



CALCULATING DERIVATIVE SURFACES FOR TERRAIN ANALYSIS

OUR PURPOSE

GIS Analysts perform *spatial analysis* when they need to derive new data from existing data. In GIS I, for example, you used the vector approach to derive a riparian buffer feature (output polygon) around a river feature (input line).

```
RiparianZone = buffer("River", "100 Feet")
```

GIS Analysts also perform spatial analysis with rasters when they need to derive new surfaces, to rasterize vector data, or to vectorize raster data. We can use the raster approach to derive, for example, a surface of terrain slopes from an input surface of terrain elevations.

```
TerrainSlope = slope("DEM", "degrees")
```

The purpose of this lab is to teach you how to perform **terrain analysis**, which is a type of spatial analysis that relies heavily on a digital elevation model (DEM), and to give you practice interpreting some common **derivative surfaces**.

A **spatial model** is the logic behind a sequence of GIS operations, which acts on one or more input datasets and produces an output dataset. When a spatial model involves multiple GIS operations, then we can use a **cartographic model** (a GIS flowchart) to illustrate the sequences of inputs, tools, intermediate outputs, and final output. In short, we design a cartographic model to show others how to build and run a spatial model correctly.

YOUR LEARNING OBJECTIVES

By the end of this lab you should have learned how to perform terrain analysis and interpret surfaces commonly derived from a DEM. Your work will be conducted in two rounds. During round one, you'll analyze your sand table terrain and develop familiarity with terrain analysis concepts and tools. During round two, you'll use the same spatial model to analyze a 'real' DEM representing the terrain around Oso, Washington, where a landslide occurred in 2014.

SOME BACKGROUND ABOUT OSO, WASHINGTON

The Stillaguamish River drains a portion of the Cascade Range and empties into Washington's Puget Sound. Oso is a town situated along the north fork of the Stillaguamish River, in Snohomish County, and approximately 70 road-miles (1.3 hr drive) northeast of the Seattle-Tacoma International Airport. According to the 2010 Census, the town was home to fewer than 200 people. Landslides have occurred in the Oso area for decades (e.g., 1949, 1951, 1967 and 2006) and the area suffered yet another landslide in 2014, which killed 14 people. For this lab, we're going to analyze the Oso area terrain as it existed in 2013 (before the 2014 landslide).

To better understand the 2013 site and the later 2014 event, it'll help if you watch "[When Nature Strikes - Landslides](#)" (6 min) and "[Anatomy of a Landslide | IN Close](#)" on YouTube (6 min).

METHODS

Round 1: Analyzing your sand table terrain

Visit the course website, download the ZIP archive for Lab 03, and extract its contents into your labs folder. You'll find a folder containing two Esri map documents (*.mxd) and two geodatabases (*.gdb). If you don't have a sand table DEM from Lab 02, then interpolate one from your spatial point sample (from Lab 01). Otherwise, open the **sandTable.mxd** map document.

Surface slope and aspect analyses

Bolstad, 2016: p485-489

Activate the Slope data frame, then add your DEM as a new layer. Slope analysis allows you to calculate the *rate of steepest of descent* for each cell neighborhood in your DEM. So, derive a **Slope** surface from your DEM (Figure 1). When calculating slope, choose 'DEGREE' as the unit of measure.

Next, use layer **Symbology** to adjust your legend properties; reduce the number of decimal places shown from many to 1 decimal place. Remove your DEM layer.

Now add the **makeEstimatesHere** feature class as a layer to your data frame and label them. These points mark locations where we want to estimate slope values.

