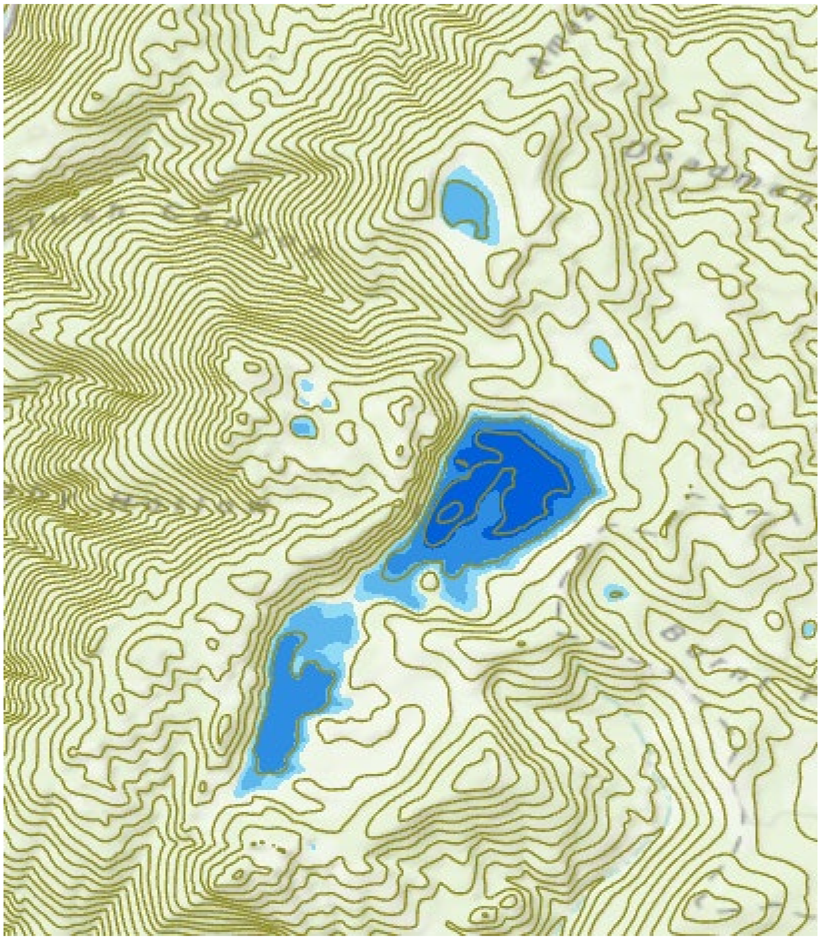
Select **Spatial Analyst Tools → Surface → Contour**. Set the inputs as follows to determine 20 m contours of the original DEM, **logan.tif**.



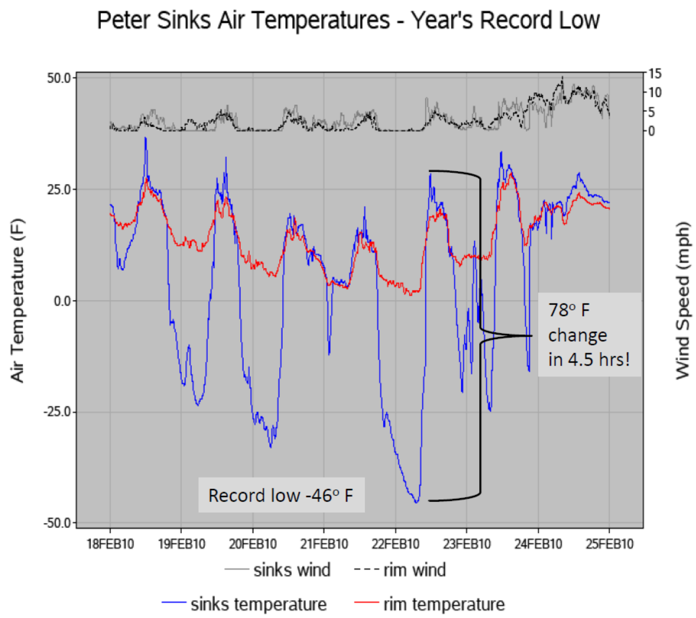
Symbolize the difference and contour layers similar to:



Zoom in on the deepest Sink; you should see something similar to the image below.



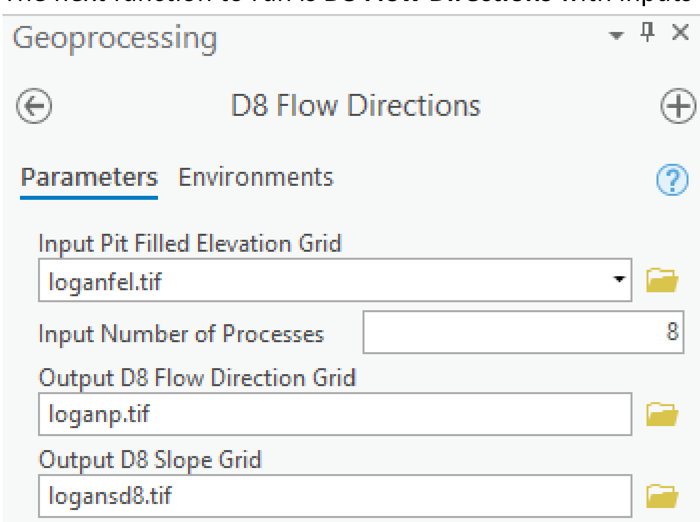
This is Peter Sink. It is a real topographic feature, not an artifact, so it is a bit erroneous to fill it. Nevertheless for the sake of a complete watershed we fill it. The website http://twdef.usu.edu/Peter_Sinks/Sinks.html gives details on the record low temperatures that have been recorded here.



To turn in. A layout showing the deepest sink in the Logan River basin. Report the depth of the deepest sink as determined by loganfel.tif – logan.tif.

