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How to Resolve Channel Travel Time Errors in the TR-55 Worksheet Using Arc Hydro Tools, HEC-GeoHMS and HEC-HMS

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This paper is meant to be used as a supplemental aid to the tutorials and user's manuals stated in the references. It is assumed that the user has basic knowledge of ArcGIS 10.4.

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Introduction

This tutorial is an illustration of a stepwise procedure for resolving errors in calculated channel travel times that occur when processing watershed parameters in HEC-GeoHMS. Channel travel time errors occur when a GIS-defined channel slope value during preprocessing of the Digital Elevation Data (DEM) is zero or negative (Adalikwu, 2021). The tutorial is intended to assist a relatively experienced ArcMap user resolve channel travel time errors that are documented in the TR55 Worksheet. Particularly, this tutorial is useful if the Muskingum method is selected by the watershed modeler as the river routing method. The K parameter value in the Muskingum routing method is the channel travel time (Song, Kong, & Zhu, 2011). This value can be obtained from the TR55 Worksheet under the channel flow characteristics. According to the TR55 methodology, a watershed's time of concentration is a hydrologic parameter estimated as the sum of travel times for channel flow, concentrated shallow flow and sheet flow (Fleming & Doan, 2013; McCuen & Okunola, 2002). Therefore, errors in channel travel times will result in incorrect computed time of concentration.

The step-by-step approach in this tutorial begins with the preprocessing of GIS data in HEC-GeoHMS up until when channel errors are encountered and how the errors are resolved.

Objective

In this tutorial, a watershed has channel travel time errors in some subbasins. The Merge Basin tool in HEC-GeoHMS is used to merge subbasins having channel travel time errors with their subbasin neighbors that are error free. For demonstration purposes, the tutorial models Mud Creek Watershed in Perkins County, South Dakota, by subdividing the watershed into eleven (11) subbasins using a threshold area of 3.5 km^2. More detailed steps on how to model a watershed are outlined in the HEC-GeoHMS User's Manual (Fleming & Doan, 2013).

Datasets and Sources

There are a lot of different sources for the datasets needed for creating a HEC-GeoHMS project. The **GeoSpatialDataGateway** on the United State Department of Agriculture (USDA) website is one place where all the datasets can be downloaded (https://gdg.sc.egov.usda.gov/GDGOrder.aspx). The other widely used data source is the Earth Resources Observation and Science (EROS) Center of the United State Geological Survey (USGS) (https://earthexplorer.usgs.gov).

Below is a list of the data requirement:

- Elevation: National Elevation Dataset (3, 10 or 30 meter)
- Hydrography: National Hydrography Dataset (1:24,000)
- Hydrologic Units: 12 Digit Watershed Boundary Dataset in HUC12 NRCS Version
- Land Use Land Cover: National Land Cover Dataset by state
- Soils: Soil Survey Geographic (SSURGO) by state or Conterminous US

Data Type	Description	Data Sources	Spatial Reference Information	Geodetic Model	Format	Source Scale Denominator	Year
National Elevation Data	The NED is a seamless mosaic of best-available elevation data.	USDA/NRCS - National Geospatial Center of Excellence (https://gdg.sc.egov.usda.gov/GDGOrder.aspx)	Grid Coordinate System: Universal Transverse Mercator	Horizontal Datum Name: North American Datum of 1983 (NAD83)	GeoTIFF	10 meters	Unknown
National Hydrography Dataset (NHD)	Provides a network of rivers and streams, including intermittent streams, ditches, and canals.				ARC/INFO Shape	24,000	2016
Soil Survey Geographic (SSURGO II) Soil	These data provide information about soil features on or near the surface of the Earth.		Horizontal Coordinate System Definition: Geographic	Horizontal Datum Name: World Geodetic System of 1984 (WGS84)	ESRI Shape file	250,000	2000 - Present
National Land Cover Dataset (NLCD)	The dataset is a generalized and nationally consistent land cover data layer for the United States		Grid Coordinate System: Universal Transverse Mercator	Horizontal Datum Name: North American Datum of 1983 (NAD83)	Tag Image File Format (TIFF)	30 meters	2011
12 Digit Watershed Boundary Dataset in HUC12	This dataset is intended to be used as a tool for water resolution				ARC/INFO Shape	24,000	2013 - Present

Table 1. Showing dataset types, description, sources, special references, geodatic models, format, source scale denominator and year of processing.

Watershed Modeling

The watershed modeling demonstrated in this tutorial processes the Mud Creek Watershed in Perkins County, South Dakota, by subdividing the watershed into eleven (11) subbasins using a threshold area of 3.5 km^2. It is assumed that the user has a working knowledge of developing HMS models using HEC-GeoHMS in ArcGIS. The user is therefore expected to obtain and process appropriate spatial data by following stated referencing to develop models on his or her own.

HEC-GeoHMS

HEC-GeoHMS is a software developed by the US Army Corps of Engineers and can be downloaded and added to Arc Map desktop as a public domain extension from their website (*https://www.hec.usace.army.mil/software/hec-hms/downloads.aspx).* The program features include data preprocessing, project setup, basin processing, watershed characteristics processing, hydrologic parameter estimation, HMS model support for creation of input files for HMS.

Data Preprocessing

Before embarking on data preprocessing, the user must create a personal geodatabase, an Arc Map document saved to a folder directory. Then dataset layers are loaded to the Arc Map as shown in Figure 1.

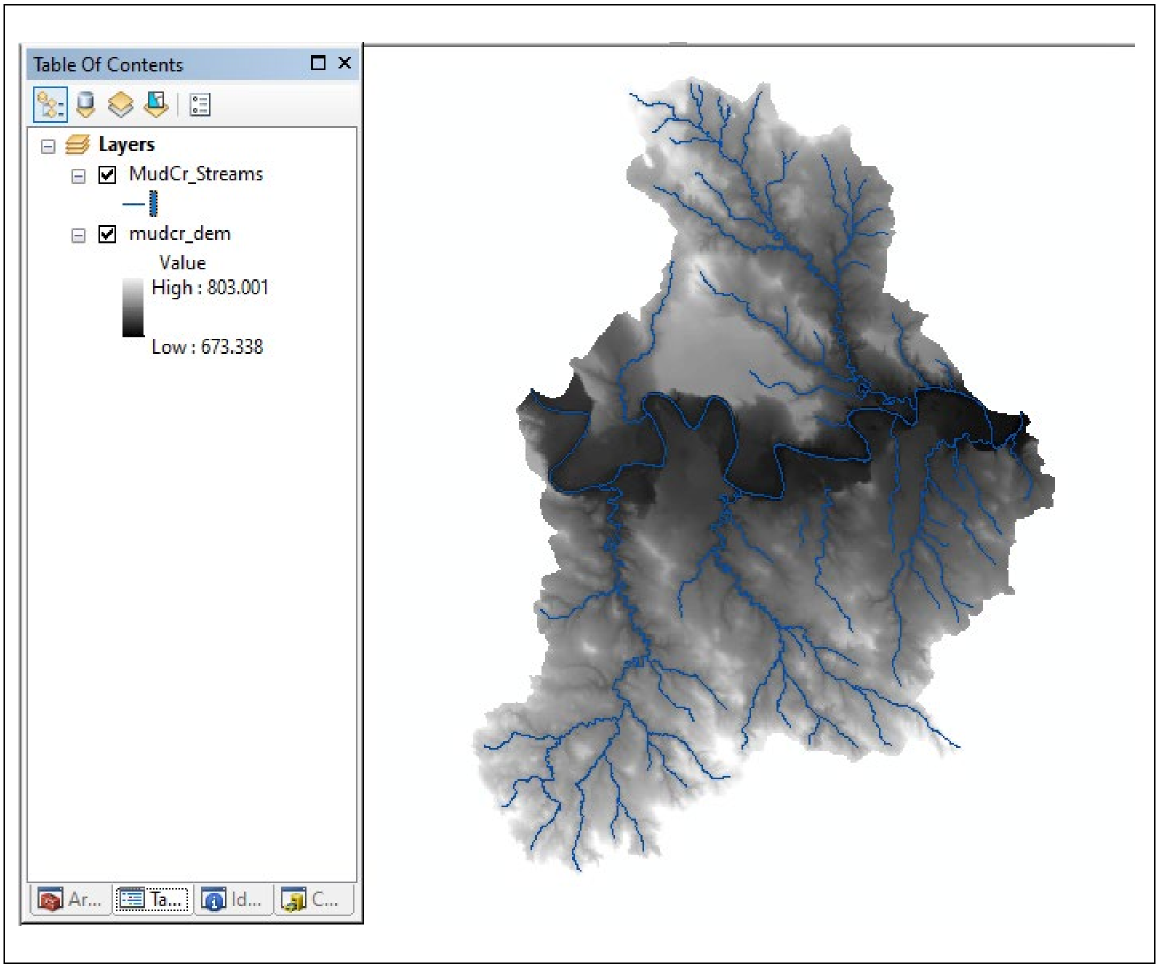


Figure 1. Showing Elevation and stream datasets loaded to Arc Map.

The preprocessing consists of steps that utilize the DEM and stream dataset to derive a drainage network. The following are data preprocessing steps:

- In the Preprocessing menu Preprocessing ▾ of the HEC-GeoHMS toolbar
  - Click on DEM Reconditioning. The DEM Reconditioning tool modifies the terrain by lowering elevation grid cells along streamlines.
  - In the pop-up window (Figure 2), select *mudcr_dem* for Input Raw DEM and *Mudcr_streams* for AGREE Stream from the drop-down menu.
  - Click OK to produce *AgreeDEM* layer (Figure 3)

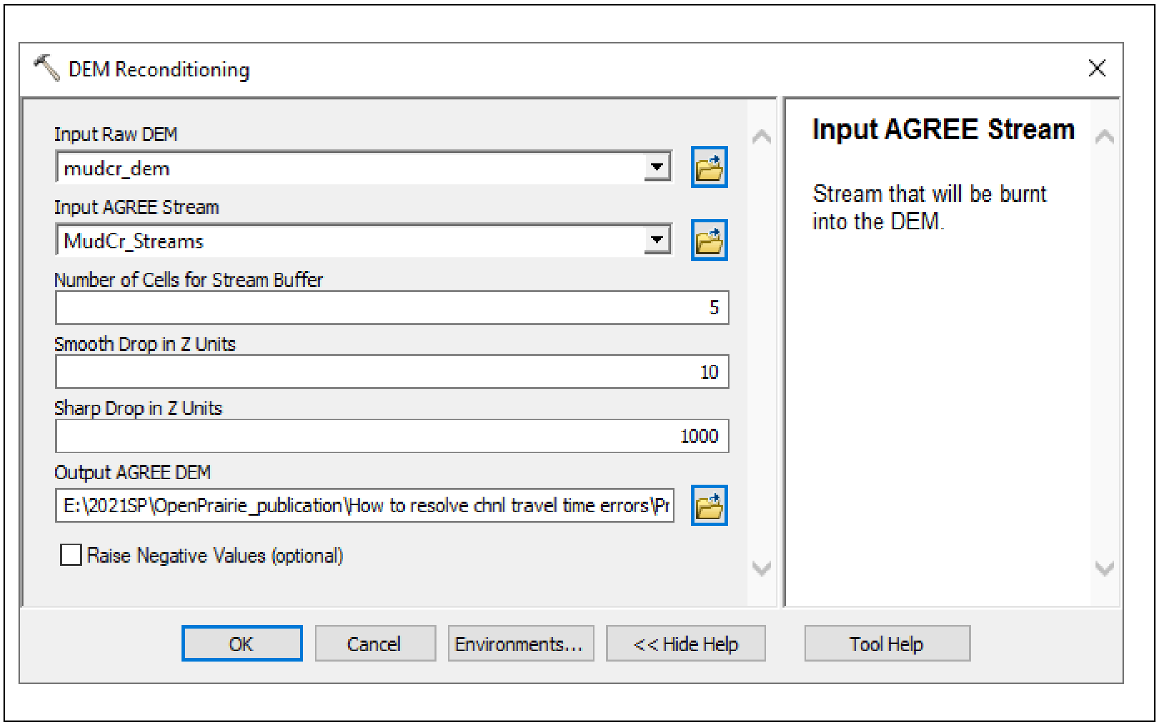


Figure 2. Showing DEM Reconditioning dialog box

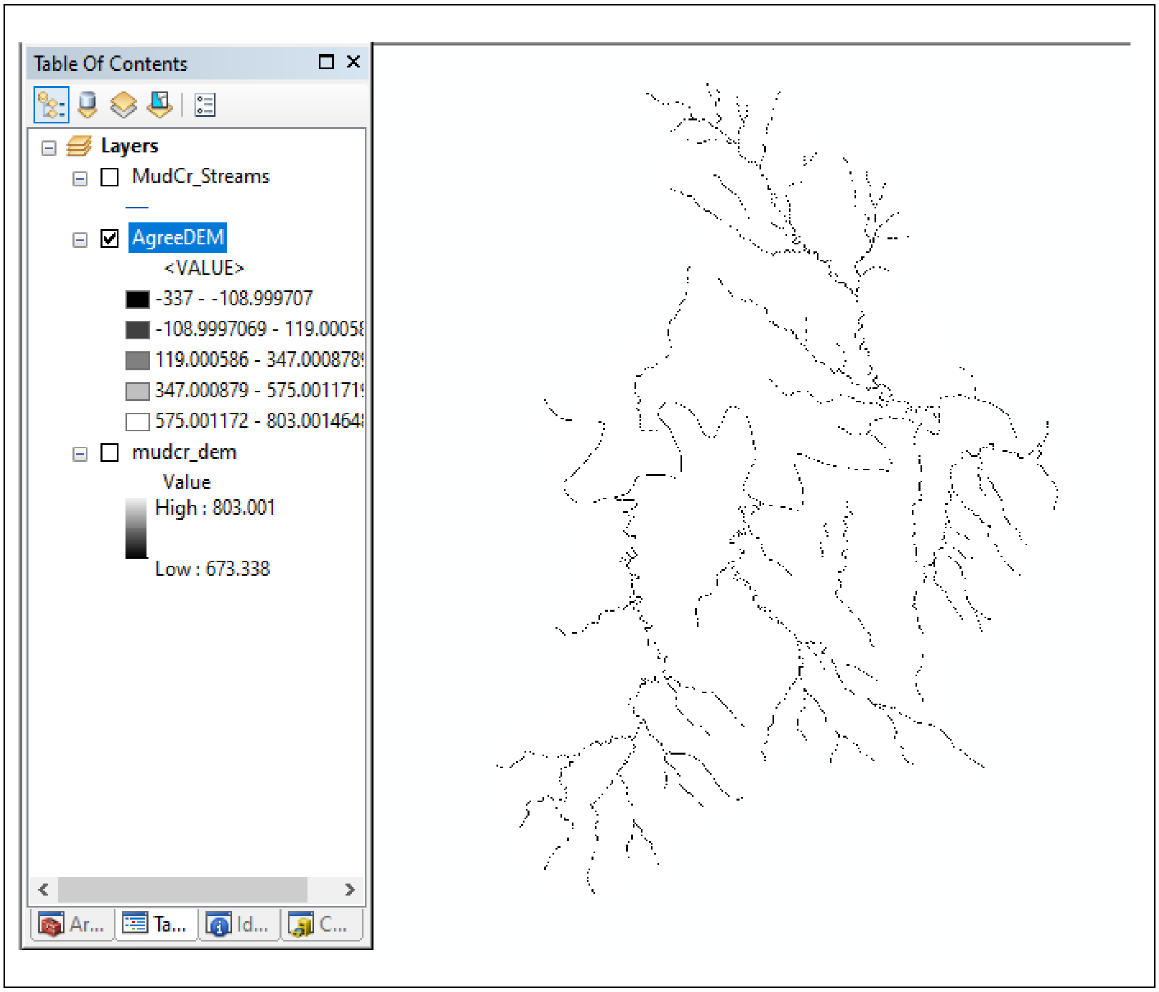


Figure 3. Showing AgreeDEM layer resulting from DEM reconditioning

- Click on Fill Sinks. The Fill Sinks tool creates depressionless DEM by increasing the elevation of pit cells in the DEM to allow water to flow along the terrain.
- In the pop-up window (Figure 4), select AgreeDEM from the drop-down menu.
- Click OK to produce *Fil* layer (Figure 5)