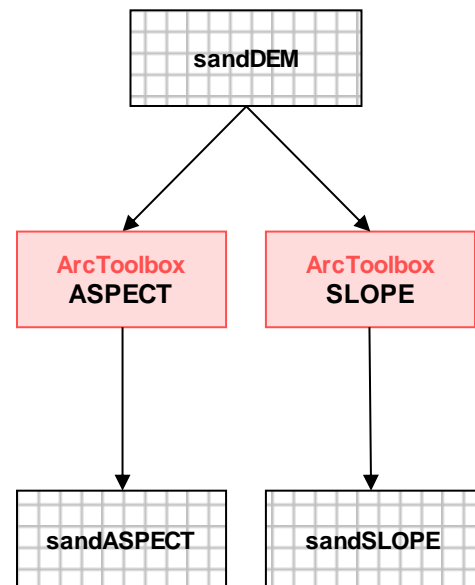


Figure 1. Aspect and slope analyses.

Activate the Aspect data frame then **Add** your DEM as a new layer. Aspect analysis allows you to calculate the *direction of steepest descent* at each cell in your DEM. Derive an **Aspect** surface from your DEM (Figure 1). Remove your DEM layer.

Next, add the **makeEstimatesHere** feature class as a layer to your data frame and label them. These points mark locations where we want to estimate aspect values.

Hillshading (aka shaded relief mapping).

Bolstad, 2016: p505-506 Kimmerling, 2012: 511-517

Hillshading is a technique that estimates the amount of solar illumination at each DEM cell. The tool works by simulating light radiating from a solar position above the DEM and comparing the light incidence angles to the orientation and steepness of the terrain in the cell neighborhood.

A *solar azimuth* is the angular direction of incoming sunlight along the horizon, measured in degrees clockwise from north (from 0° to 359.9°). A solar azimuth of 220° indicates the sun is in the southwestern sky relative to the point of interest.

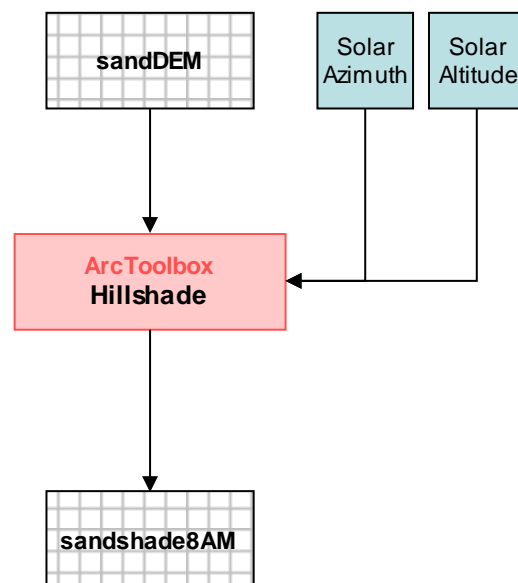


Figure 2. Calculating a hillshade model.

A *solar altitude* (aka solar elevation) is the angular direction of incoming sunlight above the horizon. Solar altitudes are expressed in degrees, from 0° (on the horizon) to 90° (overhead). Together, a solar azimuth and solar altitude describe a solar position.

Use the US Naval Observatory's "Sun or Moon Altitude/Azimuth Table" generator (click the URL below) to find the solar position at Shippensburg, PA, on the date of your birth, at three moments in time (see layout for exact times). Then, derive three **Hillshade** surfaces from your DEM (Figure 2).

<http://aa.usno.navy.mil/data/docs/AltAz.php>

Contour analysis

Bolstad, 2016: p501-504 **Kimmerling, 2012: 103-106**

Activate the `Contours` and `streams` data frame, add your DEM as a new layer. Use the **Contours** tool to generate a set of *intermediate* contours using a 1 cm interval. Next, use the **Contours** tool again to generate *index* contours at 5 cm intervals (Figure 3). Label your index contours with their respective elevations. (For Round 2 and the Oso area, use 20 m and 100 m intervals, respectively.)

Next, select your two contour layers, **Group** them, and adjust the **Symbology** and **Display** properties of each. Last, add the **makeEstimatesHere** point feature class as a layer to your data frame and label your points.

