TauDEM 5.0

WATERSHED DELINEATION USING TAUDEM

A tutorial for using TauDEM to delineate a single watershed

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Introduction

This booklet accompanies the Camtasia training video prepared to illustrate the process of Watershed Delineation using the TauDEM software.

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/taudem5.0/.

TauDEM is distributed as a Tool Box for use within the ArcGIS 9.3.1 software as well as a set of standalone command line executable programs for a PC and source code for compiling and use on other systems. TauDEM relies on other GIS software such as ArcGIS for visualization and further analysis of the outputs that it generates. This tutorial will use the TauDEM ArcGIS 9.3.1 toolbox so as to take advantage of the visualization capability that ArcGIS provides.

Computer and Data Requirements

To complete this tutorial, you will need to have ArcGIS 9.3.1, TauDEM 5.0 and MPICH2 software. ArcGIS is commercial geographic information system (GIS) software available from ESRI (www.esri.org). TauDEM 5.0 is available from http://hydrology.usu.edu/taudem/taudem5.0/ and should be installed following the instructions on this website. TauDEM uses MPICH2, a library for parallel programming message passing. MPICH2 software from http://www.mcs.anl.gov/research/projects/mpich2/ also needs to be installed. Instructions for installing MPICH2 so that it works smoothly with TauDEM are given on the TauDEM website.

Purpose

The purpose of this exercise is to illustrate digital elevation model based watershed and stream network delineation using TauDEM. By following the steps in this exercise, you will perform drainage analysis on a terrain model for the Logan River. The TauDEM tools are used to derive several data sets that collectively describe the drainage patterns of the catchment. Analysis is performed to remove the sinks in the digital elevation model and generate data on flow direction, contributing area, stream definition, and watershed delineation. These data are then be used to develop a vector representation of the stream network and watershed or river basin. This exercise shows how detailed information on the connectivity of the landscape and watersheds can be developed starting from raw digital elevation data, and that this enriched information can be used to compute watershed attributes commonly used in hydrologic and water resources analyses. This analysis may be useful as a pre-processing step for further Hydrology or Hydraulic analyses that uses the outputs from this work and may involve setting up a model to predict flows at the watershed outlet requiring information such as the watershed area, channel network and fractions of area under different land covers.

Audience

This tutorial presumes a basic working knowledge of ArcGIS with some exposure to using Geoprocessing Model Builder to string together a sequence of ArcGIS toolbox functions. This tutorial reviews the basic Digital Elevation Model (DEM) concepts needed and introduces you to the use of TauDEM tools. No prior experience with TauDEM is needed.

Overview

This tutorial is organized to first show you how to download and display grid digital elevation model data in ArcMap. Next, I show pit removal using TauDEM's Pit removal tool. I explain what pits are and why we need to remove them. Third I overview the steps involved in using TauDEM to delineate watersheds. These are quite lengthy, but one of the nice features of ArcGIS is the model builder capability for stringing together a series of commands. Rather than tediously demonstrating each step individually I will show you the model builder tool I have developed for doing this and show you how to run the tool. Examination of the tool will provide insight into how watershed delineation works. The result will be a watershed and stream network for the Logan river.

Step by Step Tutorial to delineate a single watershed for the Logan River

Steps to follow to complete this exercise are numbered. Discussion and explanation are in separate paragraphs.

1. Download the Logan River example data zip file from http://hydrology.usu.edu/taudem/taudem5.0/documentation.html. Extract all files from the zip file and add logan.tif into a blank ArcMAP document. Adjust the ArcMAP symbology.

In this exercise the folder C:\Users\dtarb\LoganDemo has been used for this work. The unzipped contents of LoganDemo.zip are illustrated below:
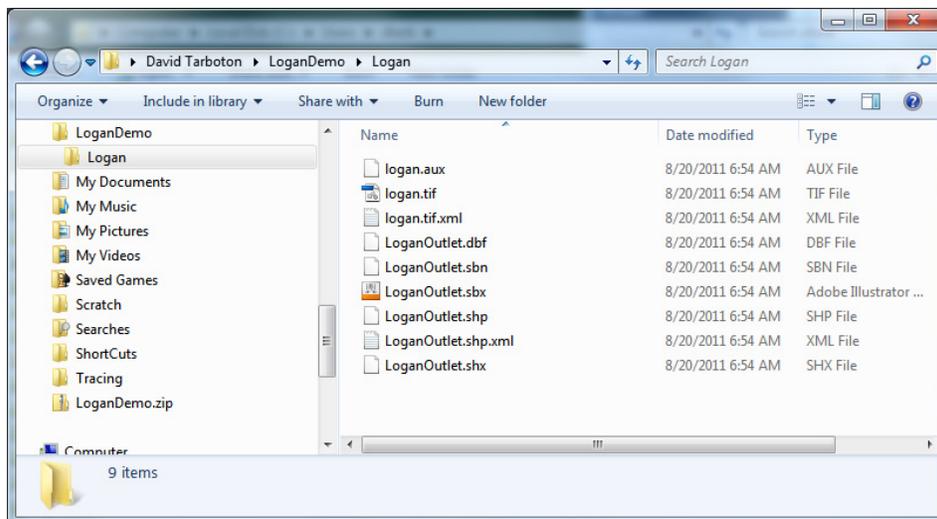
The Logan River DEM is illustrated below.
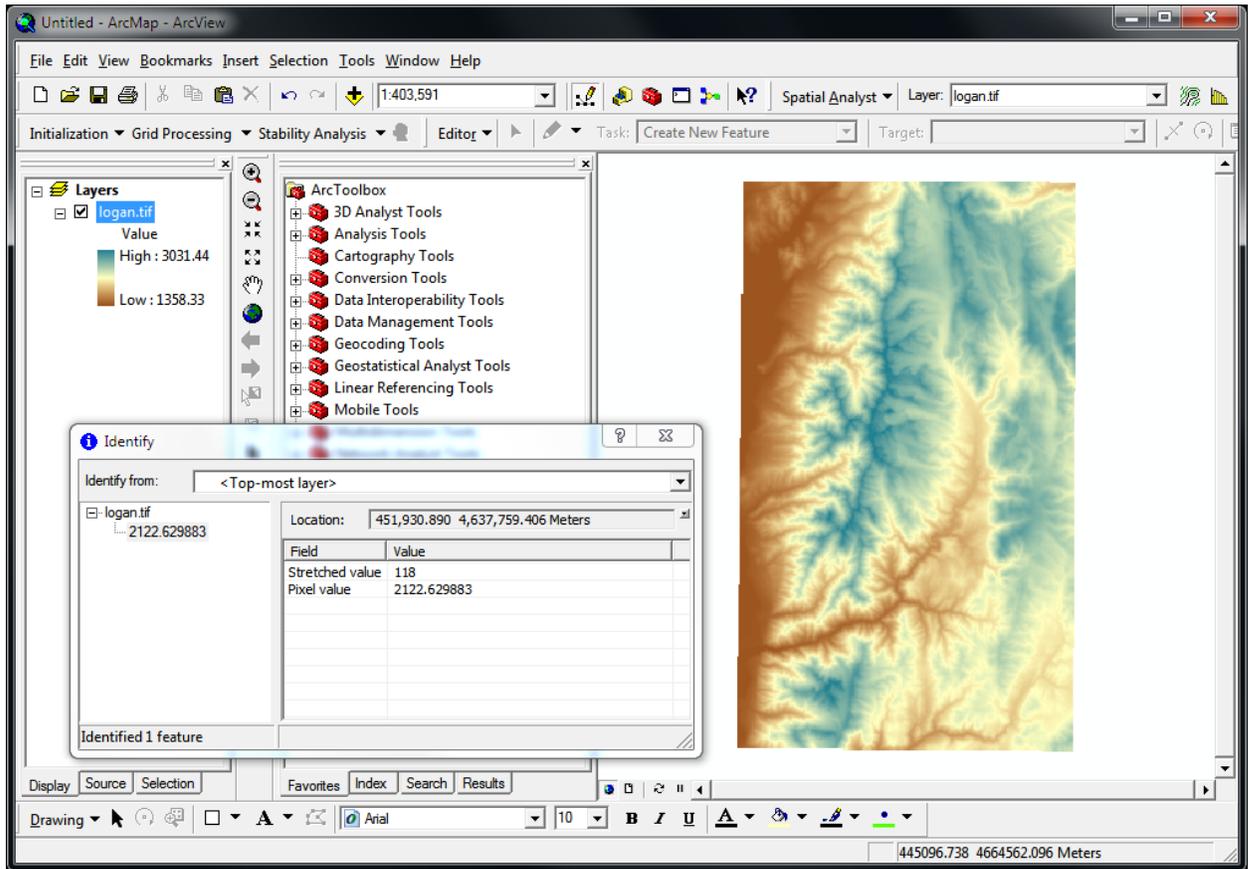
This display also shows the output from clicking on and identifying individual grid values. A DEM grid is a simple data structure that defines elevation values within a matrix of identically-sized square (or in general rectangular) grid cells as illustrated below.
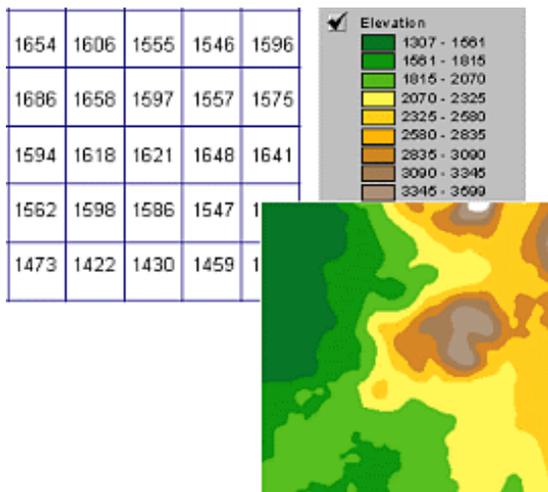
The TauDEM software derives hydrologically useful information from raw digital elevation model data. The basic idea rests on the concept of the hydrological flow field being represented by flow from each