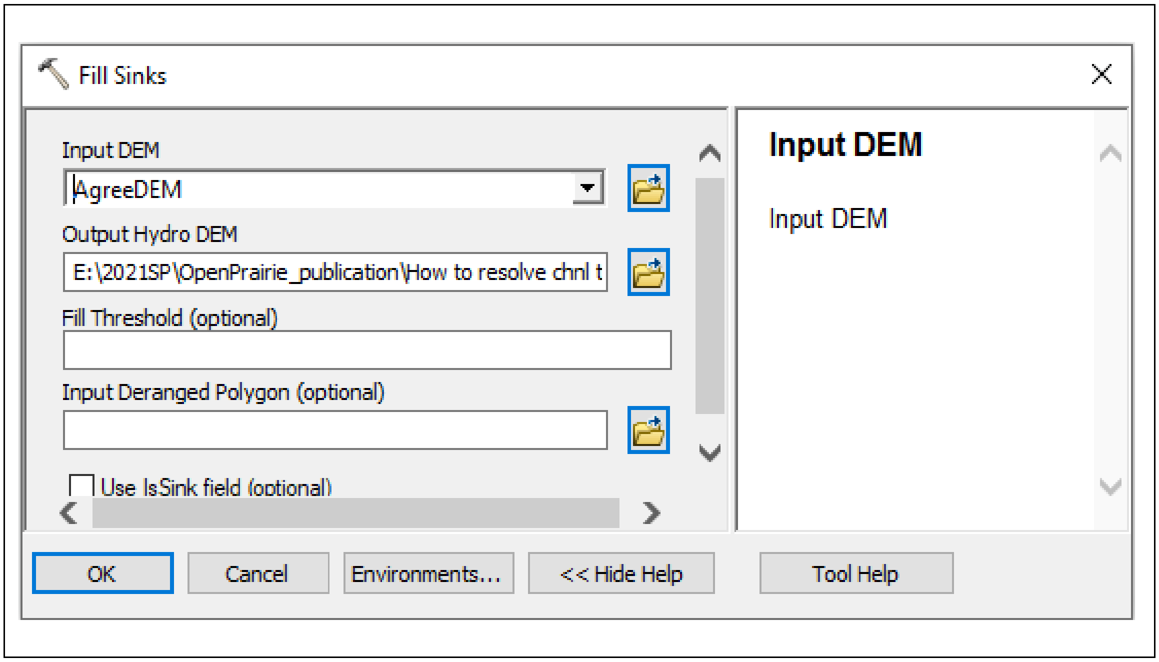


Figure 4. Showing Fill Sinks dialog box

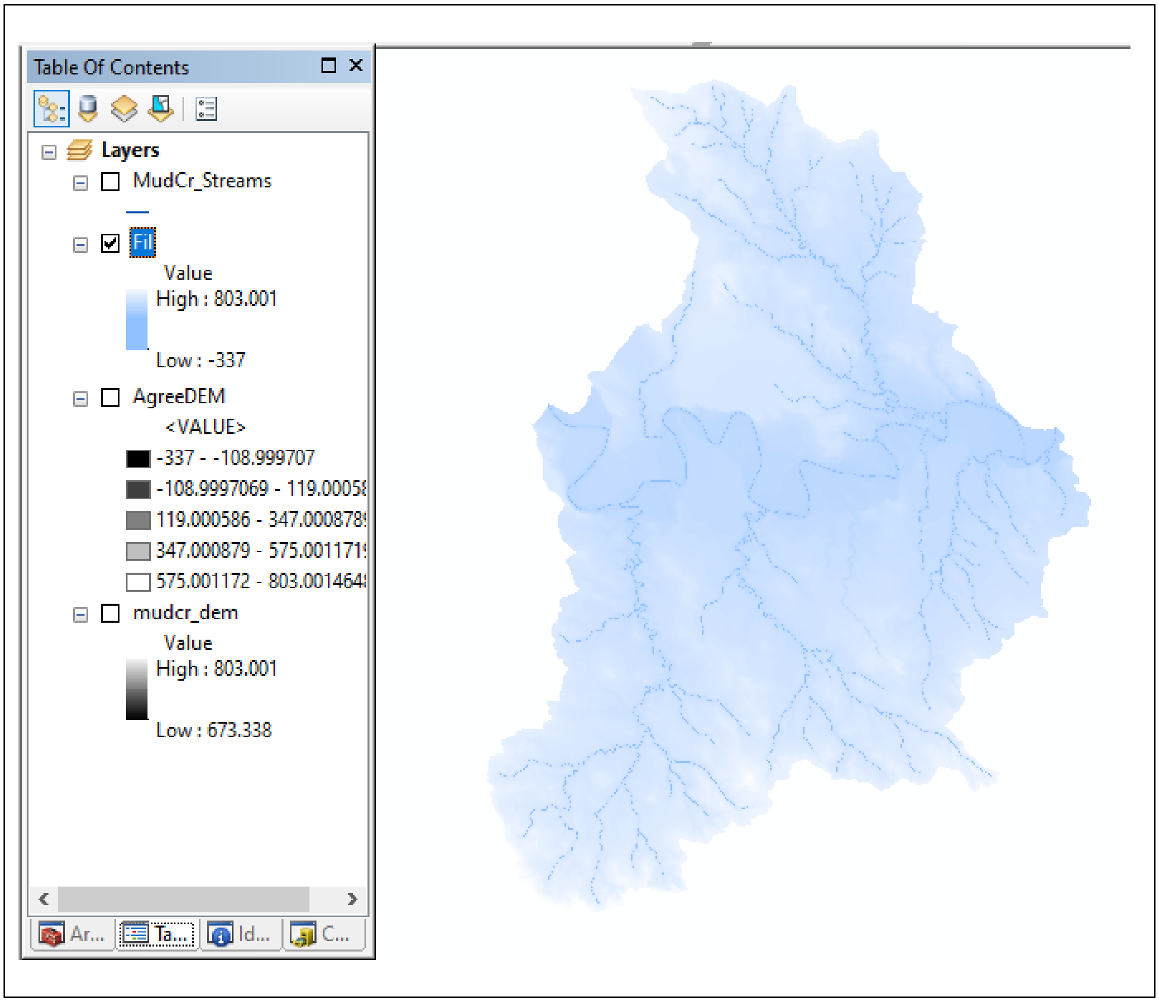


Figure 5. Showing Fil layer resulting from fill sinks processing

- Click on Flow Direction. The Flow Direction tool define the direction of steepest decent for each terrain cell in eight possible directions.
- In the pop-up window (Figure 6), confirm that the Input Hydro DEM is the *Fil* layer
- Click OK to produce *Fdr* layer (Figure 7)

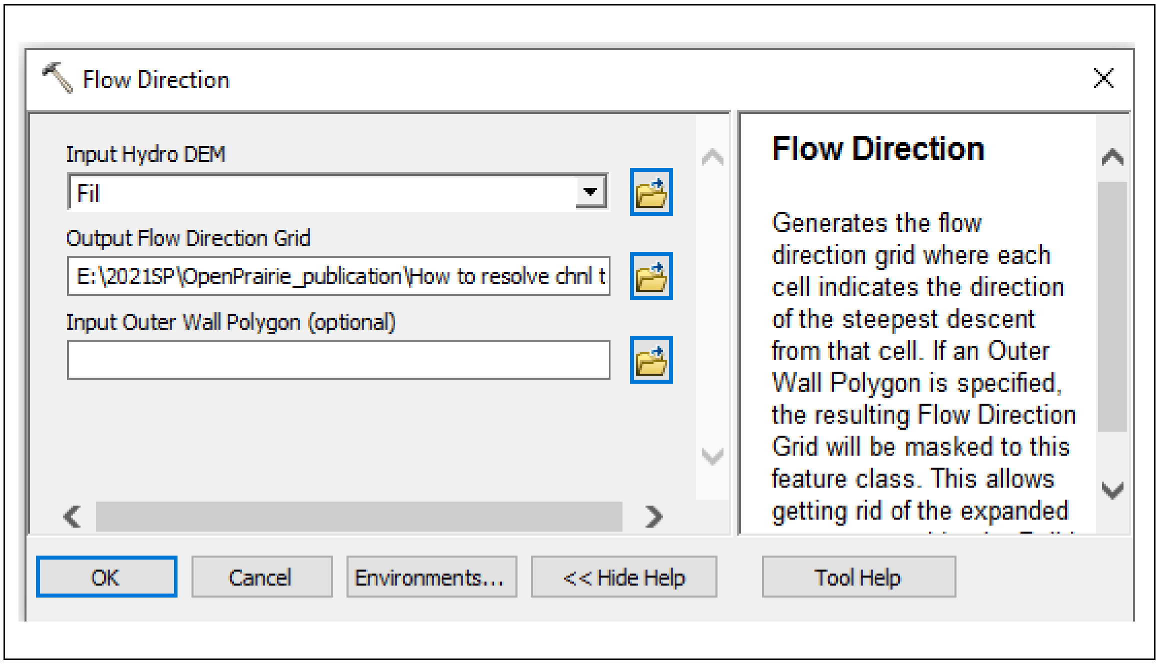


Figure 6. Showing flow direction dialog box

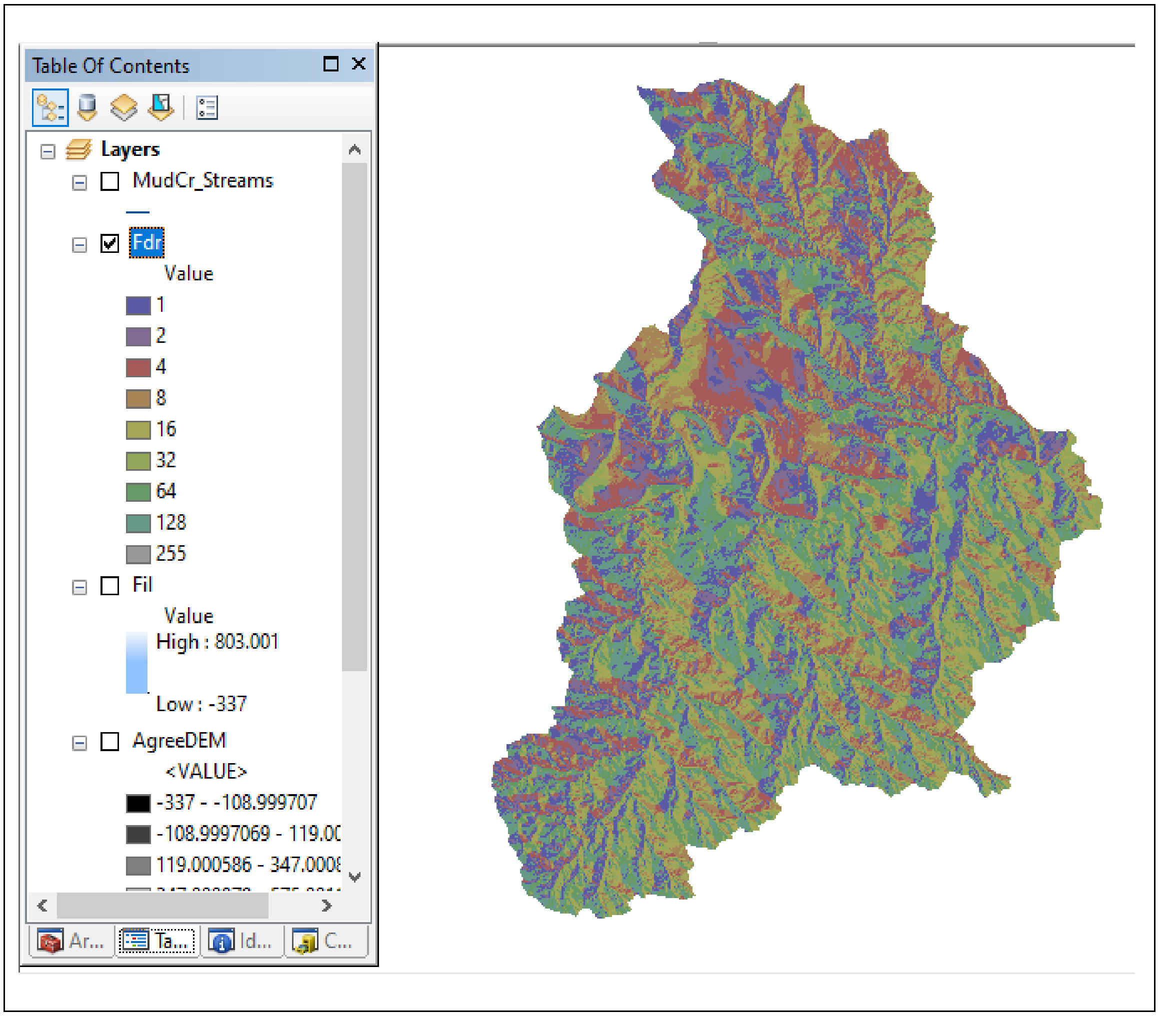


Figure 7. Showing Fdr layer resulting from flow direction processing.

- Click on Flow Accumulation. The Flow Accumulation tool determines the number of upstream cells draining to any given cell.
- In the pop-up window (Figure 8), confirm that the Input Flow Direction Grid is the *Fdr* layer.
- Click OK to produce a *Fac* layer (Figure 9)

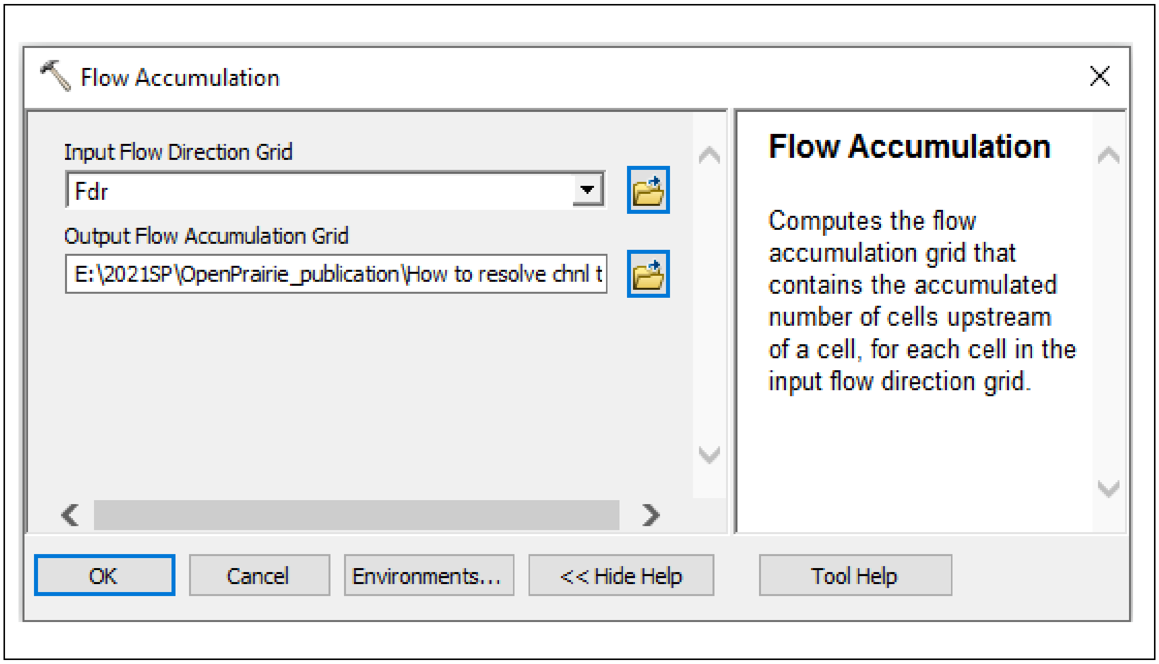


Figure 8. Showing flow accumulation dialog box

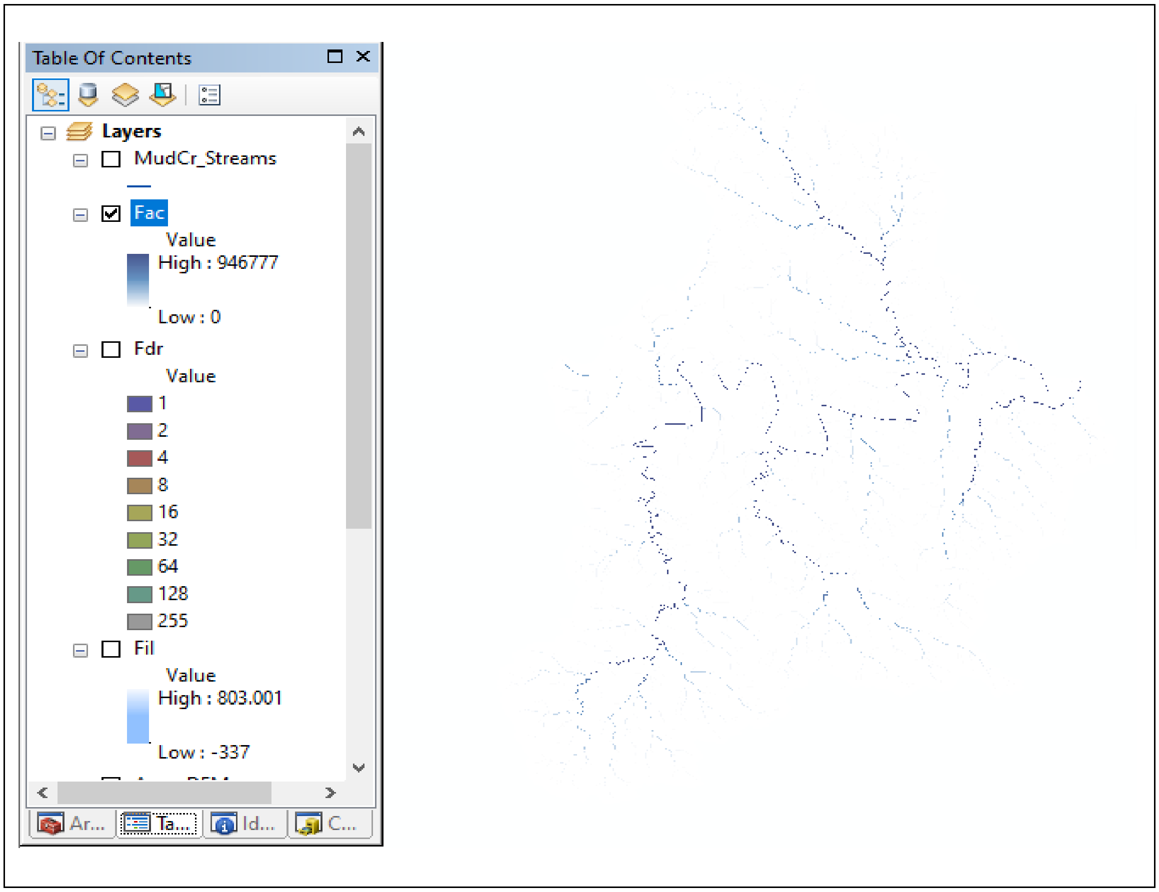


Figure 9. Showing Fac layer resulting from flow accumulation processing

- Click on Stream Definition. The Stream Definition tool classifies all cells with a flow accumulation greater than the user-defined threshold of cells in the stream network. In this illustration, the threshold for stream definition is 3.5 KM^2.
- In the pop-up window (Figure 10), confirm that the Input Flow Accumulation Grid is the *Fac* layer and the *Area Sqkm to define stream* is 3.5.
- Click OK to create *Str* layer (Figure 11).

