Conservation Applications of LiDAR

Field-Scale Watershed Analysis

A Supplemental Exercise for the Hydrologic Applications Module

Andy Jenks, University of Minnesota Department of Forest Resources

2013

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Introduction

What You'll Learn:

Basic watershed analysis functions appropriate for field-scale application.

This lesson uses detailed LiDAR derived elevation data to examine watersheds or catchments that may exist within a single or several small fields.

This lesson focuses on small areas within fields to demonstrate the basic concepts. Using these techniques on larger areas will require hydrologic conditioning to add human conveyances (i.e. culverts) not revealed with LiDAR technology. (For more on hydrologic conditioning, see the "Hydrologic Applications" module at z.umn.edu/lidarmaterials.)

This lesson provides step-by-step details for some of the automated Python scripts created by Peter Mead for the NRCS. (For more information, see "Hydrology and Terrain Analysis Tools for Using LiDAR Data" at http://www.mngeo.state.mn.us/chouse/elevation/lidar.html)

What You'll Produce:

Various hydrologic surfaces, a watershed map, a hillshade, and profiles.

Data

Data for the exercise are located in the \A_Farmer subdirectory, all in NAD83 UTM zone 15 coordinates, meters, including DEM01 – a raster elevation grid with 1m cell size and Z units in meters created from LiDAR measurements by the MN DNR. Derived feet contours at several intervals are also included. A shape file called Area_of_Interest is also used in this lesson.

Background

Elevation data, also known as terrain data, are important for many kinds of analysis, and are available from various sources in many forms and resolutions. In the U.S. there have long been available nearly nationwide data at 30 m resolution. Since the early 2000's these have largely been replaced by 10 m resolution DEMs, and now many parts of the country are developing higher resolution DEMs – 1 to 3 meters – based on LiDAR data collections.

Although the most common use of DEMs is as shaded relief background for maps, we often are interested in working with terrain data – calculating slopes, aspects, steepness or slope along profiles, viewsheds, as well as watershed and other hydrologic functions.

In the first part of this exercise, we will prepare ArcMap and data layers for analysis. In the second part, we will perform watershed analysis with a 1 meter data set from LiDAR data collected about 2012. We then use the LiDAR DEM to explore profile tools.

Part 1: Setup and preparing data layers for processing

1. Start ArcMap.

2. Add the following layers to your Table of Contents:

   A_Farmer\Imagery\ortho_1-1_1n_S_mr067_2010_1.sid

   A_Farmer\3526-30-36.gdb\3526-30-36.gdb\DEM01

   A_Farmer\Area_of_Interest.shp

   These layers were chosen for this lesson however you can substitute any area within Minnesota. Download the desired GeoDatabase and image from the following FTP locations:

   ftp://ftp.lmic.state.mn.us/pub/data/elevation/lidar/

   ftp://ftp.lmic.state.mn.us/pub/data/remote_sensing/naip/2010/

   Note: If you use another location you will have to also create an area of interest polygon layer.

3. Use ArcCatalog to create an empty File GeoDatabase. Select a directory, right click, selecting **NEW** then **File GeoDatabase**. For this exercise name the File GeoDatabase, *A_Farmer_Study*.
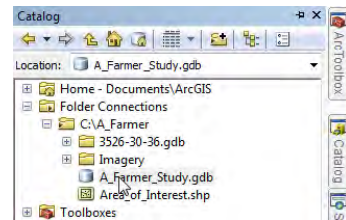
4. Create a Feature Dataset within the *A_Farmer_Study* GeoDatabase. Select the newly created *A_Farmer_Study* and right click, select **NEW** and select **Feature Dataset**. Name the dataset *Vector_Layers*. Select the coordinate system from the Layers. Click **Next** and then **Finish**, selecting the defaults for the second and third screens.

Select the *Vector_Layers* in ArcCatalog right click and select NEW then select Feature Class. Name the Feature Class *Outlet*, select the type Point Features then select Next, Next, and

Finish.

