EXERCISE 10: DERIVING STREAM NETWORKS FROM A LIDAR DTM
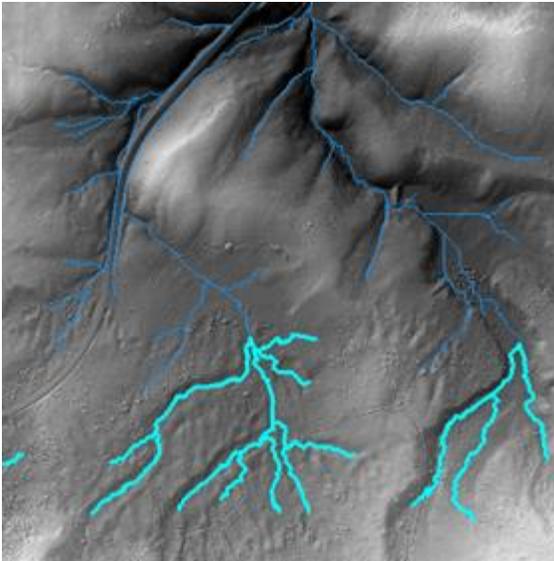
Surface water runoff profile created from ground filtered LIDAR data.

Introduction

This exercise is designed to provide you with ideas and examples for uses of LIDAR technology. Here, we will use the Spatial Analyst Hydrology tools to derive streams from our surface grid that will be attributed with stream order and flow length. We'll do all of this **only using one input**, the LIDAR ground surface grid from Exercise 9!

Required Data

- **lub_surfgrid, lub_hlshd** (from Exercise 9)

Prerequisites

- Successful completion of Exercise 9

Overview of Major Steps

I.   Set New Data Frame and Output Location
II.   Filling Peaks & Holes in a Ground Surface DTM
III. Create Flow Direction & Flow Accumulation Grids
IV.   Derive Stream Corridors
V.   Derive Flow Length and Stream Order
VI.   Create a Final Stream Shapefile from a Shreve-ordered Stream Grid

Procedure

In the last exercise you processed LIDAR data to create subsets of various data (Tree Height Canopy, Surface, Plots, etc.). These data were imported into ArcGIS with the ground surface subsequently used to derive slope, aspect, and curvature of our study area. Now we will begin to look at the shape of the land surface and relate it to surface water runoff, using some embedded tools in ArcGIS. Eventually, we will create (or 'derive') actual stream corridors using our LIDAR surface DTM.

I.) Set New Data Frame & Output Location

Before we fill sinks in our DTM surface, we will set up a new Data Frame in ArcMap and copy the surface grid to our new Data Frame, then set our output to a working directory.

1. Open **Surfrun.mxd** (the ArcMap document created in the last exercise). We will add additional datasets to this document.
2. Right click on **Layers** in the ArcMap table of contents, and select **Properties**.
3. On the **General** tab, rename the Layer group to **LIDAR Surfaces**. Click **OK**.
4. Click on **Insert | Data Frame**, right click on the new data frame and select **Properties**. Call this data frame **Surface Runoff**.

We will copy the following data from **LIDAR Surfaces** to **Surface Runoff**: **lub_surfgrid** & **lub_hlshd**.

5. Highlight both datasets by holding down the **Shift** key and clicking on each with your mouse cursor. Right click on one of the datasets while both are highlighted and select **Copy**.
6. Right click on your new data frame, **Surface Runoff** and select **Paste Layers**. You will see both layers added to your new data frame.
7. To set your working directory, right click the Windows **Start** button and select **Explore**.
8. Navigate to a desired location and create a new folder for output, by clicking **File | New | New Folder**.
9. You may give the folder any name but we suggest making it relevant (like "Exercise-10").
10. Next, click on the **Spatial Analyst** toolbar (on the ArcMap main toolbar), and select **Options**.
11. On the **General** tab, set the **Working Directory** to your new folder. You may navigate by clicking the folder icon.

Now you are ready to Fill any sinks in your LIDAR ground surface DTM....

II.) Filling Peaks & Sinks in a Ground Surface DTM

It is common to have anomalies (sinks and peaks) in digital terrain models—some of these are real and some are due to processing errors. It is essential to remove these anomalies (even the real sinks and peaks) in DTM files prior to deriving watershed characteristics so that your derived data will exhibit accurate behavior (e.g. all the streams flow in a downhill direction).

