The USUAL Watershed Tools

User Manual (v1.0)

Last updated: Oct. 26, 2022

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About the USUAL Watershed Tools

The Utah State University AppLied (USUAL) Watershed Tools, or USUAL for brevity, is an open-source, Python-based toolkit for ESRI ArcGIS Pro. The toolkit is designed to delineate watersheds, rivers, sub-catchments, and river-adjacent interfluves, as well as delineate and discretize river networks with the topological structure and feature attributes necessary for one-dimensional source-to-sink transport modeling through large watersheds.

The USUAL Watershed Tools was developed foremost by Dr. Scott David (Utah State University) and Dr. Brendan Murphy (Simon Fraser University, formerly Utah State) as part of the Watersheds & Wildfires Research Collaborative. The development of these tools was funded jointly by the National Science Foundation and the Joint Fire Science Program.

The toolkit requires an ArcGIS Pro license (2.9 or later), as well as Spatial Analyst and 3-D Analyst licenses. USUAL provides users with familiar, easy-to-use ArcGIS toolbox GUIs and is constructed as a suite of toolboxes that can be executed independently or in sequence. Additionally, standalone scripts are available to run and modify the underlying codes in a Python environment with ArcPy installed.

Citing USUAL Watershed Tools

We have made the USUAL Watershed Tools freely available for anyone to use in the hope that it will be useful to the natural science and GIS communities. However, any use of USUAL, including the modification of the available open-source codes, should be properly cited using the following reference:

> David, S.R., Murphy, B.P., Czuba, J.A., Belmont, P., Ahammad, M. (*in revision*). USUAL Watershed Tools: a new geospatial toolkit for hydro-geomorphic delineation. *Environmental Modeling and Software*.

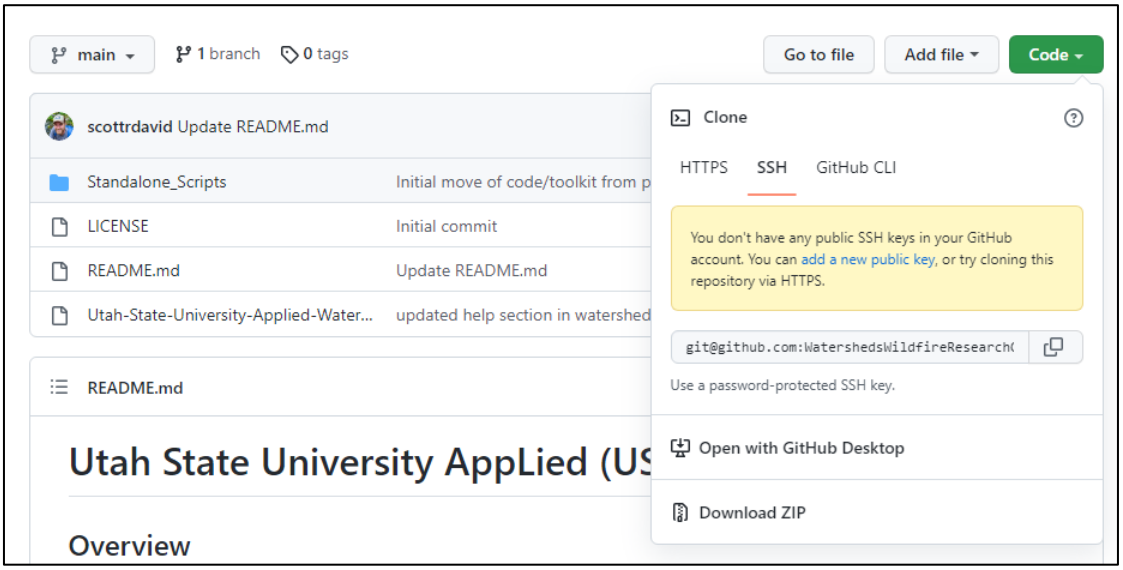
Getting Started:

Downloading USUAL Watershed Tools

1. To download the toolkit go to:

   https://github.com/WatershedsWildfireResearchCollaborative/USUAL

2. Click on dropdown arrow next to code and Download ZIP (alternatively clone the repo if you are a GitHub user)



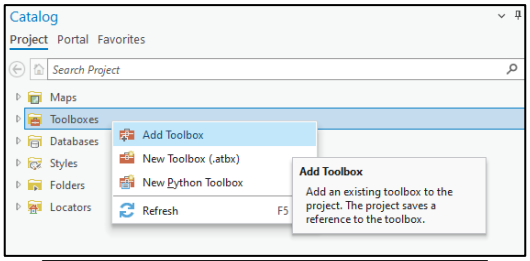
3. Navigate to the download location and unzip the compressed file.
4. Optional: Move the unzipped folder to a preferred directory that is easy to find later.