grid cell to one or more of its neighbors. For this to work the topography should not contain pits, defined as one or more grid cells surrounded completely by higher ground. The first step in hydrologic terrain analysis is pit removal. TauDEM uses a fill process to do this raising the elevation of pits until they drain. A DEM with pits removed is referred to as hydrologically correct and can be used to calculate flow directions for each grid cell. Once flow directions have been calculated, quantifying the flow field, TauDEM has several tools for deriving flow related terrain information such as the area contributing to each grid cell, the path taken by flow originating from a set of grid cells and subwatersheds and the stream network. This general approach is illustrated below, where the flow from a raw DEM to hydrologically correct DEM following pit removal, to flow field, to derived information is shown.
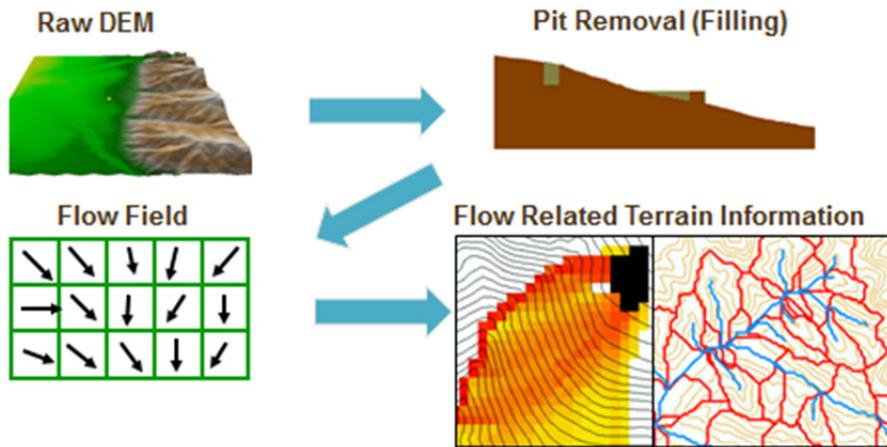
2. Open the TauDEM Tools -> Basic Grid Analysis -> Pit Remove Tool. Select the *logan.tif* grid DEM as input and set the number of processes to 4. Click OK.
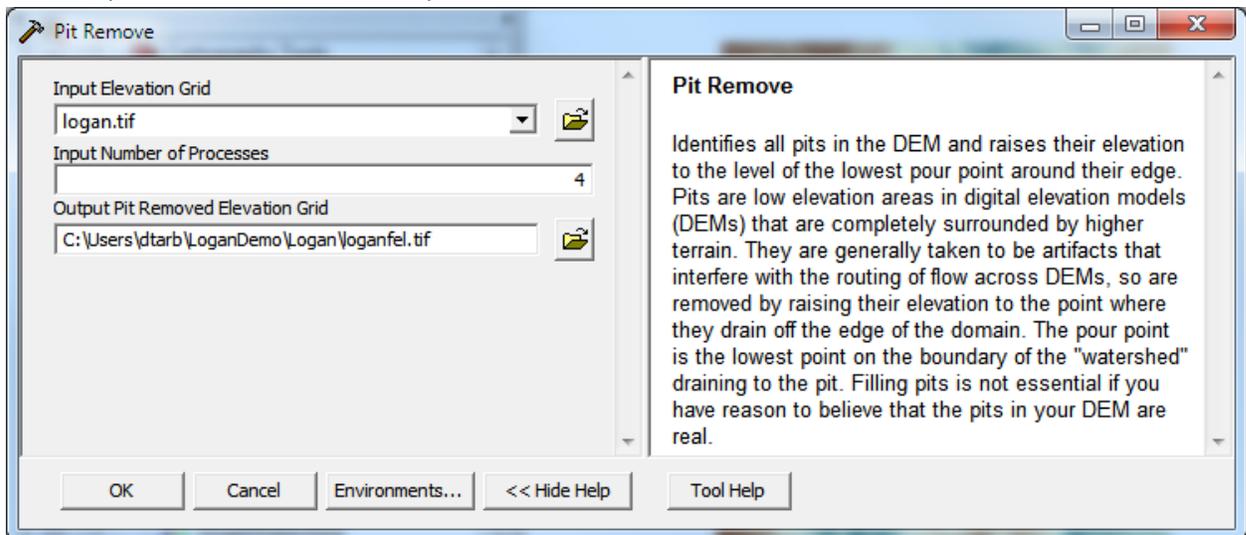
Note how when the Input elevation grid is selected the software automatically fills in output fields using TauDEM's file naming convention. This saves on some of the work involved in running these tools.