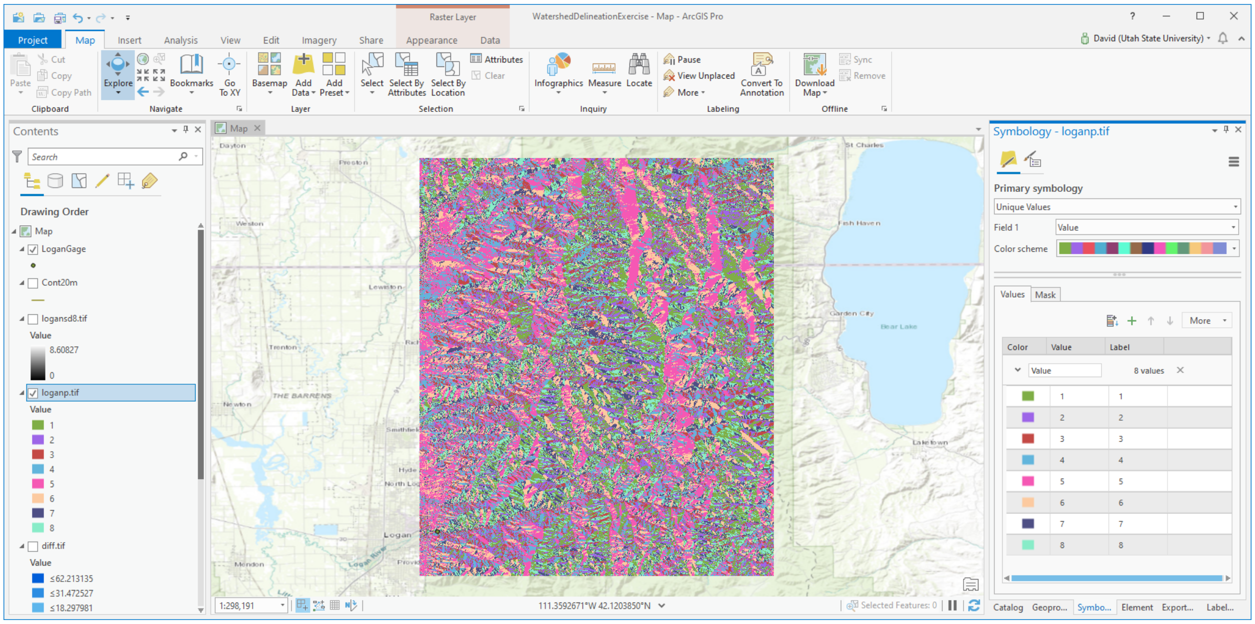
2. D8 Flow Directions

The next function to run is **D8 Flow Directions** with inputs as follows.



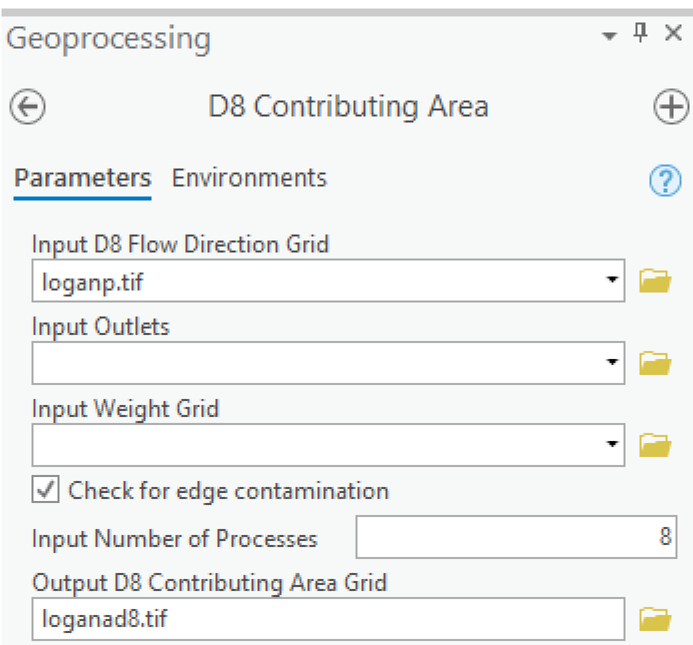
This takes as input the hydrologically conditioned elevation grid and outputs D8 flow direction and slope for each grid cell. The resulting D8 flow direction grid (name has suffix p) is illustrated. This is an encoding of the direction of steepest descent from each grid cell using the numbers 1 to 8 (counter clockwise from east). This is a simple model for the direction of water flow over the terrain.

To get the display below the symbology of loganp.tif was changed to show unique values.

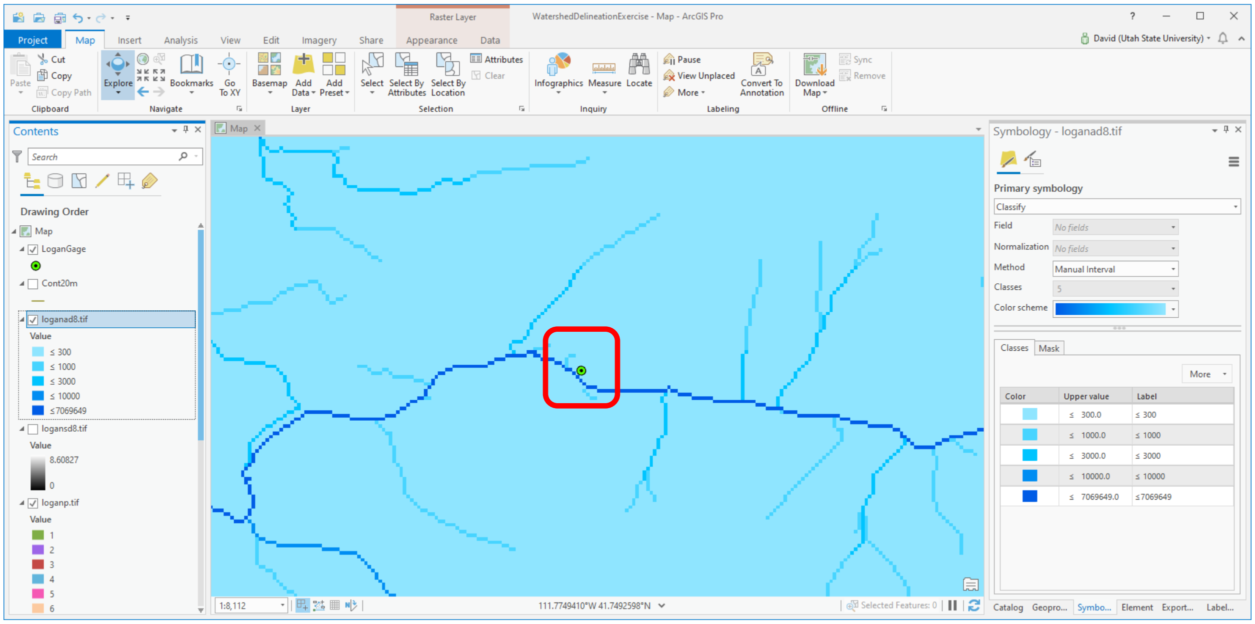


3. D8 Contributing Area

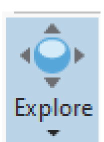
The next function to run is **D8 Contributing Area**. This function counts the number of grid cells draining through (out of) each grid cell based on D8 flow directions.



A classified symbology with multiplicative class ranges (100, 300, 1000, 3000 etc.) is often best to render contributing area values as in the illustration below.



Here I have zoomed in to near the outlet. Notice that the gage location does not align with the flow path as mapped from the DEM.

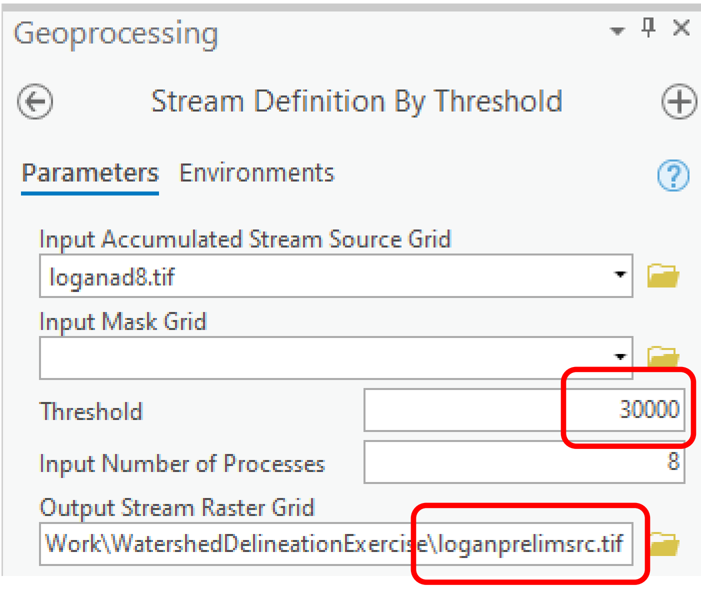
Use the Explore tool 

to identify loganad8.tif grid values. Examine the properties of loganad8.tif and note that the cell size is in degrees, the same as logan.tif examined earlier. The values of loganad8.tif represent contributing area in grid cells (a count of the number of grid cells). To obtain contributing area in area units, multiply by cell height and length.