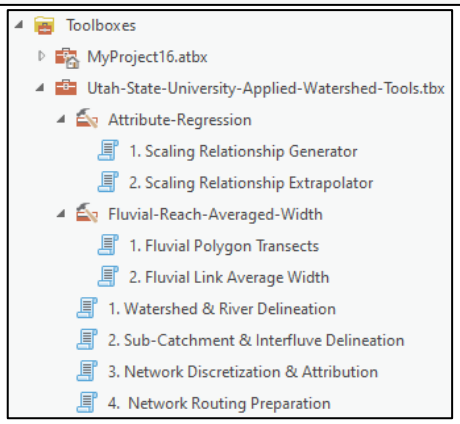
Adding USUAL Watershed Tools to ArcGIS Pro

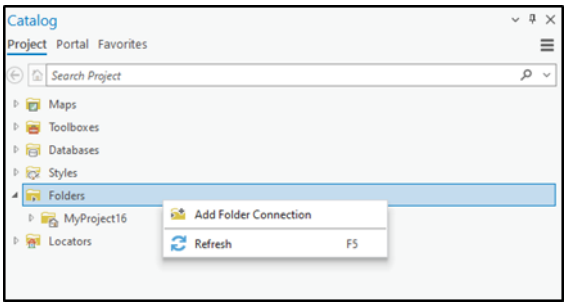
First, open a new or existing ArcGIS Pro project:

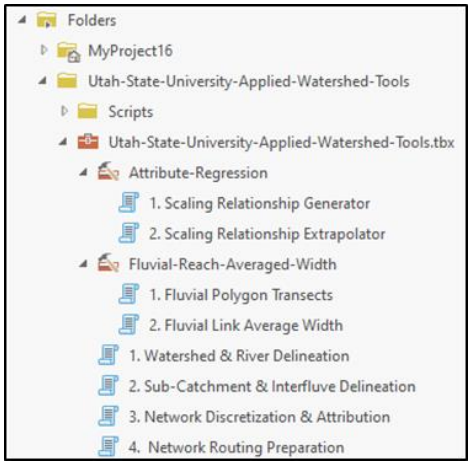
Option 1 – Adding the USUAL Tools to the ArcPro Toolboxes:

1. In the Catalog Pane, right click Toolboxes and click Add Toolbox
2. Navigate to the folder containing the toolbox named Utah-State-University-Applied-Watershed-Tools.tbx, select that file and click ok.
3. In the toolboxes folder, the USUAL toolkit should now appear and contain all of the tools









Option 2 – Accessing the USUAL Tools through Folders:

1. In the Catalog Pane, right click Folders and click Add Folder Connection
2. Navigate to the folder named Utah-State-University-Applied-Watershed-Tools, select the .tbx file and click ok.
3. This will add the Utah-State-University-Applied-Watershed-Tools folder to the Folders tab, where the toolbox can be expanded, and the tools can be accessed.

Overview of tools & workflow in USUAL

This section contains a brief description of tools contained in the USUAL Watershed Tools.