CONTOURS

Index

Intermediate

Supplementary

Depression

Permanent snow and ice

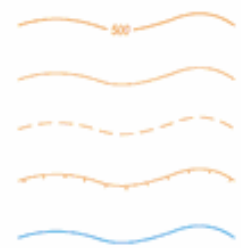


Figure 3. Illustrated examples of depression, supplementary (dashed, thin), intermediate (solid, thin), and index (solid, thick, labeled) contours.

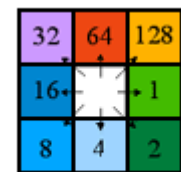
Hydrologic analyses

Bolstad, 2016: p 491 Figure 11-10 and p492-499

Continue working in your `Contours` and `streams` data frame. The next cartographic model (Figure 4) illustrates a workflow that finds stream channels in a DEM. This workflow requires several steps, which create several intermediate rasters and one final vector dataset.

The **Fill** tool creates an output raster that will look very similar to your input DEM, but the output raster will contain small fixes wherever drainage errors were found. The algorithm works by adjusting cell elevations up or down to fill any 'pits' that will trap downhill flow (see Fig11-10 on page 451). When done, remove your input DEM and keep your "sandFILL" raster.

The **Flow Direction** tool uses a 3x3 moving window to compare the elevation in a cell against the elevations in its eight neighbors and determines which of the eight neighbors will receive downhill flow (which is why the Flow Direction algorithm is commonly called the D8 algorithm). The **Flow Direction** tool creates a new integer raster containing integer codes between 1 and 128 (which indicate aspect but are not measures of aspect). Use the **Help** menu and follow the link "How Flow Direction Works" to learn what each output value represents (you'll see the diagram shown in Figure 4).



Direction coding

Figure 4. D8 flow direction coding.

The **Flow Accumulation** tool ingests a surface of D8 flow direction codes and, for each output cell, finds the number of upstream cells that contribute flow to it. Output raster cells holding large accumulation values can indicate stream channels; small values can indicate topographic highs or ridges. *Learn to read this surface by symbolizing it with only two classes/colors, and iteratively moving the class break up and down.*

The **SetNull** tool is used to test the values in an input raster. Cell values that pass the test are assigned the “NoData” value in the output raster; the other cells are given a number. In this case, it is your job to choose a flow accumulation threshold (“Value” <= ???) that lets you find low ‘not a stream’ accumulations (cells in the output that should be set to “NoData”) vs. high ‘probably a stream’ accumulations (in this case, cells in the output raster should receive the value, 1). *Use the Help menu if you need ... help.*

The **Stream to Feature** tool does just what its name implies. It will read your stream raster (containing only 1s and NODATA values) and your flow direction raster to produce vector streams. Remove all raster layer. Keep only your vectorized streams and contours.

Next, use the **Extract Multi Values to Points** tool (not shown in Figure 5) to extract values from your elevation, aspect, slope, flow direction, and flow accumulation surfaces simultaneously. This tool will find the cell under each point, extract, the value, and add the value to the point attribute table. Check your point attribute table for your results.

Last, tidy your layout and edit your text boxes. Save and print your map on 11” x 17” paper.