Your GeoDatabase should appear as shown to the right.
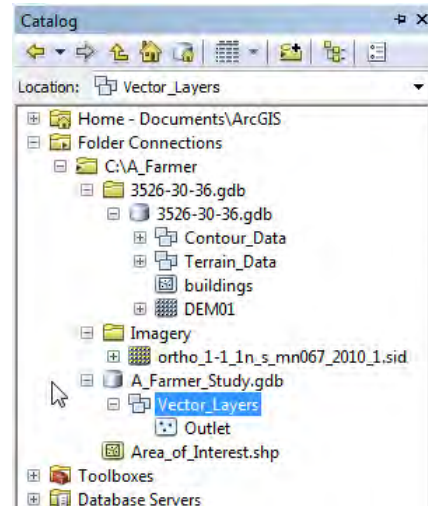
5. Next select your area of interest. For this lesson we have preselected an area. Select the *Area_of_Interest* layer and change the properties of the polygon to "hollow" and the outline color to red.

Select **File** at the main menu (upper left) and select **Map Document Properties**. Change the Default GeoDatabase to your newly created *A_Farmer_Study.gdb* and check the box labeled "Store relative pathnames to data sources". Select **Apply, OK**.
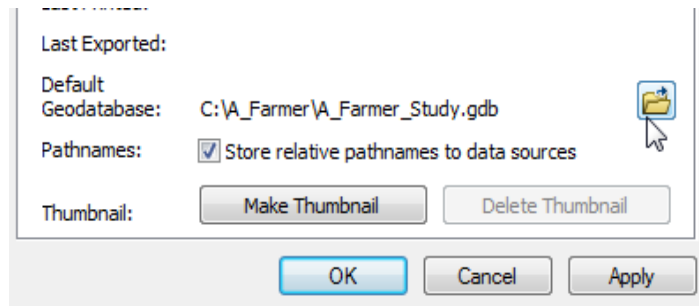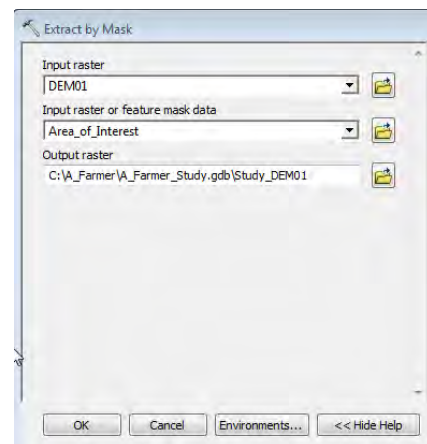
Your ArcMap should appear as below:
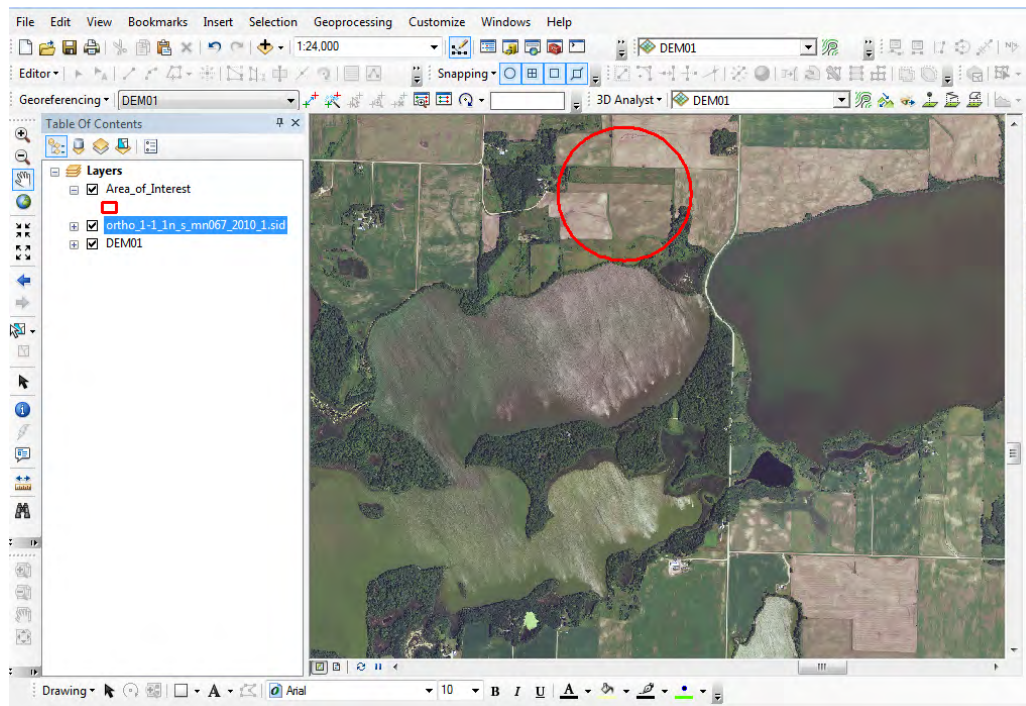
The field area we will be exploring is included in the circle. *To analyze other fields you will have to create/digitize new polygons for your areas of interest.*