The result is a new layer *loganfel* that has been added to the map. The tool dialog box gives timing information and details of the shell command that was executed in the background while completing this task. This information is useful for debugging if something goes wrong.
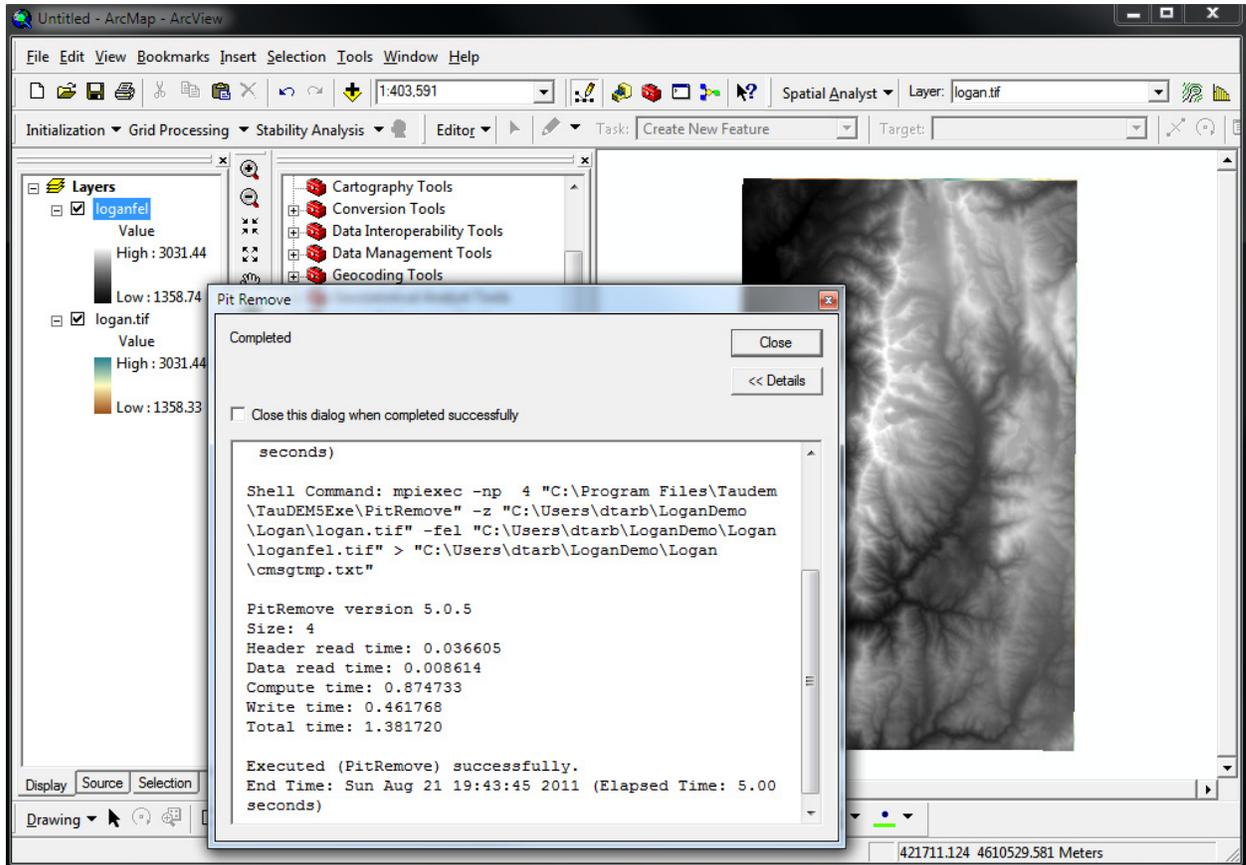
3. Use Spatial Analyst -> Raster calculator to evaluate the difference between the pit filled DEM *loganfel* and original DEM, *logan.tif*. Symbolize the output Calculation and zoom in to analyze some of the differences.
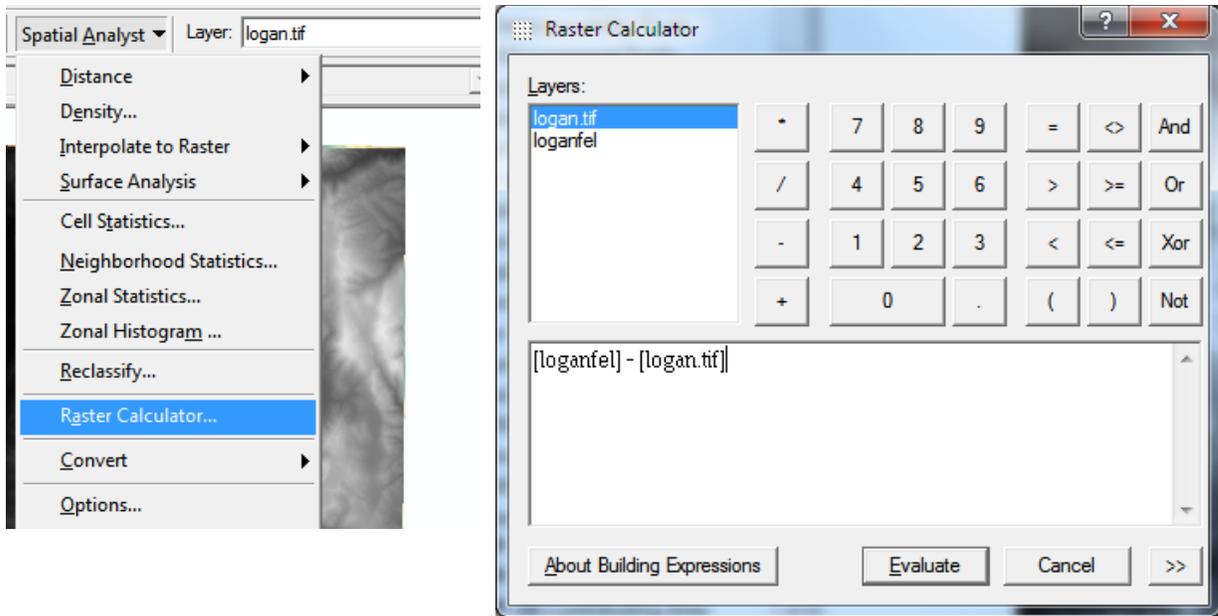
In the illustration below, 10 m contours have been overlaid over the difference layer, and some of the differences examined.
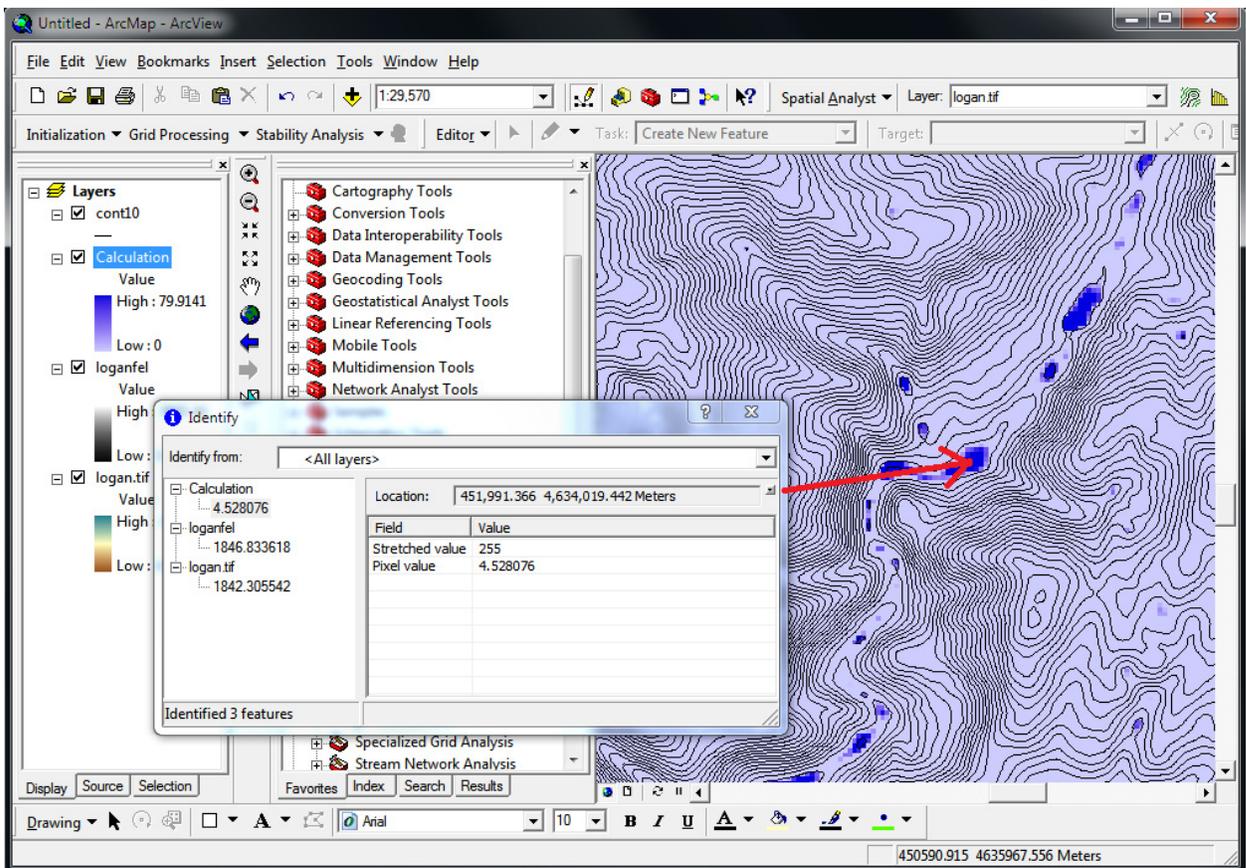
It is common to see pits along valleys where interpolation during the DEM creation process has created artificial barriers (dams) that are resolved by filling. Unless these pits are removed they become sinks