To turn in: Report the contributing area draining to a cell near the outlet location in number of cells, square kilometers and square miles. Report the area of a single grid cell. Compare your result in square miles to the USGS drainage area value for this site.

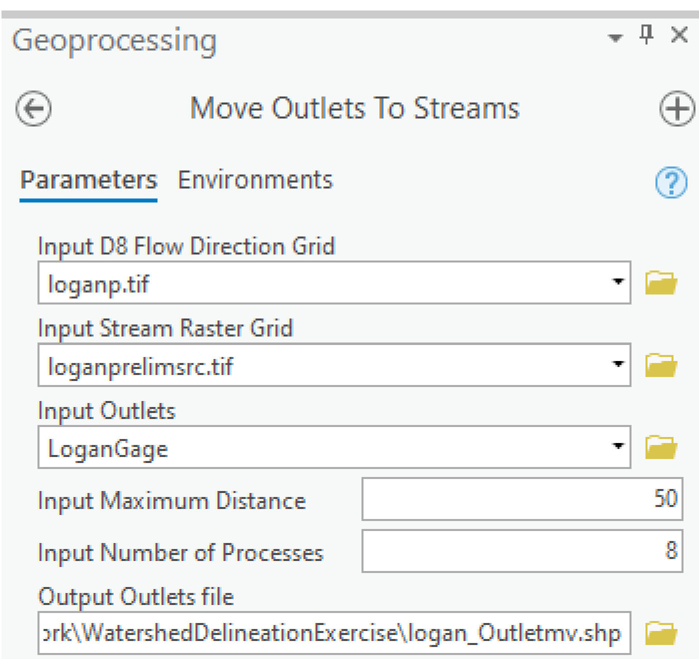
4. Preliminary Stream Raster

Use the **Stream Definition by Threshold** function (in the stream network analysis tool group) with the inputs below.

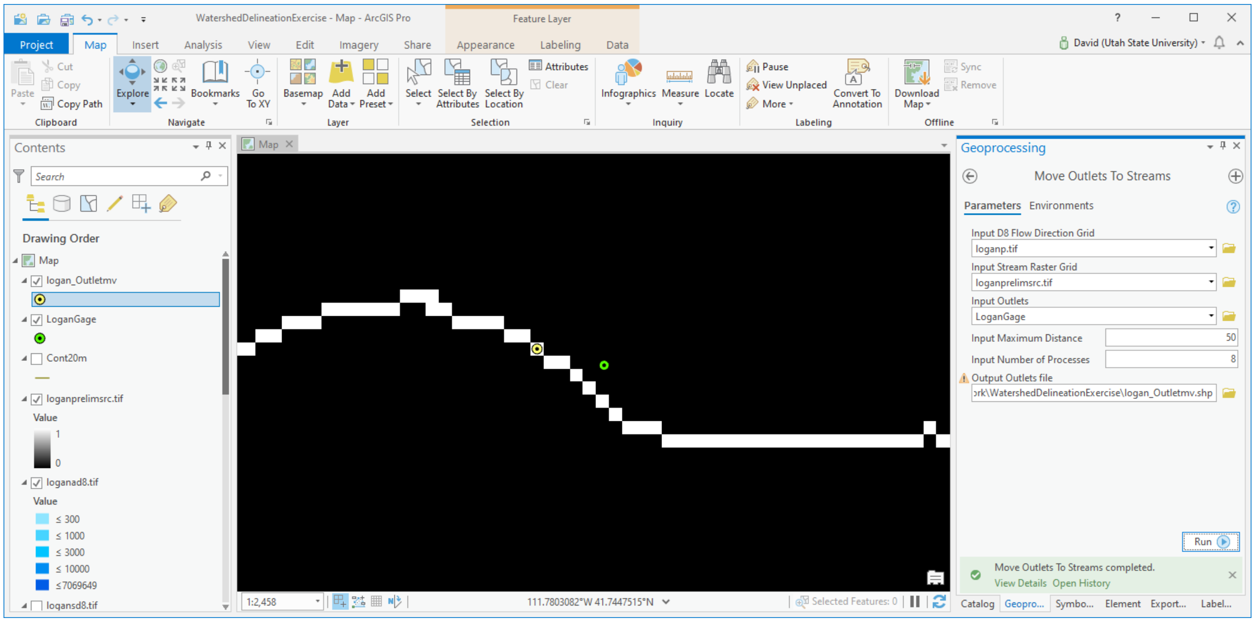


Note that I named the output “loganprelimsrc.tif” as this is a preliminary output, with an arbitrary (30000) grid cell threshold used to determine streams. This will be refined and streams delineated objectively later. This is to have a target stream raster to move the outlet to coincide with stream flow paths. A large threshold is used to avoid delineating smaller side streams that we do not want to use for the move outlet target.

5. Move Outlets to Streams



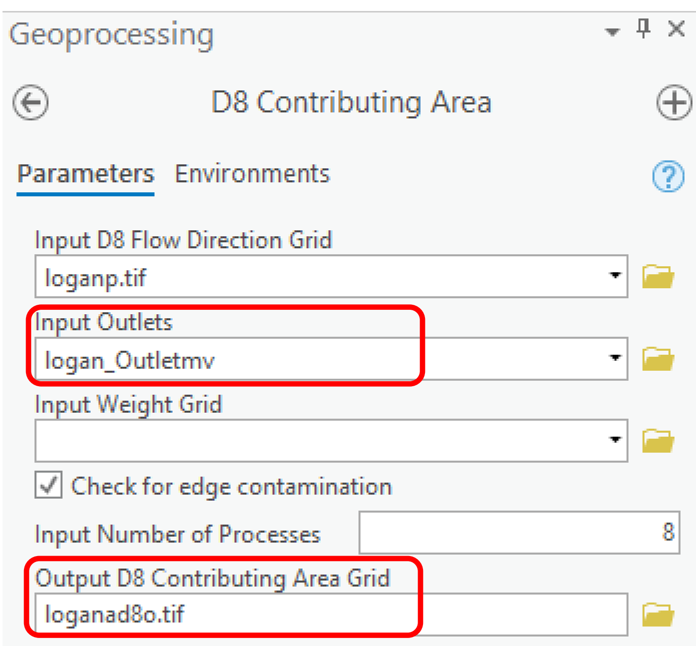
This creates a new shapefile logan_Outletmv.shp that has been aligned (moved downslope along flow directions) until it coincides with the stream raster. You may need to add this to the map. Sometimes shapefile outputs from TauDEM functions are not automatically added to the map.



As there is only one outlet, here you could have easily done this editing the shapefile by hand. This tool was really developed for cases where there are many outlets.

