GIS 4 Geomorphology

Geomorphometry of Mountain Landscapes & Upland Watersheds…a little Wildlife, too

Minimum Eroded Volume

Consider a bowl. Its volume can be found by delineating two things: a plane across its rim and its curved inner surface. Finding the volume of a watershed is much the same. A capping surface can be constructed by connecting a set of points located along the divide, while the inner surface is the modern topography represente by the DEM. The volume is simply the difference between the cap elevation and topography. "Minimum Eroded Volume" is called "Minimum Bulk Erosion (E_{bulk})" by Bellin et al. (2014), but its hopeless getting through to the Belgians (#Piorot).

0.) Workflow Overview

Detailed instructions are provided below, but the the general workflow goes like this:
Define the rim (watershed boundary polygon) –> Convert polygon to points –> Extract elevations of points –> Create a capping surface (a TIN) from points –> Convert TIN to raster –> Subtract the modern topographic surfa from the cap surface –> Calculate the volume –> Convert units to km^3.

1.) Getting Started

– If you have already completed the Watershed Delineation lesson, use those files and skip down to Step #2. Re that the filenames used here are just suggestions; yours may differ.

– Start with a projected, filled DEM and the watershed boundary polygon shapefile (*ws1_boundary*). TIN creatior (Step #6) requires a projected coordinate system and map display units in meters or feet. Alternatively, you coulc change the Data Frame to a projected coordinate system (View menu > Data Frame Properties > Coordinate System tab…select a projected coordinate system; Change the map units too, in the General tab).

– Open Attribute Table for watershed boundary polygon shapefile. Mine is named *ws1_boundary*. Add a New Fi formatted Float, named "Area". Right-click > Calculate Geometry (Area) for the polygon in km^2.

– Clip DEM to watershed boundary:
Data Management > Raster > Raster Processing > Clip tool
Input raster = *DEM*
Output extent = *ws1_boundary*
Click the box for "Use input features for clipping geometry"
Leave NoData value at the default
Output = *ws1_dem*

Make sure to save output raster in correct folder

– You should now have a DEM for just the watershed (*ws1_dem*) and one for the whole area (*DEM*). Keep both i your .mxd for now.

2.) Convert Basin Polygon to Point File
– Data Management tools > Features > Feature Vertices to Points
Input = *ws1_boundary*
Output = *rimpoints*
Point Type = ALL
Click OK

4.) Extract Rim Points Elevation Values from the DEM
– Use the full DEM as the input for this step, not the one clipped to the watershed boundary. By 'full' I mean a D that overlaps and is larger than your watershed boundary polygon:
Spatial Analyst Tools > Extraction > Extract Values to Points
Input point features = *rimpoints*
Input raster = *DEM*
Output point feature = *rimpoints_extracted*
Check the box "Append all the input raster attributes to the output features"
Click OK

– When complete, check to see if the Attribute Table of *rimpoints_extracted* contains the extracted elevation valu They will be in field called RASTERVALU. You will use this shapefile and this field as the inputs to your capping surface (TIN).

– Remove the original *rimpoints* layer from the TOC.

5.) Turn on the 3D Analyst extension (Customize > Extensions)

6.) Create TIN Surface
– TIN = Triangular Irregular Network

– 3D Analyst Tools > Data Management > TIN Management > TIN > Create TIN
Output TIN = *ws1_tincap*
Spatial Reference = Make sure your coordinate system is a projected one – matched to the C.S. you set for the Data Frame earlier (see Step #1)
Input feature class = *rimpoints_extracted*
Click in the first cell of each of the following columns and change what's there.
Make sure you choose from the drop down list that will appear once you click on it:
height_field = RASTERVALU
SF_type = masspoints
tag_field = <none>
Click OK

– When complete, a TIN should appear. It represents a theoretical pre-erosion cap surface for the watershed, as defined by *rimpoints_extracted*.

7.) Convert TIN to Raster
– 3D Analyst Tools > Conversion > From TIN > TIN to Raster
Input = *ws1_tincap*
Output raster = *ws1_caprast*
Output Data Type = INTEGER
Method = LINEAR
Sampling Distance = set to CELLSIZE (cellsize should match that of *ws1_dem* or *DEM*; check Properties > Sou
* Z Factor = 1 (see note at bottom of page)

– Turn off the TIN layer.

8.) Clip Raster to Basin Boundary
– Use *ws1_boundary* as cookie cutter to clip cap raster to the boundary of your watershed.