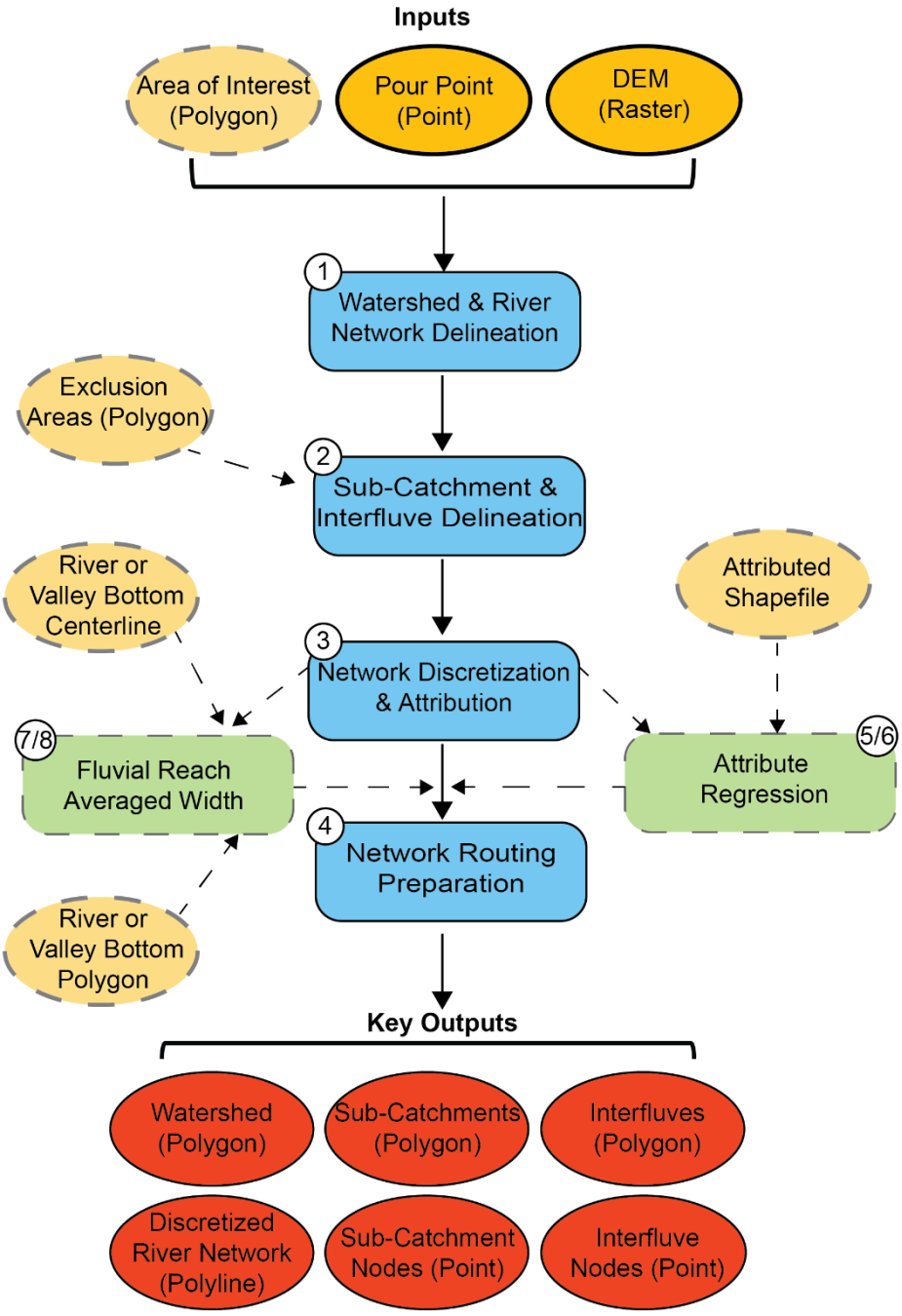


Figure 1. *The model workflow for the USUAL Watershed Tools. Rectangles represent individual tools and ovals represent inputs and outputs. Blue rectangles and solid arrows represent the minimum workflow and tools required to delineate a DEM into a watershed, its sub-catchments and interfluves features, and to generate a river network prepared for routing applications. Dashed lines represent optional tools and inputs to further attribute shapefiles. Numbers on each tool correspond to the tool descriptions in* ***Table 1****.*

Table 1. *List of tools in the USUAL Watershed Tools. Numbers correspond to those in the workflow (**Figure 1**).*

Tool Name	Description
1. Watershed & River Delineation	Delineates watershed extent and river network based on input DEM, pour point, and stream drainage area threshold.
2. Sub-Catchment & Interfluve Delineation	Delineates sub-catchments and interfluves that comprise the watershed.
3. Network Discretization & Attribution	Splits the river network up into reaches based on a user defined interval and attributes each reach with upstream drainage area, reach length, upstream and downstream elevations, and river slope.
4. Network Routing Preparation	Snaps points (nodes) to a river network and links/attributes the points with river attributes. Also, can flag portions of a river network that overlaps with a polygon of interest.
5. Scaling Relationship Generator	Uses two fields in a shapefile to create a univariant regression of x and y data. The tool can create a power law, exponential, or linear fit.
6. Scaling Relationship Extractor	Uses a field in a shapefile, a, and b coefficients to generate data based on a power law, exponential, or linear fit.
7. Fluvial Polygon Transects	Creates transects that extend across a polygon based on a user defined spacing.
8. Fluvial Link Averaged Width	Converts transects extending across a polygon into a raster representing widths throughout the polygon and calculates the average width of a line segment inside the polygon.

Folder Structure for Outputs

Key outputs from USUAL (Figure 1) and those listed in each table in the following section are written to a user-defined folder. Note, if using nested analysis, the output folder contains additional folders with outputs for each nested watershed that is based on an optional user naming structure (**Figure 2Figure 1**). Additionally, each output folder will include a 'temp' subfolder to house all intermediate outputs, within which each tool creates its own subfolder of organized outputs. The inclusion of this intermediate data is intended to help users troubleshoot problems, and this folder structure makes it easy to delete all intermediate files if the final results are satisfactory.

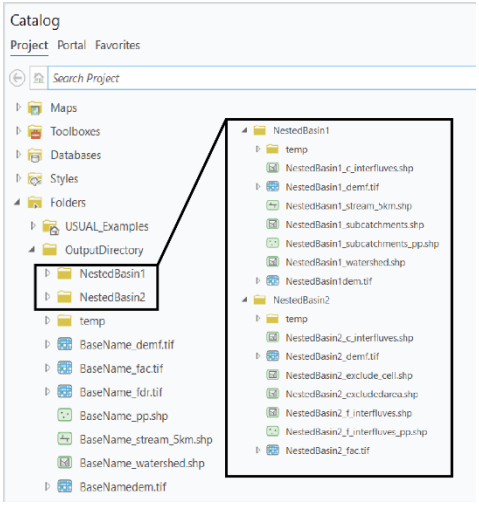


Figure 2*. Example of folder structure. Note the data is stored in the user defined Output Directory and each file is starts with a user defined Base Name. The inset shows additional files and folders produced for nested analyses. Note this example does not show all output files.*