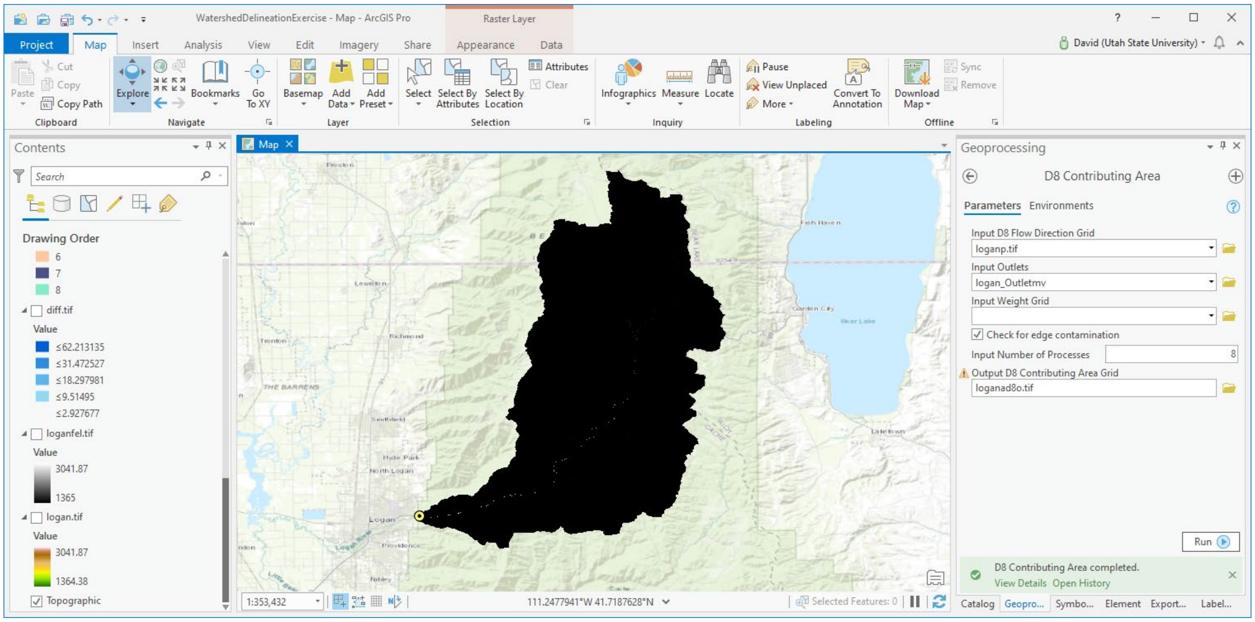
6. D8 Contributing Area upstream of outlet

Open the D8 Contributing Area tool and set inputs as follows



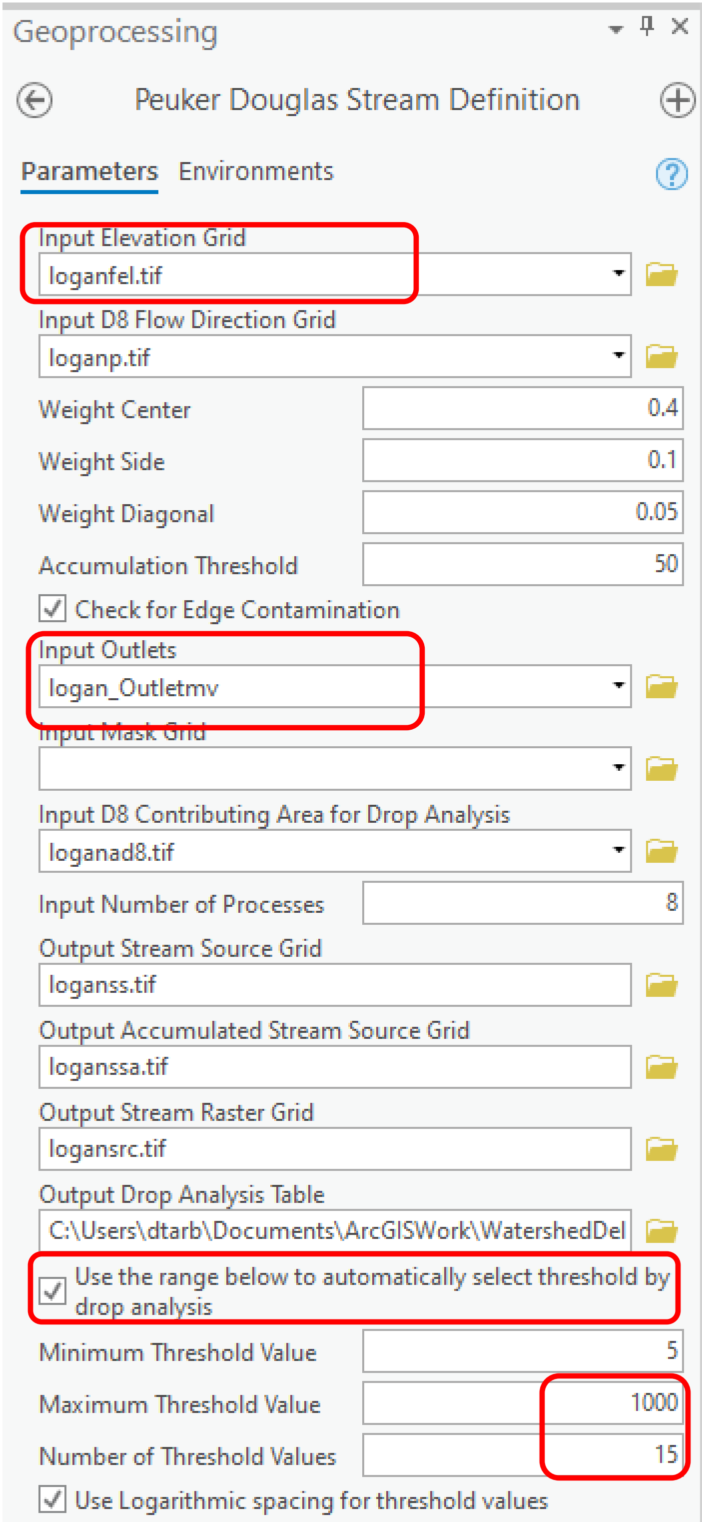
Notice that I am using loganad8o.tif for the contributing area upstream of the outlet location, that was set as logan_outletmv.

The result, zoomed to layer should show contributing area just upstream of the outlet.



7. Peuker Douglas Stream Definition

Open the Peuker Douglas Stream Definition Tool and set inputs as follows



Click “Use the range below …” to expand to set thresholds, and change the maximum threshold to 1000 and number of threshold values to 15. I found that the upper bound of 500 was too small for this dataset. As DEMs get finer, the upper bounds need to get bigger.

