

Lab 3: Geomorphic Analysis of Watersheds

Topics Covered in this Lab:

- i. Analyzing network geometry
- ii. Characterizing basin shape and relief
- iii. Landform classification

Take Home from Lab 3:

After completing this lab you should be familiar with the concepts and techniques involved in the geomorphic analysis of watersheds.

You will need to copy the contents of the 'Lab 3' folder on the course directory, including files:

- Vermont Breached (tas and dep files)
- Watershed (tas and dep files)
- streams (tas, dep, and vtr files)
- study basins (tas and dep files)

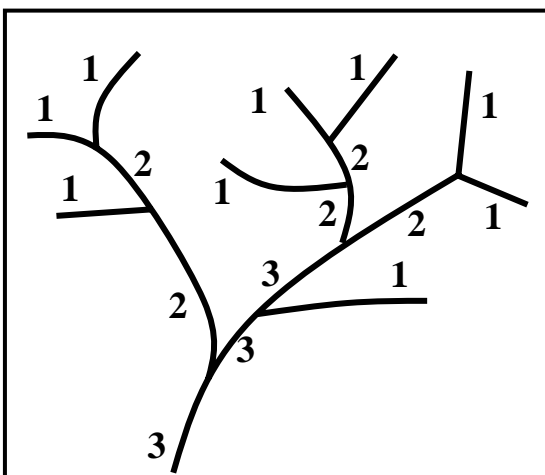
Introduction:

The drainage basin, or watershed, is the fundamental unit in geomorphology within which may be studied the relations between landforms and the processes that modify them. The study of *basin morphometry* attempts to relate basin and stream network geometries to the transmission of water and sediment through the basin. The size of a drainage basin influences the amount of water yield; the length, shape, and relief affect the rate at which water is discharged from the basin and the total yield of sediment; the length and character of the streams channels affect the availability of sediment for stream transport and the rate at which water and sediment are discharged.


i. Analyzing Network Geometry

You may recall from your introductory geography lab or geomorphology class that there are several ways to order tributaries (i.e., sections of streams) in a stream network. The most common ordering system is the Strahler approach, which designates all headwater (i.e., nearest the watershed divide) tributaries as first order, two first order channels produce a second order segment, two second orders provide a third order, and so forth


Strahler stream order




(see figure below). In the Strahler method, the order of a stream is not changed by the addition of a tributary stream of lower order. This ordering system has been found to correlate well with important basin properties in a wide range of environments. Let's examine some of these relations using an example watershed.

1. Click *Terrain Analysis* menu → *Stream Network Analysis* sub-menu → *Strahler Stream Order*, or click the  icon.
2. Select 'Vermont Breached' as the input DEM and call the output image 'Strahler'. Select 'Streams' as the mask file and

specify the value of streams in the mask as 1. You will want to generate network statistics.

3. Press OK. When the program has finished a textbox will be automatically displayed to report the relevant network statistics. For the time being, minimize this textbox but do not close it.
4. Display the image 'Strahler' using the 'qual' palette. Do not scale the palette. Zoom into the image and confirm that the Strahler ordering convention has worked. It may help for you to display the DEM, 'Vermont Breached' as well to examine the topography in the watershed. You should find that there are several first order streams near drainage divides and that the stream order near the basin outlet is five.
5. Copy the contents of the textbox containing the network statistics into an Excel worksheet.
6. Now we would like to compute the **average slope value for each Strahler stream order** in our stream watershed. First, create a slope image based on 'Vermont Breached' using the Terrain Attributes sub-program (click *Terrain Analysis* menu → *Primary Terrain Attributes* sub-menu → *Surface Derivatives* sub-menu → *Slope*, or click the  icon). **Measure slope in percent**. The output image will automatically be called 'Vermont Breached_slope'.

