

Watershed and Stream Network Delineation

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Introduction

The first step in doing any kind of hydrologic modeling involves delineating streams and watersheds, and getting some basic watershed properties such as area, slope, flow length, and stream network density. Traditionally this was (and still is!) done manually by using topographic/contour maps. With the availability of digital elevation models (DEM) and GIS tools, watershed properties can be extracted by using automated procedures. The processing of DEM to delineate watersheds is referred to as terrain pre-processing. There are several tools available online for terrain pre-processing. In this exercise, we will use Arc Hydro tools to process a DEM to delineate watershed, sub-watersheds, stream network and some other watershed characteristics that collectively describe the drainage patterns of a basin. The results from this exercise can be used to create input files for many hydrologic models. An exercise on how to use these results to create a HEC-HMS model is provided as a follow-up to this exercise.

Computer Requirements

You must have a computer with windows operating system, and the following programs installed:

1. ArcGIS 9.3 (with ArcInfo)
2. Arc Hydro tools (version that works with 9.3)

Make sure the Arc Hydro tools (version that works with 9.3) are installed on the system. There are lots of Arc Hydro tools available on the internet. The version that is used in this tutorial, and the installation instructions are available at the following link.

<ftp://ftp.ecn.purdue.edu/vmerwade/download/data/tools.zip>

You will need to have administrative access to install these tools.

Data Requirements and Description

The data files used in the exercise consist of DEM grid for Cedar Creek in northeast Indiana and the hydrography data (mainly stream network). Although the data are provided with this exercise, the steps involved in downloading the NED and NHD data from the USGS website are described in the following document.

http://web.ics.purdue.edu/~vmerwade/education/ned_nhd.pdf

It is highly recommended that you go through the exercise of downloading the data to make yourself aware of the procedure involved.

Download the data from <http://web.ics.purdue.edu/~vmerwade/education/terrain.zip>

Unzip *terrain.zip* in your working directory. The ArcCatalog-view of the data folder is shown below:



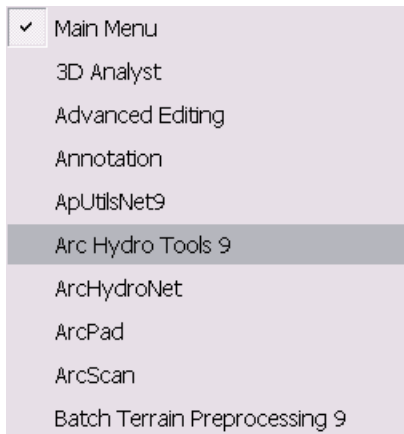
cedar_dem is a 30 DEM obtained from USGS and clipped for the study watershed (Cedar Creek). The second dataset, *streams.shp*, is a shapefile containing stream network for the study area. *Streams.shp* is extracted from that national hydrography dataset (this is done by selecting the stream network for the watershed and exporting it to a shape file). Both *cedar_dem* and *streams.shp* are already assigned a projected coordinate system (NAD_1983_UTM_16).

Note: It is very critical to assign and use consistent coordinate system for all the datasets used in delineating watersheds by using any pre-processing tool.

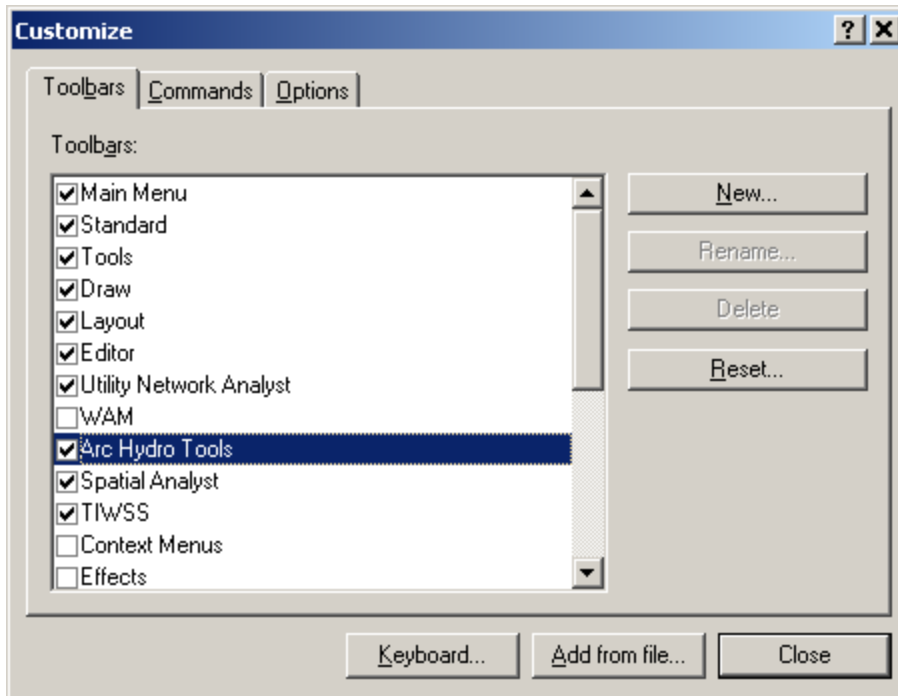
Getting Started

Open ArcMap and load Arc Hydro tools

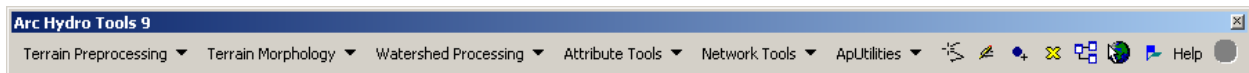
Open ArcMap. Create a new empty map, and save it as *terrain.mxd* (or any other name). **Right click** on the menu bar to pop up the context menu showing available tools as shown below.



Check the Arc Hydro Tools 9 menu. If the Arc Hydro Tools menu does not appear in the list, **click** on *Customize* (Scroll down the list to see “Customize”). In the *Customize* dialog that appears, **check** the Arc Hydro Tools box.



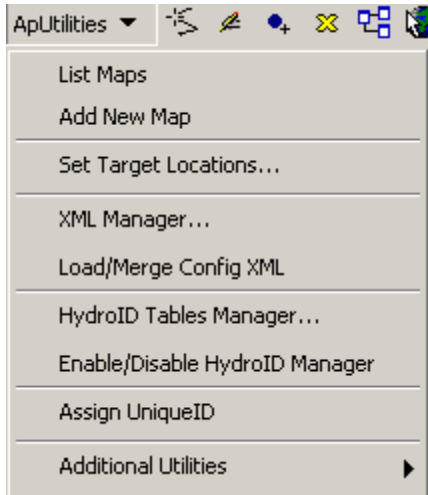
You should now see the Arc Hydro tools added to ArcMap as shown below. You can leave it floating or you may dock it in ArcMap.



Note: It is not necessary to load the Spatial Analyst, Utility Network Analyst, or Editor tools because Arc Hydro Tools will automatically use their functionality on an as-needed basis. These toolbars need to be loaded though if you want to use any general functionality that they provide such as general editing functionality or network tracing. However, the Spatial Analyst Extension needs to be activated, by clicking **Tools** → **Extensions...**, and checking the box next to Spatial Analyst.


Dataset Setup

All vector data created with Arc Hydro tools will be stored in a new geodatabase that has the same name as the stored project or ArcMap document (unless pointed to an existing geodatabase) and in the same directory where the project has been saved (your working folder). By default, the new raster data are stored in a subdirectory with the same name as the dataset or Data Frame in the ArcMap document (called **Layers** by default and under the directory where the project is stored). The location of the vector, raster, and time series data can be explicitly specified using the function *ApUtilities* → *Set Target Locations*.