This tool does a lot. It uses the Peuker Douglas approach to identify valley grid cells. Then it calculates a weighted contributing area of these, and uses the stream drop approach to objectively select a channelization threshold. Some of the output is shown below

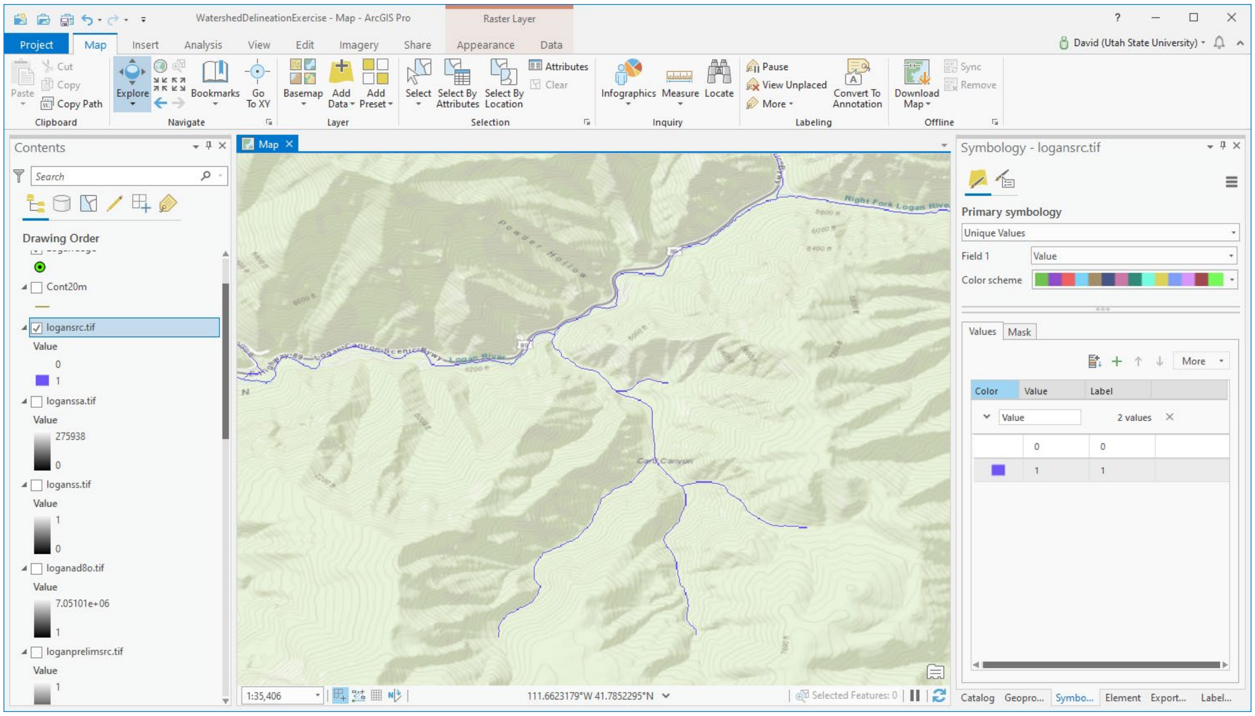
Peuker Douglas Stream Definition ()

Completed Today at 6:35:41 AM

```
Projection of Raster datasource NAD83.
Projection of Outlet feature GCS_North_American_1983.
Input file C:\Users\dtarb\Documents\ArcGISWork\WatershedDelineationExercise\loganss.tif has geographic coordinate
system.
Number of Processes: 8
Read time: 0.111221
Compute time: 0.973004
Write time: 0.199778
Total time: 1.284003
Command Line: mpiexec -n 8 DropAnalysis -fel "C:\Users\dtarb\Documents\ArcGISWork\WatershedDelineationExercise
\loganfel.tif" -p "C:\Users\dtarb\Documents\ArcGISWork\WatershedDelineationExercise\loganp.tif" -ad8 "C:\Users\dtarb
\Documents\ArcGISWork\WatershedDelineationExercise\loganad8.tif" -ssa "C:\Users\dtarb\Documents\ArcGISWork
\WatershedDelineationExercise\loganssa.tif" -o "C:\Users\dtarb\Documents\ArcGISWork\WatershedDelineationExercise
\logan_Outletmv.shp" -drp "C:\Users\dtarb\Documents\ArcGISWork\WatershedDelineationExercise\logandrp.txt" -par 5 1000
15 0
DropAnalysis version 5.3.7
Input file C:\Users\dtarb\Documents\ArcGISWork\WatershedDelineationExercise\loganssa.tif has geographic coordinate
system.
Input file C:\Users\dtarb\Documents\ArcGISWork\WatershedDelineationExercise\loganp.tif has geographic coordinate
system.
Input file C:\Users\dtarb\Documents\ArcGISWork\WatershedDelineationExercise\loganad8.tif has geographic coordinate
system.
Warning: Projection of Outlet feature and Raster data may be different.
Projection of Raster datasource NAD83.
Projection of Outlet feature GCS_North_American_1983.
Input file C:\Users\dtarb\Documents\ArcGISWork\WatershedDelineationExercise\loganfel.tif has geographic coordinate
system.
Threshold DrainDen NoFirstOrd NoHighOrd MeanDFirstOrd MeanDHighOrd StdDevFirstOrd StdDevHighOrd Tval
5.000000 0.006046 14095 4069 36.015610 76.379120 50.091576 92.232285 -36.541470
7.300108 0.004624 8015 2404 45.305882 89.694778 60.393055 103.000786 -26.336918
10.658316 0.003927 5635 1692 52.373775 100.258698 67.184494 110.830925 -21.749876
15.561371 0.003311 3836 1118 62.358723 112.712234 76.279083 119.226433 -16.870031
22.719936 0.002828 2698 775 71.603806 125.056725 82.816925 125.126953 -13.965076
33.171600 0.002418 1915 552 81.769096 133.438202 88.459007 125.829102 -10.907504
48.431248 0.002056 1388 398 86.299606 142.187088 94.560318 134.246155 -9.387682
70.710670 0.001744 954 287 95.462738 153.690582 97.310295 138.145081 -7.999764
103.239098 0.001475 670 195 104.936157 164.812546 101.784843 141.226044 -6.577958
150.731323 0.001257 469 142 110.020012 185.473648 100.486404 147.725647 -6.959490
220.070969 0.001058 329 101 115.244926 197.211090 109.393272 162.669113 -5.815090
321.308350 0.000850 227 77 115.851673 194.411163 110.455865 158.617685 -4.416564
469.117157 0.000743 157 54 128.016800 206.000076 121.823746 159.750549 -3.731461
684.921204 0.000636 101 33 170.856049 224.275421 148.432129 152.864273 -1.781840
999.999695 0.000540 66 22 170.585602 245.467194 149.626541 159.429581 -2.049924
684.921204  Value for optimum that drop analysis selected - see output file for details.
Processes: 8
Read time: 0.329261
Compute time: 7.863070
Total time: 8.192331
Command Line: mpiexec -n 8 Threshold -ssa "C:\Users\dtarb\Documents\ArcGISWork\WatershedDelineationExercise
\loganssa.tif" -src "C:\Users\dtarb\Documents\ArcGISWork\WatershedDelineationExercise\logansrc.tif" -thresh 684.921204
```