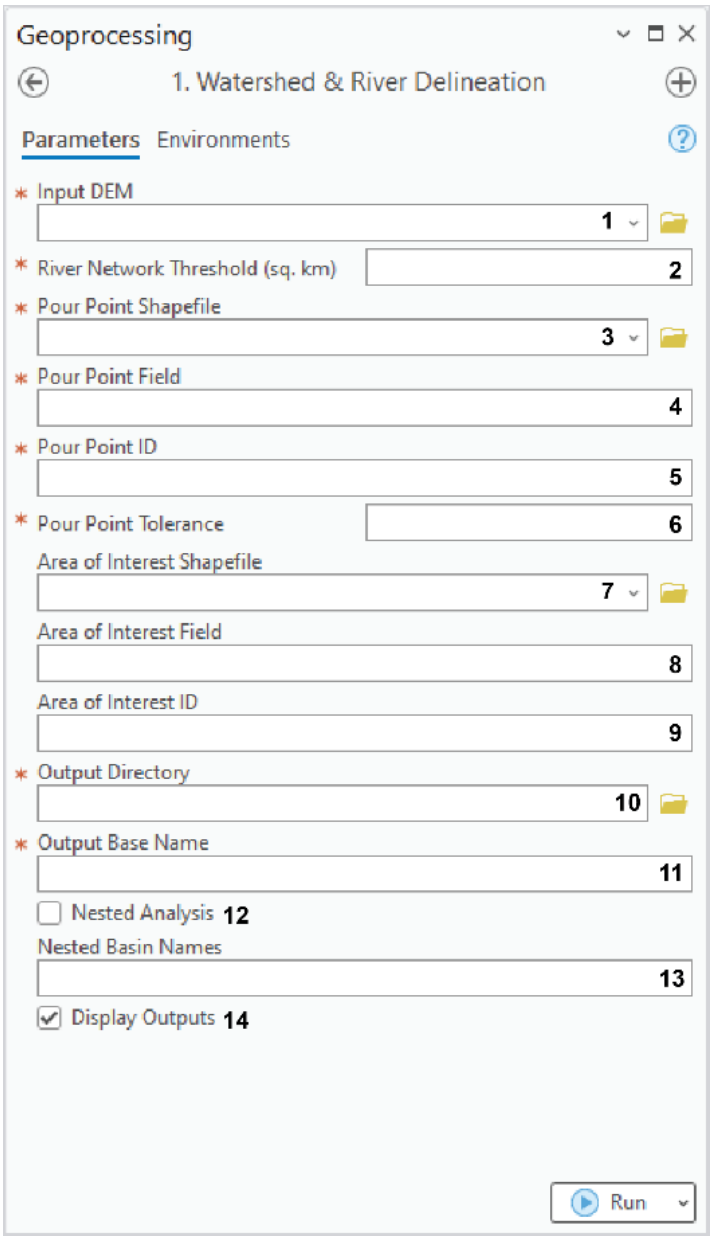
Table 2. Relative directory paths to where each tool creates temporary folders to store all intermediate files. Note tools 5 and 6 do not generate intermediate files and tools 7 and 8 use the same temporary directory to store data. If temp folder is deleted after running tool 7, then it will be recreated if tool 8 is used.

Tool Name	Temporary data folder name
1. Watershed & River Delineation	Output_directory/temp/wtrshd
2. Sub-Catchment & Interfluve Delineation	Output_directory/temp/Subbasin
3. Network Discretization & Attribution	Output_directory/temp/RiverDisc
4. Network Routing Preparation	Output_directory/temp/DataCleaning
5. Scaling Relationship Generator	N/A
6. Scaling Relationship Extractor	N/A
7. Fluvial Polygon Transects	Output_directory/temp/Transects
8. Fluvial Link Averaged Width	Output_directory/temp/Transects

Using the GUI in ArcGIS Pro

In the following sub-sections, an image showing each tool in the USUAL Watershed Tools (**Figure 1**) is provided. Each numbered input in the image corresponds to a description of the input in the following table.

1. Watershed and River Delineation



Watershed & River Delineation

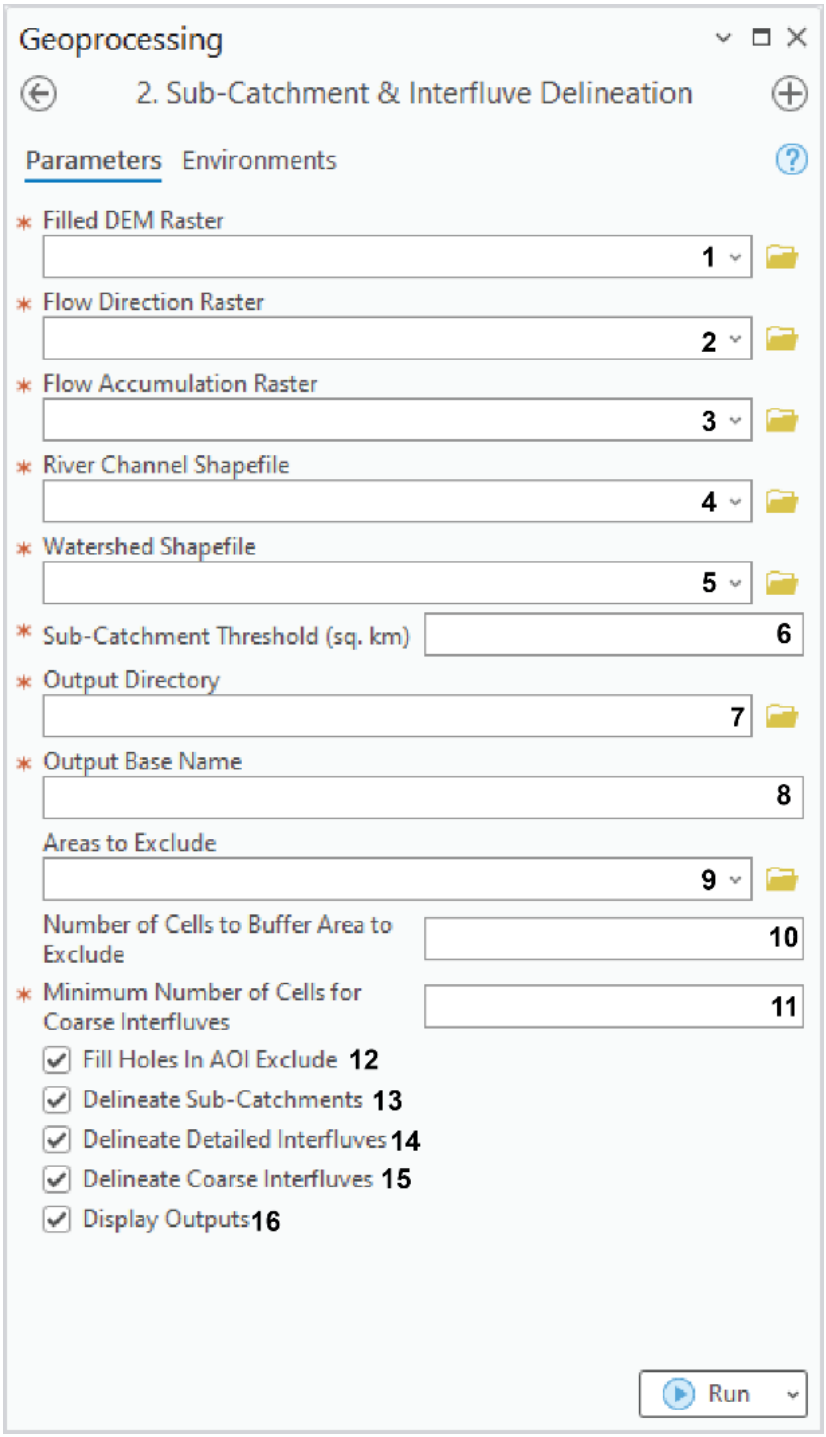
Inputs			
Name	**Type**	**Required**	**Description**
1. Input DEM	Raster	Yes	Digital elevation model
2. River Network Threshold	Double	Yes	Upstream most drainage area value for channel delineation (in km^2)
3. Pour Point Shapefile	Point Shapefile	Yes	Shapefile containing downstream point(s) of interest