Open **ArcToolbox→Spatial Analyst Tools→ Extraction** and select **Extract by Mask**. As shown select the *DEM01* as input and feature mask as Area_of_Interest. Name the output *Study_DEM01*. Select **OK.**

Your ArcMap should now appear as below:
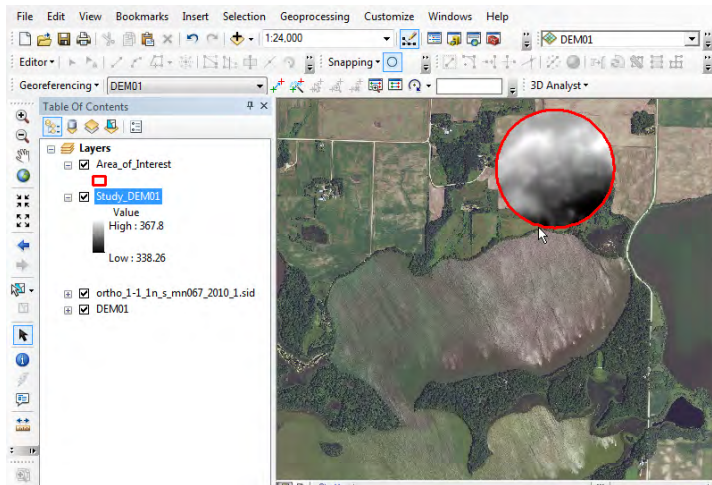
Now, you have created a subset of the rather large LiDAR-derived 1 meter resolution DEM so it only includes the small area of the fields you wish to study.

6. We will now use the fill command to fill pits in the *Study_DEM01*. Pits are local depressions along which a stream would be expected to flow. These depressions may be real, or they may be due to errors in the data. However, a DEM is a representation of a waterless terrain surface, (the flow algorithms used here are programmed on this basis). So, local pits or flat areas may "trap" our route-finding when we are trying to identify downhill directions. The simplest of watershed processing routines begins by filling the pits. More sophisticated ones may fill the pits, and "burn in" a stream line, along which the DEM is lowered after filling to maintain a downstream flow.

Apply the **Fill** tool from the **Hydrology** toolbox. Specify the *Study_DEM01* as input, and something like *Fill_Study_D1* for the output name. Don't bother with the Z limit, here and in the subsequent tasks, and click on OK to run the tool.
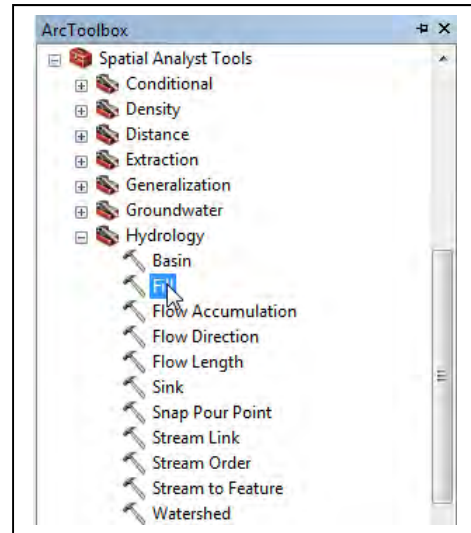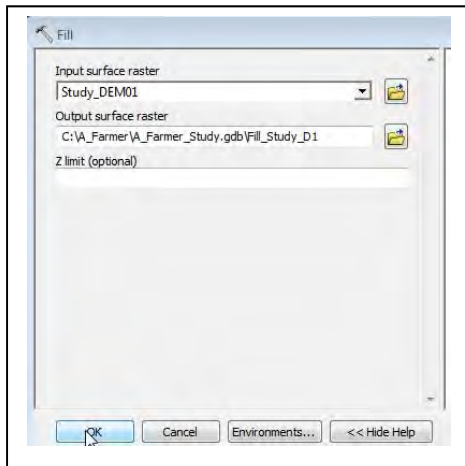
After a minute, the filled data set should be automatically added to your view. Use **Arc Toolbox→Spatial Analyst Tools→ Math→ Minus** to subtract the *Fill_Study_D1* (Input raster 1) from the *Study_DEM01* (Input raster 2), name the output layer *Difference*. Zoom to the displayed results. In Symbology, change Display Background Value to "No Color". Make sure all the other DEM's are unchecked in the Table of Contents. Notice the location and range of the fills; it should look something like shown on the right.