and isolate portions of the watershed. This is why pit removal is generally the first thing done with a DEM.

The next step is to define the outlet point. This is done by creating a shapefile giving the outlet point.

4. Open ArcCatalog and create a shapefile named MyOutlet. At the Create New Shapefile prompt click on Edit to Import the Spatial Reference from Logan.tif, to ensure that the shapefile and DEM have consistent spatial references. TauDEM requires this as it does not do any spatial reference transformations.
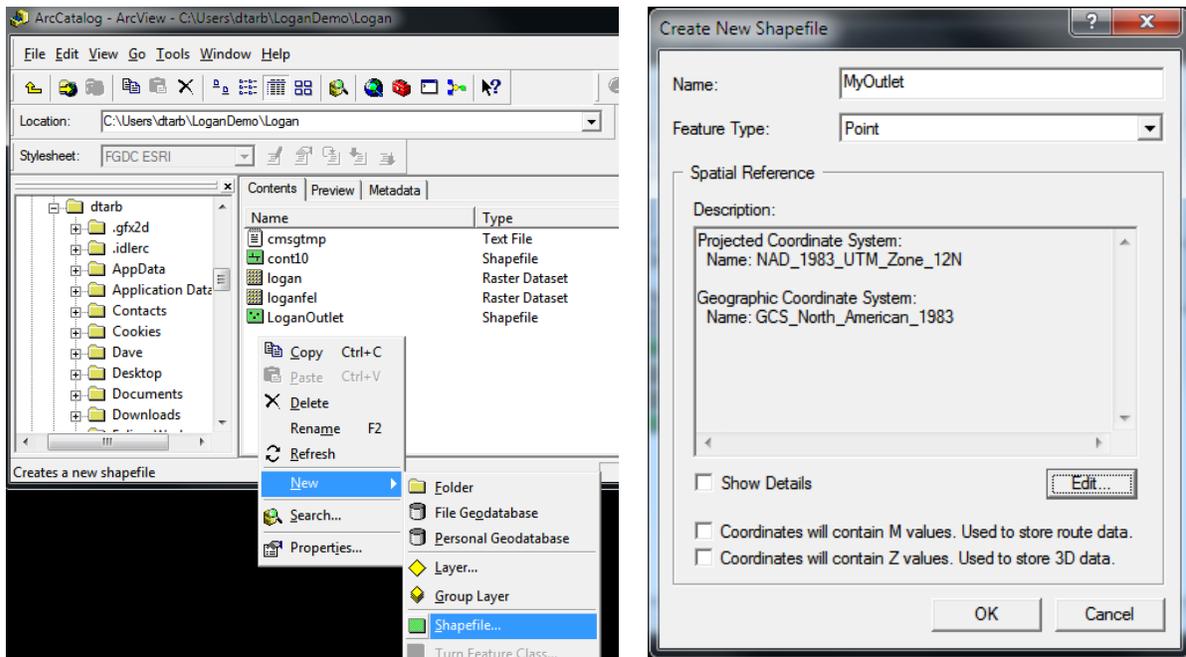
5. Close ArcCatalog and backin ArcMap add MyOutlet.shp and in the Editor toolbar Start Editing. Make sure that the Editor Toolbar Task is set to Creat New Feature and that the Target is MyOutlet.
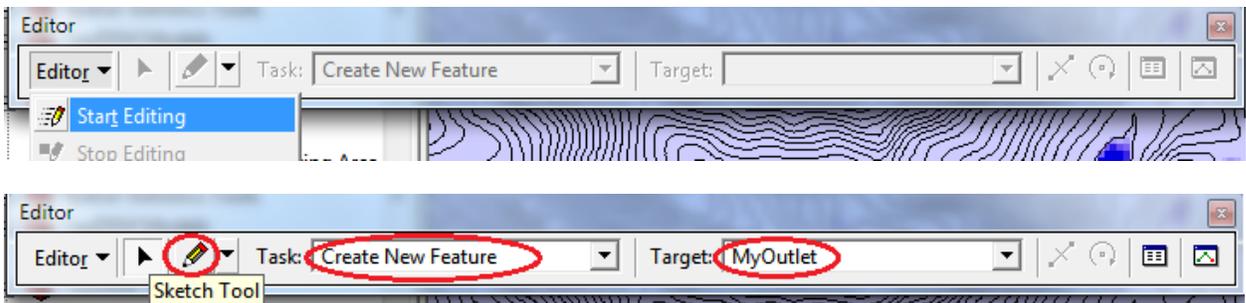
6. Zoom to a likely location for an outlet and create a new feature, then save and stop editing.
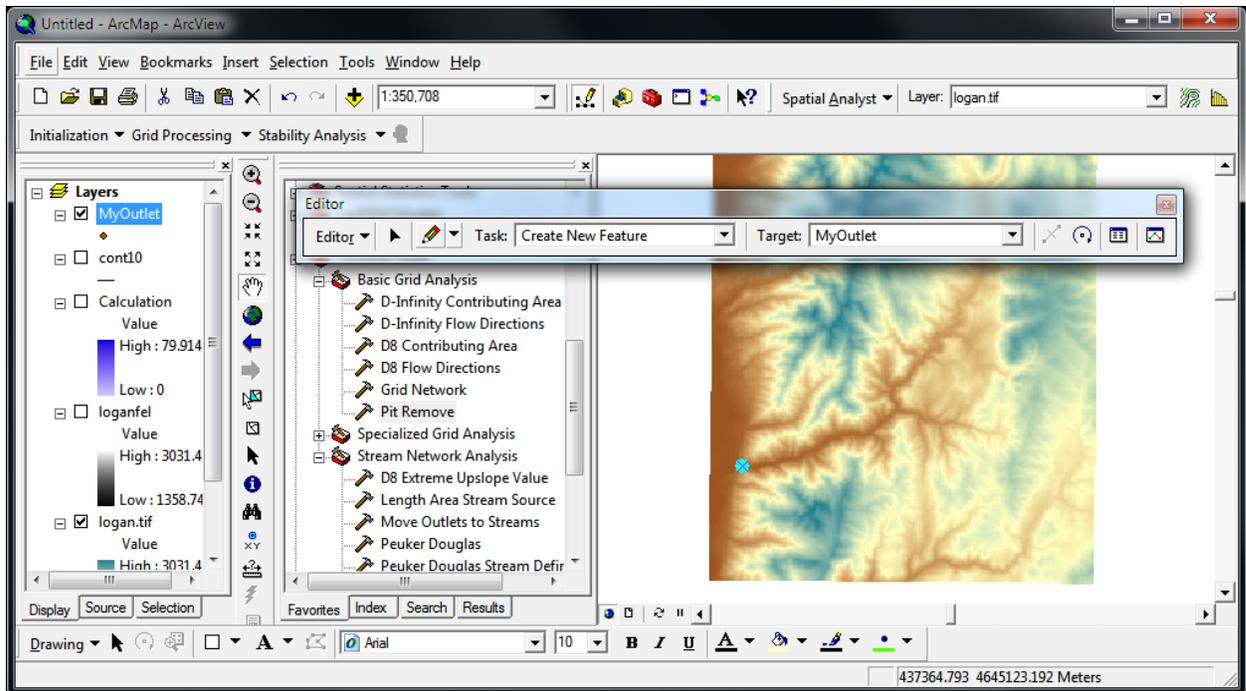
It is not required for the outlet to be precisely located where there will be a stream as TauDEM has a tool to move outlets to streams that will be used. Alternatively, if the outlet point location is available from some other source (e.g. location information about a stream gauge), it can be created from that information.