4. Pour Point Field	Attribute Field Name	Yes	Field name of attribute containing point identifiers
5. Pour Point ID	Field Value	Yes	Value(s) of interest in the pour point field
6. Pour Point Tolerance	Double	Yes	Maximum distance a pour point can shift to intersect highest flow accumulation cell* (in map units)
7. Area of Interest Shapefile	Polygon Shapefile	No	Shapefile denoting area to perform analysis
8. Area of Interest Field	Attribute Field Name	No	Field name of attribute containing polygon identifiers
9. Area of Interest ID	Field Value	No	Value(s) of interest in the area of interest field
10. Output Directory	Folder Path	Yes	Directory path to write all outputs to
11. Output Base Name	String	Yes	Name to append to all output files†
12. Nested Analysis	Boolean	No	Toggles on or off nested analysis
13. Nested Basin Names	String	No	Output names for nested basins†
14. Display Outputs	Boolean	Yes	Automatically loads outputs to ArcGIS Pro
Outputs			
Name	**Type**		**Description**
[Base Name‡]_dem.tif	Raster		Digital elevation model
[Base Name]_demf.tif	Raster		Sink filled digital elevation model
[Base Name]_fdr.tif	Raster		Flow direction values
[Base Name]_fac.tif	Raster		Flow accumulation values
[Base Name]_pp.shp	Point Shapefile		Pour point(s) used for watershed delineation
[Base Name]_watershed.shp	Polygon Shapefile		Polygon of watershed extent
[Base Name]_stream_[River Network Threshold]_km.shp	Polyline Shapefile		Polyline of river channel