You can leave the default settings if they are pointing to the same directory where the ArcMap document is saved.

Load the data to ArcMap

Click on the Add icon  to add the raster data. In the dialog box, **navigate** to the location of the data; **select** the raster file *cedar_dem* containing the DEM for Cedar creek and **click** on the Add button. The added file will then be listed in the Arc Map Table of contents. Similarly **add** *stream.shp*, and save the map document.

Terrain Preprocessing

All the steps in the Arc Hydro Terrain Preprocessing menu should be performed in sequential order, from top to bottom. All of the preprocessing must be completed before Watershed Processing functions can be used. DEM reconditioning and filling sinks might not be required depending on the quality of the initial DEM. DEM reconditioning involves modifying the elevation data to be more consistent with the input vector stream network. This implies an assumption that the stream network data are more reliable than the DEM data, so you need to use your knowledge about the accuracy and reliability of the data sources when deciding whether to do DEM reconditioning. By doing DEM reconditioning you can increase the degree of agreement between stream networks delineated from the DEM and the input vector stream networks.

Note: Depending on the size of the datasets, processes like DEM Reconditioning, Filling Sinks and Flow accumulation can take from few minutes to up to one hour or more. Therefore if you are using this tutorial as a guide for another larger dataset, be patient!

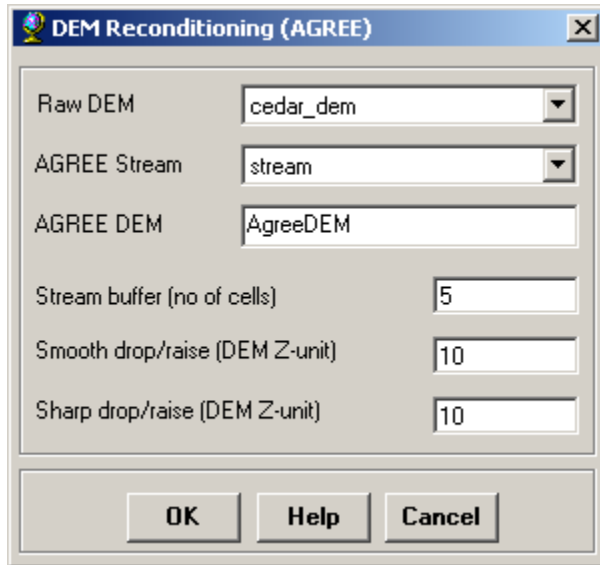
1. DEM Reconditioning

This function modifies a DEM by imposing linear features onto it (burning/fencing). It is an implementation of the AGREE method developed Center for Research in Water Resources at the University of Texas at Austin. For a full reference to the procedure refer to the web link: <http://www.ce.utexas.edu/prof/maidment/GISHYDRO/ferdi/research/agree/agree.html>.

The function needs as input a raw dem and a linear feature class (like the river network) that both have to be present in the map document.

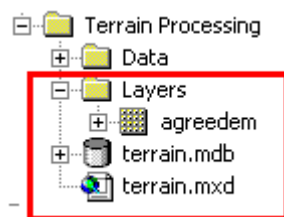
On the ArcHydro toolbar, **select** *Terrain Preprocessing* → *DEM Manipulation* → *DEM Reconditioning*.

Select the appropriate Raw DEM (cedar_dem) and AGREE stream feature (stream). **Set** the Agree parameters as shown. You should **reduce** the *Sharp drop/raise* parameter to 10 from its default 1000. The output is a reconditioned Agree DEM (default name AgreeDEM).

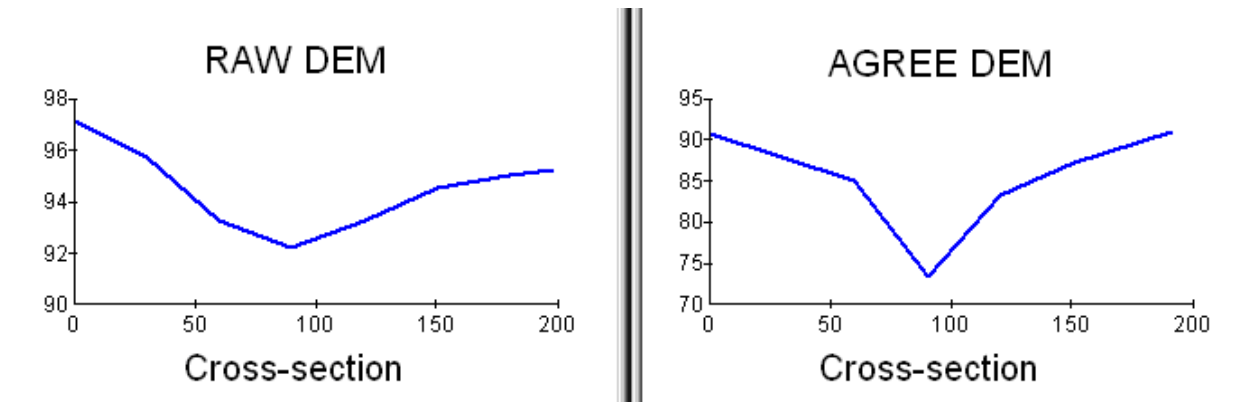


This process takes about 2 to 3 minutes! **Click OK** on the “...processing successfully completed” message box. Examine your working folder, and you will notice that a folder named Layers has been created. This is where ArcHydro will store its grid results. A personal geodatabase with the same name as your ArcMap document has also been created as shown in the following ArcCatalog view:

Note: If you do not see Layers folder and a new geodatabase in your working folder, Arc Hydro tool is probably storing your results in some other directory. Check your Target Locations under ApUtilities menu.



What AgreeDEM (or DEM reconditioning) does is pushes the raw DEM along the stream to create a distinct profile along the streams which otherwise does not exist in raw DEMs. This is mainly due to lack of elevation data along streams in raw DEMs. For example, the figure below shows how the cross-section profile at a given location changes when the DEM is reconditioned.



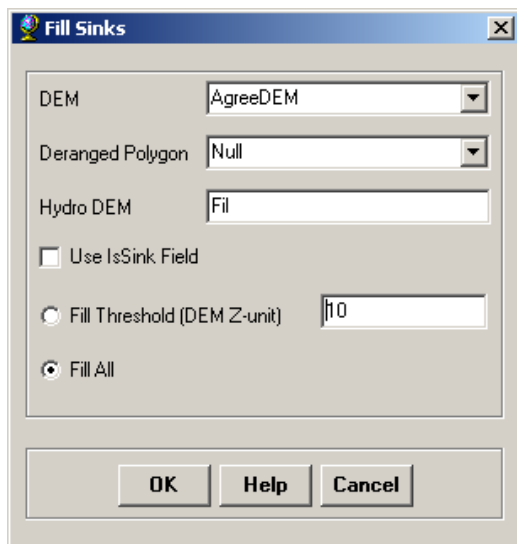
Note: You can use the Interpolate Line tool (to draw a line across any stream) and then Create Profile Graph tool in 3D Analyst to examine a profile cross section across a stream. Make sure you change the layer (cedar_dem and AgreeDEM to see the profiles for these two datasets):

2. Fill Sinks

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

On the ArcHydro Toolbar, **select** *Terrain Preprocessing* → *Data Manipulation* → *Fill Sinks*.

Confirm that the input for DEM is *AgreeDEM* (or your original DEM if Reconditioning was not implemented). The output is the Hydro DEM layer, named by default *Fil*. This default name can be overwritten. **Leave** the other options **unchanged**.