Direction Coding

The **Flow Direction utility** is a roving window that looks at the eight neighboring cells of each input cell and determines which of those eight is the lowest. It then assigns the direction value (1, 2, 4, 8, 16, 32, 64, or 128) of the lowest cell to the corresponding output cell. However, if the lowest cell is above the center cell or if there are more than one "lowest" cells, the output cell is assigned a value that does not correspond to any of the eight cardinal directions—these are the sinks that must be repaired...
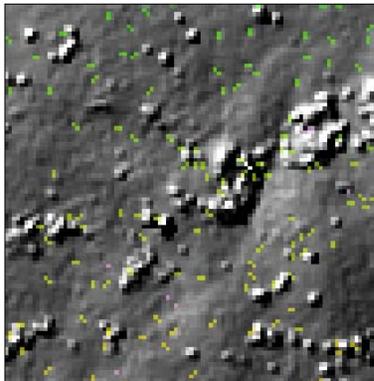
Sinks *are indicated by the colored cells. These are removed using the Fill Tool.*

Let's begin by looking at the sinks in our lidar-derived surface...
1. Open the Arc Toolbox from the ArcMap main menu, by clicking the Toolbox icon.
2. Find the **Spatial Analyst** toolbox and expand it by clicking the **+** button next to the name.
3. Double click the **Flow Direction** tool in the **Hydrology** toolbox
    4. Set the input surface raster to **lub_surfgrid** (the lidar-derived surface grid)
    5. Navigate to your output directory and call the output flow direction raster **temp_flowdir**
    6. Click **OK**. Your results will be automatically added to your ArcMap document (see description of the Flow Direction output in the sidebar).
7. Double click the **Sinks** tool (in the **Hydrology** toolbox)
    8. Set the input flow direction raster to **temp_flowdir**
    9. Call the output raster **Sinks**
    10. Click **OK**
11. When **Sinks** automatically loads into your ArcMap document, deactivate all other data sets by unchecking the box by each name—except for the hillshade (**lub_hlshd**).
12. Observe the sinks displayed over the hillshade image. Now, you'll repair those sinks...
13. Double-click the **Fill** tool (in the **Hydrology** toolbox)
    14. Set the input surface raster to **lub_surfgrid**
    15. Call the output surface raster **lub_fil**
    16. Click **OK**.

When **lub_fil** automatically displays, you'll notice it looks no different than **lub_surfgrid** but you'll see in a moment that the sinks have been filled...

III.) Create Flow Direction & Flow Accumulation Grids

Flow direction is a crucial layer necessary for deriving watershed characteristics. In the previous section, you created a flawed Flow Direction surface (**temp_flowdir**) which was used to identify the sinks. Now, we'll create a useable Flow Direction surface from the filled surface model...
1. Double click the **Flow Direction** tool
    2. Enter **lub_fil** as the input surface raster
    3. Call the output flow direction raster **lub_fldir**
    4. Call the optional output drop raster **lub_drop** (*or leave this option blank*).
    5. Click **OK**.
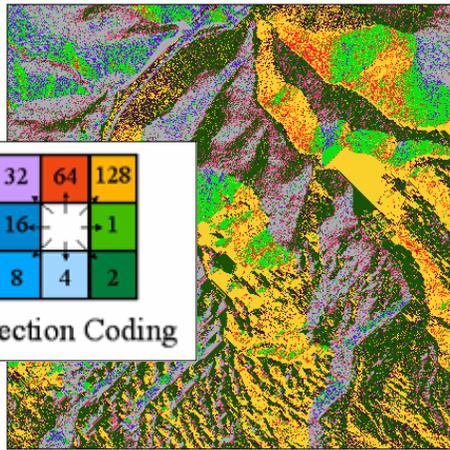
Direction Coding

Flow Direction Raster

There are eight potential flow directions (see Direction Coding above) assigned to each cell in the Flow Direction grid which correspond to specific directions. Surface runoff will always be in the steepest downslope direction.

*The **Flow Accumulation** function calculates accumulated flow as the accumulated weight of all cells flowing into each downslope cell in the output raster and is calculated from the flow directions raster. Flow accumulation is "additive" meaning that if two upstream cells flow into one downstream cell, the downstream cell will hold the sum of the two upstream cells. The flow accumulation numbers increase from the headwaters downstream to the confluence.*

6. Observe your output. Zoom into a location on the flow direction grid. Do the directions make sense? (*use elevation values in the **lub_surfgrid** as a reference*). Note in this case, the output from the Flow Direction utility only has eight values (1, 2, 4, 8, 16, 32, 64, 128). Thus, we can be confident that all of the sinks were filled (there are no intermediate values that indicate sinks). Next, let's calculate flow accumulation values to help determine which cells are along stream corridors...

7. To create a flow accumulation grid double click the **Flow Accumulation** tool

8. Set the input flow direction raster to **lub_fldir** (our valid flow direction grid created in the last step)

9. Call the output flow accumulation raster **lub_accum**

10. Click **OK**

11. The output raster should automatically load into your ArcMap document (see description in sidebar).

12. Right click on **lub_accum** and select **Properties**.

13. On the **Symbology** tab, set the color ramp to range from **Cyan** to **Hot Pink**, click **OK**. This will accentuate the flow accumulation grid cells so that they are more easily seen.