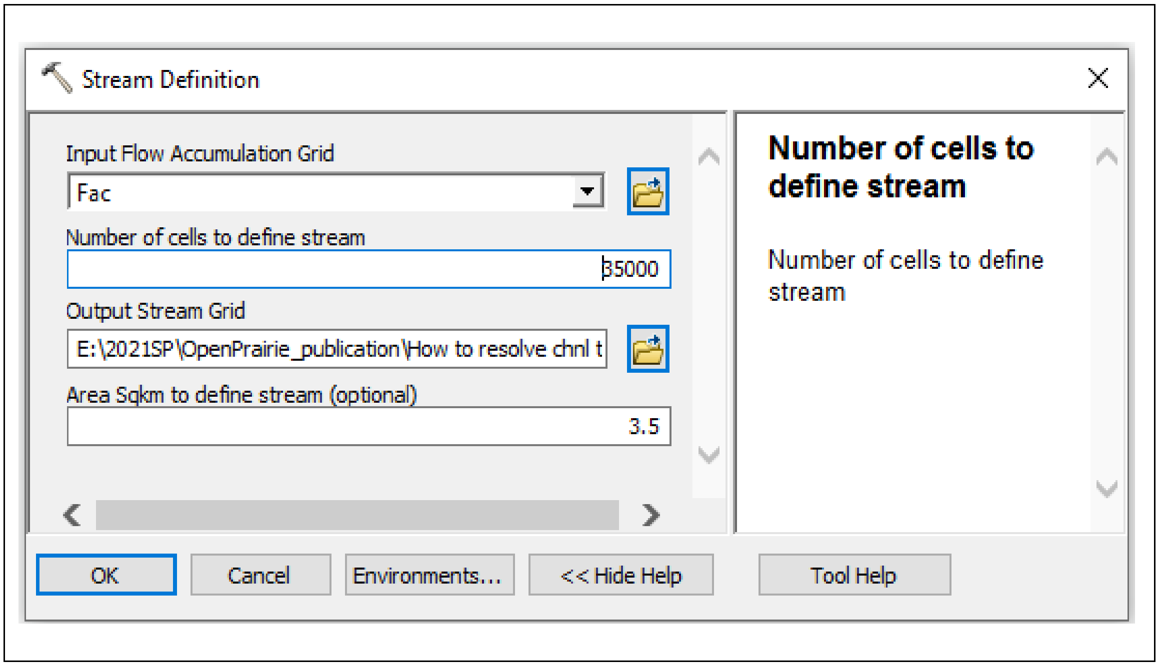


Figure 10. Showing stream definition dialog box

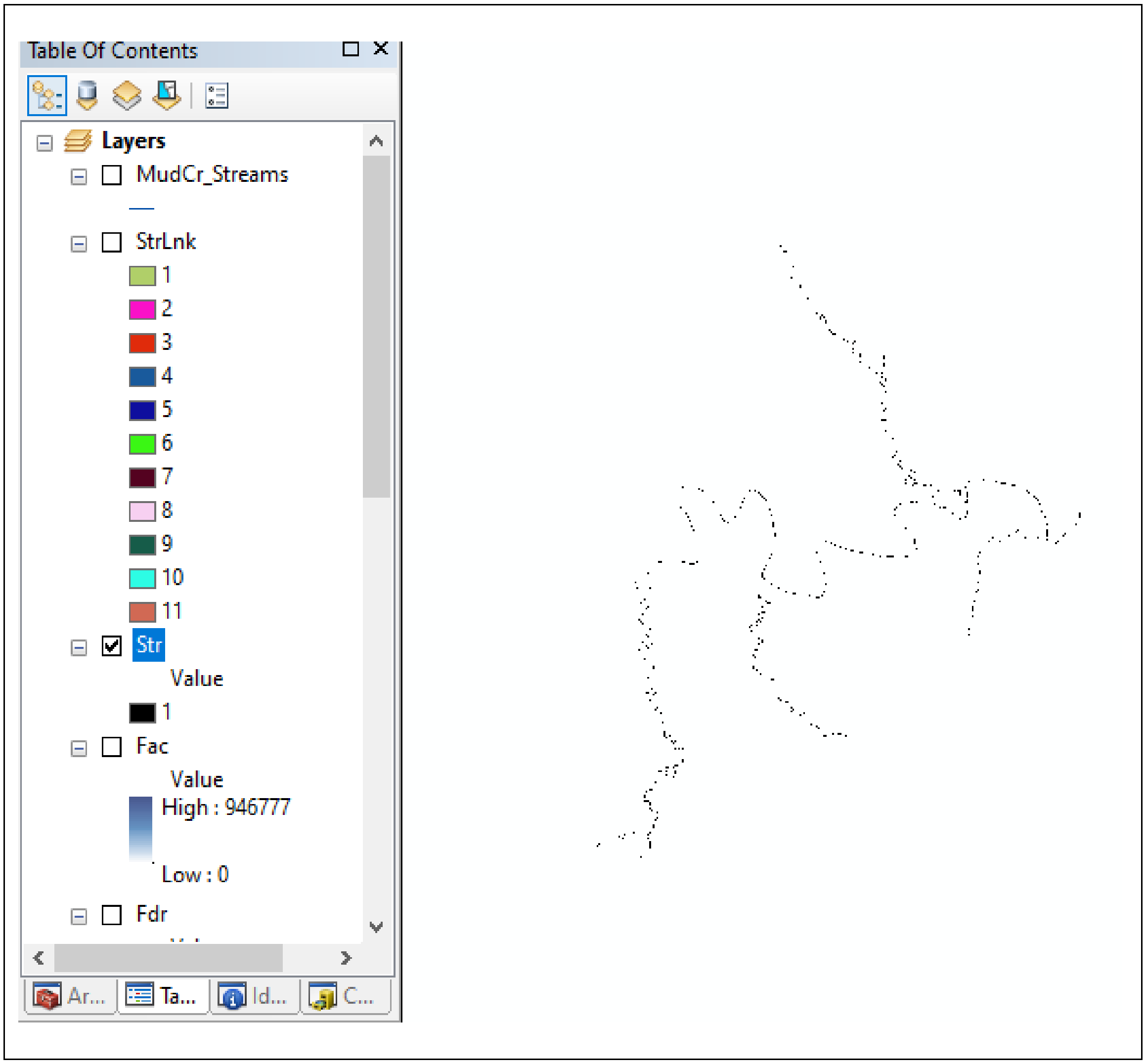


Figure 11. Showing Str layer resulting from stream definition.

- Click Stream Segmentation. The Stream Segmentation tool divides the stream grid into segments.
- In the pop-window (Figure 12), confirm that the Input Stream Grid is *Str,* and the Input Flow Direction Grid is *Fdr*.
- Click OK to create *StrLnk* layer (Figure 13)

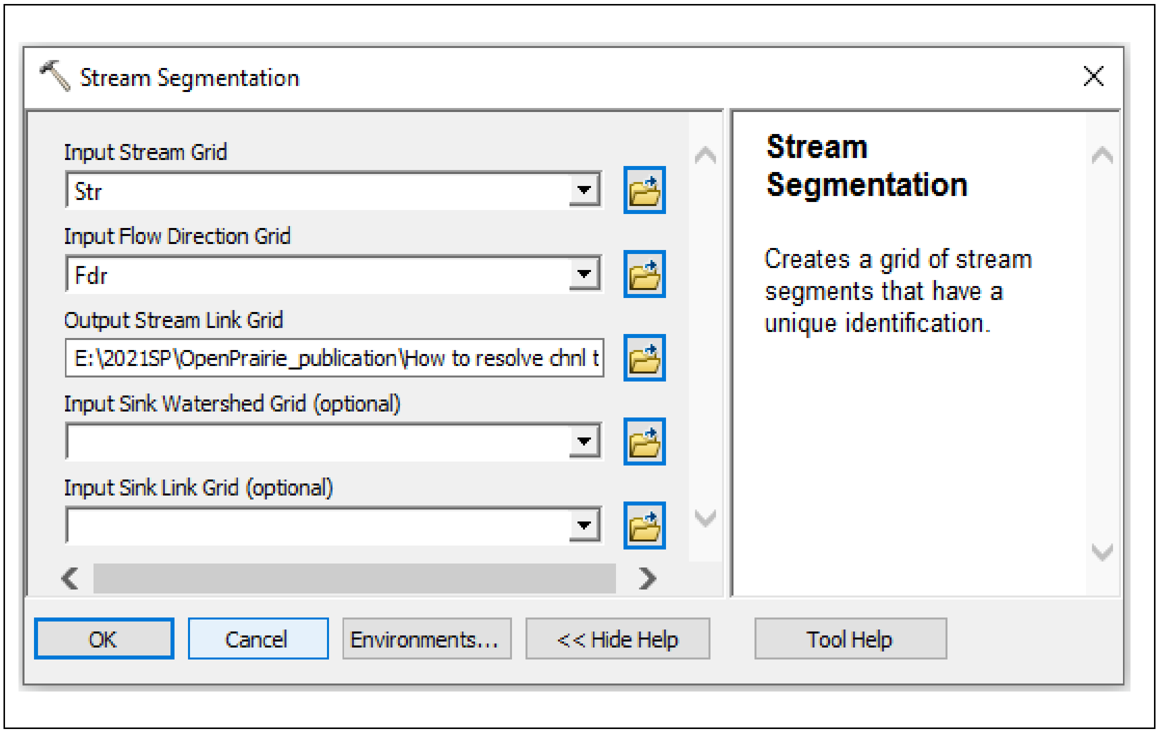


Figure 12. Showing stream segmentation dialog box

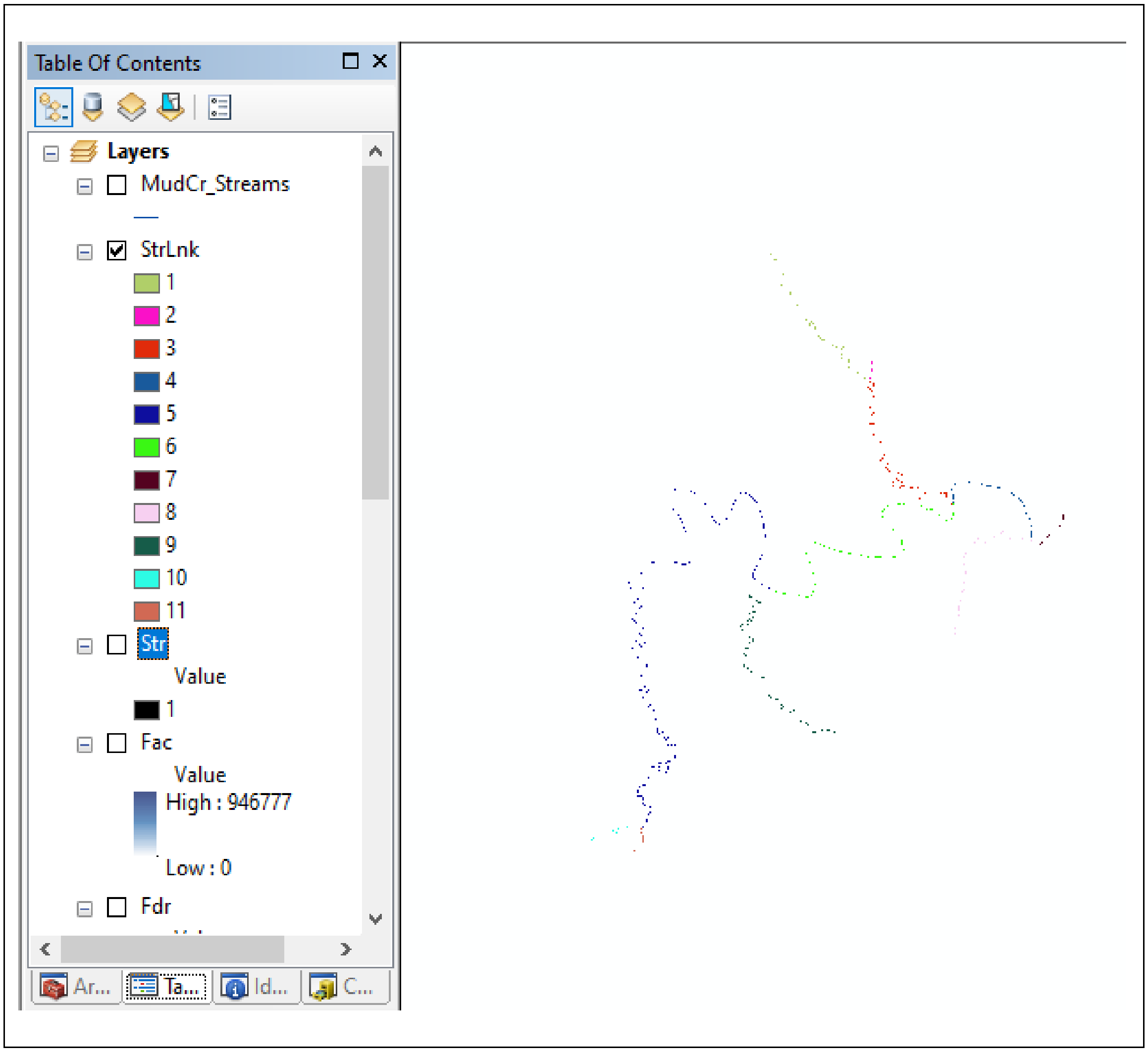


Figure 13. Showing StrLnk layer resulting from stream segmentation

- Click on Catchment Grid Delineation. The Catchment Grid Delineation tool delineates a subbasin for every stream segment.
- In the pop-up window (Figure 14), confirm that the Input Flow Direction Grid is *Fdr*, and Input link Grid is *StrLnk*.
- Click OK to create *Cat* layer (Figure 15)