The complete process of watershed delineation using TauDEM tools involves a sequence of steps
- *Pit Remove*
- Definition of outlet (approximate) (Edit shapefile)
- *D8 Flow Directions*
- *D8 Contributing area*
- Calculation of preliminary stream network raster using a contributing area threshold (*Stream Definition by Threshold*)
- *Move Outlets to Streams*
- *Peuker Douglas Stream Definition*
- *Stream Reach and Watershed*
- *Watershed Grid to Shapefile*

The italicized text indicates the corresponding TauDEM function for each step. We have already completed the first two steps. Rather than do each separately, a model builder tool has been constructed to run these functions together. This is illustrated below.
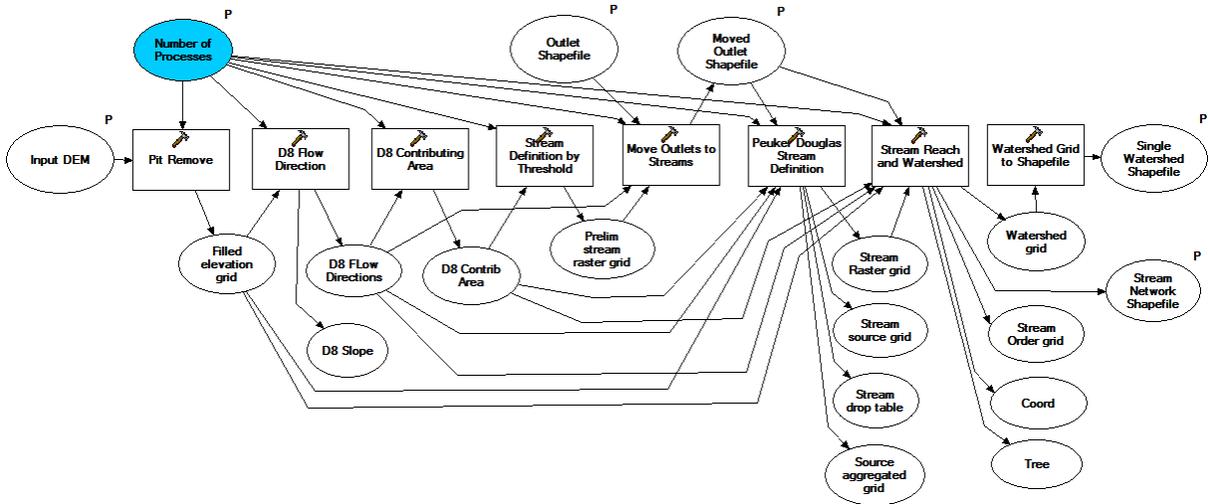
Following through the sequence illustrated in this function you can see the steps involved and how watershed delineation works. The workflow is organized to flow from left to right.

At the left is the Input DEM. This is used in the Pit Remove function, producing the Filled elevation grid output. The number of parallel processes is an input parameter for all functions. The Filled elevation grid is input to the calculation of D8 flow directions, a function that outputs D8 flow directions and D8 slope. D8 flow directions give an encoding of the direction of steepest downward slope from each grid cell to one of its neighbors. D8 flow directions are an input to the D8 Contributing Area tool. This counts the number of grid cells draining through each grid cell. Initially D8 contributing Area is used as input to the Stream Definition by threshold function. This defines a preliminary stream raster grid as all grid cells with contributing area greater than a designated threshold. 10000 is used in this tool. The precise value does not matter too much here as the preliminary stream raster is used only as a target for the Move Outlets to Streams function that adjust the approximately located outlet point to lie on the streams. After Move Outlets to Streams, the next function to run is Peuker Douglas Stream Definition. This is quite an elaborate function and involves first calculating a grid of stream sources following the Peuker Douglas methodology for identifying valley grid cells. This typically represents a disconnected skeleton like depiction of the stream network. These grid cells are then aggregated using a weighted contributing area calculation to produce the source aggregated grid, that is connected like a stream network. The function then goes through a Drop Analysis process to determine an appropriate threshold of the source aggregated grid to be used to map streams and the resulting streams are mapped in the Stream Raster grid. The result is a stream network where drainage density has been objectively determined based on the geomorphology, and all this has happened with little human intervention. After Peuker Douglas, the next function to run is Stream Reach and Watershed. This outputs a vector stream network shapefile and grid representing the watershed as a whole. In this workflow the parameter has been set (not shown) to mark a single watershed. The Stream Reach and Watershed function also has the option to delineate subwatersheds draining to each stream reach. The last function to run is Watershed Grid to Shapefile. This function uses ArcGIS built in functionality to create a shapefile of the watershed grid.