* Set value to 0 if not using snap pour points.

† When setting output base and nested basin names any inputs can be used. However, it is advised to begin the name with a letter and not to include spaces. ArcGIS tools occasionally fail when filenames begin with numbers and file paths contain spaces.

‡ Base name used in output file names is set by the output base name in 10 above. Additionally, if using a nested analysis, the full watershed will be named using base name and then subfolders with nested watersheds will contain the same files but with the nested base names used as the prefix in place of base name.

2. Sub-Catchment and Interfluve Delineation



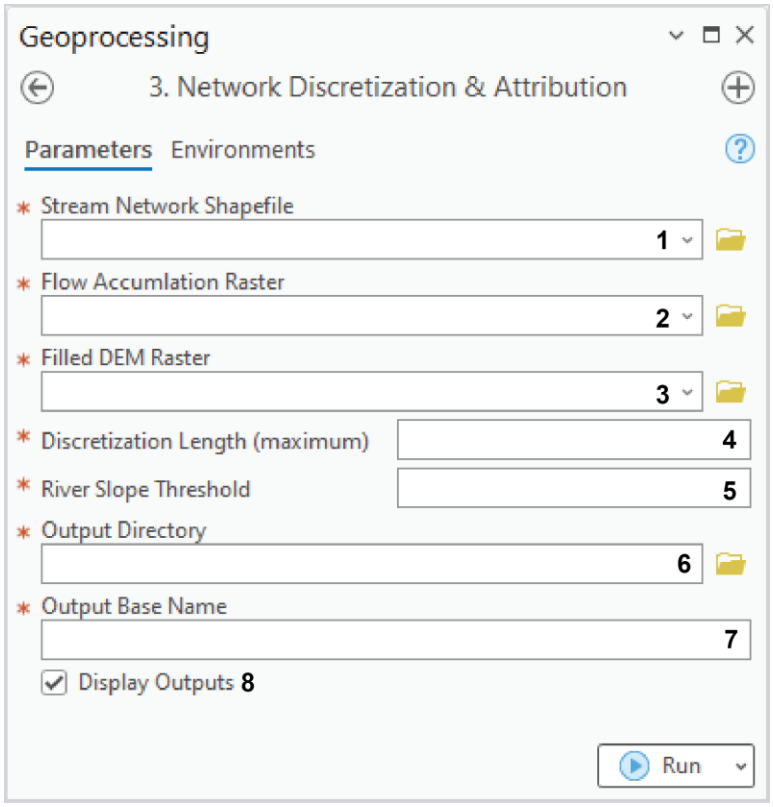
Sub-Catchment & Interfluve Delineation

Inputs			
Name	**Type**	**Required**	**Description**
1. Filled DEM	Raster	Yes	Filled digital elevation model
2. Flow Direction	Raster	Yes	Flow direction raster
3. Flow Accumulation	Raster	Yes	Flow accumulation raster
4. River Channel Shapefile	Polyline Shapefile	Yes	Shapefile delineating river path
5. Watershed Shapefile	Polygon Shapefile	Yes	Shapefile delineating watershed extent
6. Sub-Catchment Threshold	Double	Yes	Drainage area threshold for specifying sub-catchments
7. Output Directory	Folder Path	Yes	Directory path to write all outputs to
8. Output Base Name	String	Yes	Name to append to all output files
9. Areas to Exclude	Polygon Shapefile	No	Shapefile delineating areas to exclude from sub-catchment and interfluve delineation
10. Number of Cells to Buffer Area to Exclude	Double	No	Number of cells to buffer area to exclude shapefile
11. Minimum Number of Cells for Coarse Interfluves	Double	No	Minimum number of cells required to delineate a coarse interfluve
12. Fill Holes in AOI to Exclude*	Boolean	Yes	Removes all holes in area to exclude shapefile*
13. Delineate Sub-Catchments	Boolean	Yes	Toggles on or off sub-catchment delineation
14. Delineate Detailed Interfluves	Boolean	Yes	Toggles on or off detailed interfluve delineation
15. Delineate Coarse Interfluves	Boolean	Yes	Toggles on or off coarse interfluve delineation
16. Display Outputs	Boolean	Yes	Automatically loads outputs to ArcGIS Pro Map

* This will fill any holes in the area to exclude polygon. Holes can be created when buffering an irregularly shaped polygon and this fixes that issue. Turn off if you have intentional holes in your input polygon

Outputs		
Name	**Type**	**Description**
[Base Name]_subcatchments.shp	Polygon Shapefile	Delineated sub-catchments
[Base Name]_subcatchments_pp.shp	Point Shapefile	Pour points for each sub-catchment
[Base Name]_f_interfluves.shp	Polygon Shapefile	Detailed delineated interfluves
[Base Name]_f_interfluves_pp.shp	Point Shapefile	Pour points for each detailed interfluve
[Base Name]_c_interfluves.shp	Polygon Shapefile	Coarse delineated interfluves
[Base Name]_excludedarea.shp	Polygon Shapefile	Copy of input area to exclude clipped to watershed extent
[Base Name]_exclude_cell.shp	Polygon Shapefile	Area to exclude shapefile reshaped to DEM cell edges and buffered

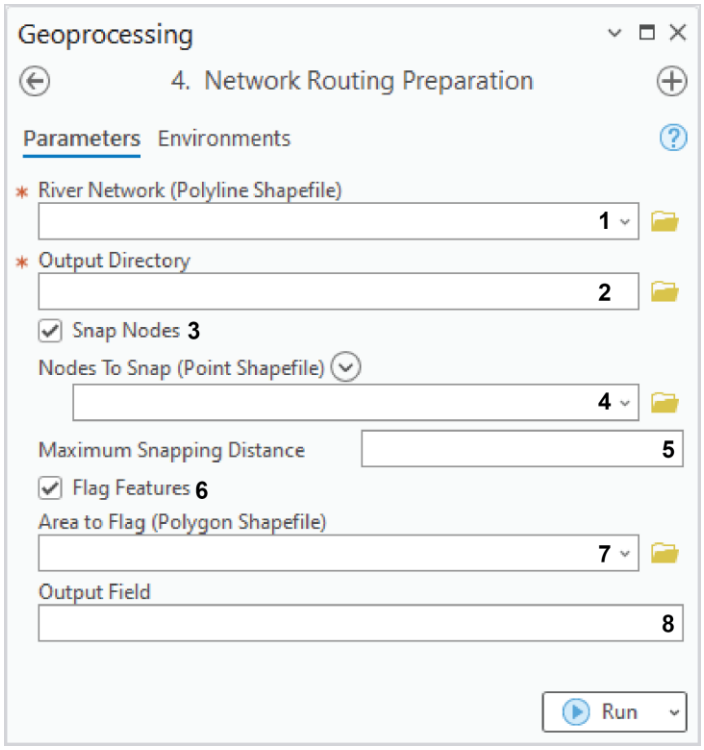
3. Network Discretization and Attribution



Network Discretization & Delineation

Inputs			
Name	**Type**	**Required**	**Description**
1. Stream Network Shapefile	Polyline Shapefile	Yes	Shapefile delineating river network
2. Filled DEM	Raster	Yes	Digital elevation model
3. Flow Accumulation Raster	Raster	Yes	Flow accumulation raster
4. Discretization Length	Double	Yes	Maximum distance to split polylines (in map units)
5. River Slope Threshold	Double	Yes	Minimum allowed river slope (dimensionless slope; e.g., m/m or ft/ft)
6. Output Directory	Folder Path	Yes	Directory path to write all outputs to
7. Output Base Name	String	Yes	Name to append to all output files
8. Display Outputs	Boolean	Yes	Automatically loads outputs to ArcGIS Pro Map
Outputs			
Name	**Type**	**Description**	
[Base Name]_network.shp	Polyline Shapefile	Discretized and attributed river network	