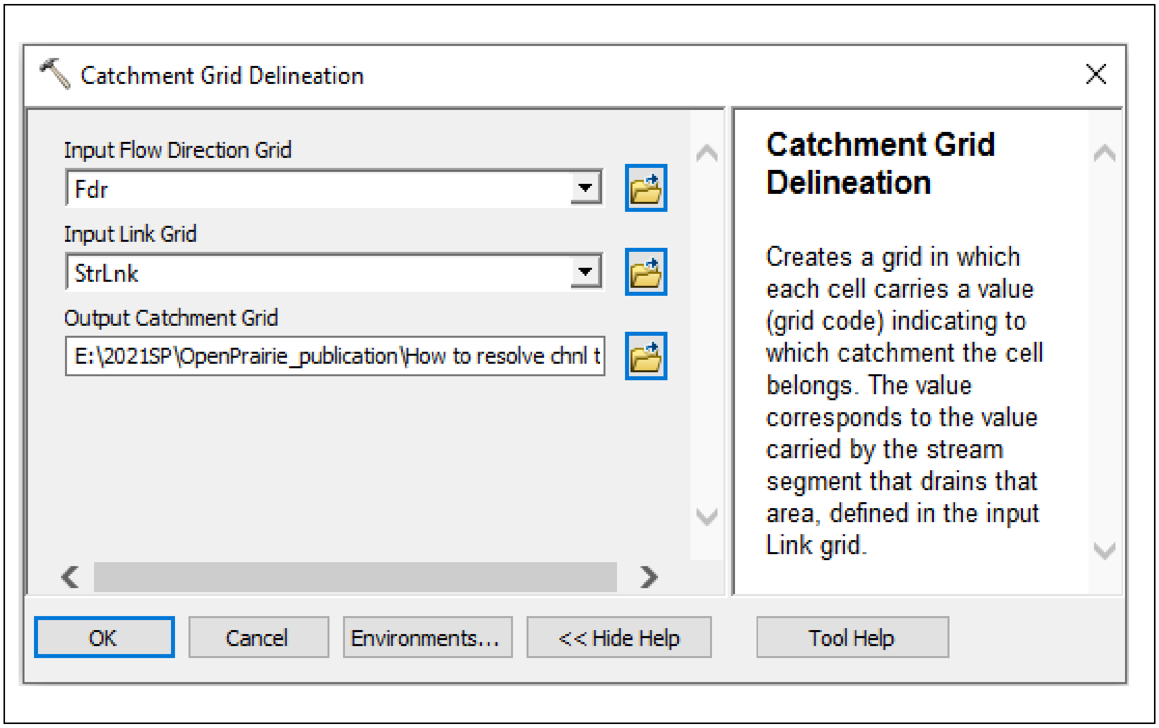


Figure 14. Showing catchment grid delineation dialog box

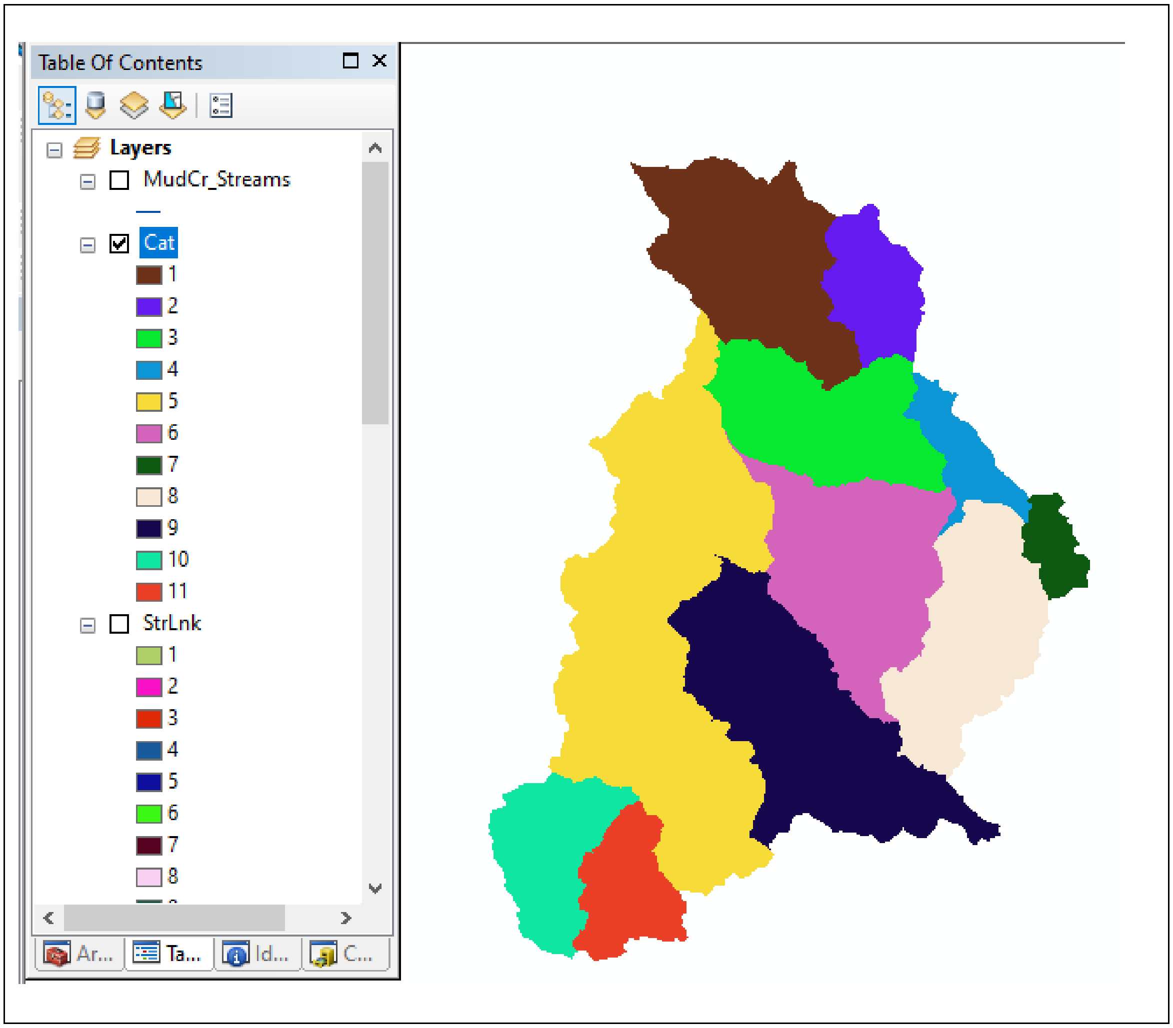


Figure 15. Showing Cat layer resulting from Catchment delineation.

- Click Catchment Polygon Processing. The Catchment Polygon Processing tool creates a vector layer of subbasins.
- In the pop-up window (Figure 16), confirm that the Input Catchment Grid is *Cat*.
- Click Ok to create *Catchment* layer (Figure 17)

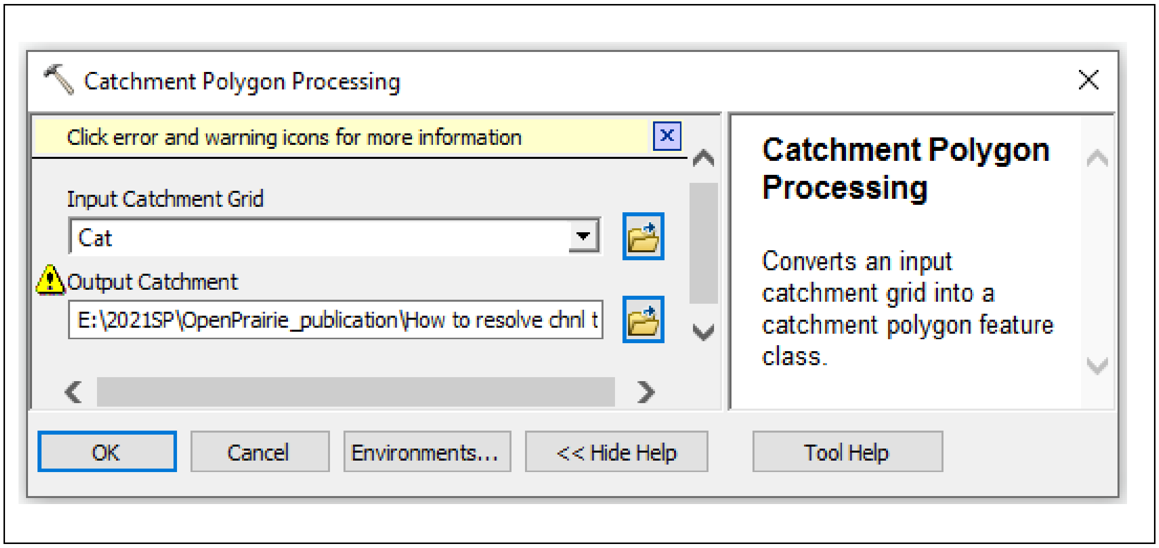


Figure 16. Showing catchment polygon processing dialog box

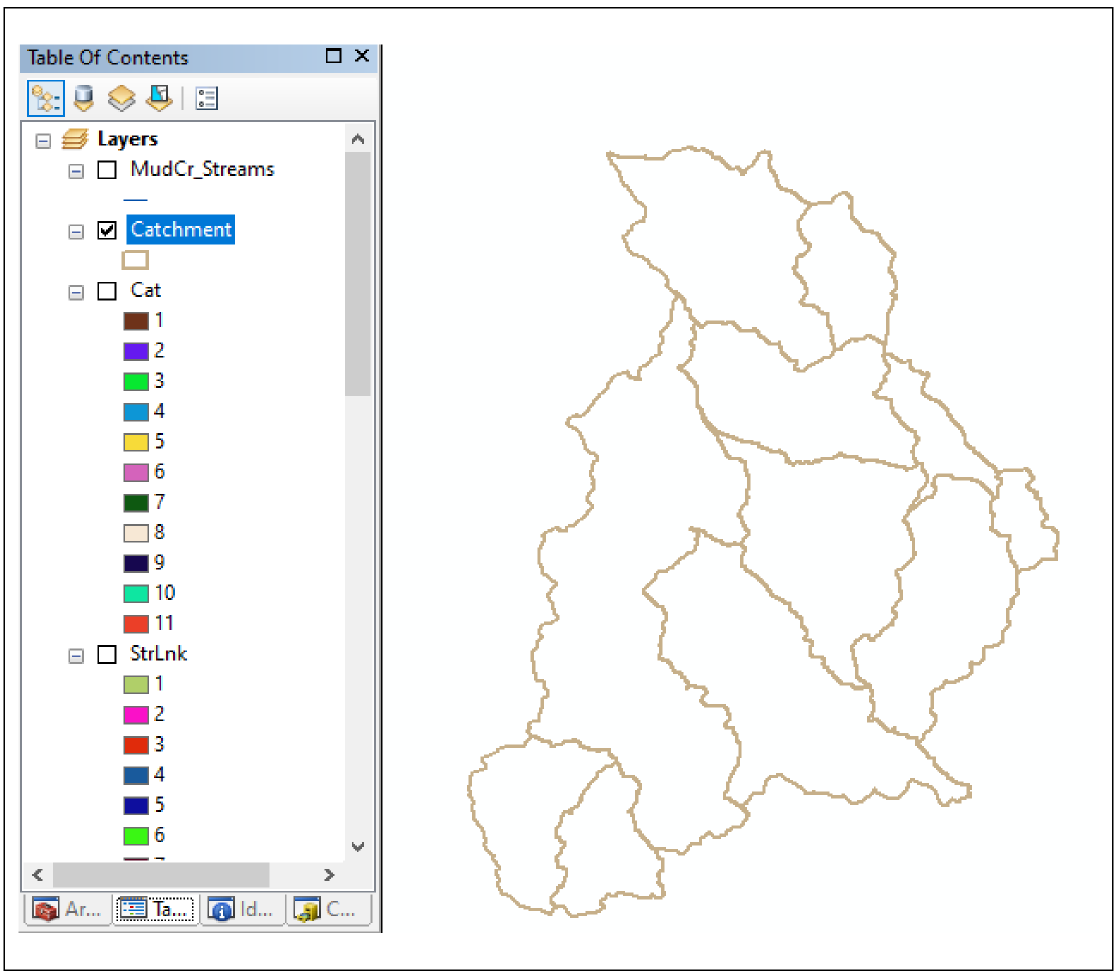


Figure 17. Showing Catchment layer resulting from Catchment Polygon Processing.

- Click Drainage Line Processing. The Drainage Line Processing tool creates a vector stream layer.
- In the pop-up window (Figure 18), confirm that the Input Stream Link Grid is *StrLnk*.
- Click OK to create *DrainageLine* (Figure 19)

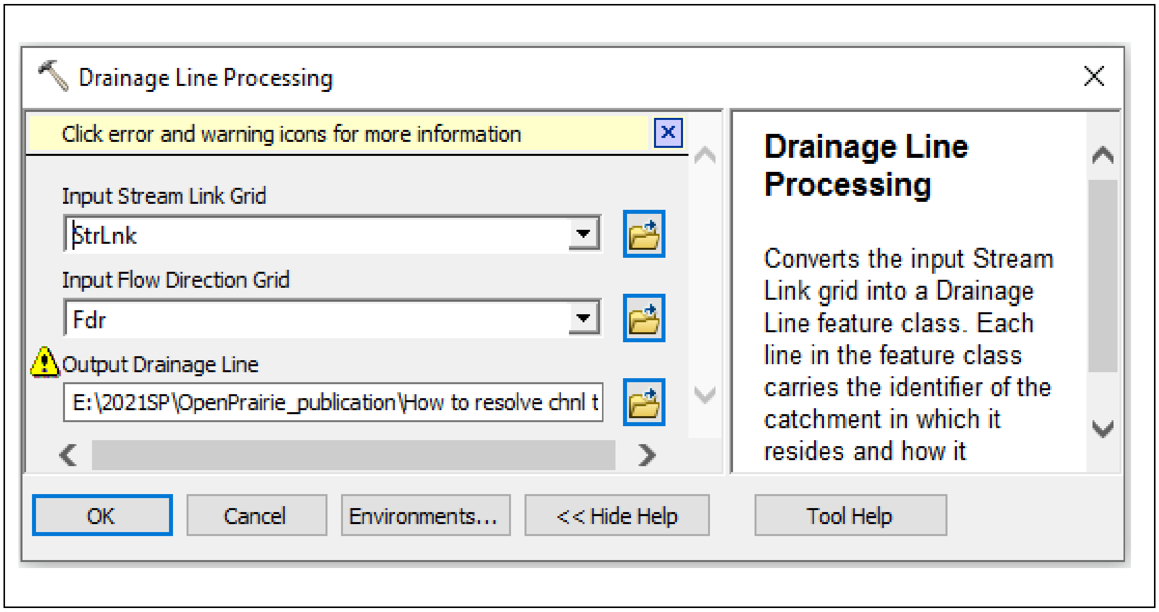


Figure 18. Showing drainage line processing dialog box

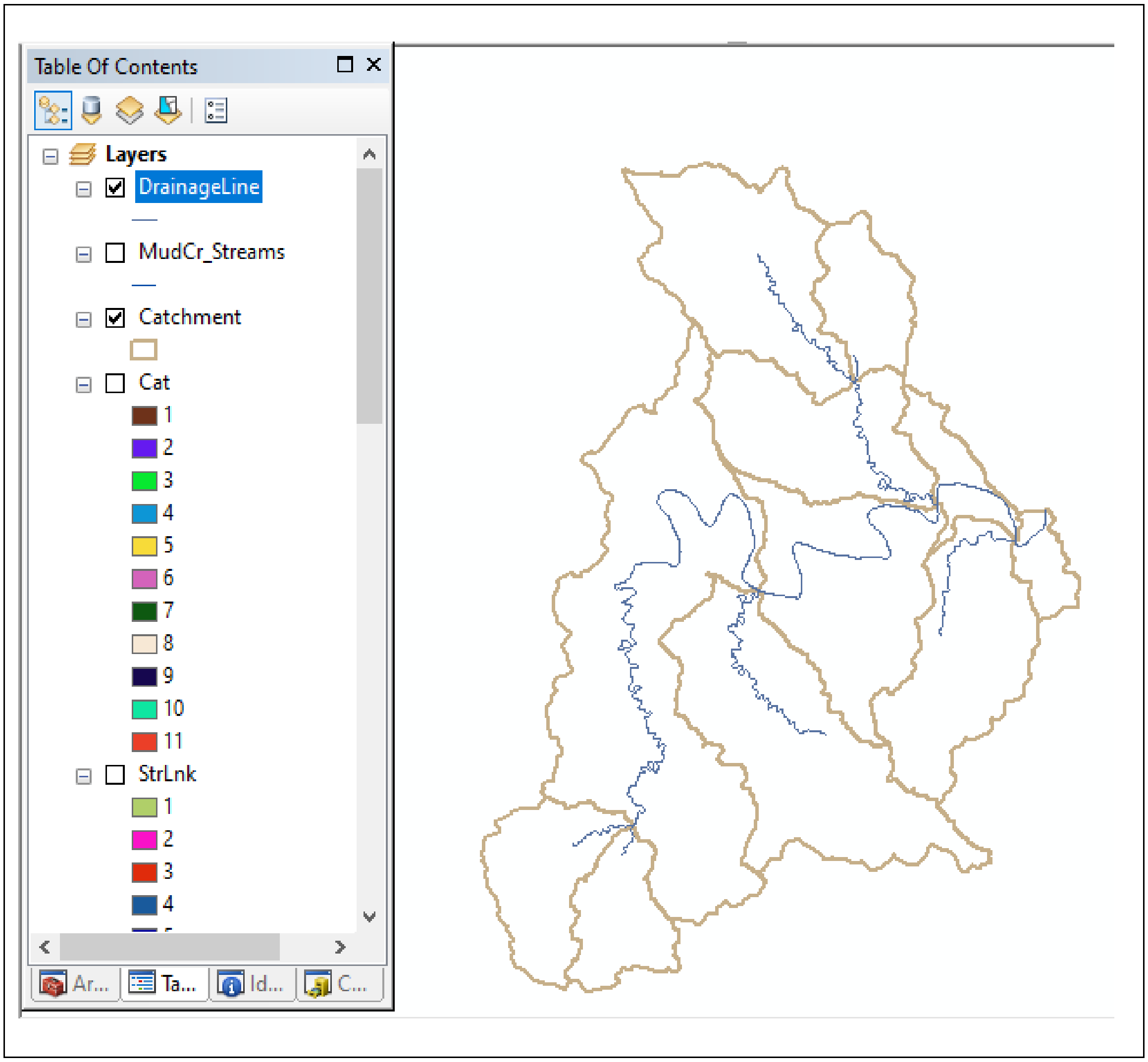


Figure 19. Showing DrainageLine resulting from Drainage line processing.