These are the areas that were filled. You should notice that values of the *Difference* layer to be 0 to .850006 meters. This is within the range of the error from the original LiDAR derived DEM. If these values were much higher we should adjust the optional Z limit on the Fill command.

To keep the ArcMap uncluttered remove the *Difference* and the *DEM01* layers from the Table of Contents. We will analyze the filled DEM (Fill_Study_D1) in Part 2 of the exercise.

Part 2: Analysis and Processing

Overview

The products of this exercise will be a delineated watershed, approximate flow path, and watershed outlet within the area of interest.

We will be applying the **Arc Toolbox→Spatial Analysis Tools→ Hydrology** tools in the following order (The order is important):

1. Flow Direction
2. Flow Accumulation
3. Establish a Stream Threshold with Arc Toolbox→Spatial Analysis Tools→ Reclass→Reclassify,)
4. **Snap Pour Point** (after editing the point feature Outlet to place the outlet/drain at the lowest part of the stream network)
5. Watershed

Detailed Instructions

1. First, determine the direction of water flow from each cell in the DEM raster.

Apply the **Flow Direction** tool, using the *Fill_Study_D1* as your input, and specifying a flow direction output data layer; name the output *f_direction*. Check the box "Force all edge cells to flow outward".
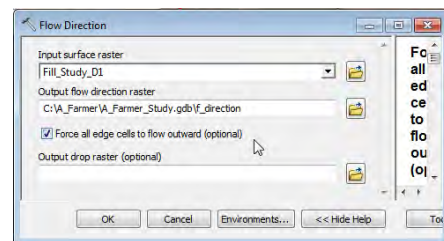
This flow direction layer will contain a direction coding, with a set of numbers that define the cardinal and sub-cardinal direction, something like the figure to the right. The number 1 in a cell means water flows due east, 128 indicates northeast, 64 water flows north, and so on. This is a discreet categorization, all the water flows from a cell to an adjacent cell in only one of 8 directions. This method is known as the D8 flow direction, to distinguish it from methods that can send a portion of the water from a cell to multiple neighboring cells.
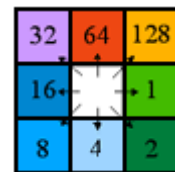
Your output from the flow direction tool should look something like the figure to the right, and the symbols should show 8 values from 1 to 128, corresponding to flow direction.
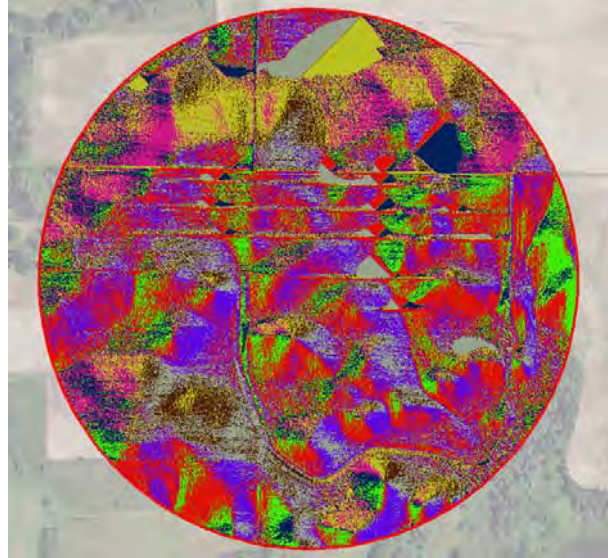
2. Next, determine accumulation of flow across the DEM raster by applying the **Flow Accumulation** tool from ArcToolbox. This finds the highest points, and accumulates the area (or number of cells) downhill, according to the flow direction.

Specify the input as *f_direction*, name the flow accumulation raster as *f_accum*, ignore the weight raster, and specify an output data type of Float.
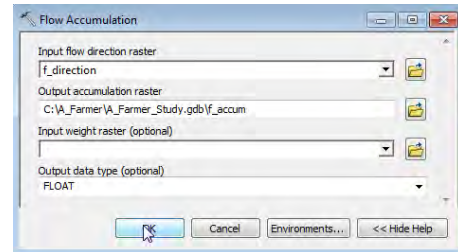
This should generate a display similar to the graphic at right. If you look closely, you will see some narrow, perhaps intermittent white lines in a dark background.