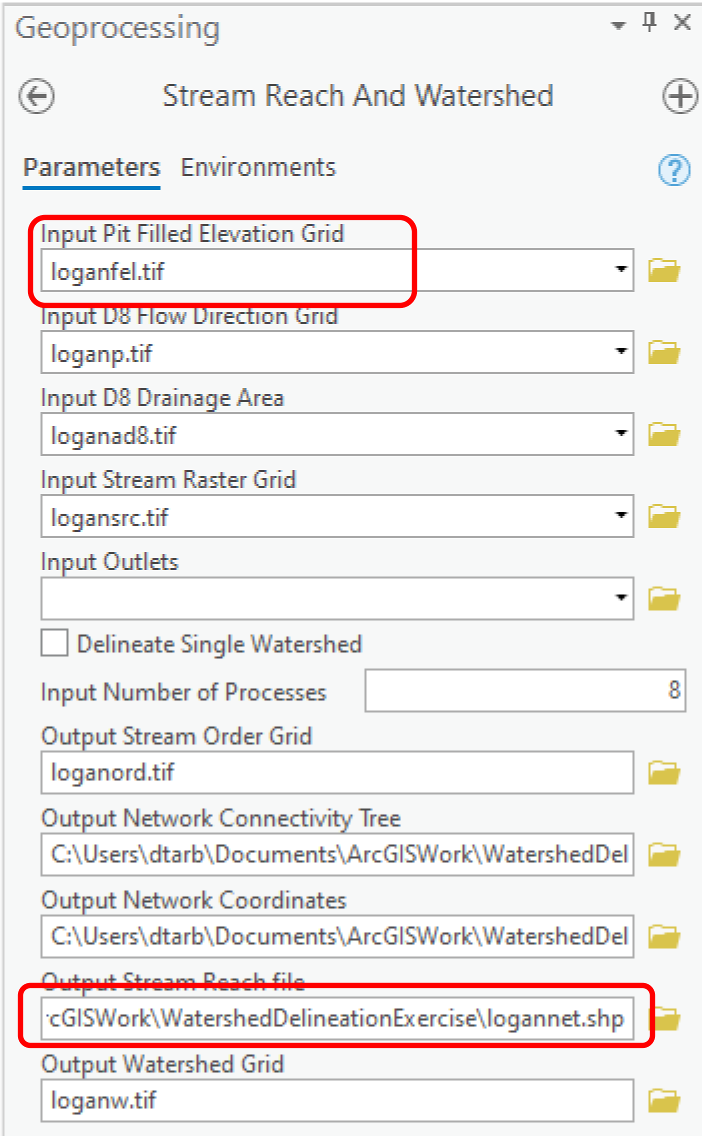
This indicates that in this case a threshold of 684 grid cells was selected as the optimum to delineate the stream network at the highest resolution consistent with this geomorphology rule.

Zooming in and changing symbology for logansrc.tif you can see the raster cells mapped as streams.

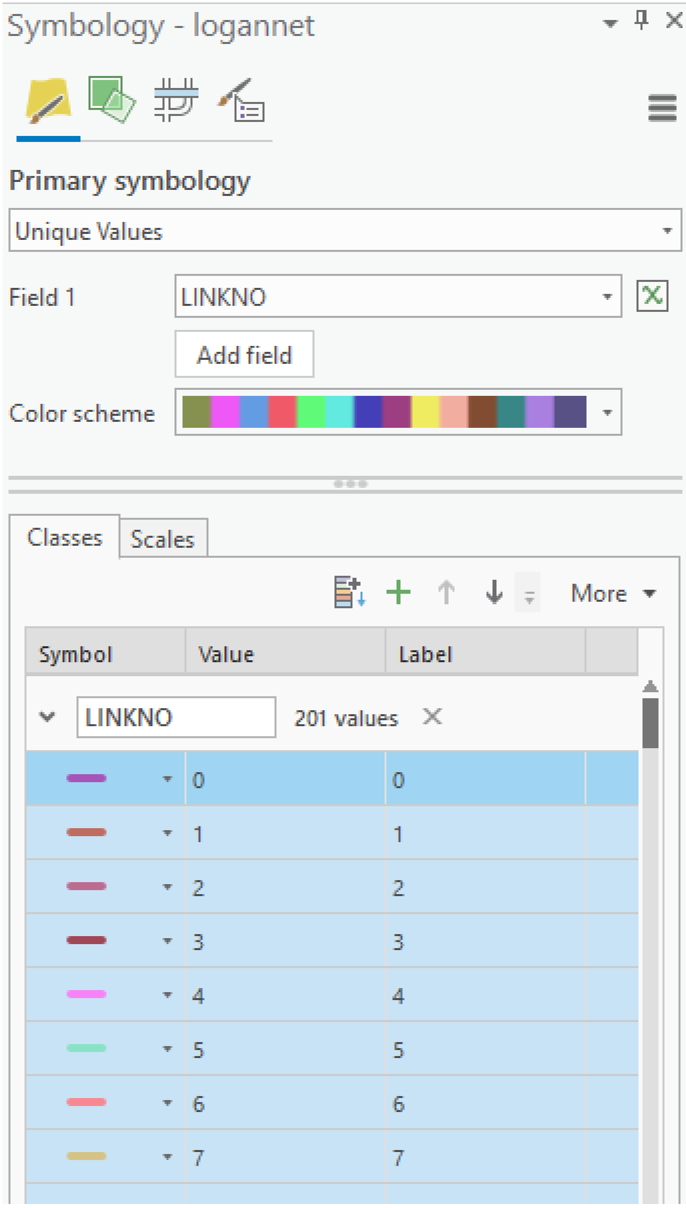


8. Stream Reach and Watershed

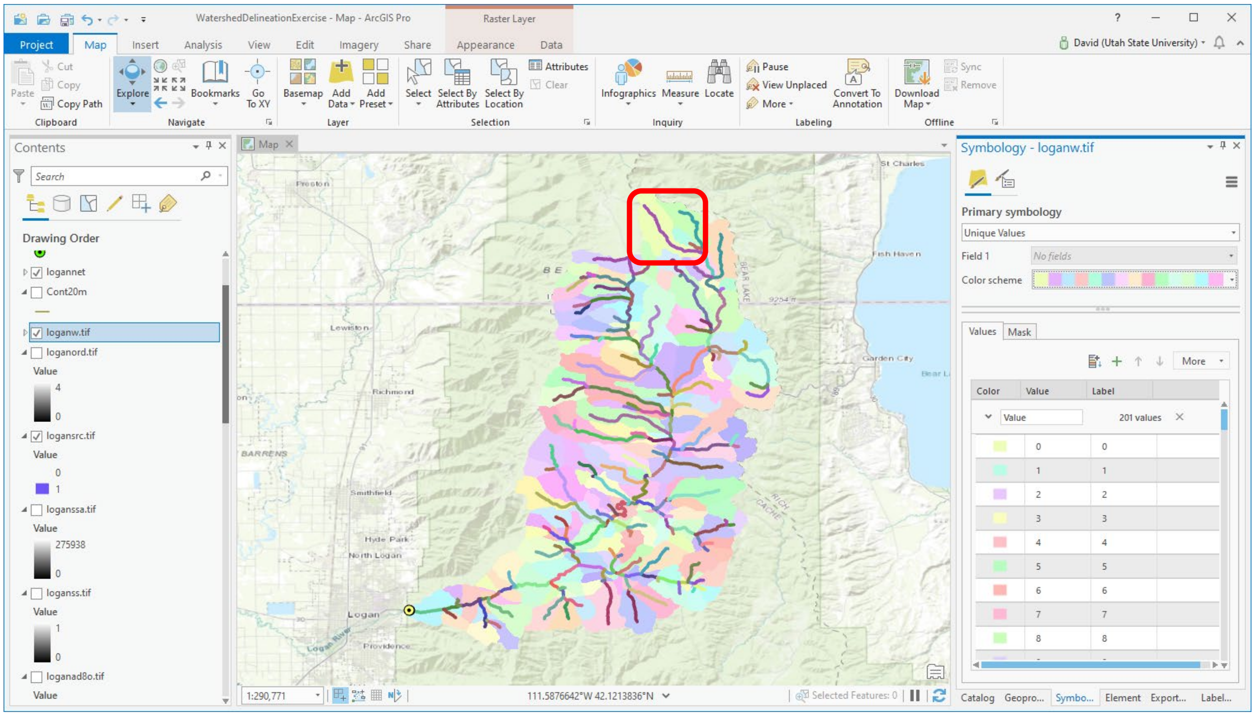
Open the Stream Reach and Watershed tool and set the following inputs



Add the shapefile "logannet.shp" that was created and symbolize stream segments (links) with unique values based on LINKNO.