- Click on Adjoint Catchment Processing. The Adjoint Catchment tool aggregates upstream subbasins at every stream confluence.
- In the pop-window (Figure 20), confirm that the Input Drainage Line is *DrainageLine.*
- Click OK to create the *AdjointCatchment* layer (Figure 21).

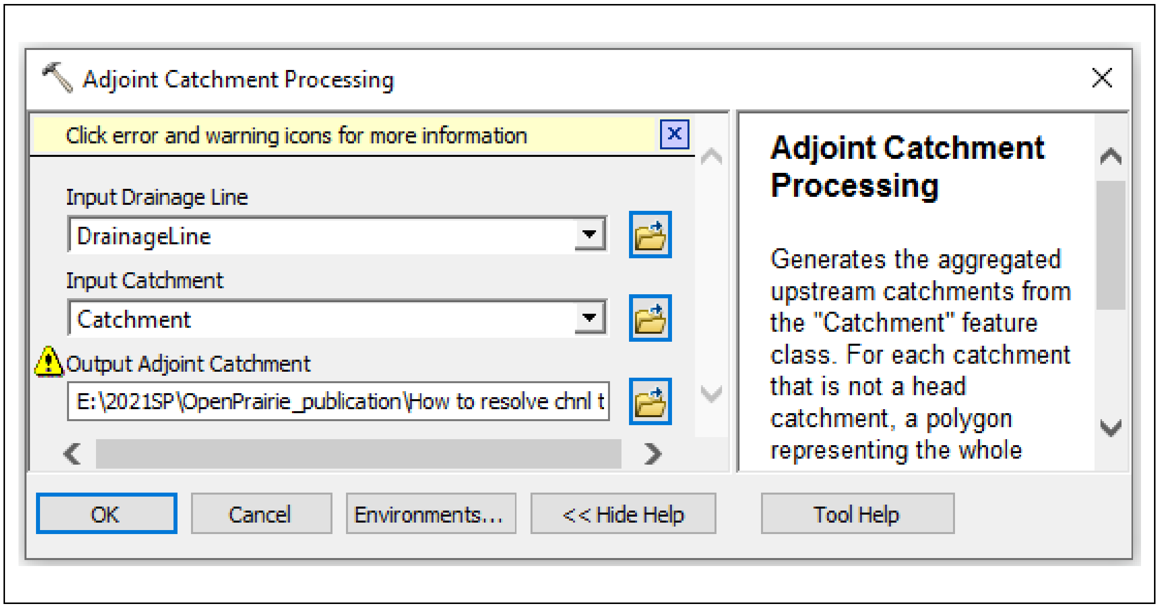


Figure 20. Showing adjoint catchment processing dialog box

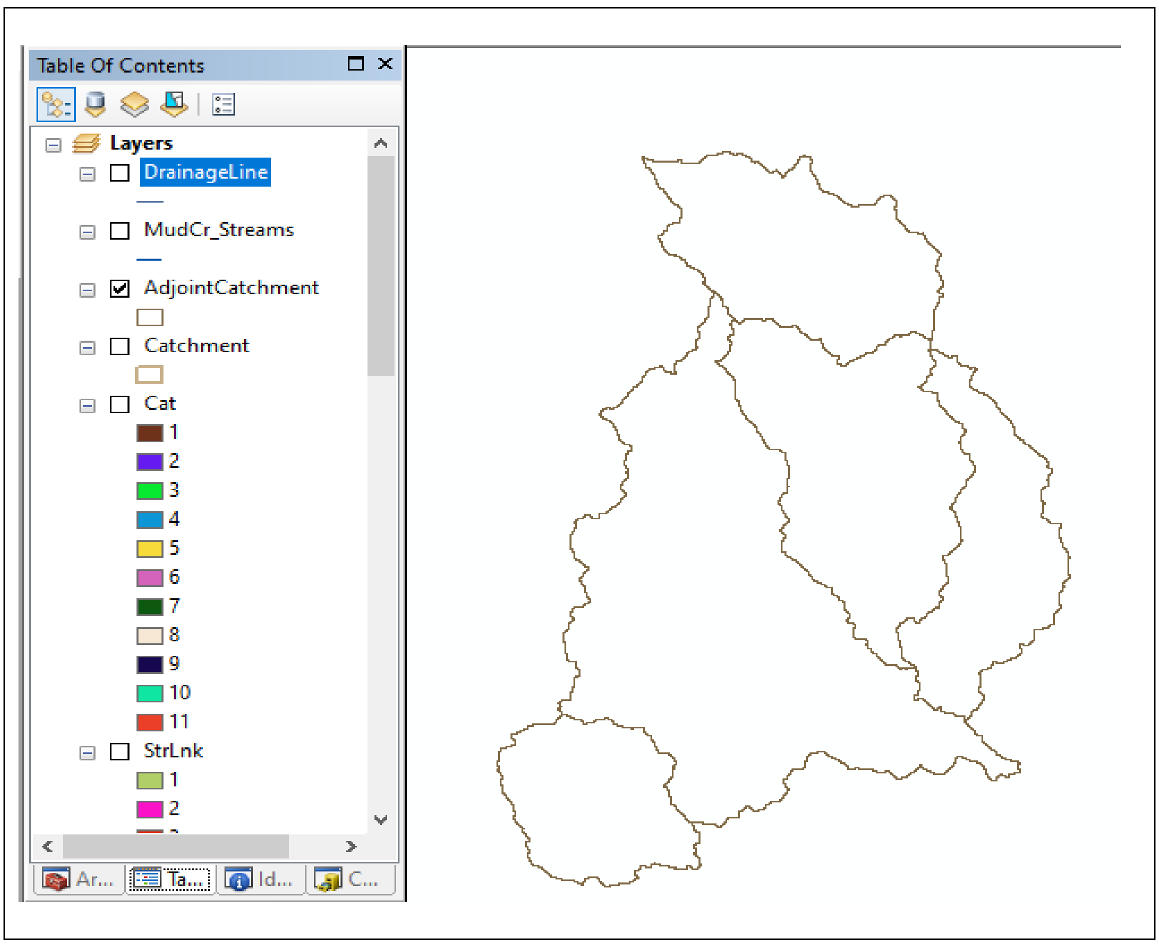


Figure 21. Showing AdjointCatchment resulting from Adjoint Catchment Processing.

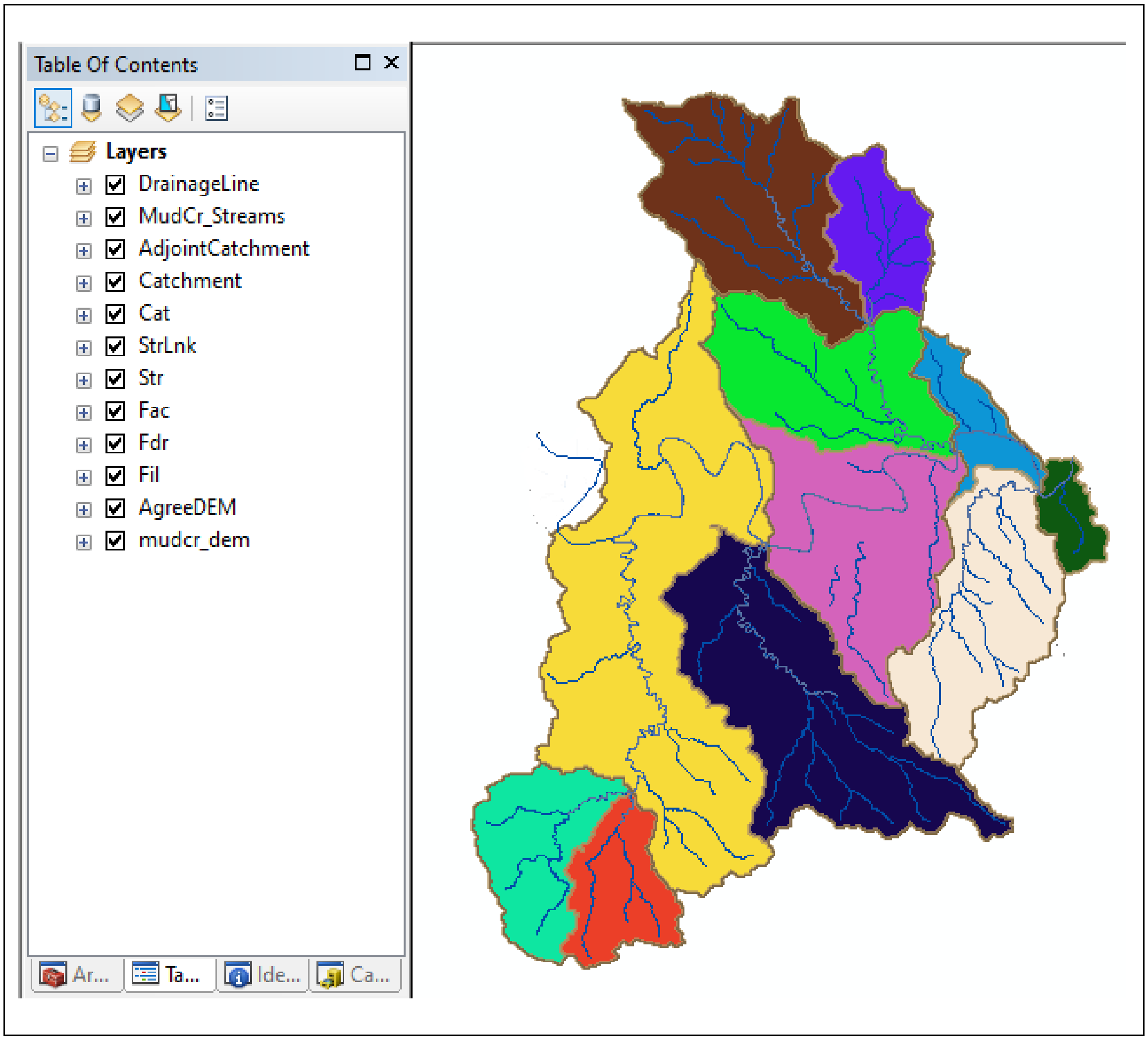
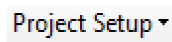


Figure 22. Showing final product of data preprocessing.

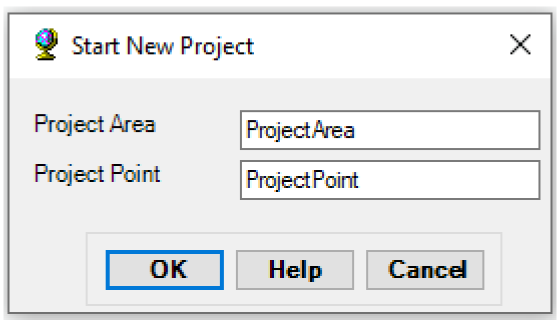
Project Setup

The next step in the modeling process is to set up a project. The following are the Project Setup steps.

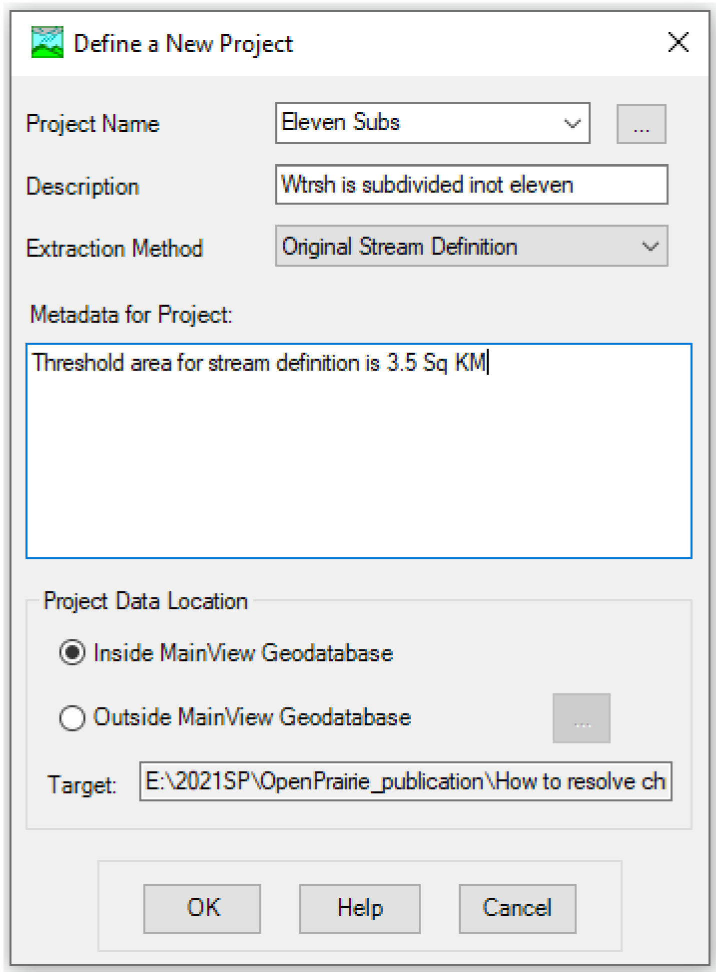
- On the HEC-GeoHMS Tools bar
  - Click on *Project Setup* 

menu.
  - Click on *Start New Project* 

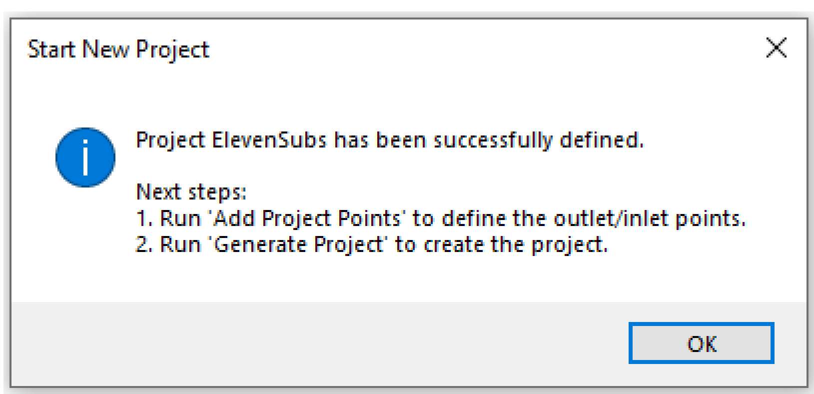
  - In the poop-up *Start New Project* window, click OK.



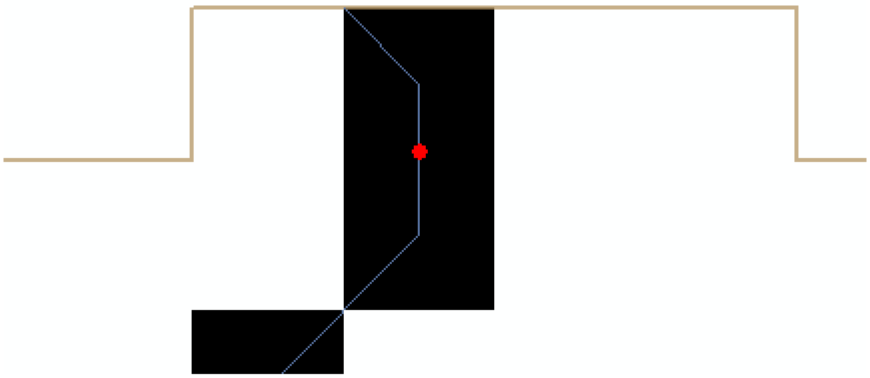
  - In the pop-up *Define a New Project window*, enter a project name, description, meta data for the project, check the *Inside Mainview Geodatabase* box, and click OK.