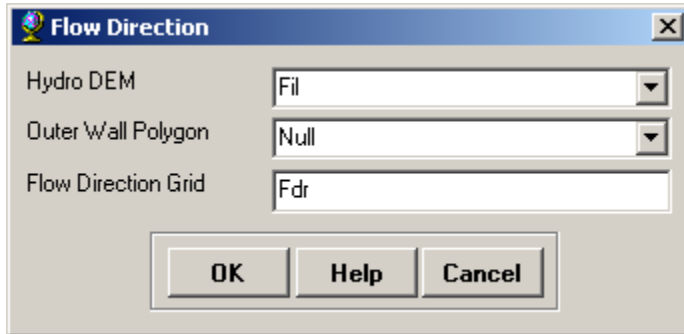
Press OK. Upon successful completion of the process, the *Fil* layer is added to the map. This process may take few minutes.

3. Flow Direction

This function computes the flow direction for a given grid. The values in the cells of the flow direction grid indicate the direction of the steepest descent from that cell.

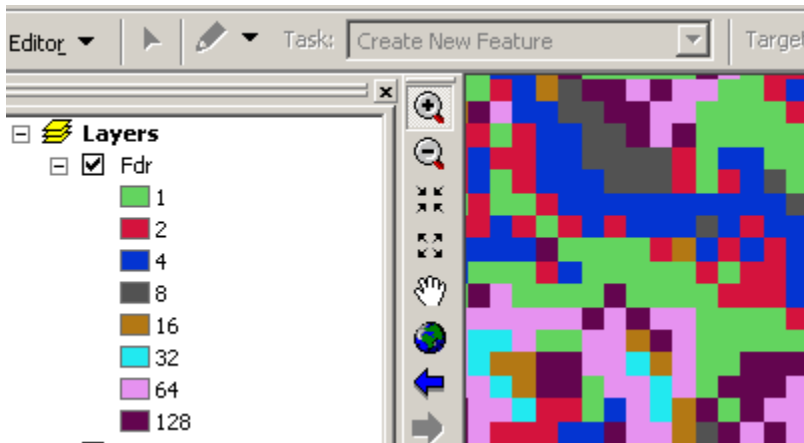
On the ArcHydro toolbar, **select** *Terrain Preprocessing* → *Flow Direction*.

Confirm that the input for Hydro DEM is *Fil*. The output is the Flow Direction Grid, named by default *Fdr*. This default name can be overwritten.



Press *OK*. Upon successful completion of the process, the flow direction grid *Fdr* is added to the map.

The **zoomed-in** version of the *Fdr* grid should look like the map below with each color in the cell having one of the eight numbers shown in the legend representing the flow direction according to the eight-point pour flow direction model.

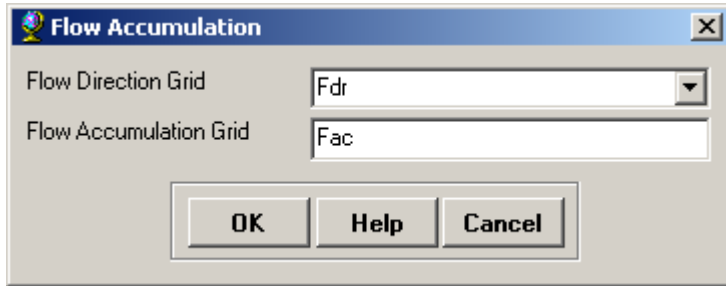


4. Flow Accumulation

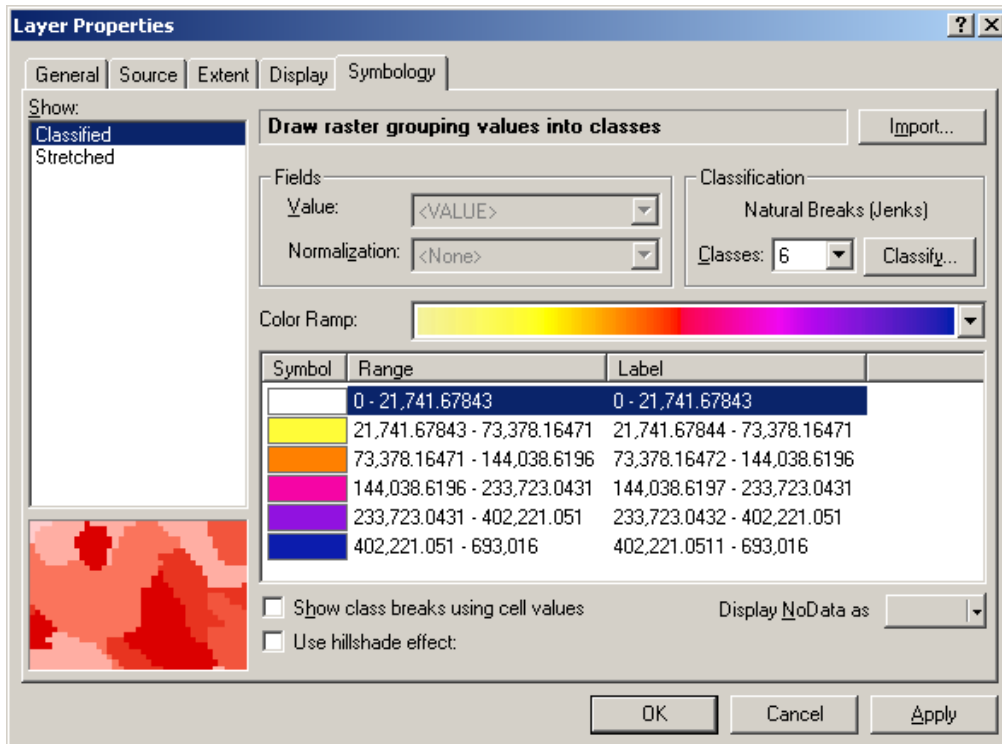
This function computes the flow accumulation grid that contains the accumulated number of cells upstream of a cell, for each cell in the input grid.

On the ArcHydro toolbar, **select** *Terrain Preprocessing* → *Flow Accumulation*.

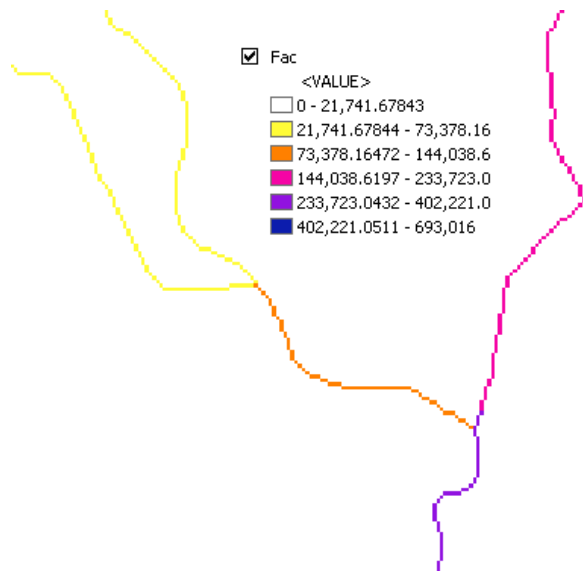
Confirm that the input of the Flow Direction Grid is *Fdr*. The output is the Flow Accumulation Grid having a default name of *Fac* that can be overwritten.




Press OK. Upon successful completion of the process, the flow accumulation grid *Fac* is added to the map. This process may take several minutes for a large grid! **Adjust** the symbology of the Flow Accumulation layer *Fac* to a multiplicatively increasing scale to illustrate the increase of flow accumulation as one descends into the grid flow network.



Zoom-in to a stream network junction to see how the symbology changes from light to dark color as the number of upstream cells draining to a stream increase from upstream to downstream as shown below.