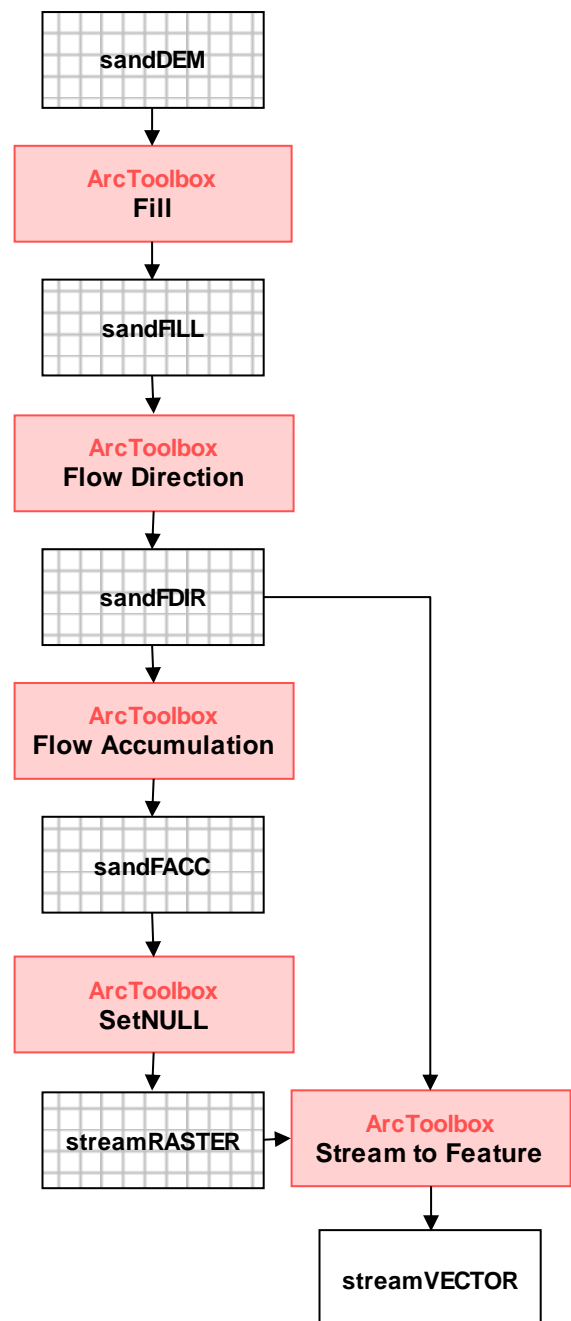


Figure 5. Finding stream channels.

Table EX. Results of your sand table terrain analyses.

Label	Elevation (unit)	Aspect (unit)	Slope (unit)	Flow direction (coded value)	Flow accumulation (unit)
A					
...					
Z					

QUESTIONS ABOUT YOUR SAND TABLE TERRAIN:

- Question 1.** Build a table to report your date, time, and solar position values
- Question 2.** Build a second table (see Table EX above) to present your terrain analysis results. Be sure to report your units of measure.

Round 2: Analyzing the terrain around Oso, Washington

Open the **OsoWashington.mxd** map document and follow the same cartographic models shown above (Figures 1-4) to analyze the terrain in the Oso area. The only differences are:

1. When using the NAVY website to find solar positions, specify March 22, 2014 for Arlington, WA, which is a larger populated place near Oso. See your map document for exact times.
2. Use the 2013-vintage DEM to derive your slope, aspect, flow, and morning hillshade surfaces, but use the 2014-vintage DEM to derive your afternoon hillshade surface.

Next, edit your text boxes and tidy your layout to create a professional-looking display of results. For the large data frame, Zoom to Full Extent, then manually reset the map scale to 1:16,000. For the smaller data frames, Zoom to Full Extent, then reset the map scale to 1:90,000. Save your work. Last, print a copy of your layout on 11" x 17" paper then cut, fold, and staple your hardcopy as instructed.

QUESTIONS ABOUT THE TERRAIN IN THE OSO AREA:

- Question 3.** Build a third table to report your date, times, and solar position values, then use these values and Figures 11-8 & 11-29 of your text (Bolstad, 2016) to help you describe your hillshade surfaces in words.
- Question 4.** Build a fourth table (see Table EX above) to present your terrain analysis results.
- Question 5.** Choose one record in your fourth table to serve as an example, then convince me that you understand the meaning of every single number in that row.
- Question 6.** Use the flow accumulation value you just described (for Q5) and your **USGSdem** cell size to find the upstream area (a.k.a., the watershed area) for that point.
- Question 7.** Using information from the videos you've been given and the data you derived, tell your *data-driven* story of the Oso area. Don't be vague; I am literally tasking you to use your surfaces and extracted values to augment the story told in those videos.