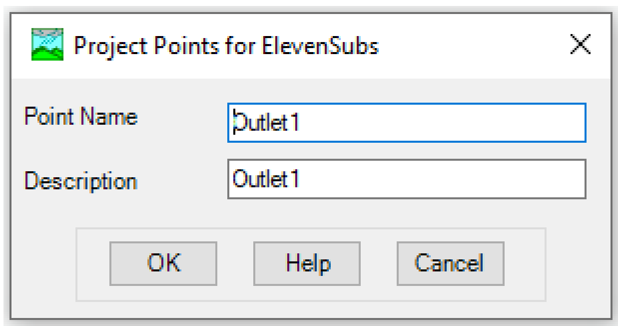
- In the pop-up *Start New Project* window, click Ok.

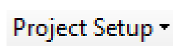
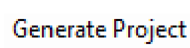


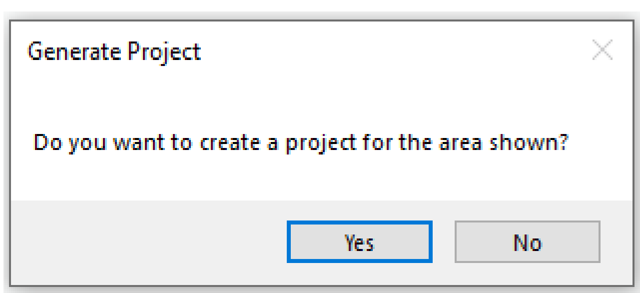
- On the HEC-GeoHMS tool bar, click *Add Project Points* icon 
- On the Preprocessed map layer, define the project outlet point.



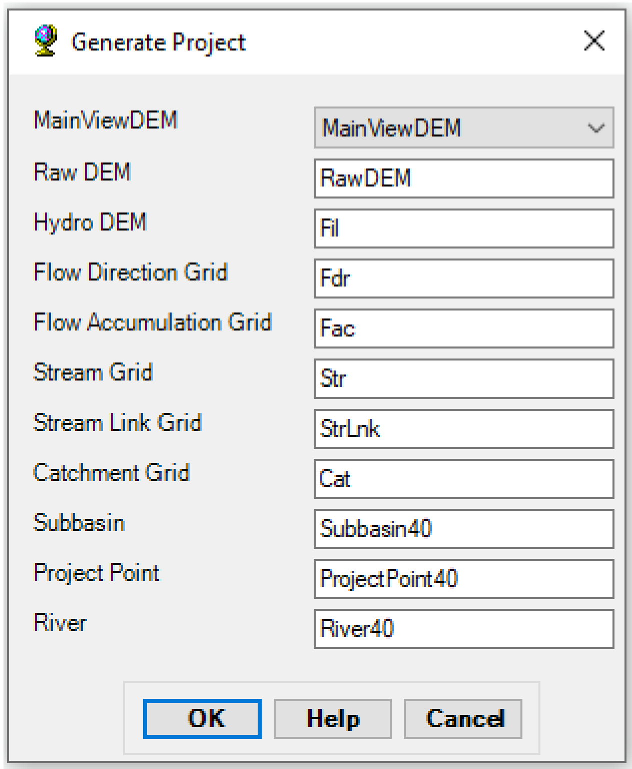
- In the Project Points pop-up window, click OK.



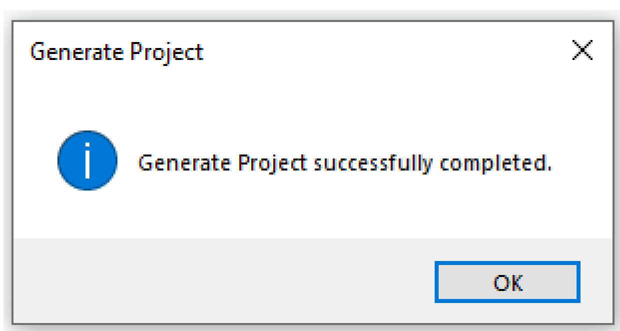
- Click on Project Setup  menu.
- Click on Generate Project 
- In the pop-up Generate Project window, click OK.



- Click Ok in the new pop-up window.



- Click OK after Project has been successfully generated.



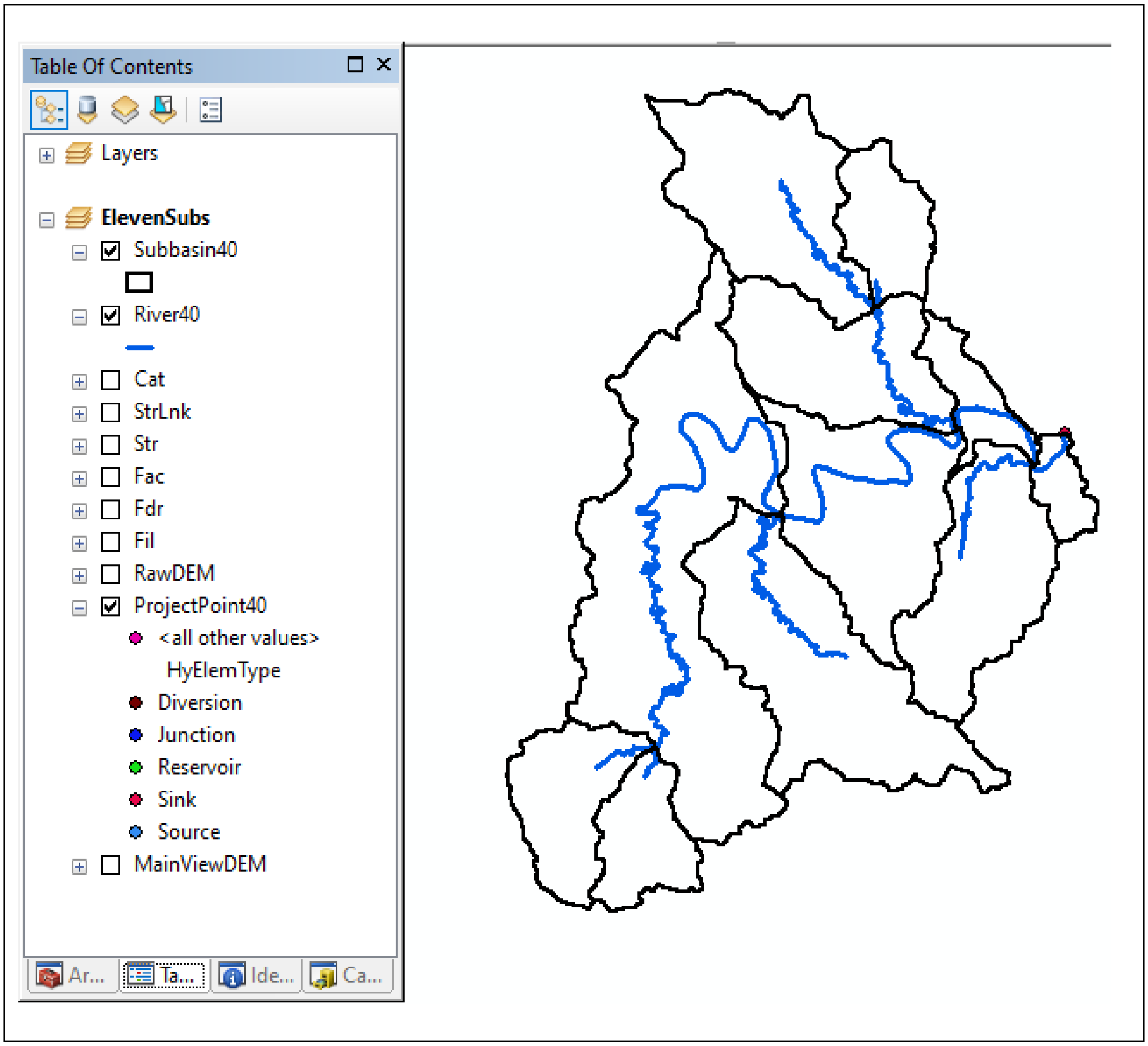


Figure 23. Showing the product of Project Setup processing

Basin Processing

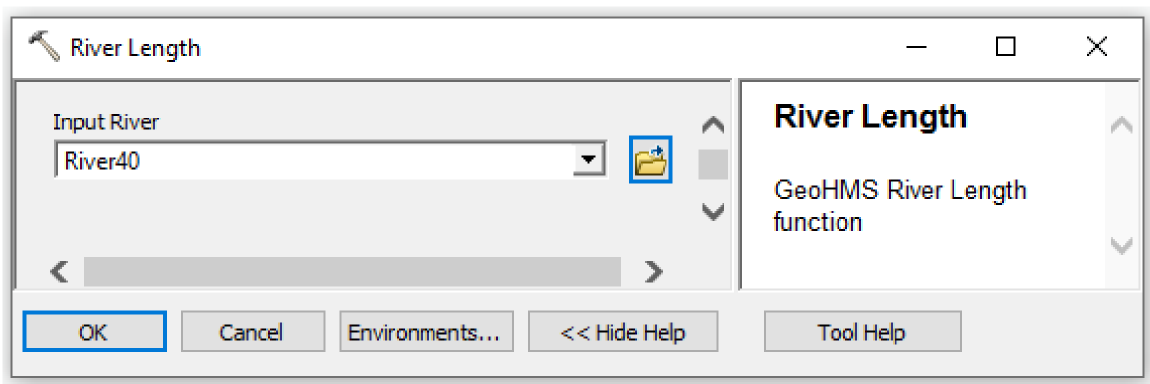
In this illustration, there was no need for *Basin Processing* Basin Processing at this point.

The illustration therefore proceeded with Watershed characteristics processing.

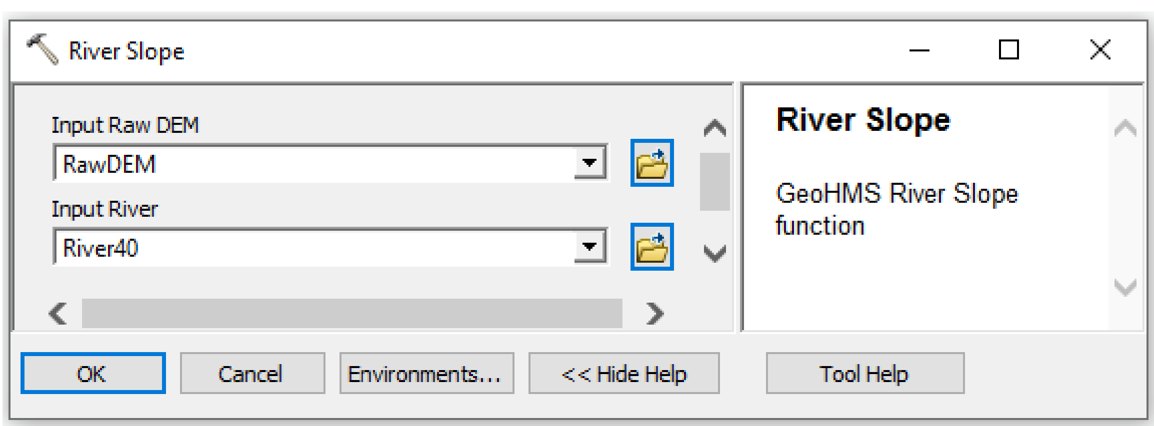
Watershed Characteristics Processing

In this step, physical characteristics such as stream lengths, upstream ad downstream elevations and slopes are extracted from the datasets. The following are the characteristics processing steps:

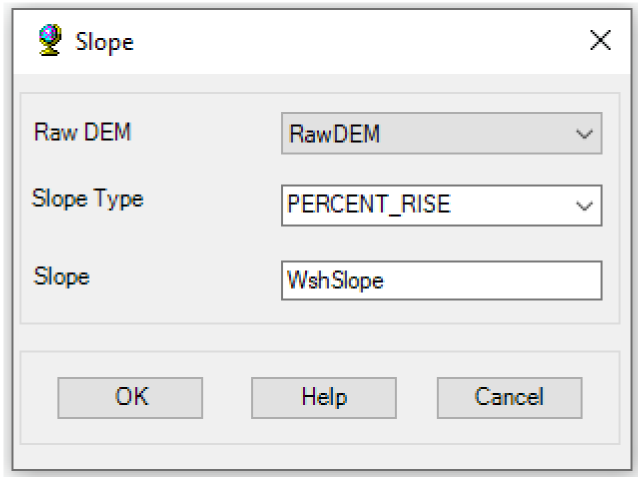
- In the Characteristics menu Characteristics of the HEC-GeoHMS tolls bar
  - Click on *River Length* River Length and click OK in the pop-up window River Length tool window.



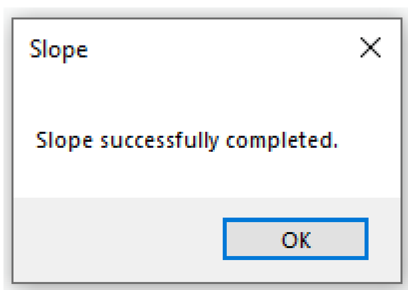
  - Click on *River Slope* River Slope and click OK in the pop-up window River Slope tool window.



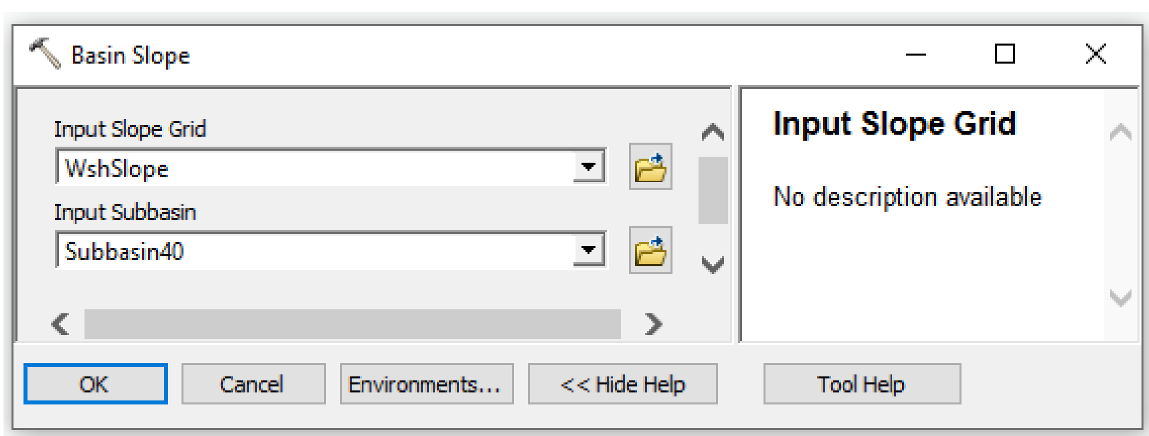
  - In the Terrain Processing menu Terrain Preprocessing of the Arc Hydro Tools bar
  - Click on *Slope* Slope and click OK in the pop-up window Slope window.



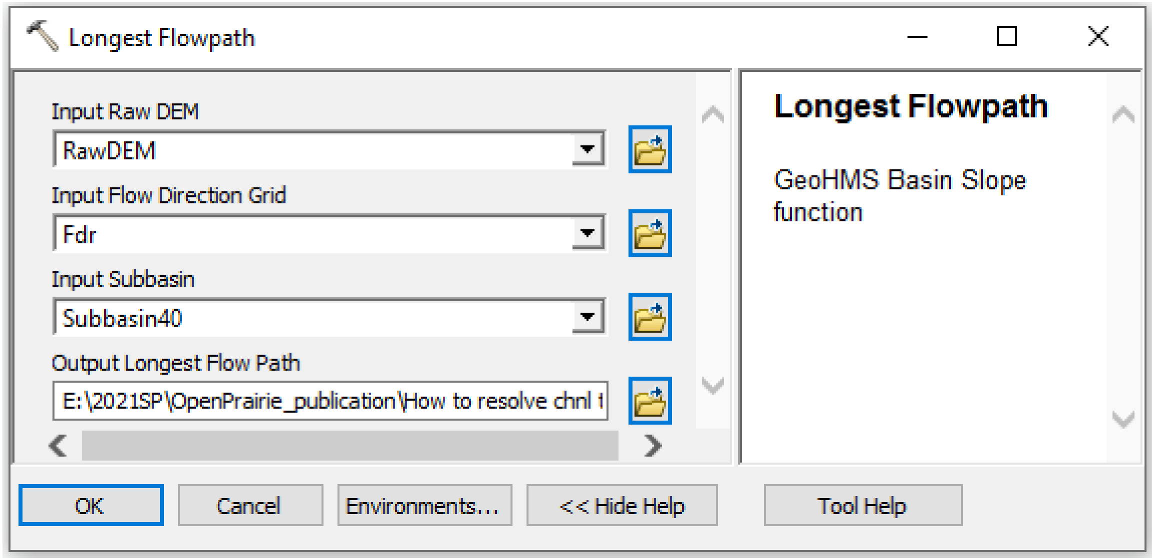
- Click OK in the pop-up window to successfully complete slope processing.