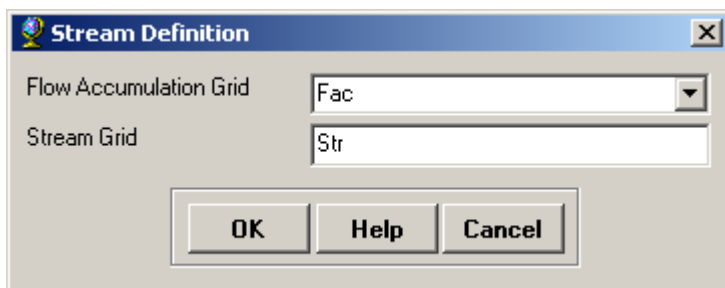


If you **click** at any point along the stream network on *Fac* grid using the identify button , you can find the area draining to that point by **multiplying** the *Fac* number by the area of each cell (cell size x cell size which is 30.89 x 30.89 in this case). **Save** the map document.

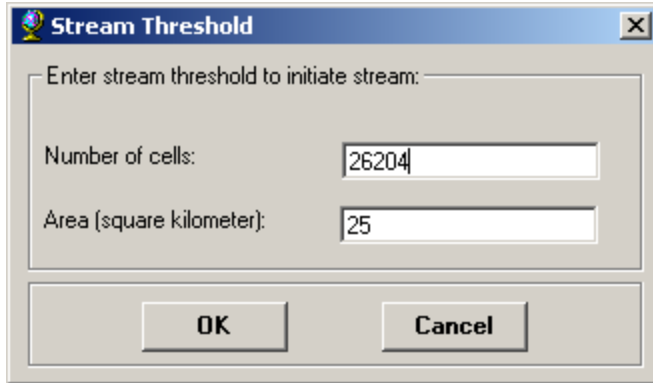
5. Stream Definition

On the ArcHydro toolbar, **select** *Terrain Preprocessing* → *Stream Definition*.

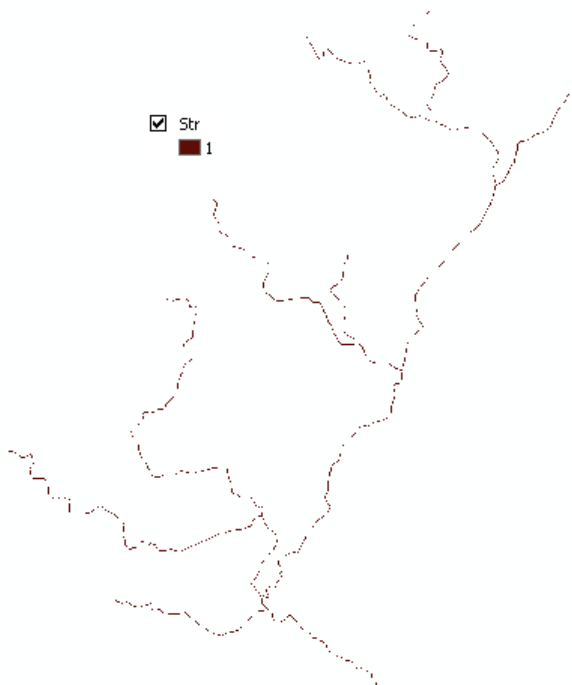
Confirm that the input for the Flow Accumulation Grid is *Fac*. The output is the Stream Grid named *Str*, default name that can be overwritten.



A default value is displayed for the river threshold. This value represents 1% of the maximum flow accumulation: a simple rule of thumb for stream determination threshold. The threshold drainage area to generate a stream is then $6390 \times 30.89 \times 30.89 / 1000000 = 6.09 \text{ km}^2$. However, any other value of threshold can be selected. For example, the USGS Elevation Derivatives for National Applications (EDNA <http://edna.usgs.gov/>) approach uses a threshold of $5000 \times 30 \times 30$ m cells (an area of 4.5 km^2) for catchment definition. A smaller threshold will result in a denser stream network and usually in a greater number of delineated catchments. Objective methods for the selection of the stream delineation threshold to derive the highest resolution network consistent with geomorphological river network properties have been developed and implemented in the TauDEM software (<http://www.engineering.usu.edu/dtarb/taudem/>). For this exercise, **choose** 25 km^2 as the threshold area (@ 4% of the maximum flow accumulation), and click OK.



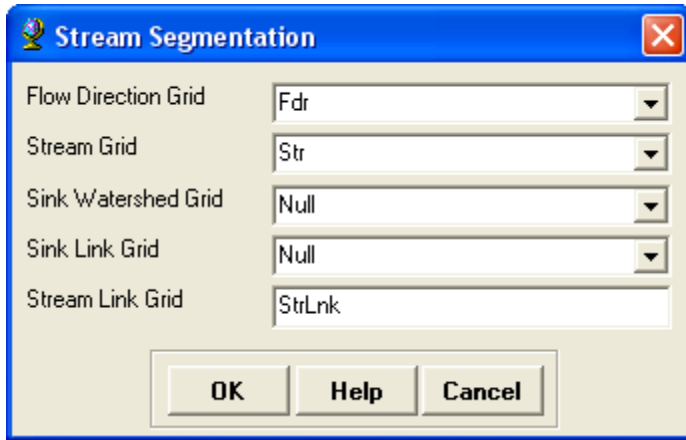
Upon successful completion of the process, the stream grid *Str* is added to the map. This *Str* grid contains a value of "1" for all the cells in the input flow accumulation grid (*Fac*) that have a value greater than the given threshold (26204 as shown in above figure). All other cells in the Stream Grid contain no data. The cells in *Str* grid with a value of 1 are symbolized with black color to get a stream network as shown below:



6. Stream Segmentation

This function creates a grid of stream segments that have a unique identification. Either a segment may be a head segment, or it may be defined as a segment between two segment junctions. All the cells in a particular segment have the same grid code that is specific to that segment.

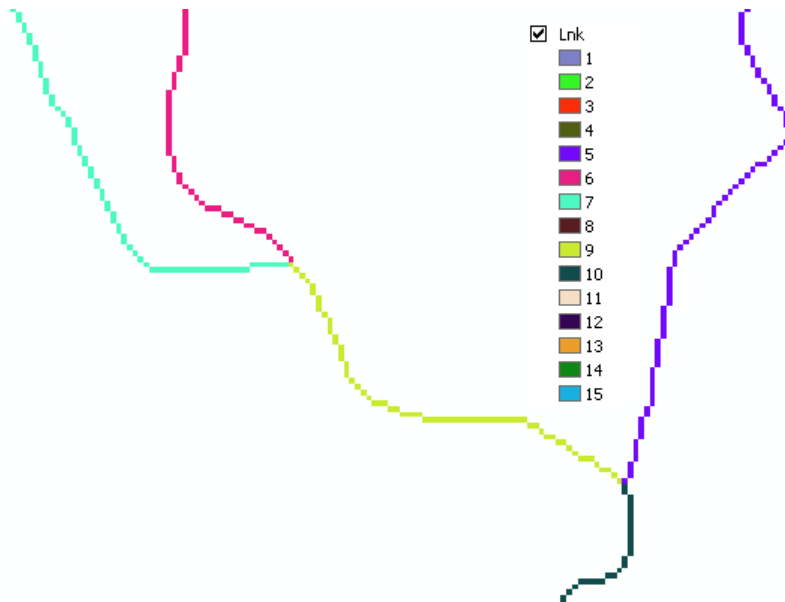
On the ArcHydro toolbar, **select** *Terrain Preprocessing* → *Stream Segmentation*.