The Geoprocessing model illustrated above is not part of the regular TauDEM install. It needs to be downloaded separately.

7. Download and save the TauDEM Model Builder Models toolbox appropriate for your machine (TauDEMModels32.tbx or TauDEMModels64.tbx) from http://hydrology.usu.edu/taudem/taudem5.0/downloads.html. Add TauDEMModels**.tbx to ArcToolbox. Select Edit to examine the workflow discussed above. Close without making any edits.
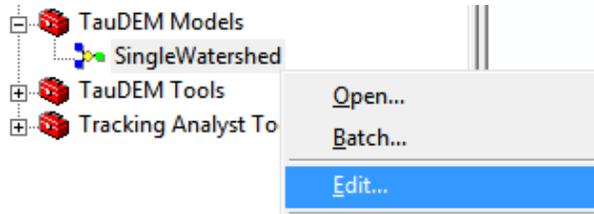
[See note 1 below if your toolbox opens with an X through it]
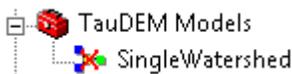
8. Open the SingleWatershed tool. Select *logan.tif* as the Input DEM. Select MyOutlet as the Outlet Shapefile (This is not optional – the optional indication is a bug). Fill in information for the Stream Network Shapefile and Watershed Shapefile. These inputs should be entered by clicking on the folders at the right of each box so that fully qualified paths with names ending in .shp are generated. Just entering names in the boxes often results in errors. Click OK.
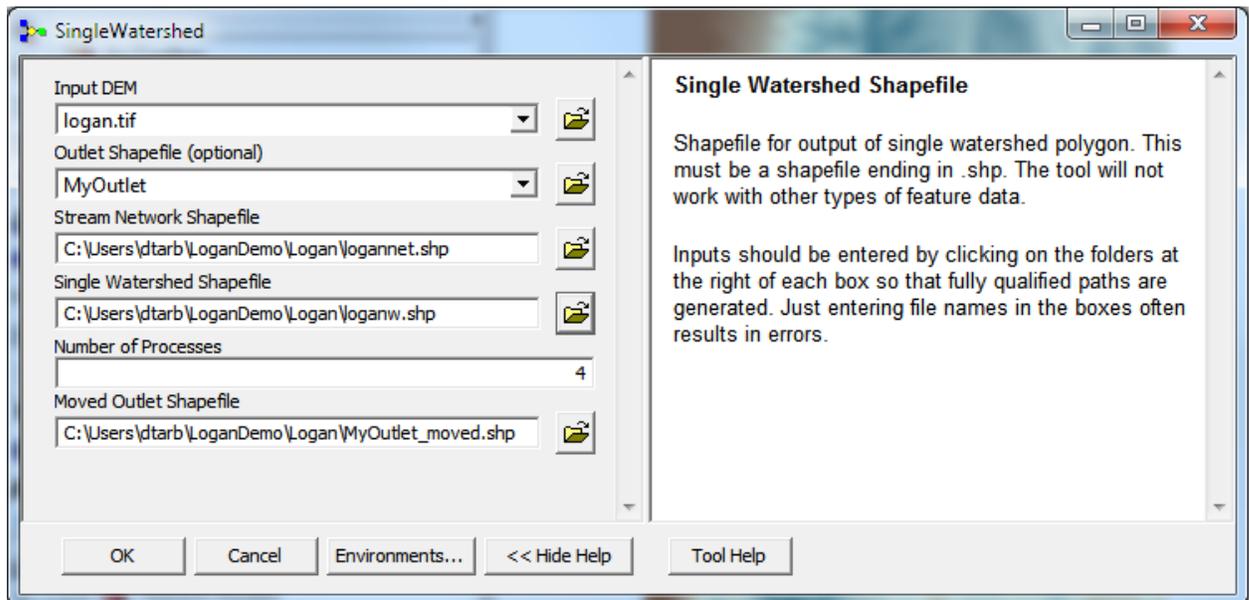
The screen will flash a number of times as each task executes. If all goes well the dialog box should show Completed with no errors and give details of the timing and shell scripts that were executed as part of this process.

```
SingleWatershed                                                              ▣

Completed                                                      ┌──────────┐
                                                               │  Close   │
                                                               └──────────┘
                                                               ┌──────────┐