7. Click *Statistical Analysis* menu → *Descriptive Statistics* to launch the *Generate Statistics* sub-program. Select 'Vermont Breached_slope' as the 'Data Image' and 'Strahler' as the 'Feature Definition Image'. Specify 0 as the background value, i.e., the non-stream value in the 'Strahler' image. We wish the output statistic to be the *average* and the output type to be a text file named 'Strahler average slopes'.
8. Open 'Strahler average slopes' in TAS's text editor (*File* menu → *Text Editor*). You will need to specify that the file has a .txt extension. Copy these average slope values corresponding to Strahler stream orders one through five and paste them into a new column in your Excel worksheet with the heading 'Slope'
9. Now let's calculate the ***average drainage area for each Strahler order***. Launch the *Watershed* sub-program. Select 'Vermont Breached' as the input DEM and call the output image 'Strahler Basins'. Specify *Use stream file to find Strahler order basins* as the *Watershed Method*. Select 'Streams' as the stream image. Press OK.
10. When the *Watershed* sub-program has completed, display 'Strahler Basins' in the 'qual' palette. Do not scale the palette. Overlay the vector file 'streams' in the 'mono_black' palette and confirm that the watershed algorithm has worked properly.
11. Open the *Area* sub-program by clicking *GIS Analysis* menu → *Area*, or clicking the  icon. Select 'Strahler Basins' as the input image, *Text* as the output type, and square meters as the output units. Press OK. A textbox reporting the results of the area analysis is automatically displayed. We are only interested in the values corresponding with Strahler stream orders from one through five. Copy these values into a new column of your Excel worksheet and give the column the title 'Area'. The drainage area of second order streams includes that of first order, and third order drainage areas include second and first order basins, and so forth. Therefore, create a new column called 'Total Area' in which the drainage area for each Strahler order is the sum of the area draining directly to that basin order and all lower order basins.
12. Create a new column in your worksheet called 'Average Area' and compute the values as the 'Total Area' divided by the 'Number of Channels'.

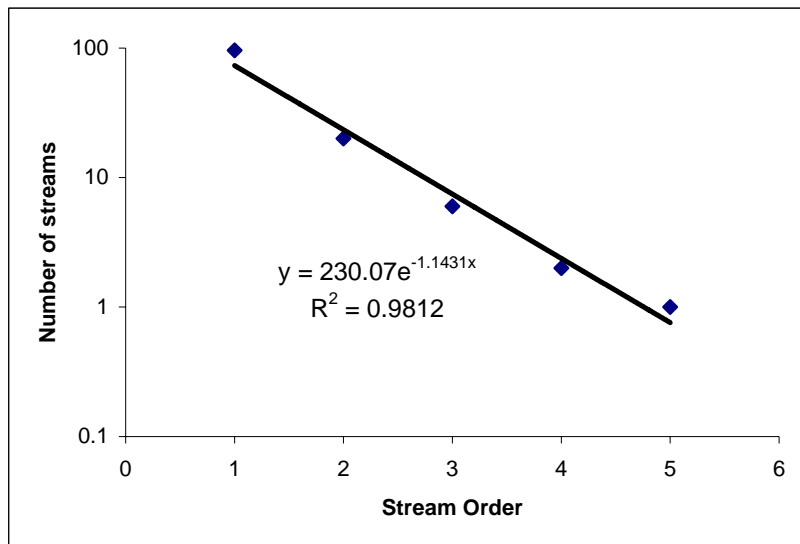
Now we have all of the data needed to explore the relevant properties of the stream network geometry in this study watershed. Strahler plots (or charts) show the relation between the Strahler stream order on the X-axis and some basin property on the Y-axis. The Y-axis is always log-transformed and exponential trend lines can be fit to the data points. An example of the Strahler plot relating stream order to the number of channels in our study watershed is given below.

Q1. Create Strahler plots for average stream length, average stream slope, and average drainage area. Use logarithmic scales for both the x and y axes. Don't forget to label your axes and to fit an exponential trend line, as in the example below. Print your plots and attach them to the submitted component of this lab. (6 marks)

Q2. Comment on the direction and strength of the relations. (4 marks)

Q3. This study watershed is contained within a larger regional watershed of Strahler order 7. The geology throughout this watershed is relatively consistent. Based on the

relation in your Strahler plot, estimate what the stream slope and drainage area are near the outlet of this larger watershed. (2 marks)