Out of five inputs, Sink Watershed Grid and Sink Link Grid are optional. Sink watershed grid may be used to specify the areas located within sink drainage areas, where the stream links should not be generated. Sink Link may be used also to specify areas where stream links should not be generated.

Leaving the optional grids *Null*, **confirm** that *Fdr* and *Str* are inputs for Flow Direction Grid and Stream Grid, respectively. The output is the Stream Link Grid, with the default name *StrLnk* that can be overwritten.

Press OK. Upon successful completion of the process, the link grid *Lnk* is added to the map.



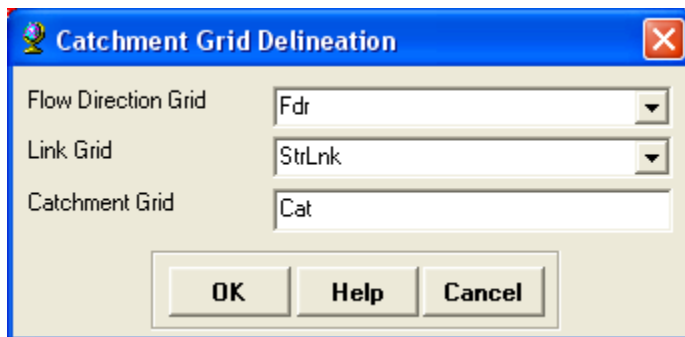
At this point, notice how each link has a separate value. **Save** the map document.

7. Catchment Grid Delineation

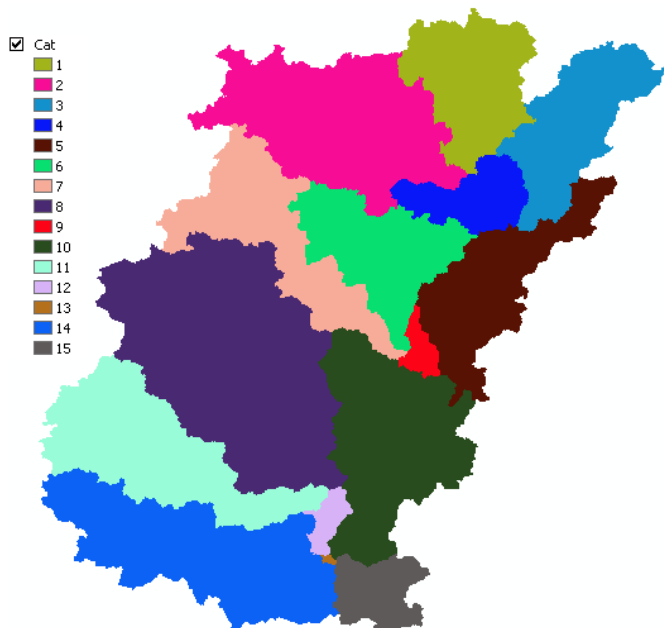
This function creates a grid in which each cell carries a value (grid code) indicating to which catchment the cell belongs. The value corresponds to the value carried by the stream segment that drains that area, defined in the stream segment link grid

On the ArcHydro toolbar, **select** *Terrain Preprocessing* → *Catchment Grid Delineation*.

Confirm that the input to the Flow Direction Grid and Link Grid are *Fdr* and *StrLnk* respectively. The output is the Catchment Grid layer with *Cat* as its default name that can be overwritten by the user.



Press OK. Upon successful completion of the process, the Catchment grid *Cat* is added to the map. If you want, you can recolor the grid with unique values to get a nice display (**use properties** → *symbolology*).



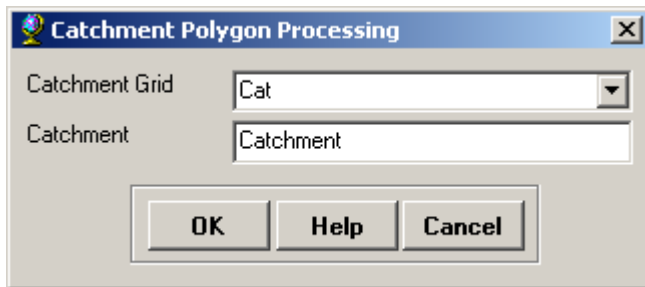
8. Catchment Polygon Processing

The three functions: Catchment Polygon Processing, Drainage Line Processing and Adjoint Catchment Processing convert the raster data developed so far to vector format. The rasters created until now have all been stored in a folder named *Layers*. The vector data will be stored in a feature dataset also named *Layers* within the geodatabase associated with the map document. Unless otherwise specified under *APUtilities* → *Set Target Locations*, the geodatabase inherits the name of the map document (terrain.mdb in this case) and the folder and feature dataset inherit their names from the active data frame which by default is named *Layers*.

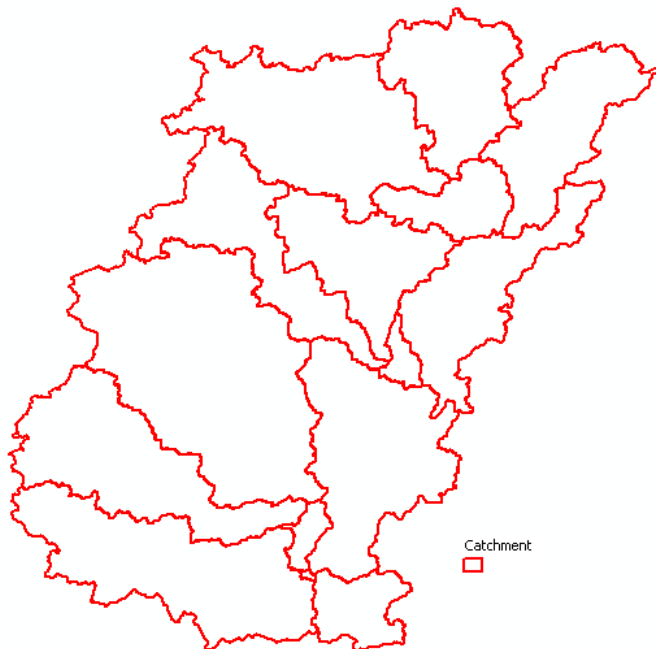
On the ArcHydro toolbar, select *Terrain Preprocessing* → *Catchment Polygon Processing*.

This function converts a catchment grid into a catchment polygon feature.

Confirm that the input to the CatchmentGrid is *Cat*. The output is a polygon feature class, having the default name *Catchment* that can be overwritten.



Press OK. Upon successful completion of the process, a polygon feature class named *Catchment* is added to the map.



Open the attribute table of *Catchment*. Notice that each catchment has a *HydroID* assigned that is the unique identifier of each catchment within *Arc Hydro*. Each catchment also has its Length and Area attributes. These quantities are automatically computed when a feature class becomes part of a geodatabase.