                                                               │ << Details│
                                                               └──────────┘

☐ Close this dialog when completed successfully

  ┌─────────────────────────────────────────────────────────────────────┐▲
  │   Link compute time: 0.027768                                        │
  │   Link write time: 2.730439                                          │
  │   Watershed compute time: 0.180286                                   │
  │   Write time: 0.867975                                               │
  │   Total time: 4.142033                                               │
  │                                                                      │
  │   Executed (Stream Reach and Watershed) successfully.                │
  │   End Time: Sun Aug 21 21:27:04 2011 (Elapsed Time: 8.00 seconds)    │
  │   Executing (Watershed Grid to Shapefile): WatershedGridToShapefile c:\Users\dtarb│
  │   \Scratch\Logan\loganw.tif C:\Users\dtarb\LoganDemo\Logan\loganw.shp│
  │   Start Time: Sun Aug 21 21:27:04 2011                               │
  │                                                                      │
  │   Executed (Watershed Grid to Shapefile) successfully.               │
  │   End Time: Sun Aug 21 21:27:07 2011 (Elapsed Time: 3.00 seconds)    │
  │ Executed (Model23) successfully.                                     │
  │ End Time: Sun Aug 21 21:27:07 2011 (Elapsed Time: 44.00 seconds)     │▼
  └─────────────────────────────────────────────────────────────────────┘
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The results illustrate what was achieved by this process.

This shows the original outlet selected and how it was moved to be on the stream.