DELIVERABLES

Build a well-written lab report. Include your names, lab title, and date on the first page, and insert page numbers. Your report should include five sections and headings: Purpose, Objectives, Methods and Data, Results and Answers, and Summary. Build concise *Purpose* and *Objective* sections using your own words. I've given you nearly every method needed, so just list them. Explain in detail, however, how you chose your critical stream threshold value and used the SetNull tool to discriminate 'stream' cells from 'not stream' cells. The *Results and Answers* section should contain numbered answers to the questions above. Use the *Summary* section to highlight "light bulb" moments or lingering issues.

All lab reports should be typed and printed on 8.5" by 11" stock. Before drafting your report, set all page margins to be 0.7", except for the left margin, which should be set to 1.2". Set the normal font face to be Bookman Antiqua or Georgia and set the normal font size to be 11 points. Use 1.5 line spacing. Your tables must also meet these requirements. All headings should be in **bold** face. Attach printed copies of your layouts – do not insert them as figures.

APPENDIX

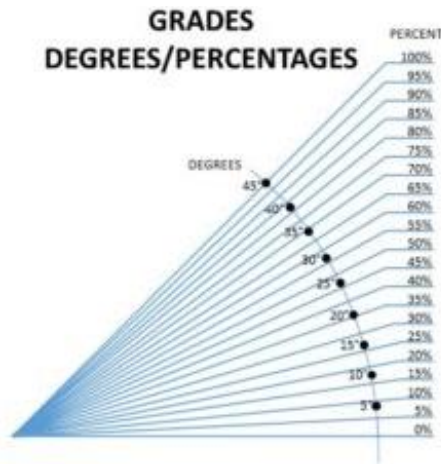


Figure A1: Diagram of slope gradient, in **degrees of upward arc** and **percent of run length**. If slope rise == slope run, then slope gradient can be described as ‘45 degrees of slope’ or as ‘100% slope.’

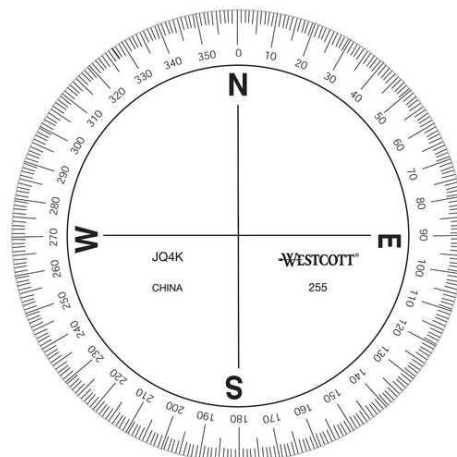


Figure A2: The azimuth scale, in ‘**degrees from North.**’ If aspect == 340 degrees from North, then the aspect of the slope can be describe as facing north-by-northwest.

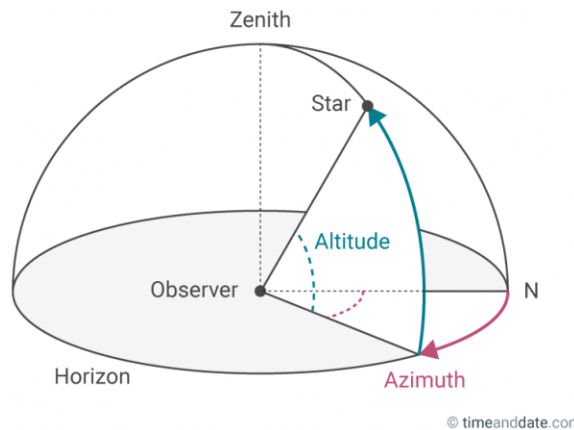


Figure A3: The position of the sun can be described relative to an observer on the ground using both a solar altitude value (see A1) and a solar azimuth value (see A2).