Shape*	OID*	Shape_Len	Shape_Area	HydroID	GridID
Polygon	1	49419.94502	41456657.10	1	1
Polygon	2	78392.38462	77087019.80	2	2
Polygon	3	53805.96436	41754316.11	3	3
Polygon	4	32864.26167	19201871.74	4	4
Polygon	5	66222.72572	44562996.60	5	5
Polygon	6	52694.01530	41361253.37	6	6
Polygon	7	78207.06125	48826121.41	7	7

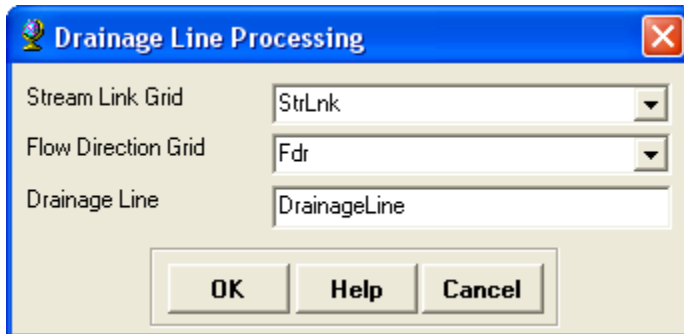
Record: 1 Show: All Selected Records (0 out of 15 Selected)

9. Drainage Line Processing

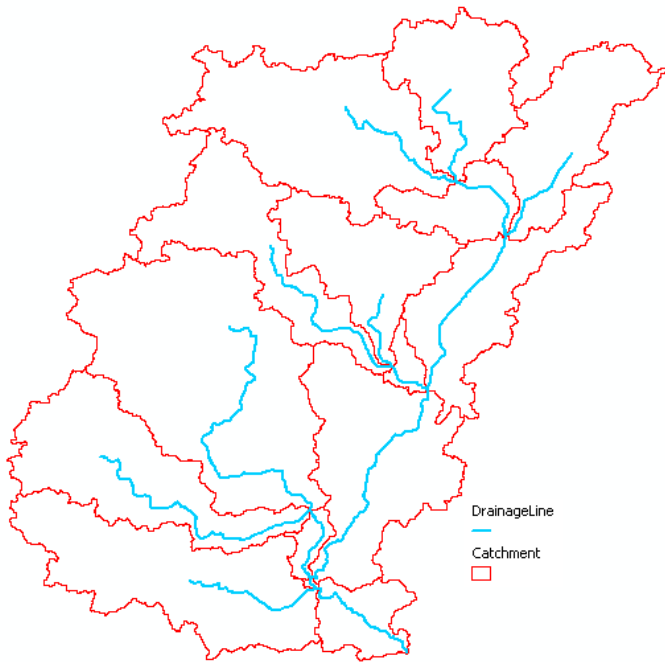
This function converts the input Stream Link grid into a Drainage Line feature class. Each line in the feature class carries the identifier of the catchment in which it resides.

On the ArcHydro toolbar, select *Terrain Preprocessing* → *Drainage Line Processing*.

Confirm that the input to Link Grid is *Lnk* and to Flow Direction Grid *Fdr*. The output Drainage Line has the default name *DrainageLine* that can be overwritten.



Press OK. Upon successful completion of the process, a linear feature class named *DrainageLine* is added to the map.

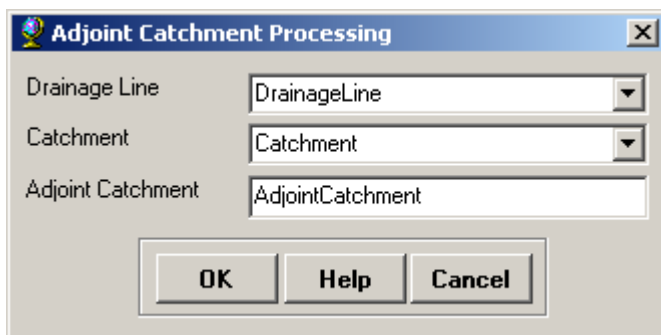


10. Adjoint Catchment Processing

This function generates the aggregated upstream catchments from the *Catchment* feature class. For each catchment that is not a head catchment, a polygon representing the whole upstream area draining to its inlet point is constructed and stored in a feature class that has an *Adjoint Catchment* tag. This feature class is used to speed up the point delineation process.

On the ArcHydro toolbar, **select** *Terrain Preprocessing* → *Adjoint Catchment Processing*.

Confirm inputs for Drainage Line and Catchment are *DrainageLine* and *Catchment*, respectively. Output is Adjoint Catchment, with default name *AdjointCatchment* that can be overwritten.



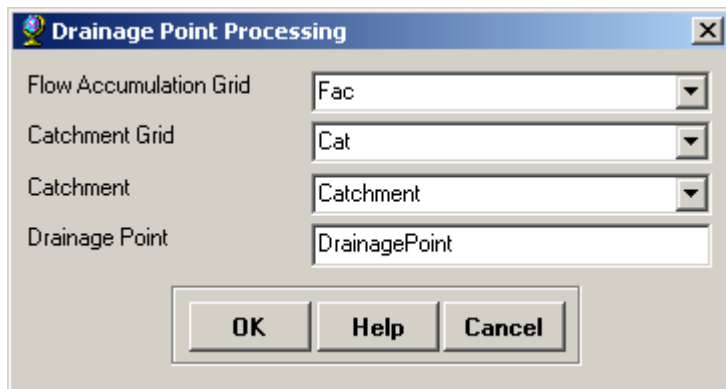
Press OK. Upon successful completion of the process, a polygon feature class named *AdjointCatchment* is added to the map.

11. Drainage Point Processing

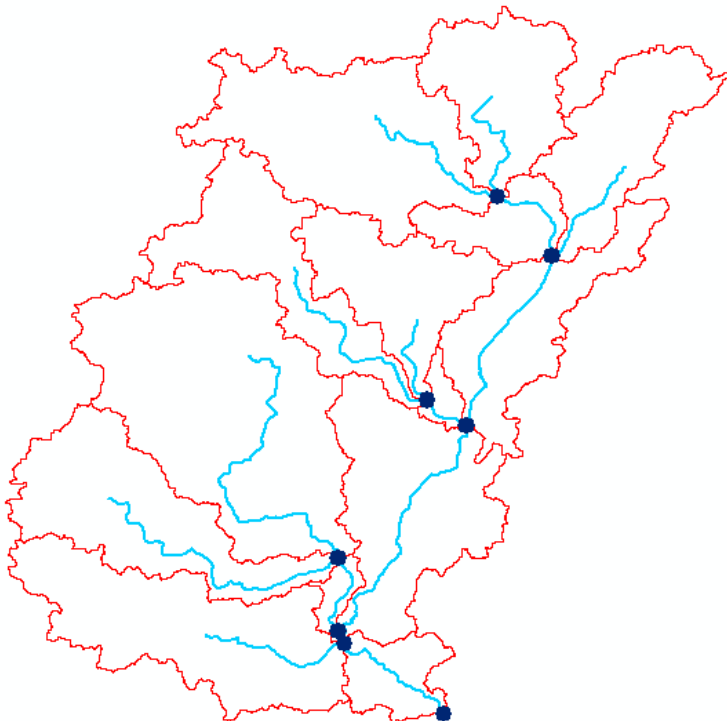
This function allows generating drainage points associated with individual catchment.

On the ArcHydro toolbar, select *Terrain Preprocessing* → *Drainage Point Processing*.

Confirm the inputs as shown below. The output is Drainage Point with default name *DrainagePoint* that can be overwritten.



Press OK. Upon successful completion of the process, a point feature class named “DrainagePoint” is added to the map.