Notice the maximum and minimum value for the data layer; they will be something like 257,909 and 0. These are the number of cells that drain to any given cell. For example, a cell with a value of 12,847 receives water from that many cells.

3. Reclassify data to show stream path

In any given small region and geology, there is usually a rough correspondence between drainage area, here measured with flow accumulation, and stream initiation. For example, once a drainage area of 10,000 square meters is reached, a pronounced surface flow may form. Since the LiDAR derive layer has cells that are 1 m by 1 m, each cell counts for 1 square meter. So if we symbolize the flow accumulation layer so all cells above 10,000 are blue, and all equal or below are no color, we will get an approximate idea of where the streams will be found. (This threshold is made for this exercise, but is probably not too far off. It is important to realize this threshold varies with terrain and should be determined for each situation).

You may apply the symbolization by reclassifying the flow accumulation layer into two classes, and setting the lower threshold to 10,000, the upper threshold to the maximum value.
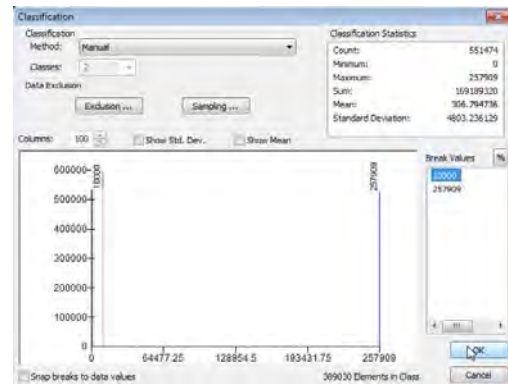
Spatial Analyst Tools→Reclass→Reclassify,
Classify, use NoData for the under 10,000 values and 1 for above 10,000, name the output, *d_streams*
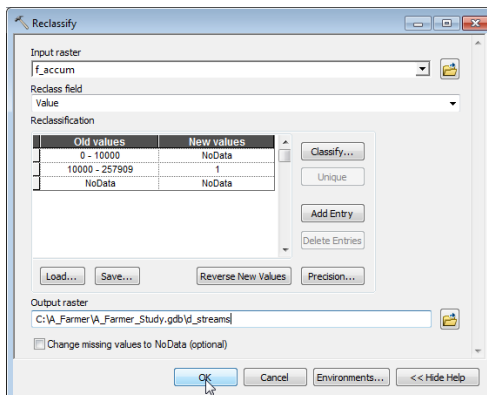
A useful but optional step at this point is to convert the raster d_streams to a polygon layer. This will be useful in our final step when we want to clearly see the possible stream channels. Use Spatial Analyst Tools→Hydrology →Streams to Feature. Name the output *streams_vector.*
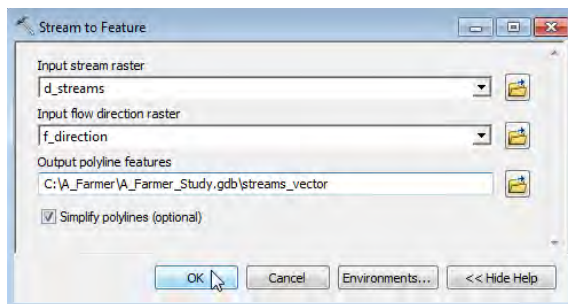
4. Now we must digitize a watershed outlet point.

Add the new empty *outlet* layer you created earlier, make it the active editing target, and display the DEM with the recolored flow accumulation grid over it.

Zoom into the southeast quadrant, so that your view looks similar to that at right. Digitize a point near the location shown below, along the stream near the outlet to the largest watershed in the DEM.