14. Zoom in to some of the accumulation grid cells using ArcMap's Zoom-In tool on the main toolbar. Since the flow of water accumulates in a downslope direction, you may observe that flow accumulation grid cells are faint in tributaries of upstream cells (cyan = low values).

15. Zoom into a "stream" segment of grid cells and query the cells along an accumulation corridor using the ArcMap query tool. Remember, accumulation is additive in a downstream direction—do your grid cells show this?
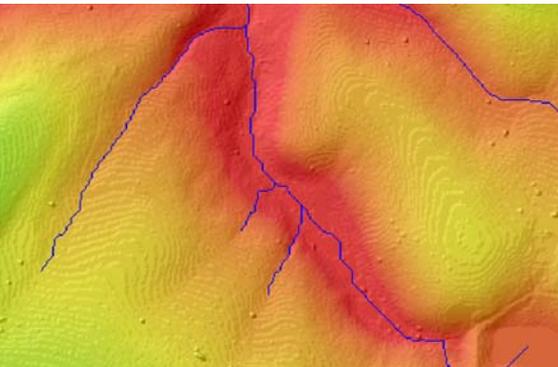
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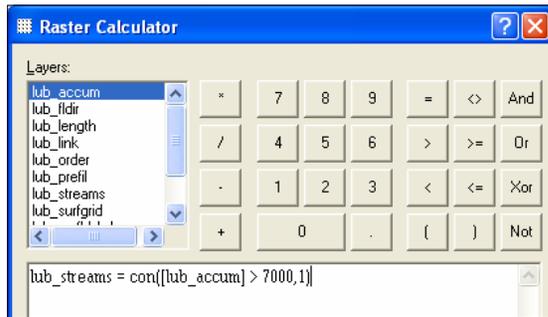
Note: Make sure that you follow this syntax EXACTLY, the raster calculator can be picky if you miss a bracket] or a parentheses). To help you avoid syntax typos, you can double click names, symbols, and numbers from the listed datasets, and keys provided.

*A portion of **lub_streams** (blue) displayed over the hill-shaded **lub_surfgrid** raster layer. The **lub_streams** layer was extracted from all cells in the **lub_accum** layer with a flow accumulation value of greater than 7000.*

IV.) Derive Stream Corridors

Not every pathway in a DTM is a true stream. In order for a stream to exist (at least by Hydrological standards) it must meet specific criteria. In our case, we will set an arbitrary one: in order for a stream to exist, it must have an accumulation values (*from **lub_accum***) in every cell along the pathway greater than 7000. We will run a quick calculation in the **Raster Calculator** to derive our streams from our flow accumulation grid.

1. On the ArcMap main toolbar, click on **Spatial Analyst | Options**, and set the Working Directory to the output location for this exercise (e.g. where you are currently sending all other output). Click **OK**.
2. Click **Spatial Analyst | Raster Calculator**
3. We will use the **con( )** command to set a threshold value of accumulated cells that define a watershed.
4. Enter the following equation into the Raster Calculator:

lub_streams = con([lub_accum] > 7000,1)

*** See important note on left***

The above command line translates to...."output file = condition(lub_accumulation values > 7000, assign a value of "1") ...where 1 is equal to or synonymous to "TRUE" (where the condition evaluates to true).

The result is a grid representing where streams would transport our threshold flow value of 7000 or greater...and all from a LIDAR surface DTM.

If you display **lub_streams** with **lub_accum** (with lub_accum beneath lub_streams in the ArcMap table of contents) you will see that not every potential stream path was converted into a true stream. Okay, now lets derive a few more datasets that will be used to attribute our streams layer...

V.) Derive Flow Length & Stream Order

Flow length is used to determine the distance along a particular flow path. This may be computed in an UPSTREAM or DOWNSTREAM direction. The flow length measurement is often used to calculate the *time concentration* of a basin, which is a fundamental watershed parameter used to compute peak discharge for a watershed. Time of concentration is the longest time required for a particle to travel from the watershed divide (top of the watershed-upstream) to the watershed outlet (where the watershed drains-downstream). We will compute flow length here:

1. In the **Spatial Analyst | Hydrology** toolbox double click **Flow Length**
    2. Enter **lub_fldir** for the input flow direction raster
    3. Call the output raster **lub_length**
    4. Set the direction of measurement to **UPSTREAM**
    5. Click **OK**.

Observe your results by zooming in on a segment of stream and query the cell values along a stream corridor using the ArcMap query tool.