4. Network Routing Preparation

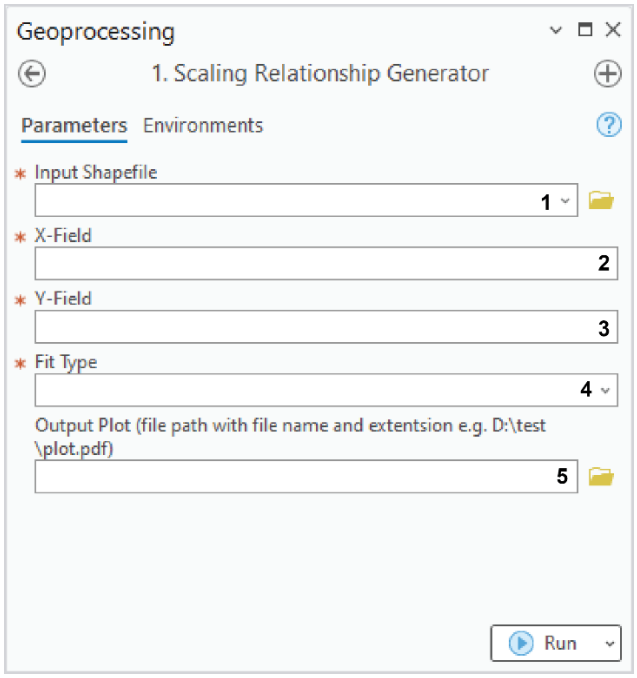


Network Routing & Preparation

Inputs			
Name	**Type**	**Required**	**Description**
1. River Network Shapefile	Polyline Shapefile	Yes	Shapefile delineating river network
2. Output Directory	Folder Path	Yes	Directory path to write all outputs to
3. Snap Nodes	Boolean	Yes	Toggles on or off node snapping
4. Nodes to Snap	Point Shapefile(s)	No	Points to snap to the river network
5. Maximum Snapping Distance	Double	Yes	Maximum distance to move points* (in map units)
6. Flag Features	Boolean	No	Toggles on or off feature flagging
7. Area to Flag	Polygon Shapefile	No	Polygon overlapping river reaches to flag
8. Output Field	Boolean	No	Auto loads outputs to ArcGIS Pro Map
Outputs			
Name	**Type**	**Description**	
[Input nodes]_snap_att.shp	Point Shapefile(s)	Nodes snapped to the river network and attributed with river attributes	

* If you want to snap all points set this value to a large number e.g. 50000.

5. Scaling Relationship Generator

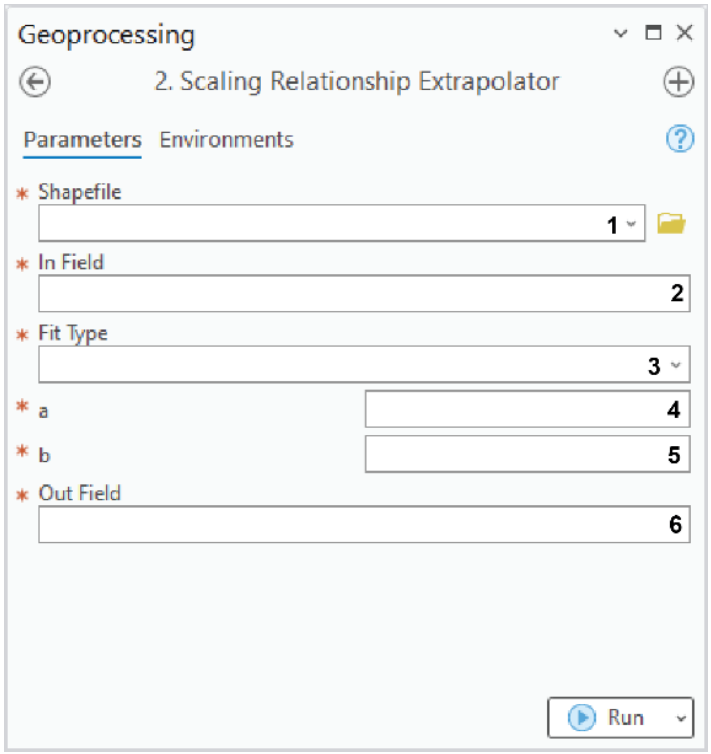


Scaling Relationship Generator

Inputs			
Name	**Type**	**Required**	**Description**
1. Input Shapefile	Shapefile	Yes	Shapefile containing fields with x and y data
2. X-Field	Field	Yes	Field containing numeric x-data for fitting
3. Y-Field	Field	Yes	Field containing numeric y-data for fitting
4. Fit Type	String	Yes	Drop down menu to choose fitting equation
5. Output Plot	Path and File Name	No	Path, file name, and file type to save image of output plot to

Outputs		
Name	**Type**	**Description**
Modifies: Input Shapefile	Field	Writes a coefficient to shapefile
Modifies: Input Shapefile	Field	Writes b coefficient to shapefile