Remember, the figure at the right is zoomed to about ¼ of the DEM extent. You'll want to zoom in much closer to digitize the point, so you can place it near the center of one of the stream cells.
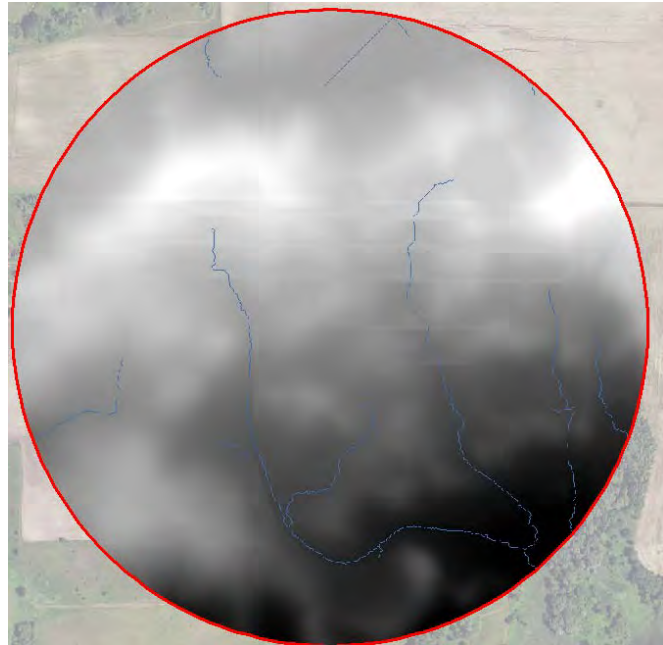
A zoom something like that shown here is more appropriate.

Start Editing, add your point, then save your edits and stop editing.

Now apply the **Hydrology→Snap Pour Point** tool with the following information:

- Specify *Outlet* as your input raster or feature pour point dataset,
- any pour point field, (OBJECTID is fine)
- the flow accumulation raster you created earlier, *f_accum*
- a new output raster to contain your raster pour point, name it *r_pour_pt*
- An appropriate snap distance, something like about 3 cells.
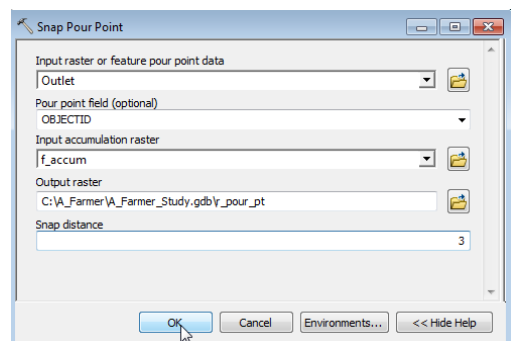
This should create a raster with a single cell for a value, near your digitized outlet.

5. Now, run the **Hydrology→Watershed** tool, specifying your flow direction raster (*f_direction*), your just created raster pour point layer (*r_pour_pt*), leaving the pour point field as Value, and specifying an appropriately-named output watershed, like *watershed*.
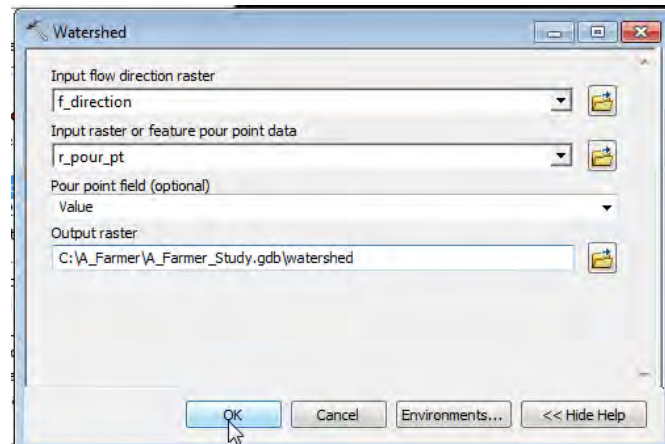
This should create a watershed layer something like the image shown below. Change the color, and make the raster 50% transparent.

Add the streams_vector to better display the flow paths.

6. To add a hillshade effect:

Arc Toolbox→Spatial Analyst Tools→Surface Analysis – Hillshade, specify 25 for the Altitude and model shadows. Name the output file something like *hillshade25*.