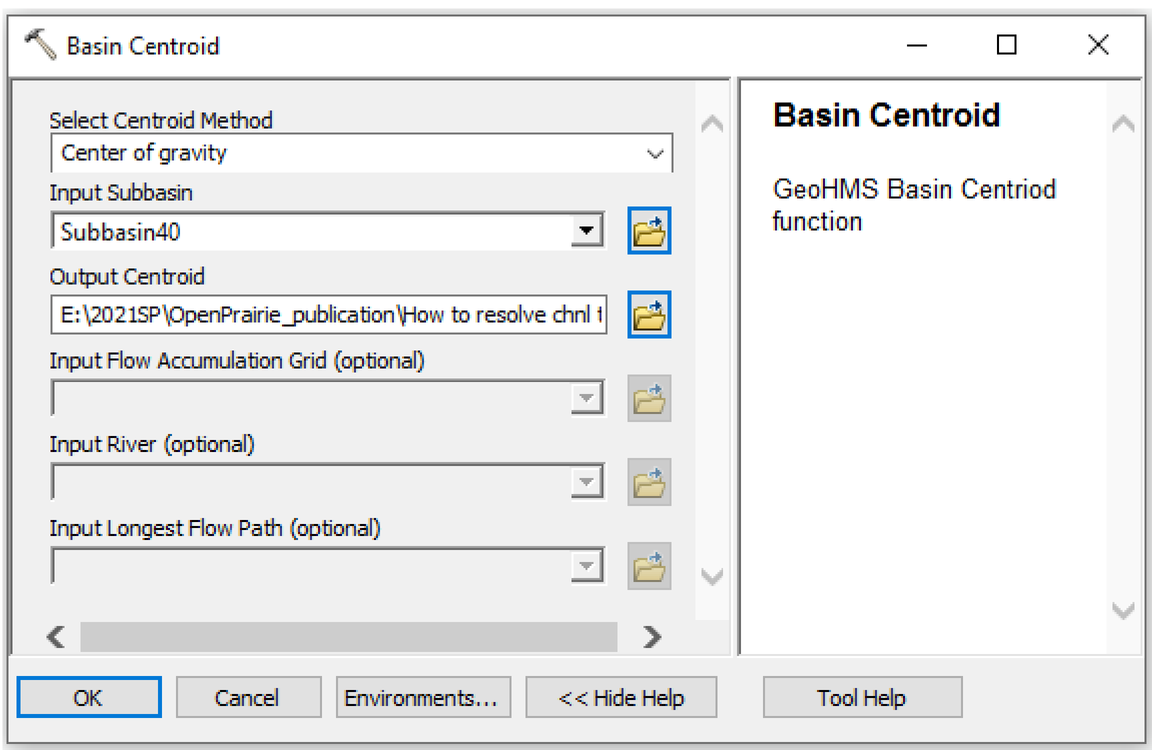
- In the Characteristics menu Characteristics ▾ of the HEC-GeoHMS tolls bar
- Click on *Basin Slope* Basin Slope , select WshSlope as the Input Slope Grid from the drop-down menu in the pop-up Basin Slope tool window, click OK.



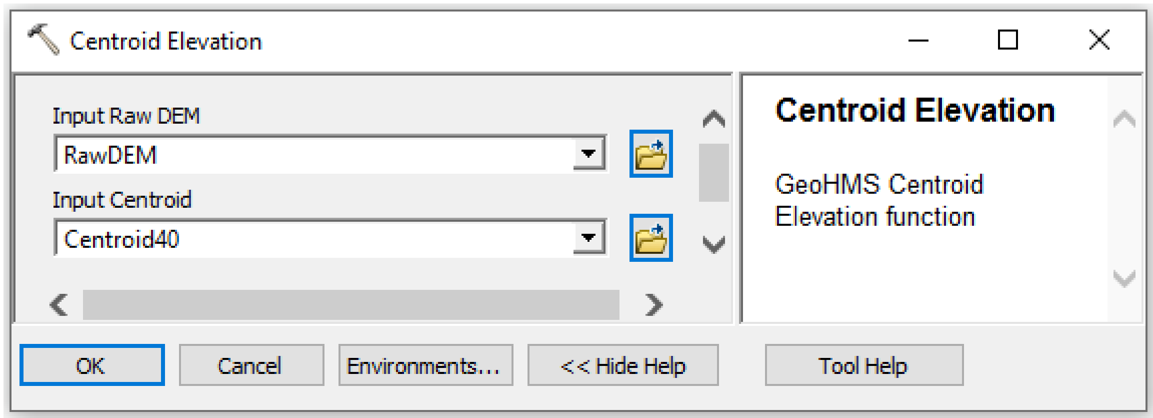
- Click on *Longest Flowpath* Longest Flowpath, in the Longest Flowpath tool window, click OK.



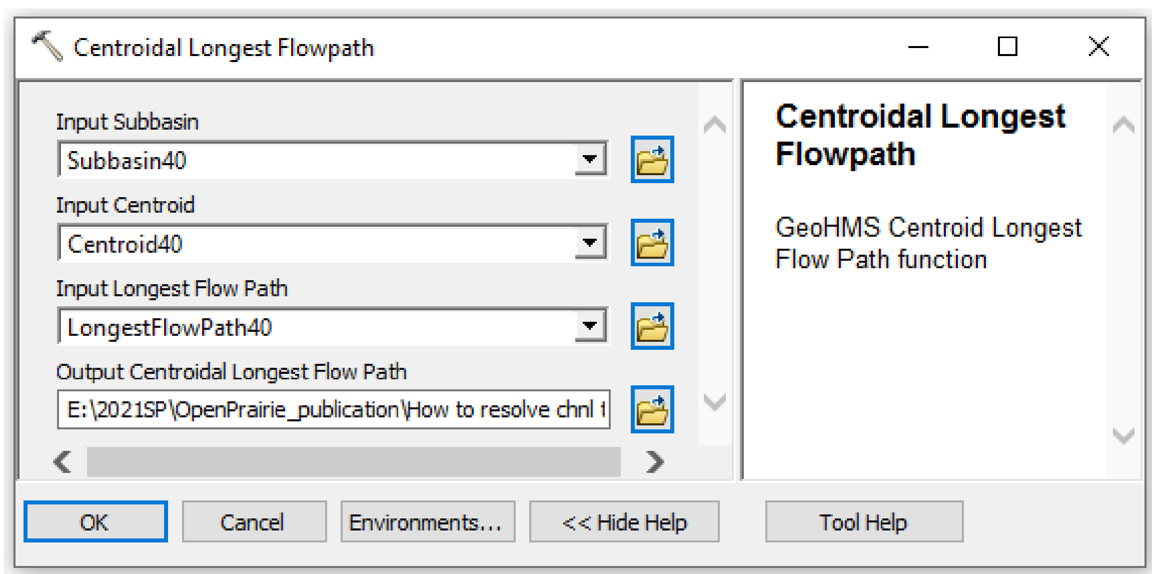
- Click on *Basin Centroid* Basin Centroid, in the Basin Centroid tool window, click OK.



- Click on *Centroid Elevation* Centroid Elevation , in the pop-up Centroid elevation tool window, click OK.

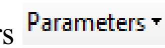


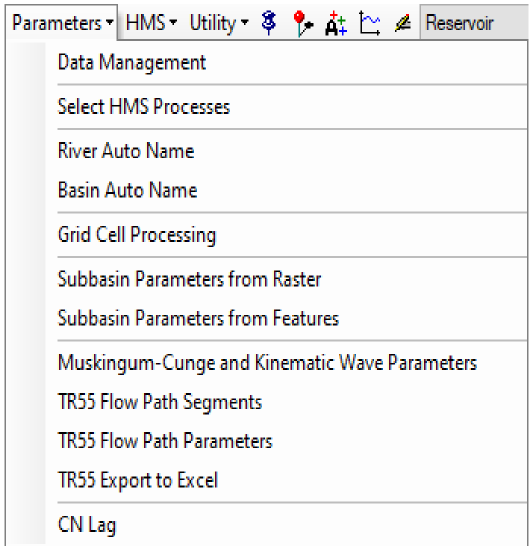
- Click on Centroidal Longest Flowpath Centroidal Longest Flowpath , in the Centroidal Longest Flowpath tool window, click OK.



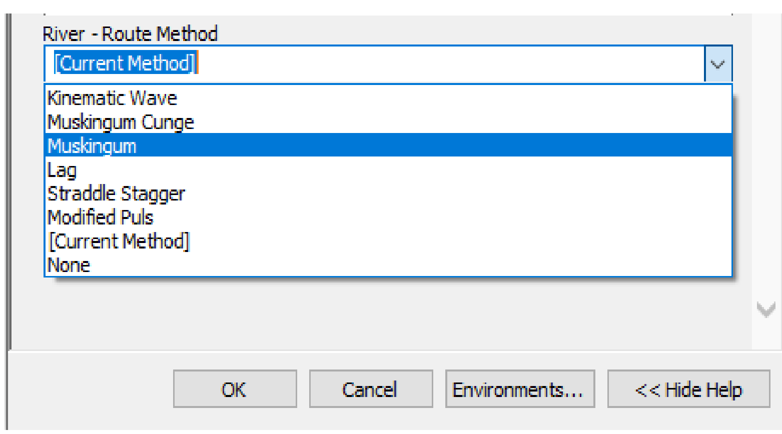
Hydrologic Parameter Estimation

The next step in the creating the HMS models is hydrologic parameter estimation. The *Parameters* menu is used to estimate hydrologic parameters for subbasin (loss method and transform method) and reach (river route method) processes.

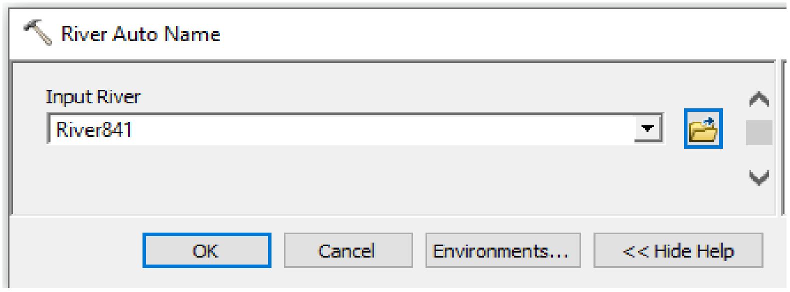
- In the HEC-GeoHMS menu tool bar, Click on the Parameters  menu to display the submenu.



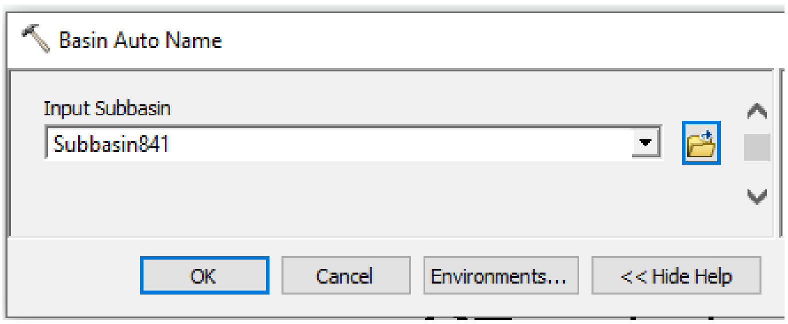
- In the *Select HMS Processes*, make sure to select Muskingum as the river route method after selecting other desired processes from the dropdown menus and click OK.



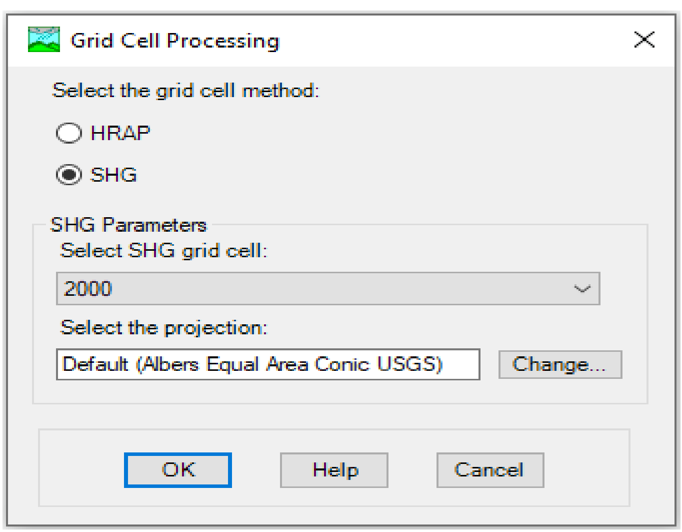
- Select the *River Auto Name* and click OK.



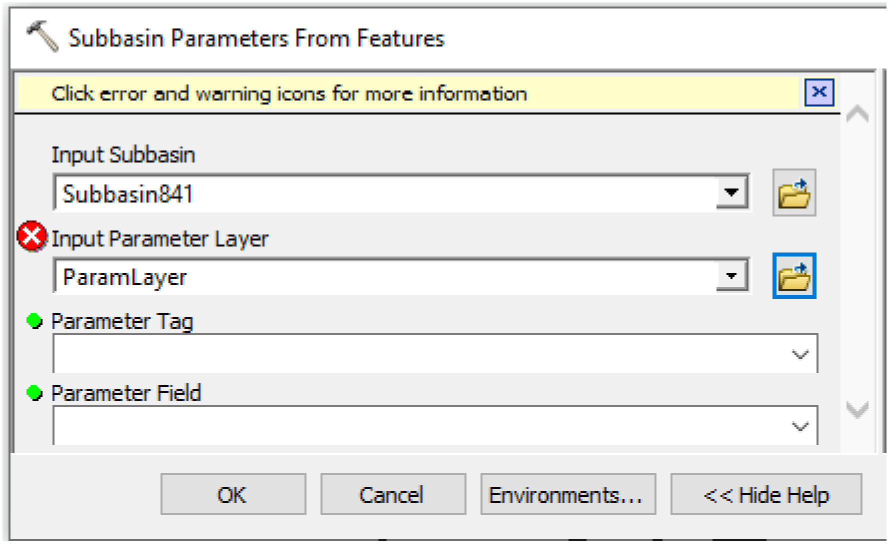
- Select *Basin Auto Name* and click OK.



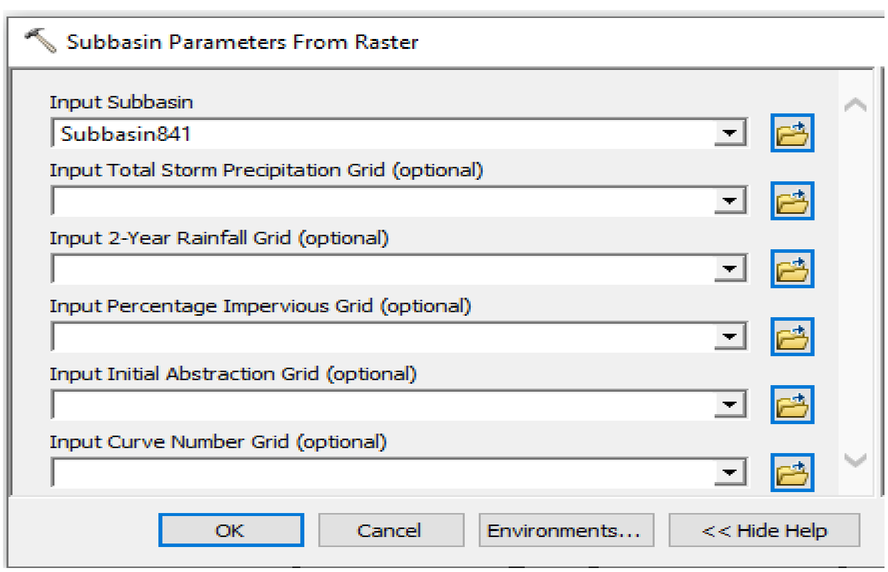
- Click on *Grid Cell Processing* only if you plan on using gridded precipitation, select the grid cell method and click OK.