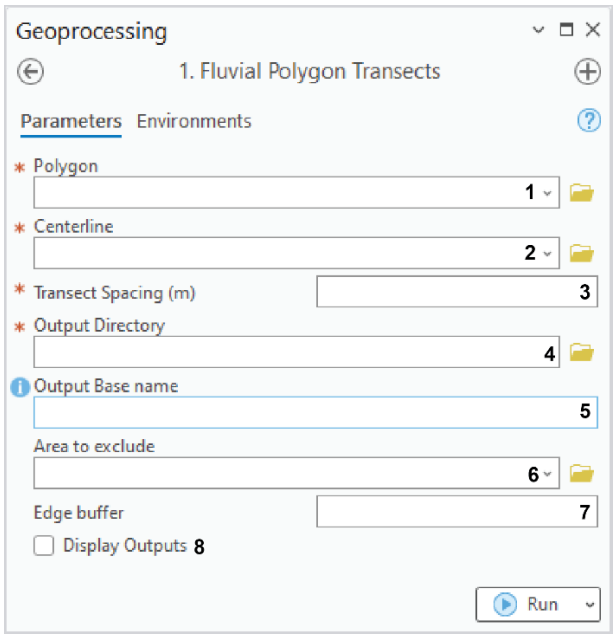
6. Scaling Relationship Extrapolator



Scaling Relationship Extrapolator

Inputs			
Name	**Type**	**Required**	**Description**
1. Input Shapefile	Shapefile	Yes	Shapefile containing field with x-data
2. In Field	Field	Yes	Field numeric containing x-data for fitting
3. Fit Type	String	Yes	Drop down menu to choose fitting equation
4. a	Double	Yes	Coefficient a to use in fitting equation
5. b	Double	Yes	Coefficient b to use in fitting equation
6. Out Field	String	Yes	Name of field to write data to
Outputs			
Name	**Type**	**Description**	
Modifies: Input Shapefile	Field	Adds output field and writes y-data to the field	

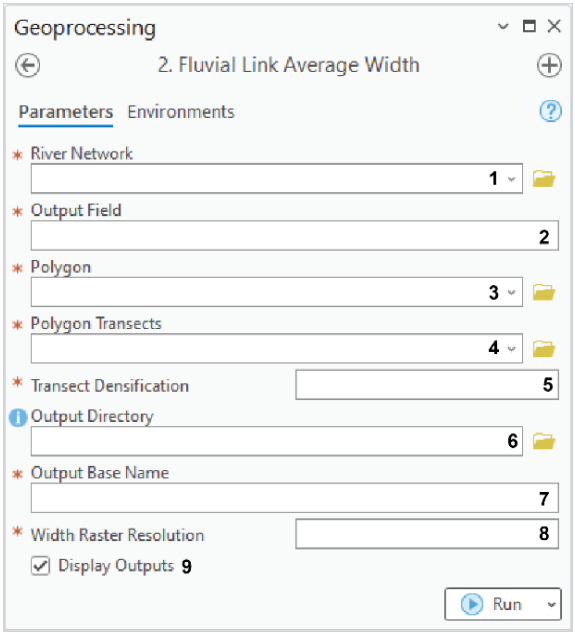
7. Fluvial Polygon Transects



Fluvial Polygon Transects

Inputs			
Name	**Type**	**Required**	**Description**
1. Polygon	Polygon Shapefile	Yes	Elongate polygon shapefile (e.g. river or valley bottom polygon)
2. Centerline	Polyline Shapefile	Yes	Polyline shapefile extending through center of input polygon
3. Transect Spacing	Double	Yes	Spacing along polygon to generate transects (in map units)
4. Output Directory	Folder Path	Yes	Directory path to write all outputs to
5. Output Base Name	String	Yes	Name to append to all output files
6. Area to Exclude	Polygon Shapefile	No	Polygon specifying area not to generate transects
7. Edge Buffer	Double	No	Radius around intersection of polygon and centerline to not generate transects (in map units)
8. Display Outputs	Boolean	Yes	Automatically loads outputs to ArcGIS Pro Map
Outputs			
Name	**Type**	**Description**	
[Base Name]_transects.shp	Polyline Shapefile	Lines extending across the polygon to nearest vertex	
[Base Name]_transects_nodes.shp	Point Shapefile	Points used to connect lines across polygon	

8. Fluvial Reach Averaged Width



Fluvial Link Averaged Width

Inputs			
Name	**Type**	**Required**	**Description**
1. River Network	Polyline Shapefile	Yes	Shapefile delineating river network
2. Output Field	String	Yes	Field name to write output reach averaged width to
3. Polygon	Polygon Shapefile	Yes	Upstream most drainage area threshold for channel delineation
4. Polygon Transects	Polyline Shapefile	Yes	Maximum distance to split polylines
5. Transect Densification	Double	Yes	Specifies spacing between points along a transect for interpolation
6. Output Directory	Folder Path	Yes	Directory path to write all outputs to
7. Output Base Name	String	Yes	Name to append to all output files
8. Width Raster Resolution	Double	Yes	Specifies resolution of output polygon width raster
9. Display Outputs	Boolean	Yes	Automatically loads outputs to ArcGIS Pro Map

Outputs		
Name	**Type**	**Description**
[Base Name]_widthraster.tif	Raster	Raster containing all interpolated widths inside of polygon
Modifies: Input River Network	Shapefile	Adds reach averaged width values to input River Network

Working with Standalone Scripts

Accessing Python Scripts

Standalone scripts are provided with the GitHub download in a folder called Standalone_Scripts. If using the standalone Python scripts, ensure you are working in a Python environment with ArcPy installed (note ArcPy requires an active ESRI license). This can be done natively in ArcGIS Pro using Jupyter Notebook or the Python command line. Alternatively, you can set up any external environment with ArcPy installed, for instance Anaconda distribution of Python using an environment with ArcPy installed.

Modifying Scripts

Upon opening each script, near the top is a variable called usegui, this variable needs to be changed from "True" to "False". Directly following the usegui variable, there is a section labeled "User Inputs". Here, you can set each of the variables and data inputs in the script. If you modify the scripts, you can embed your modified scripts into the GUI (assuming no changes to the inputs or options) by right clicking the tool in the GUI and clicking edit. This will open the original Python script, which you can delete the original code and copy and paste your modified script into. Note, if you edit the underlying code and then intend to return to using the GUI, ensure you change the usegui variable back to True.