Symbolize loganw.tif with unique values. You should see a depiction of the stream network and associated subwatersheds similar to the below



Examine the attribute table for logannet.shp. These attributes are defined at http://hydrology.usu.edu/taudem/taudem5/help53/DataFileFormatsAndFileNamingConventions.htm

To turn in: Report the following attributes for the most downstream and most upstream stream reach (link). The most upstream link is boxed in red above.

- *LINKNO,*
- *DSContArea (this is contributing area at the downstream end of the link in m²),*
- *StrmOrder (this is the stream order associated with each stream reach),*
- *DOUTSTART (this is the distance to the outlet from the start of the stream link in m).*

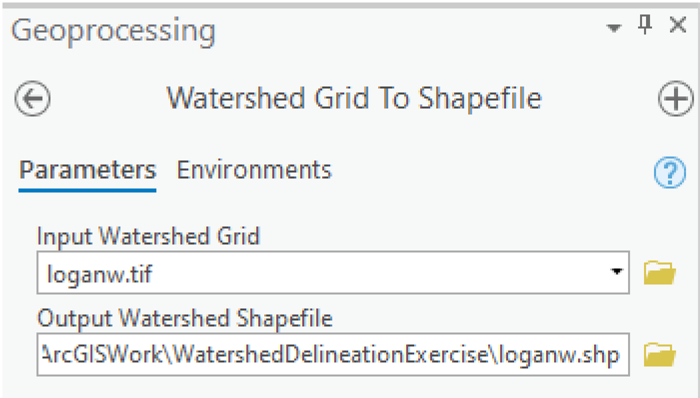
Report the length of the main stream and Logan River drainage area based on the delineated stream network. Check this against area determined above.

Report the total length of streams in the Logan River Stream network (from statistics on the Length attribute – which is in m).

Report the drainage density of the Logan River Stream network.

9. Convert subwatersheds to polygons

Open the Watershed Grid to Shapefile tool and set the following inputs.

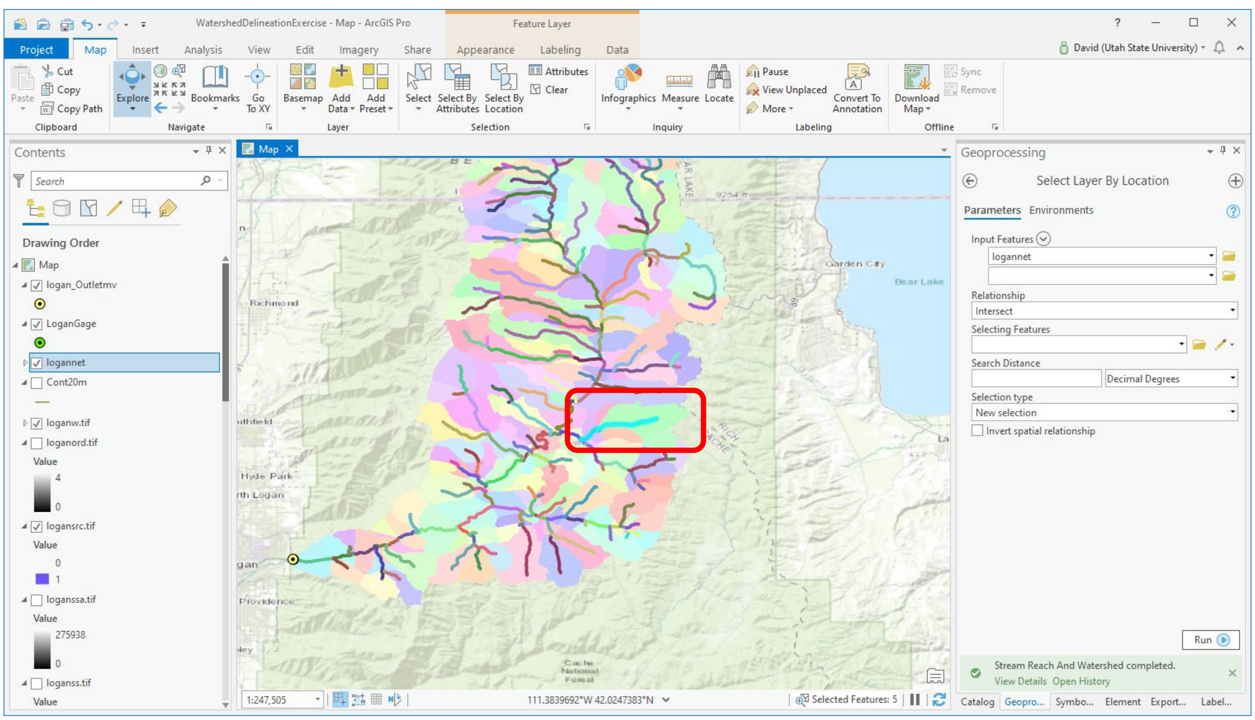


The result is a polygon corresponding to each subwatershed. The gridcode field in the resulting polygon maps onto subwatershed grid values, that corresponds with LINKNO in logannet.shp.

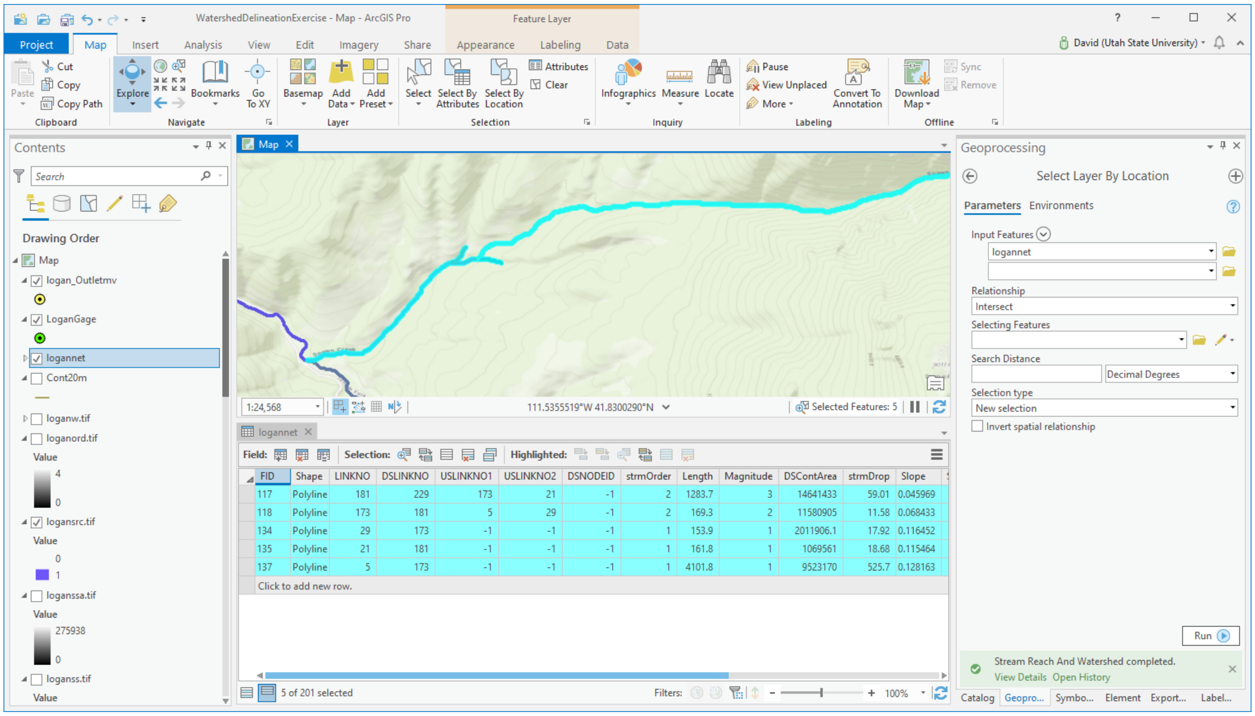
You now have a set of data that has established connectivity between subwatersheds and stream reaches, and upward and downward connectivity of stream reaches, that can serve as a basis for further modeling and analysis.