Make the hillshade semi-transparent (**Layer Properties→ Display**, set at 50%). You should get a display that looks approximately like the graphic below.
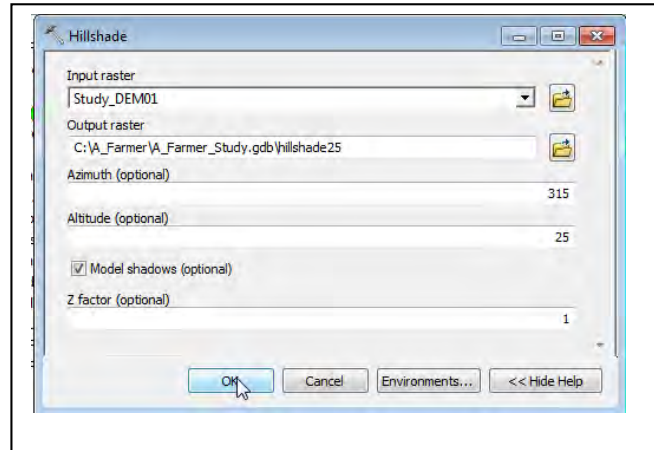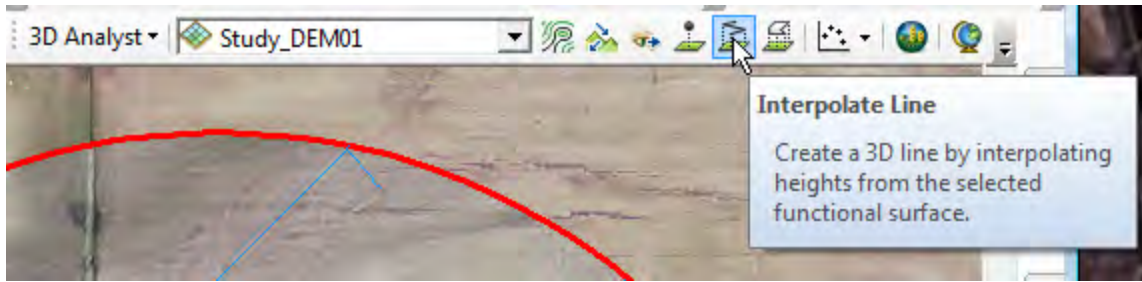

7. To examine a profile of a particular location on the image, use 3D Profile.

Turn on the 3-D Analyst extension:

Customize→Extensions, then check 3D Analyst, then **Customize→Toolbars→** and also check 3D Analyst.

This displays a set of off tools, including the icons below.

Use the Interpolate Line tool to draw a line perpendicular to the stream.

Then select the Profile Graph tool to show a cross-section of the field along the drawn line crossing the stream. Right click on the Profile Graph and select Properties to change the title and footer.
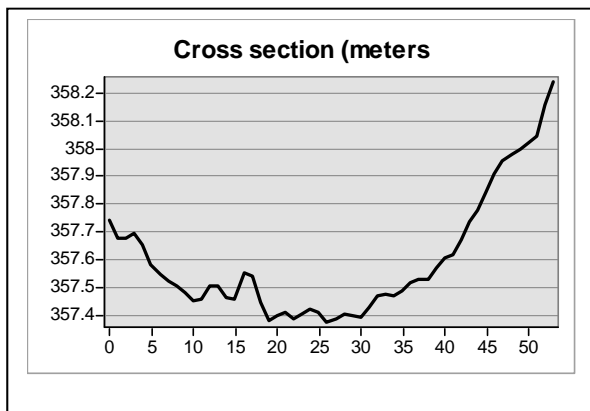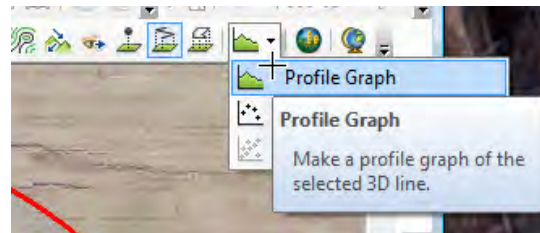
You may choose to draw several cross-sections.

8. Convert the watershed raster to a polygon and calculate the area.

Use **Arc Toolbox→ Conversion Tools→From Raster→ Raster to Polygon** to convert *watershed* raster layer to a polygon layer named *watershed_polygon*.

Open the attribute table for the *watershed_polygon* layer. Select the **Add Field**, call it ACRES, type float. Right click on the column heading ACRES, use **Calculate Geometry** to measure the area into acres. It should be 63.72661 acres.

9. Finally you may wish to display the most detailed contours delivered with the elevation data. They are found in the 3526-30-36.gdb in the Contour_Data Feature Dataset, titled *Contours*.

In the image below the contours are have been clipped to the *Area_of_Interest* and a simplified version of the Contour labels are turned on in the **Contour→ Properties→Labels**. The background photo is set at a 50% transparency.