Watershed Processing

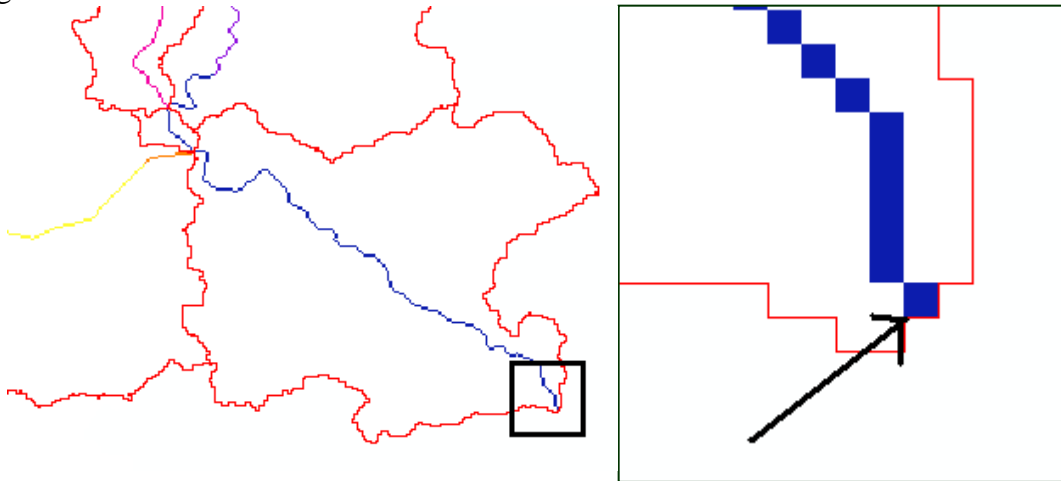
Arc Hydro toolbar also provides an extensive set of tools for delineating watersheds and subwatersheds. These tools rely on the datasets derived during terrain processing. This part of the exercise will expose you to some of the Watershed Processing functionality in Arc Hydro.

1. Batch Watershed Delineation

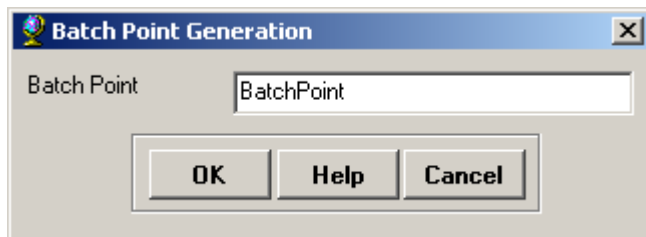
This function delineates the watershed upstream of each point in an input Batch Point feature class.

The Arc Hydro tools Batch Point Generation  can be used to interactively create the Batch Point feature class. We will use this tool to locate the outlet of the watershed. Arrange your display so that Fac, Catchment and DrainageLine datasets are visible. **Zoom-in** near the outlet of the Cedar creek basin (bottom right). The display should look similar to the figure shown below and be zoomed in sufficiently so you can see and click on individual grid cells. Our goal is to create an outlet point on the flow accumulation path indicated by *Fac* grid where the flow leaves

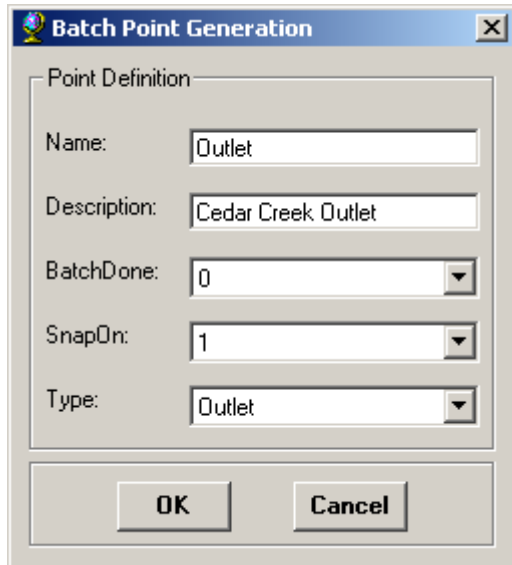
the Cedar creek basin. **Click** on the icon  in the Arc Hydro Tools toolbar. **Click** on the outlet grid cell at the watershed outlet as shown below:



Confirm that the name of the batch point feature class is *BatchPoint*.



A point is then created at the location of mouse click, and the following form is displayed:



Fill in the fields Name and Description - both are string fields. The BatchDone and SnapOn options can be used to turn on (select 1) or off (select 0) the batch processing and stream snapping for that point. **Select** the options shown above. The input information is saved in the attribute table of the BatchPoint feature class. **Click OK**. You should see that a single point feature class has been created comprising an outlet point where you clicked.

When snapping is turned on, if your point is sufficiently near to a drainage line (within around 5 grid cells) then the point will be snapped (i.e. moved) to a nearby drainage line before delineation of the upstream watershed, otherwise the local watershed draining to the point will be delineated.

Note: You can create more points using the same technique at other locations of interest, but for this exercise we will limit our “batch” delineation to only one point (outlet).

To perform a batch watershed delineation

On the Arc Hydro toolbar, **select** *Watershed Processing* → *Batch Watershed Delineation*.



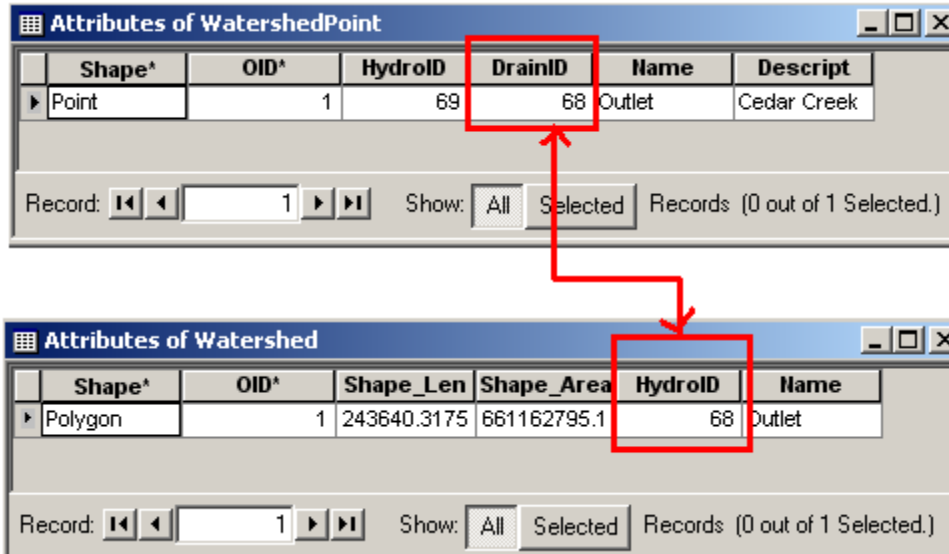
Confirm that *Fdr* is the input to Flow Direction Grid, *Str* to Stream Grid, *Catchment* to Catchment, *AdjointCatchment* to AdjointCatchment, and *BatchPoint* to Batch Point. For output, the Watershed Point is *WatershedPoint*, and Watershed is *Watershed*. *WatershedPoint* and *Watershed* are default names that can be overwritten.

Press OK. You will get a message indicating that 1 point has been processed.

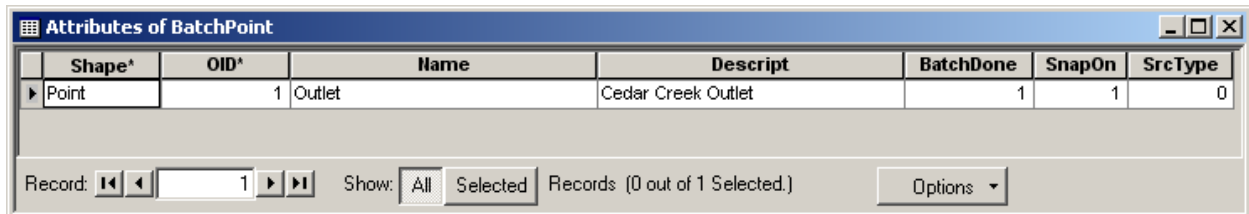
The delineated watersheds for the selected point should correspond closely to the outline of the Cedar creek watershed as shown below (it will match with *cedar_dem*, and all other derived products):



The new watershed is stored in the *Watershed* feature class and another feature class named *WatershedPoint* is also added to the map. **Open** the attribute table of *Watershed* and *WatershedPoint*, and you will see that these two are related through *HydroID* – the *DrainID* of *WatershedPoint* is equal to the *HydroID* of the *watershed*.