– Data Management Tools > Raster > Raster Processing > Clip
Input raster = *ws1_caprast*
Ouput extent = *ws1_boundary*
Click the box for "Use input features for clipping geometry"
Output = *ws1_capclip*
Click OK

9.) Calculate Difference Between Clipped Cap and DEM Topography
– Spatial Analyst > Map Algebra > Raster calculator, use buttons to create the script below. It may seem like you should use *ws1_dem* instead of the larger *DEM*, but it just works better if you don't.
Output = *ws1_diff*
Double-click on the layer names, single click on the operator buttons:

"ws1_capclip" – "DEM"

10.) Find Pixel Count and Pixel Area
– Right-click on the *ws1_diff* raster, Properties > Symbology > choose Classified in left-side frame > click Classif button, find the SUM in the Classification Statistics box at upper right. It might seem like you should use COUNT but don't. SUM is the number of pixels in the difference raster- a number in the millions. Write this number down

– Find pixel dimensions in Properties > Source > Cellsize of your <u>original DEM</u> (not the difference raster). Write th number down – you'll use it in the next step.

<u>Example Pixel Area Calc</u>
27.33m x 27.33m = 746.93 m^2

**** IMPORTANT NOTE: The DEM data I provide my students is likely 30m resolution, which in this**

example is 27.33m resolution due to the particular latitude location and projection we use. ArcGIS, however, may show the cellsize (Properties > Source) to be something unusually small (i.e., 0.00027.3 This number must be reinterpreted. Since you know its a 30m DEM, read it as 27.33 (or whatever mak sense with the specific values shown in Source tab for your data). Do not use the tiny number. I think this problem is specific to ASTER DEM data from USGS EarthExplorer website, but still not sure. If anyone knows a fix, please write me.

11.) Calculate Minimum Eroded Volume

SUM x Area of a Single pixel = Volume in m^3

Example
(1,056,785) x $(27.33)^2$

– Report the minimum eroded volume to 2 decimal places in cubic kilometers (00.00 km^3).

Example Calculation for Watershed #1
Watershed boundary polygon = ws1_boundary
Watershed DEM = ws1_dem
Full DEM = DEM
TIN = ws1_tincap
Raster = ws1_caprast
Clipped raster = ws1_capclip
Difference raster = ws1_diff

Example Calcs
SUM = 1,056,785
DEM pixel size = 27.33m x 27.33m = 746.93 m^2
Calculate volume –> (1,056,785.99)(27.33)(27.33) = 789,418,395.51 m^3
Convert units from m^3 to km^3 –> Divide m^3 by 1,000,000,000 (one billion) to get km^3
Minimum Eroded Volume = 0.79 km^3

12.) Optional: Use Google Earth to check out what your watershed looks like

13.) Optional: Calculate Ratio of Volume to Area (See RVA lesson)

14.) Repeat Steps for Additional Watersheds

Pixel Size Change After TIN-to-Raster Conversion from ESRI ArcDesktop Help
The Z-Factor variable is used to convert the z-units of the output raster. The output heights are multiplied by this value. A default Z Factor variable is calculated to convert the z-units to the same unit of measure as x,y if, and only if, x-, y-, and z-units are defined in the spatial reference of the input TIN and are standard projected units (for example,. meters, feet). If x-, y-, and z-units

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are the same, a value of 1.0 is used. If any of the units are undefined, a value c
1.0 is used. When there's no output extent defined in the Geoprocessing Analysis
Environment, the extent is calculated from the TIN, ensuring the entire data area
covered by the output raster. In this calculation, the lower left origin of the TI
based on its rectangular extent, is used as the cell center of the lower left rast
cell. In raster space, a cell's location is the lower left corner of the cell,
rather than cell center. It may appear the output raster's extent exceeds that of
the input TINs. When there's an output extent defined in the Geoprocessing Analysi
Environment, the TIN To Raster tool uses the origin of the specified extent as the
lower left cell boundary for the output raster. This is for consistency of behavic
with other raster tools and facilitates use of a snap raster. The X and Y max valu
of the output raster are then determined by using the origin plus the cellsize
specified in the TIN To Raster tool to see how many rows and columns fit within th
user-specified extent. Therefore, the actual X and Y max values of the output migh
not exactly match the user-defined values if width or height of extent is not ever
divisible by cellsize.
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GISTutorials Video – Extract Raster Values to Shapefile in ArcMap

GISTutorials Video – Locating the Raster Calculator and Other Tools in ArcMap 10

Search terms for ArcGIS Resource Center (help.arcgis.com): TIN to Raster, Fundamentals of Surfaces, Terrain

More Volume-related Metrics

Volume of Lake Basin

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GENERAL OVERVIEW

In order to measure the volume of a dry lake basin using a DEM, a lake shoreline contour must be found, the DE clipped to this extent, and the elevation difference between modern topography and a lake surface raster calculated. A simple unit conversion completes the process. In this example, we use a 30m DEM and a shorelin 1500m ASL. We assume the lake has simply dried up (no erosion of sediment, no new sediment added). Additic work to reconstruct the shape of the former lake basin would need to be completed if incision or infilling has occurred since the time the lake drained. This method is similar to RVA (see ‘RVA’ post).