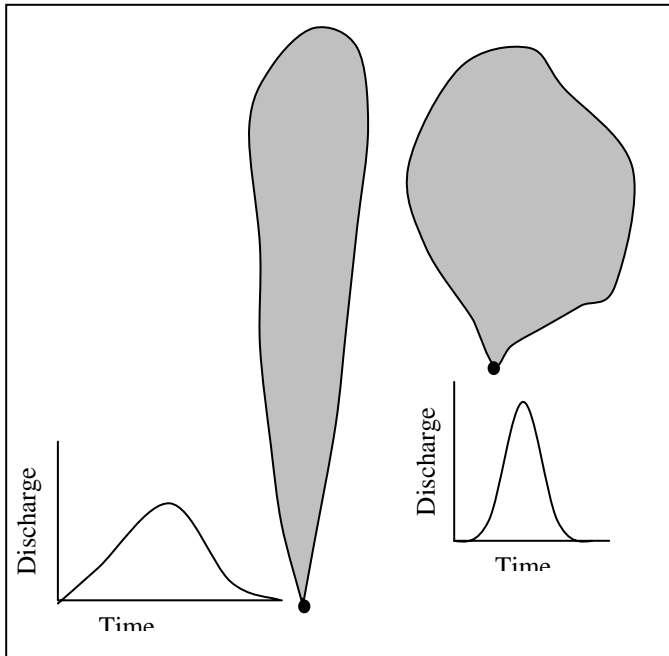
Drainage density is one of the most important basin morphometrics, the total stream length in a watershed divided by the watershed area. It is a valuable indicator of the relation between climate, vegetation, and the resistance of rock and soil to erosion. Under similar climate conditions, impervious rocks supports a higher drainage density compared with permeable rock. Semi-arid areas have higher drainage densities than arid and humid areas with the same geology because of the rapid runoff and sparse vegetation.

1. The image 'study basins' contains five small catchments contained within the Vermont watershed that we have been studying. Display this image and examine the five catchments. We are going to calculate the drainage density for these five basins.
2. Click *Terrain Analysis* menu → *Basin Morphometry* sub-menu → *Drainage Density*. The drainage density window opens. Select 'streams' as the stream image with a stream value of 1. Specify 'Vermont Breached' as the DEM and select 'study basins' as the watershed image. Zero is the background value in this image.
3. Press OK. When the sub-program has completed, a textbox is automatically displayed reporting the drainage density and two related morphometrics for each of the five catchments.

Q4. What is the range of values for drainage density for the five catchments? The global range in drainage density is between 0.5 and 30, with some catchments have values as high as 100. Explain why the drainage density of these catchments is so low (hint: consider the natural setting, Vermont, and the computational limitations involved). (4 marks)

ii. Characterizing Basin Shape and Relief

Relation between basin shape and discharge



The diagram at the side compares the discharge hydrographs of two basins with very different shapes. The more elongated basin has a dampened response, compared to the 'flashier' hydrograph of the circular shaped basin. This pattern results because of the first basin has a much broader distribution of flow path lengths, and therefore, a wide range of travel times.

1. Click *Terrain Analysis* menu → *Basin Morphometry* sub-menu → *Shape and Relief Indices*. The shape indices window will open. Select 'study basins' as the watershed image and specify 0 as the background

value (this will force the program to ignore all zero values in 'study basins'). Select 'Vermont Breached' as the depressionless DEM.

2. Press OK. A textbox automatically displays when the program is complete and a list of basin shape and relief indices are given for each of the five catchments. Many of the reported indices convey the same information. An in-depth description of each of these indices can be found in Selby (1985, pg. 295) and Ritter (1995, pg. 152). We will only examine a few commonly used indices.

Q5. The elongation ratio is equal to one for a circular basin and approaches zero for a straight line. List the basin numbers and elongation ratios in order from most circular to most elongated. Based on basin shape alone, which catchment is most likely to experience flash flooding and why do you think so? (3 marks)

Q6. The relief ratio, the maximum relief divided by the longest flow-path, indicates the overall steepness of a basin. Rank the five basins in terms of their relief ratios. Based on the relief ratio alone, which of the five catchments is most likely to experience flash flooding and why? (2 marks)

A *hypsothetic curve* expresses the proportion of total basin height as a function of the proportion of total basin area. In other words, a hypsothetic analysis reveals how much

of the basin occurs between specific contours. This is essentially describing the distribution of mass above a datum (i.e. a plane defined by the elevation of the basin outlet). The hypsometric integral (HI) can be calculated from the area under the curve, and expresses, as a percentage, the volume of the original basin that remains unweathered.

3. Click *Terrain Analysis* menu → *Basin Morphometry* sub-menu → *Hypsometric Analysis*. Perform a hypsometric analysis for each of the five catchments in 'study basins'. Choose *Chart* as the output type.

Q7. Rank the five catchments in 'study basins' from lowest to highest in terms of their HI values? Which basin is the most weathered and which is the least? (3 marks)

Q8. The range of typical values for HI in natural watersheds is from 20% to 80%. How do these five catchments compare to this range and what does this imply in terms of the amount of erosion that has occurred in the area? (2 marks)

Q9. Comment on the range of HI values between the five catchments. Is this surprising? Why or why not? (2 marks)