You can also **open** the attribute table of *BatchPoint* to see that the value of “BatchDone = 0” that you assigned to this point earlier is now equal to “1”. This tells ArcHydro that the batch processing is done. Due to some reason, if you decide to delineate the watershed for this point again, make sure BatchDone is **set** to “0”, or else ArcHydro will skip this point.



Delineating Watersheds for existing points (eg. USGS gaging sites)

If you have an existing shapefile or feature class with a set of points that you would like to use instead of interactively creating points, you can do so by using the following guidelines:

- Make sure the points are close enough (within snapping distance) to the corresponding drainage line features so that they can be snapped before delineating watersheds.
- Create two new fields (if already do not exist) in your point shapefile or feature class named BatchDone and SnapOn. Both are Integer type (you can check the field properties of BatchPoint). Also, you can create other fields such as Name, Description, etc. that exist in BatchPoint, but these fields are not used in the delineation process.


- Make sure all points have “BatchDone” = 0 and “SnapOn” = 1. This will tell ArcHydro that the watersheds for these points are not delineated and the program can snap these points to nearest drainage lines before delineating watersheds.
- Go to Watershed Processing→Batch Watershed Delineation, and make sure you specify the shapefile/feature class that has the batch points for the Batch Point drop-down box (by default the program will use BatchPoint feature class).


Notes:

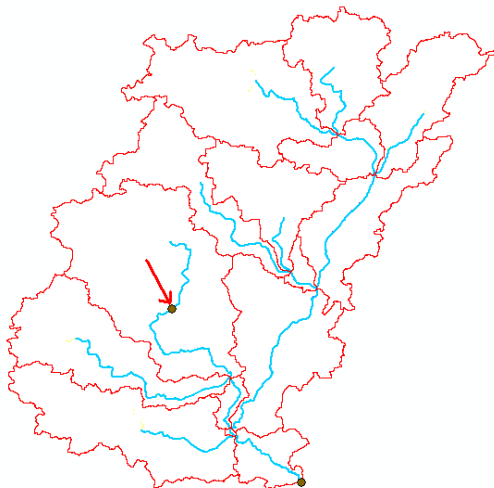
- Another way to delineate watersheds for existing points is to just load/append these points to the BatchPoint feature class. However, if you want to distinguish your points (for whatever reason) from the default BatchPoint, it is better to just keep them in separate feature class.
- The WatershedPoints that are created as a result of batch watershed delineation will not have any attributes from the USGS gages or any other point feature class that you used in delineating the watersheds. If you want to associate the watershed points with attributes from your point features, you will need to use join and relates or other ways of linking these attributes to watershedpoints. This discussion is beyond the scope of this exercise.

2. Interactive Point Delineation

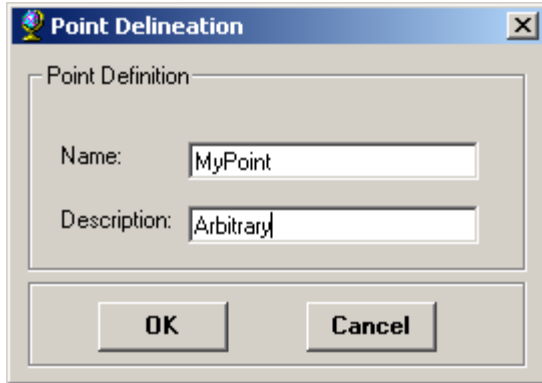
An alternative to delineate watersheds when you do not want to use the batch mode (process a group of points simultaneously) to generate the watershed for a single point of interest is the

Point Delineation tool .

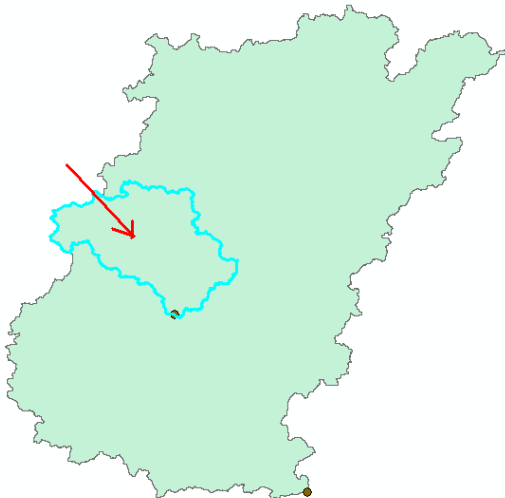
Click on the Point Delineation icon  in the ArcHydro toolbar to activate the tool. **Zoom-in** to the network and **click** the mouse (along the drainage line) to create your point of interest.



Fill-in the name and comment as shown below in the form below.



The new point will be added to the *WatershedPoint* feature class, and the new Watershed will be added to the *Watershed* feature class.




3. Batch Subwatershed Delineation

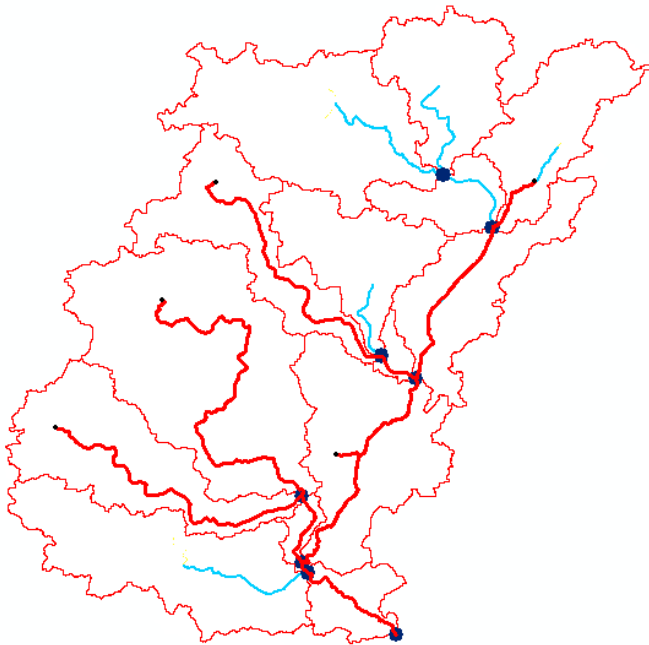
This function delineates subwatersheds for all the points in a selected Point Feature Class. Input to the batch subwatershed delineation function is a point feature class with point locations of interest. In this context a watershed, such as was delineated above is the entire area upstream of a point, while a subwatershed is the area that drains directly to a point of interest excluding any area that is part of another subwatershed. Subwatersheds delineated from a set of points are therefore by definition non-overlapping because the watershed draining to a point that is within another watershed is excluded from the subwatershed of the downstream point. On the other hand, watersheds may overlap (For example, the two watersheds in the Watershed feature class overlap with each other). To use the same points that were used for watershed delineation to delineate sub-watersheds, you need to open the attribute table of the points and use the field calculator to set `BatchDone = 0` (this will tell Arc Hydro that sub-watersheds are not delineated for these points). To **perform sub-watershed delineation**, you should use *Watershed Processing* → *Batch Subwatershed Delineation* option in the ArcHydro toolbar.

4. Flow Path Tracing

The flow path defines the path of flow from the selected point to the outlet of the catchment following the steepest descent. You can use this option to trace the flow path (the path along with water will flow to the outlet) for any point in the watershed. **Click** on *the Flow Path*

Tracing icon  in the ArcHydro toolbar to activate the tool.

Click your mouse at any point to determine the flow path. If you select a point along the stream network, the flow path will follow the exact path of the stream.



OK. You are done!