Lake Basin Instructions

1.) Downloaded DEM from the National Elevation Data Seamless Server website (http://seamless.usgs.gov/) or other source.

2.) Project the DEM (Data Management Tools > Projections and Transformations > Raster > Project Raster).

3.) Fill the DEM (Spatial Analyst Tools > Hydrology > Fill tool)

4.) Delineate the basin boundary (Spatial Analyst > Surface > Contour List > enter 1500). The unit of elevation fo most DEMs is meters. Check Properties > Source if there's a question.

5.) If the contour does not completely enclose the lake basin, edit the polyline/polygon (Editor toolbar) to ensure that it does.

6.) Use the polygon to clip the DEM (Data Management > Raster > Raster Processing > Clip).

7.) Convert the polygon to Points (Data Management > Features > Feature Vertices to Points). Consider thinning simplifying the polygon if the number of vertices slows processing.

8.) Extract the elevation of shoreline points and append these values to the point attribute table (Spatial Analyst : Extraction > Extract Values to Points or Extract Multiple Values to Points).

9.) In 3D Analyst, create a TIN surface (3D Analyst Tools > TIN Management > Edit TIN) using the extracted poin as input feature class. Elevations will appear in a new field called RASTERVALU.

10.) Change height field to RASTERVALU, set SF-Type to Masspoints, and run the tool.

11.) Convert the TIN to Raster (3D Analyst > Conversion > From TIN > TIN to Raster) with Output data type as Integer, Method as Linear, Sampling distance as Cellsize.

12.) Clip TIN raster to lake polygon (Data Management > Raster > Raster Processing > Clip). Make sure to the check the little box.

13.) Calculate the difference between the plane of the former lake surface (TIN) and modern topography (DEM) using Raster Calculator (Spatial Analyst > Map Algebra > Raster Calculator).

14.) Calculate the volume by first finding the total number of pixels between the two surfaces. Right-click raster : Properties > Symbology > Classified, click Classify button, in the Classification Statistics at upper right locate the Sum value. Multiple the Sum by the area of a single pixel. This gives you cubic meters. Make sure you check the Properties > Source > Cell size of your DEM; cell size varies with latitude and projection.

15.) Convert m3 to km3 for final volume.

RVA – Ratio of Volume to Area

RVA is the ratio of 3D volume (V) of a watershed to its 2D planimetric area (A). It is found after you have calculate the volume of a basin (see Minimum Eroded Volume or Lake Basin Volume). The index is a means to compare groups of watersheds in different phases of development. RVA is useful in comparing the relative effects of uplift and denudation in a tectonically stable mountain range versus one actively uplifting. Report RVA values to 2 dec places for each watershed.

Refs:

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Frankel (2002) MS thesis at Lehigh University
Granger et al. (1996) Journal of Geology 104
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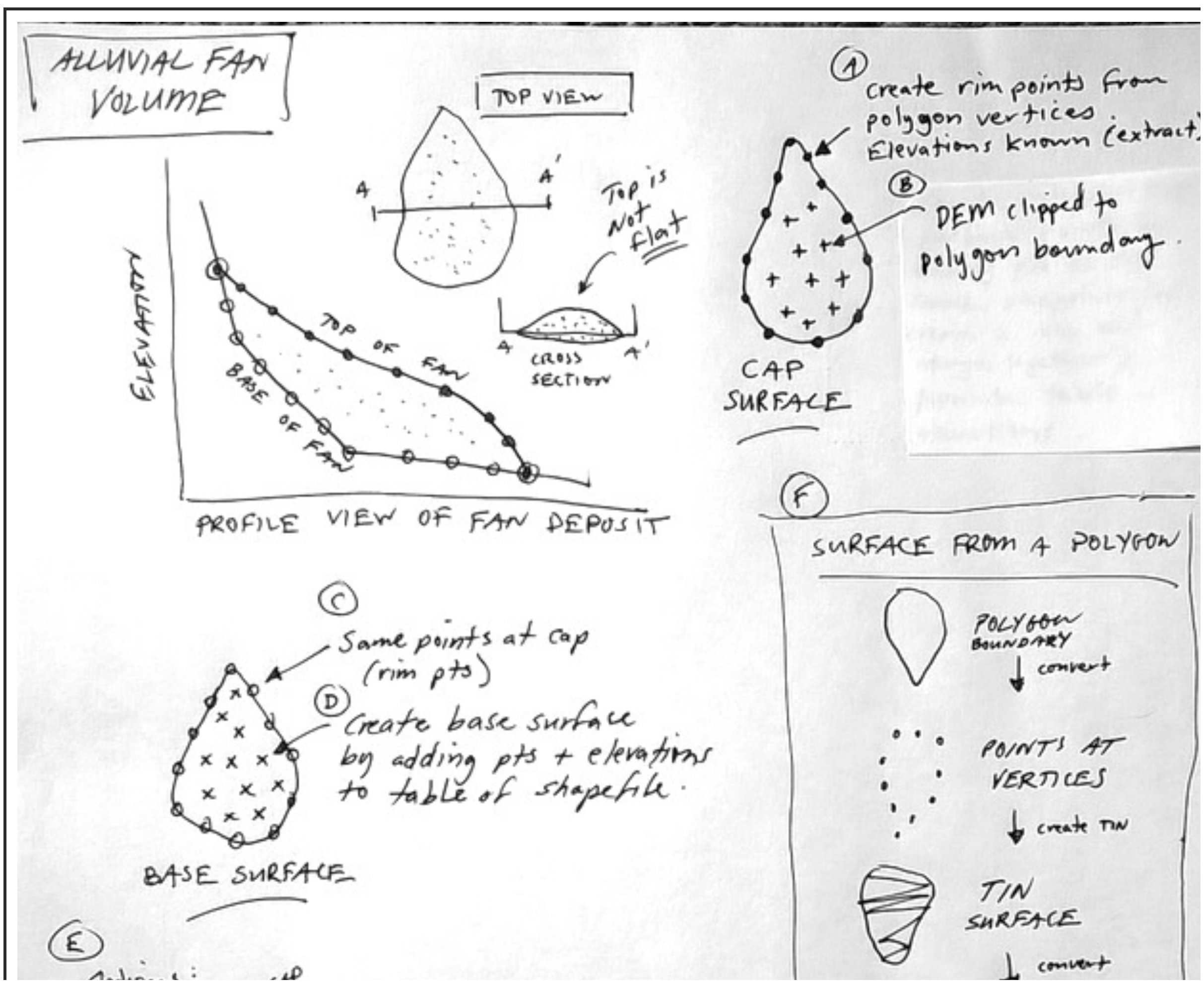
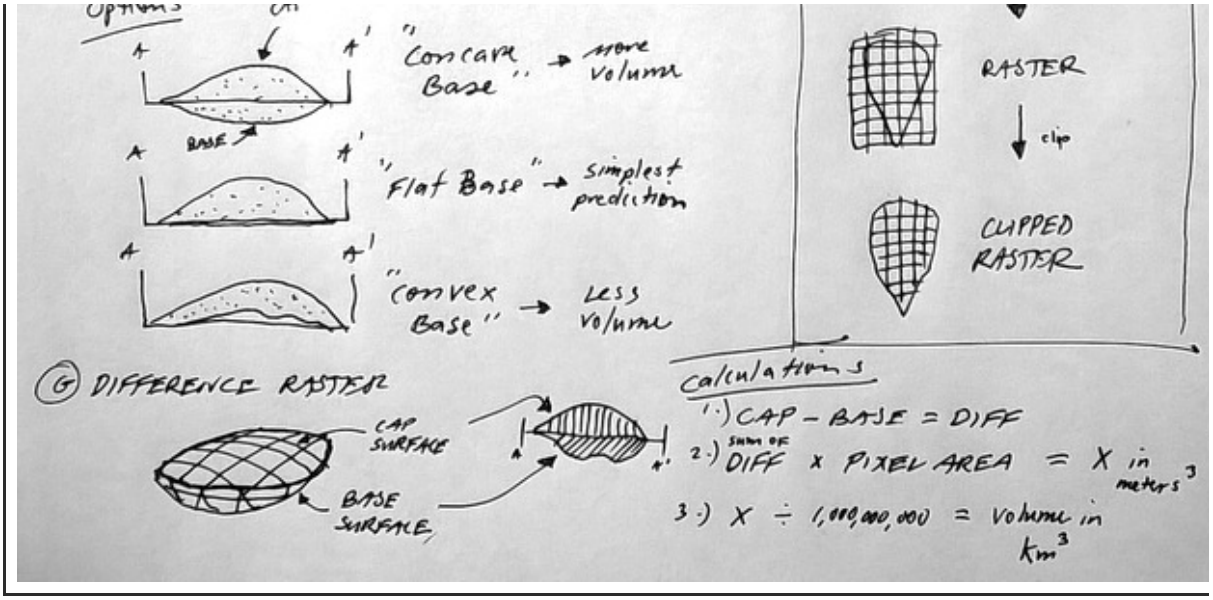
Volume of an Alluvial Fan





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