6. Click on the **Information query tool** and the click on many grid cells representing streams.
    7. Observe that the distance (or length) values increase in a downstream direction.

Mathematically this is useful because it provides a sequential downslope/downstream path of flow which is unavailable with a vector stream shapefile or coverage. Now let's order the stream segments using the *Shreve Method* (Shreve, 1967—*see notes at left*).

8. In the **Spatial Analyst | Hydrology** toolbox, double click **Stream Order**
    9. Enter **lub_stream** as the input stream raster
    10. **lub_fldir** for flow direction
    11. Call the output **lub_shreve** ('shreve' for the methods)
    12. Setting the method to **SHREVE**. Click **OK**.

Observe your results. You have created a number of derived datasets originating with the LIDAR filtered ground points that created our surface DTM. Something to ponder...if performing

Stream Order Methods

STRAHLER - Headwater arcs are assigned an order or 1. When two or more arcs of the same order converge, then the arc downstream of the confluence is assigned an order one greater than that of the upstream arcs.

SHREVE - Headwater arcs are assigned an order of 1. When two or more arcs converge, then the arc downstream of the confluence is assigned an order equal to the sum of the orders of the upstream arcs.

NOTE: For both STRAHLER and SHREVE, when there is divergent flow (i.e. a stream breaks into two or more downstream arcs, e.g. braids and deltas), then the downstream arcs retain the order of the upstream arc. However, if the divergent arcs come back together, then the order of the arc downstream of the convergence will not be increased.

the same tasks with a 10meter DEM, would your results be similar?

VI.) Create a Stream Shapefile from a Shreve-ordered Stream Grid

We will now create a shapefile (vector) output of our Shreve-ordered stream grid. The output shapefile will hold our Shreve ranking but will also have "To" and "From" nodes at each stream junctions (where one stream joins another) linking our watershed network together in a sequential downstream order.

1. In the **Spatial Analyst** toolbox, double click **Stream to Feature**
   2. Enter **lub_shreve** for the input stream raster
   3. Enter **lub_fldir** for the input flow direction raster
   4. Navigate to your output directory and call the output polyline features, **lub_plyln.shp**
   5. Ensure that **Simplify Polylines** is checked
   6. Click **OK**
7. Your output will be automatically loaded into your ArcMap document.
8. Right click on **lub_plyln.shp** and select **Open Attribute Table.**

We will query our streams so that you may observe the tiered stream network you have just created.

9. With the mouse cursor, right click the column heading **TO_NODE** and select **Sort Descending.**
10. We will highlight the upper-most streams in our watershed: With the **Crtl** key depressed, click your mouse cursor to the left of the first record (with the highest **TO_NODE** value) and drag it down until you've selected about 1/3 of the records.
11. Observe the corresponding "top of watershed" streams (graphic on next page) highlighted in your ArcMap view
11. Now, scroll to the bottom of the attribute table using the **scrollbar**
12. Highlight records with **TO_NODE** values of **1** through the **TO_NODE** value that represent the lowest 1/3 (or so) of the watershed.

These are your "bottom of watershed" streams, which will drain the most water since they are

*Click and drag with the **Ctrl** key depressed to highlight many records at*

Attributes of lub_plyln2

FID	Shape'	ARCID	GRID_CODE	FROM_NODE	TO_NODE
69	Polyline	70	1	75	74
71	Polyline	72	1	77	74
67	Polyline	68	1	70	73
70	Polyline	71	1	76	68
72	Polyline	73	1	78	68
64	Polyline	65	1	69	67
73	Polyline	74	1	79	67
63	Polyline	64	1	68	66
74	Polyline	75	1	80	66
66	Polyline	67	1	72	65
75	Polyline	76	1	81	65
61	Polyline	62	1	66	64
62	Polyline	63	1	67	64
68	Polyline	69	1	74	63
76	Polyline	77	1	82	63
52	Polyline	53	1	54	58
56	Polyline	57	1	61	58
53	Polyline	54	1	58	57
59	Polyline	60	1	64	57
58	Polyline	59	1	63	56
65	Polyline	66	1	71	56
51	Polyline	52	1	57	53
60	Polyline	61	1	65	53
49	Polyline	50	1	55	52
57	Polyline	58	1	62	52
46	Polyline	47	1	51	49
50	Polyline	51	1	56	49

Record: |◄ ◄ 0 ► ►| Show: All Selected Records (23 out of 77 Selec

accumulating flow not only from the top of the watershed, but also from their tributaries along the way.

This concludes our exercise, 'Deriving Surface Water Characteristics from a LIDAR DTM. There are many more analysis tools available in Arc to work with watersheds

Ordered Stream Network *Streams at top of watershed selected (left), streams at bottom of watershed selected (right).*