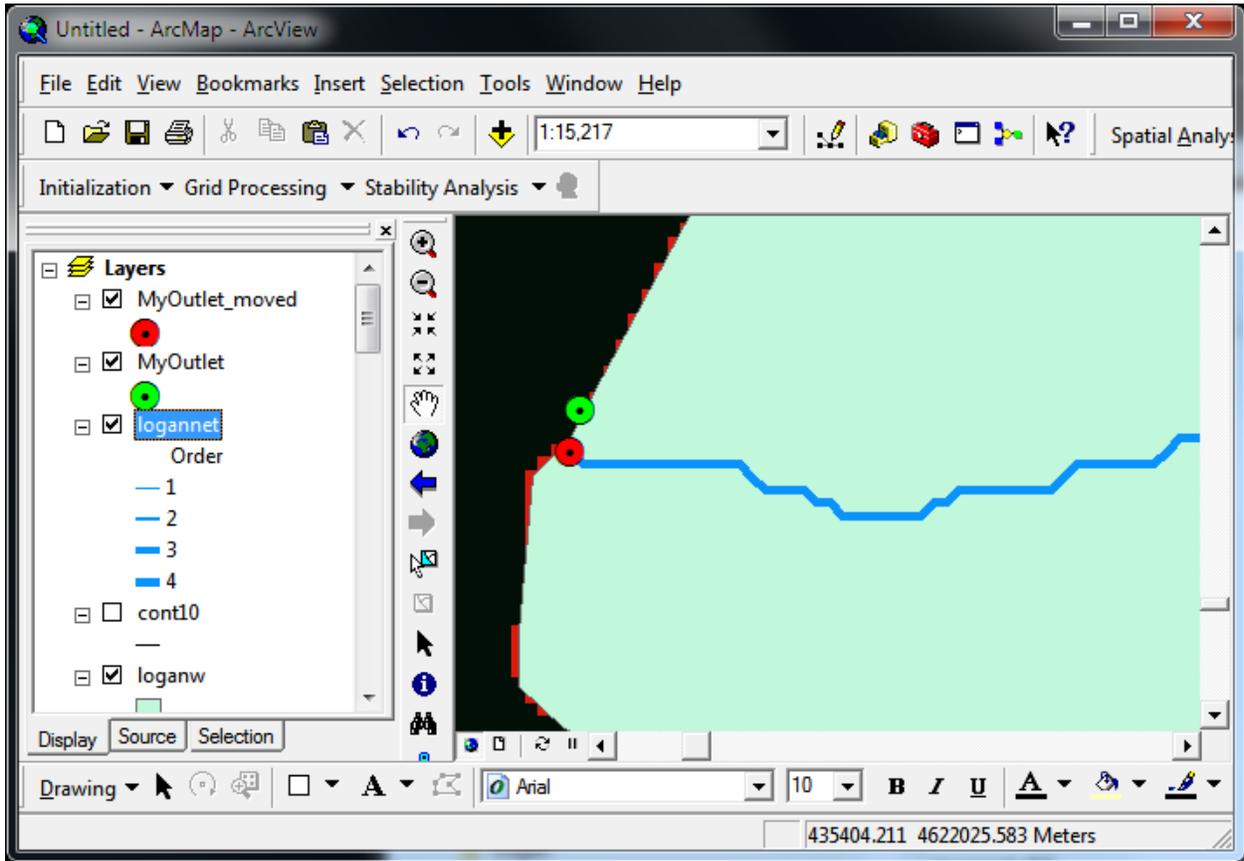
This shows the single watershed delineated with stream network symbolized based on stream order.
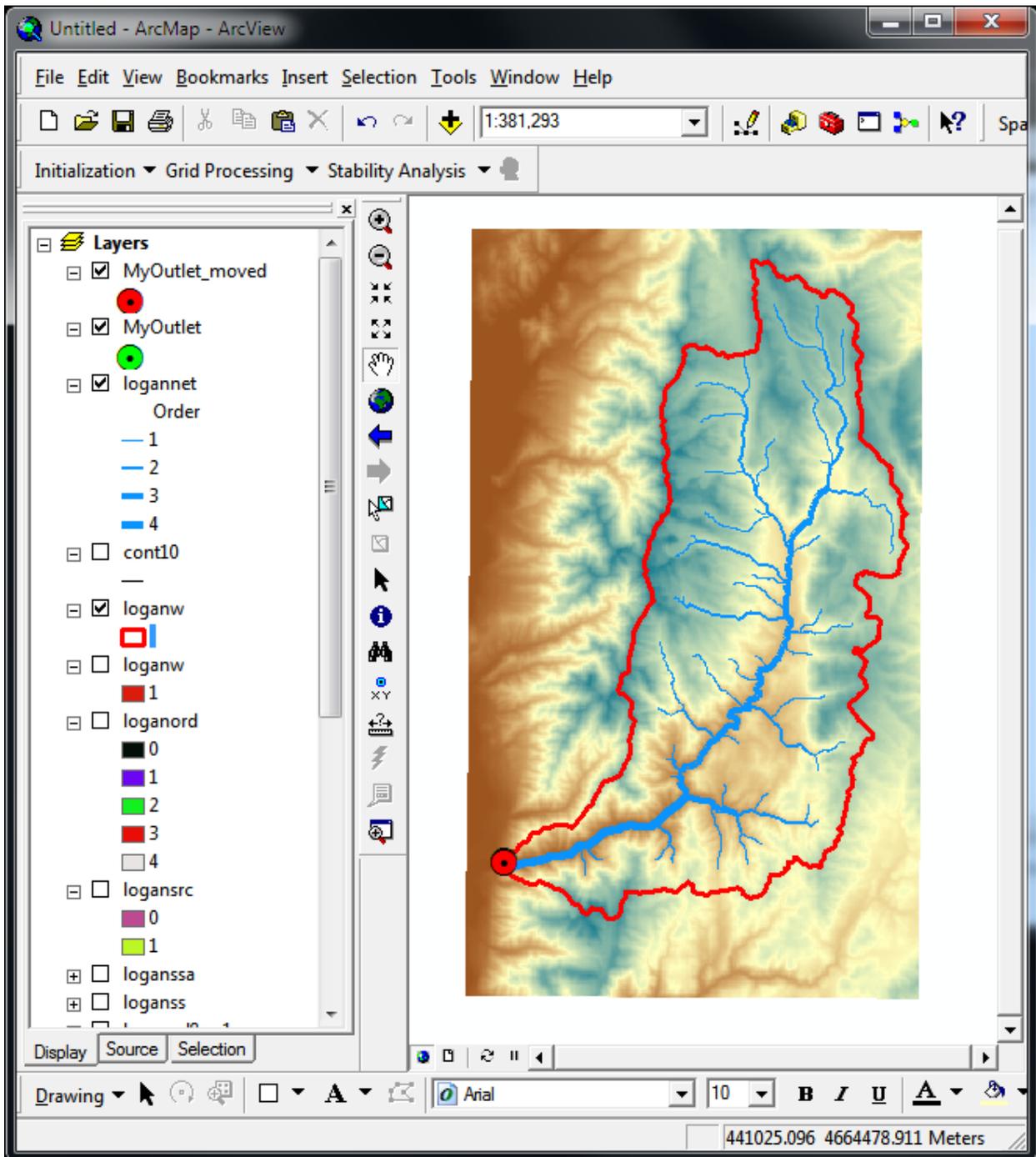
This shows the attributes of a stream network link displayed using the identify tool. Downstream and upstream connectivity, stream order, length, slope and drainage area information is included.
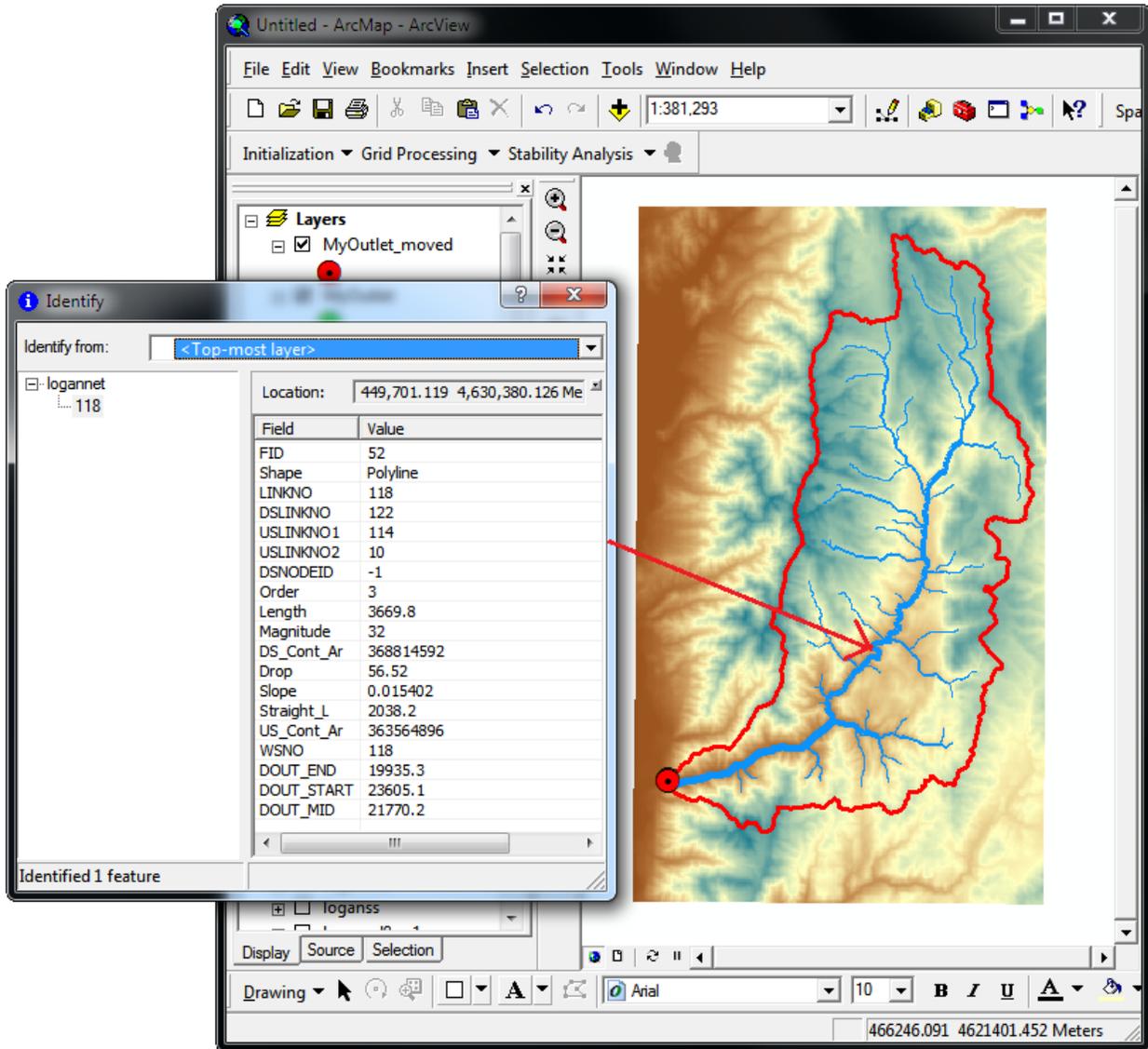
Notes

1. The SingleWatershed Geoprocessing tool depends on the tools in the TauDEM tools toolbox. It was built on a computer with these in the default location c:\program files\taudem for 32 bit machines and C:\Program Files (x86)\Taudem for 64 bit machines. If on your machine the are in a different location the SingleWatershed tool may be unable to find the necessary TauDEM tools. The symptom of this is that the tool appears with a red X through it
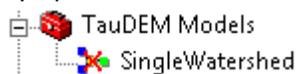
To fix this you need to edit the SingleWatershed tool
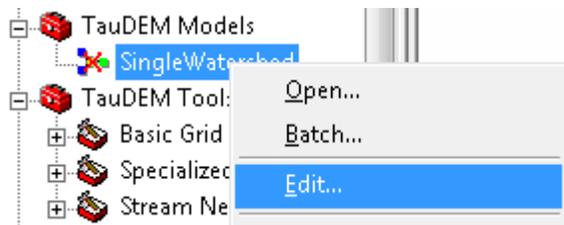
In the editor double click on each tool with a red X through it
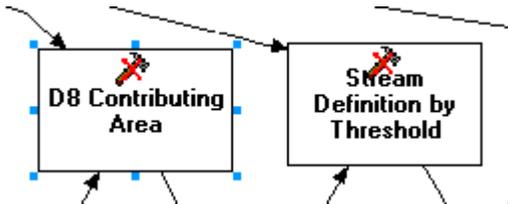
and navigate to the corresponding tool in the alternative location and click Add.
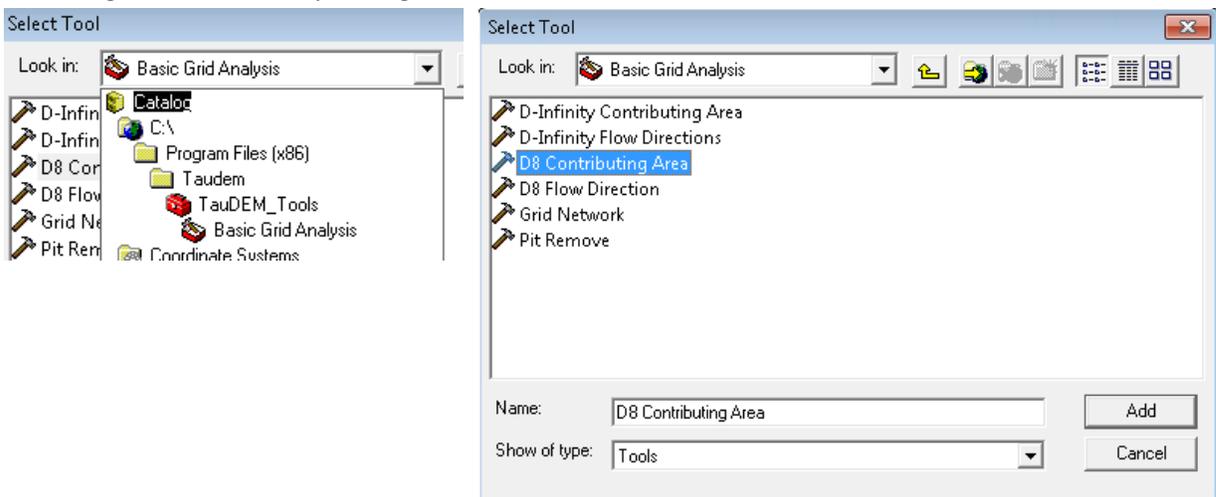
Once this is complete, close the editor saving the changes. In going through this process it is necessary to trigger the validation in each tool. This can be done by changing the inputs in a small way (e.g. changing a file name), then changing them back, so that the validation error warnings go away. I have found this process a little bit fragile to get just right, so you may need to run the model from within the model builder environment if you are having trouble.