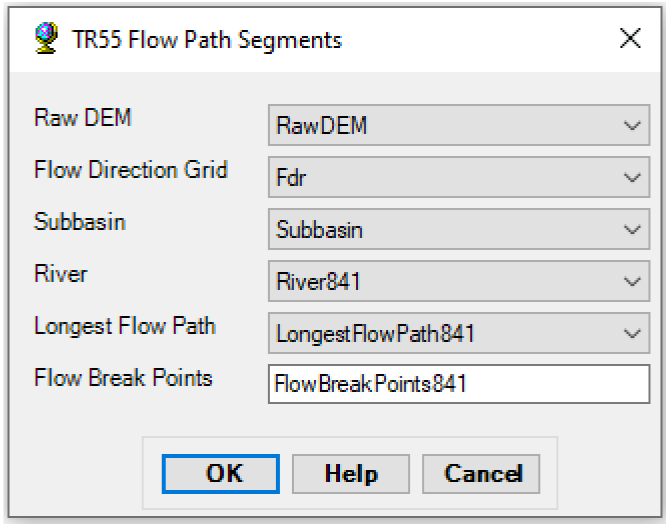
- Click on *Subbasin Parameters From Features* if you plan to calculate the average hydrologic parameters for each subbasin, upload all required from polygon features using the dropdown menus and click OK.



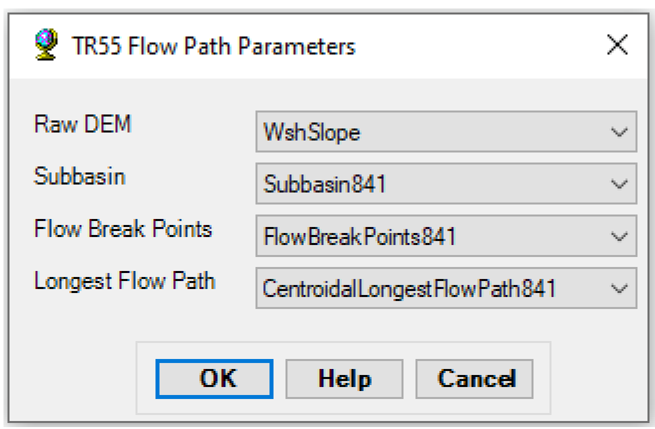
- Click on *Subbasin Parameters From Raster,* upload all required parameters using the dropdown menus and click OK.



- Click on *TR55 Flow Path Segments* and click OK.



- Click on *TR55 Flow Segment Parameters* and click OK.



- Click on *TR55 Export Tt Parameters to Excel* and click OK. This tool exports the TR55 flow segments to an Excel spreadsheet (Figure 1)

In this illustration, channel travel time errors occurred in the reaches in W1020 and W1050 subbasins (Figure 24) and are presented as #NUM! and #DIV/0! in the Excel worksheet. In Table 2, W1020 and W1050 have channel slope values of -0.0001 and 0.0, respectively.

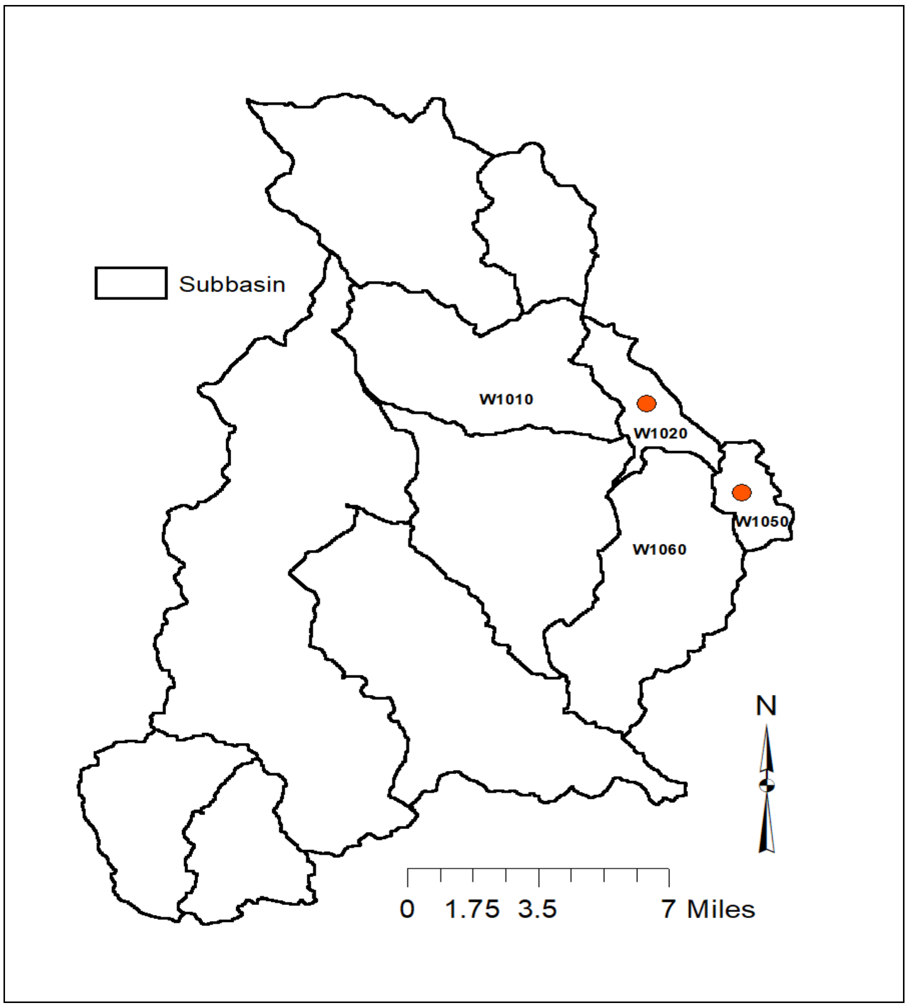


Figure 24. Showing eleven (11) subbasins showing W1020 and W1050 subbasins where channel travel time errors occur.

Worksheet for computation of time of travel according to TR-55 methodology

Blue - GIS defined, Green - user specified, White and yellow - calculated, Red - final result

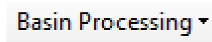
Watershed Name	W990	W1000	W1010	W1020	W1030	W1040	W1050	W1060	W1070	W1080	W1090
Watershed ID	99	100	101	102	103	104	105	106	107	108	109
Sheet Flow Characteristics											
Manning's Roughness Coefficient	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Flow Length (ft)	100	100	100	100	100	100	100	100	100	99.9998	99.9999
Two-Year 24-hour Rainfall (in)	1	1	1	1	1	1	1	1	1	1	1
Land Slope (ft/ft)	0.01	0.0548	0.0463	0.0148	0.0761	0.0445	0.039	0.035	0.3365	0.0097	0.1566
Sheet Flow Tt (hr)	0.58	0.29	0.31	0.50	0.26	0.32	0.34	0.35	0.14	0.59	0.19
Shallow Concentrated Flow Characteristics											
Surface Description (1 - unpaved, 2 - paved)	1	1	1	1	1	1	1	1	1	1	1
Flow Length (ft)	11683	10808	16085	7567	10766	15502.665	6763.7386	12717.91	15198.76	12585.711	10658.45
Watercourse Slope (ft/ft)	0.0182	0.0187	0.0144	0.0197	0.0191	0.0155	0.0222	0.0163	0.0179	0.0216	0.0234
Average Velocity - computed (ft/s)	2.18	2.21	1.94	2.26	2.23	2.01	2.40	2.06	2.16	2.37	2.47
Shallow Concentrated Flow Tt (hr)	1.49	1.36	2.31	0.93	1.34	2.14	0.78	1.71	1.96	1.47	1.20
Channel Flow Characterisitics											
Cross-sectional Flow Area (ft2)	20	20	20	20	20	20	20	20	20	20	20
Wetted Perimeter (ft)	20	20	20	20	20	20	20	20	20	20	20
Hydraulic Radius - computed (ft)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Channel Slope (ft/ft)	0.0043	0.0076	0.003	-0.0001	0.0018	0.0007	0	0.0051	0.0038	0.0041	0.0047
Manning's Roughness Coefficient	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Average Velocity - computed (ft/s)	3.26	4.33	2.72	#NUM!	2.11	1.31	0.00	3.55	3.06	3.18	3.40
Flow Length (ft)	15382	2010	9102	6548	53965	13618.981	1497.0084	11838.67	22309.081	5227.6603	2459.428
Channel Flow Tt (hr)	1.31	0.13	0.93	#NUM!	7.11	2.88	#DIV/0!	0.93	2.02	0.46	0.20
Watershed Time of travel (hr)	**3.38**	**1.78**	**3.55**	**#NUM!**	**8.71**	**5.34**	**#DIV/0!**	**2.99**	**4.12**	**2.52**	**1.59**
Number of watersheds	11										
MXD Path	chnl trvl times.mxd										

Table 2. Worksheet showing negative and zero channel slope values and channel travel time errors in W1020 and W1050 subbasins.

Using the Merge Basin tool to resolve channel travel time errors.

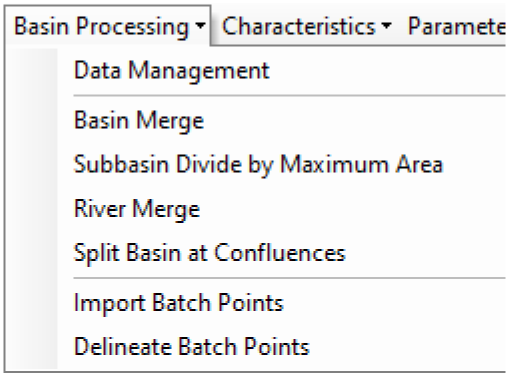
After inspecting the TR55 worksheet and identifying the subbasins with channel travel time errors, the Merge Basin tool is used to merge the subbasins that have errors with any of their error free neighbors, using the following step.

- Using Select Feature tool  in the ArcMAp tools menu, click on the layers you want to merge (hold down CNTL+SHIFT keys on the keyboard to select multiple layers as shown below).

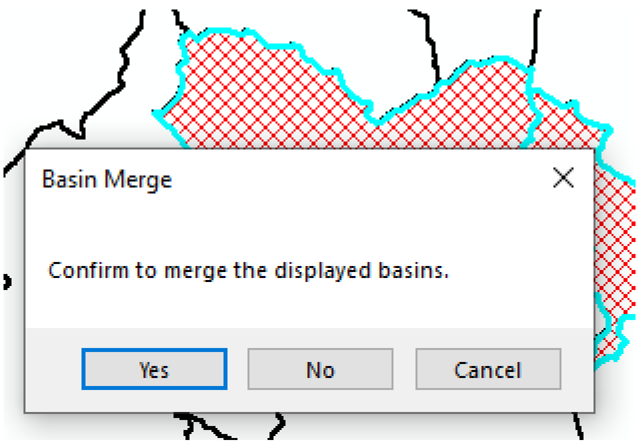
- In the Basin Processing tab 

, on the HEC-GeoHMS menu bar, click on Basin Merge 

.



- In the pop-up Dialog Box



- Click Yes confirm merge.

This final step merges W1010 and 1020 subbasins to produce W8570 subbasin, and 1060 and 1060 subbasin to produce W8610 subbasin, respectively (Figure 25). After the merging exercise, the user will once again complete the stream and subbasin characteristics processing and the hydrologic parameters estimation processing. Thereafter, a new Excel worksheet will be produced, displaying all error free subbasins as shown in Table 3. However, in this illustration, the number of subbasins in the watershed are reduced from eleven subbasins to nine subbasins after merging.

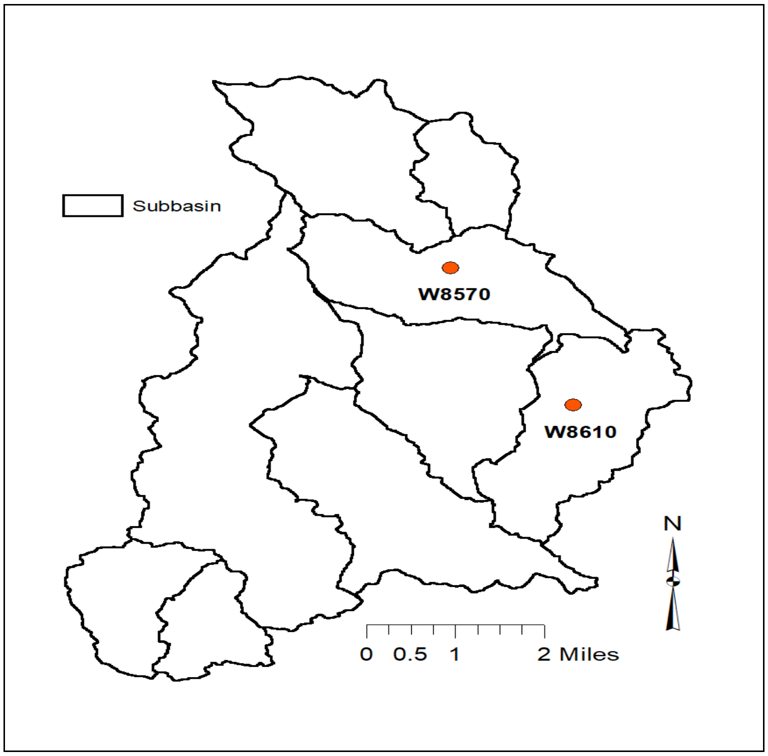


Figure 25. Showing W8570 and W8610 after merging

Worksheet for computation of time of travel according to TR-55 methodology

Blue - GIS defined, Green - user specified, White and yellow - calculated, Red - final result

Watershed Name	W8540	W8550	W8570	W8580	W8590	W8610	W8620	W8630	W8640
Watershed ID	854	855	857	858	859	861	862	863	864
Sheet Flow Characteristics									
Manning's Roughness Coefficient	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Flow Length (ft)	100	100	100	100	100	100	100	99.9998	99.9999
Two-Year 24-hour Rainfall (in)	1	1	1	1	1	1	1	1	1
Land Slope (ft/ft)	0.01	0.0548	0.0463	0.0761	0.0445	0.035	0.3365	0.0097	0.1566
Sheet Flow Tt (hr)	0.58	0.29	0.31	0.26	0.32	0.35	0.14	0.59	0.19
Shallow Concentrated Flow Characteristics									
Surface Description (1 - unpaved, 2 - paved)	1	1	1	1	1	1	1	1	1
Flow Length (ft)	11683	10808	16085	10766	15503	12717.9104	15198.7595	12585.7112	10658.445
Watercourse Slope (ft/ft)	0.0182	0.0187	0.0144	0.0191	0.0155	0.0163	0.0179	0.0216	0.0234
Average Velocity - computed (ft/s)	2.18	2.21	1.94	2.23	2.01	2.06	2.16	2.37	2.47
Shallow Concentrated Flow Tt (hr)	1.49	1.36	2.31	1.34	2.14	1.71	1.96	1.47	1.20
Channel Flow Characterisitics									
Cross-sectional Flow Area (ft2)	20	20	20	20	20	20	20	20	20
Wetted Perimeter (ft)	20	20	20	20	20	20	20	20	20
Hydraulic Radius - computed (ft)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Channel Slope (ft/ft)	0.0043	0.0076	0.0016	0.0018	0.0007	0.0046	0.0038	0.0041	0.0047
Manning's Roughness Coefficient	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Average Velocity - computed (ft/s)	3.26	4.33	1.99	2.11	1.31	3.37	3.06	3.18	3.40
Flow Length (ft)	15382	2010	17767	53965	13619	15360.5441	22309.0807	5227.6603	2459.4281
Channel Flow Tt (hr)	1.31	0.13	2.48	7.11	2.88	1.27	2.02	0.46	0.20
Watershed Time of travel (hr)	**3.38**	**1.78**	**5.11**	**8.71**	**5.34**	**3.33**	**4.12**	**2.52**	**1.59**
Number of watersheds	9								
MXD Path	chnl trvl times.mxd								

Table 3. Showing no channel travel time errors after merging for W8570 and W8610 subbasins.

To finish developing the HMS models, the user can find more detailed steps in the HEC-GeoHMS User's Manual (Fleming & Doan, 2013) and HEC-HMS User's manual (USACE, 2016).

References

Adalikwu, P. (2021). A Study of Geographic Information System-Based Watershed Processing for Hydrologic Analysis of Ungauged Watersheds. South Dakota State University,

Fleming, M. J., & Doan, J. H. (2013). HEC-GeoHMS Geospatial Hydrologic Modeling Extension User's Manual Version 4.2. US Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Centre, Davis, CA.

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Song, X.-m., Kong, F.-z., & Zhu, Z.-x. (2011). Application of Muskingum routing method with variable parameters in ungauged basin. Water Science and Engineering, 4(1), 1-12.

USACE. (2016). Hydrologic modeling system HEC-HMS: User's manual. In: Hydrologic Engineering Center Davis, CA.