10. Examining the data structure for Spawn Creek

Zoom in on Spawn Creek – the area shown below



Select just the 5 links indicated to see their attribute table values. These are 5 tributaries mapped for spawn creek.



To turn in:

A table that reports for the 5 stream links in the Spawn Creek tributary of the stream network the following attributes:

- *Link number*
- *Downstream link number*
- *Upstream link number 1*
- *Upstream link number 2*
- *Downstream contributing area*
- *Length*
- *Identifier of corresponding watershed (WSNO)*

Prepare a diagram that shows, based on your answers to the above, how connectivity between subwatersheds, stream links and upstream and downstream links is encoded.

Some independent less directed work

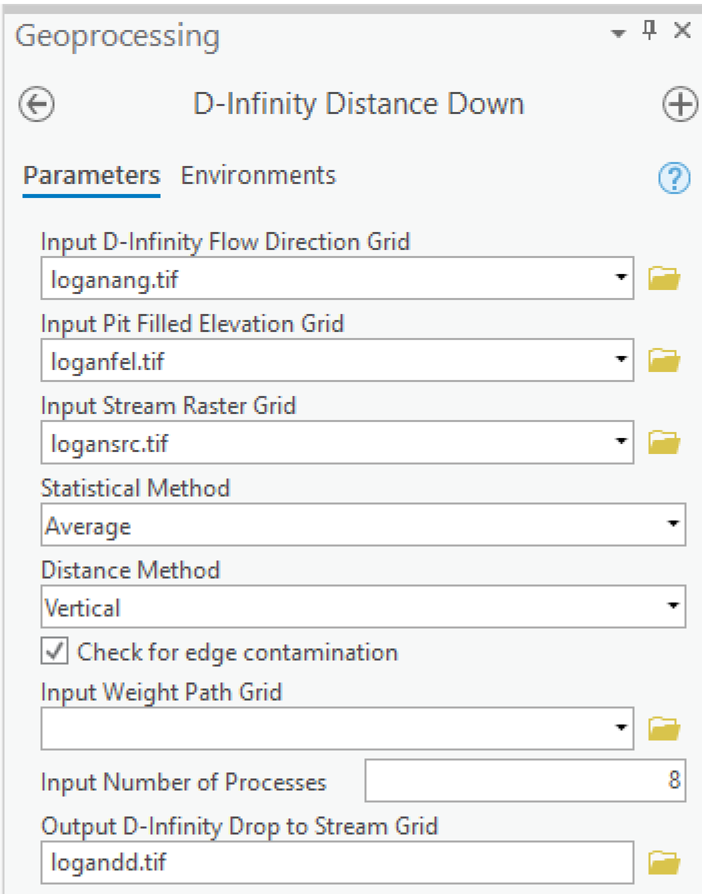
Wetness Index

Use D-Infinity Flow Directions, D-Infinity Contributing area and Topographic Wetness Index tools to evaluate the topographic wetness index for the Logan River Watershed. Use the outlet to restrict calculations to upstream of the outlet. Prepare a layout that depicts the topographic wetness index over part of the Logan River Watershed (showing the whole watershed may not be zoomed in enough to show detail). Pick a threshold (e.g. wetness index of 20 or 25) to depict saturated areas according to this TWI threshold.

To turn in: Layout depicting topographic wetness index and saturated areas according to wetness index. Include explanations and interpretation of what you present.

Height above nearest drainage (HAND)

Use D-Infinity Distance Down with the Distance Method "Vertical" to evaluate height above the nearest drainage for the Logan River.



Prepare some layouts to illustrate the result. Include topographic contours and delineated streams in the layout. I suggest zooming in near streams of interest and using symbology or height above nearest drainage thresholds (e.g. 1 m, 3 m, 5 m …) to illustrate areas that may be flooded if the water reaches these depths.

To turn in. One or more layouts or illustrations of height above the nearest drainage. Include explanations and interpretations of what you present.

OK. You are done!

Summary of items to turn in.

1. *The number of rows and columns in logan.tif and fulldem.tif. The name of the Geographic Coordinate System of these DEMS (this should be the same for both). The cell size in meters in the N-S and E-W direction corresponding to cell size in degrees from the Raster Information.*

2. *A layout showing the deepest sink in the Logan River basin. Report the depth of the deepest sink as determined by loganfel.tif – logan.tif.*
3. *Report the contributing area draining to a cell near the outlet location in number of cells, square kilometers and square miles. Report the area of a single grid cell. Compare your result in square miles to the USGS drainage area value for this site.*
4. *Report the following attributes for the most downstream and most upstream stream reach (link). The most upstream link is boxed in red above.*
   - *LINKNO,*
   - *DSContArea (this is contributing area at the downstream end of the link in m^2),*
   - *StrmOrder (this is the stream order associated with each stream reach)*
   - *DOUTSTART (this is the distance to the outlet from the start of the stream link in m).*
5. *Report the length of the main stream and Logan River drainage area based on the delineated stream network. Check this against area determined above.*
6. *Report the total length of streams in the Logan River Stream network (from statistics on the Length attribute – which is in m).*
7. *Report the drainage density of the Logan River Stream network.*
8. *A table that reports for the 5 stream links in the Spawn Creek tributary of the stream network the following attributes:*
   - *Link number*
   - *Downstream link number*
   - *Upstream link number 1*
   - *Upstream link number 2*
   - *Downstream contributing area*
   - *Length*
   - *Identifier of corresponding watershed (WSNO)*
9. *Prepare a diagram that shows, based on your answers to the above, how connectivity between subwatersheds, stream links and upstream and downstream links is encoded.*
10. *Layout depicting topographic wetness index and saturated areas according to wetness index. Include explanations and interpretation of what you present.*
11. *One or more layouts or illustrations of height above the nearest drainage. Include explanations and interpretations of what you present.*