ES322 Introduction to Watershed Morphometry

Morphometric analysis of watersheds involves the quantification of the channel network and related parameters such as drainage area, gradient and relief. See attached handout p. 168-169 for overview of stream ordering and the types of morphometric calculations that are commonly used in analyzing watersheds.

Review the attached topographic map of the hypothetical Mingo Creek drainage basin. In this mythical world, the drainage divide surrounding Mingo Creek is perfectly rectangular (labeled as "drainage boundary" on the base map). Observe the landmarks, benchmarks (BM X and BM Y), and control points (A, B, C, D). The drainage network and contour lines are also shown on the map. The maximum basin elevation as measured at one of the bench marks is 1286 ft AMSL; the lowest basin elevation as measured at one of the bench marks is 1118 ft AMSL. Note each stream channel segment is labeled with a number ranging from 1 to 15.

Using ruler, engineers scale, calculator and thinking caps; calculate/determine/otherwise answer the following questions related to watershed morphometry and channel configuration. SHOW ALL OF YOUR MATH WORK AND UNIT ALGEBRA!!

1. Which direction is the Mingo Creek drainage flowing? Explain your answer.
2. What is the elevation of BM "X"
3. What is the elevation of BM "Y"
4. Calculate the fractional scale of the map.
5. Given the contour interval, label the elevation of each contour line on the map.
6. Calculate the stream gradient in m/m (dimensionless ratio) between the following control points:
   a. A to D
   b. B to D
   c. A to C
   d. B to C
   e. C to D
7. Using a red colored pencil, draw the internal drainage divide for the Whiskey Run sub-basin.
8. Examine the grid network on the base map,
   a. what is the map distance between each tic in the Easting direction? (inches)
   b. What is the ground distance between each tic in the Easting direction? (meters)
   c. What is the map distance between each tic in the Northing direction? (inches)
   d. What is the ground distance between each tic in the Northing direction? (meters)

9. What is the total basin relief of the drainage basin? (in feet? In meters? In km?)

10. Calculate the total drainage area for the Mingo Creek Basin:
    a. Square meters:
    b. Hectares:
    c. Square km:
    d. Square mi:
    e. Acres:

11. On the map, label each stream segment with the corresponding Strahler Stream Order. Fill in the data table below:

Channel ID	Order	Length (m)	Gradient (m/m)
1	____	_______	______________
2	____	_______	______________
3	____	_______	______________
4	____	_______	______________
5	____	_______	______________
6	____	_______	______________
7	____	_______	______________
8	____	_______	______________
9	____	_______	______________
10	____	_______	______________
11	____	_______	______________
12	____	_______	______________
13	____	_______	______________
14	____	_______	______________
15	____	_______	______________

Total Stream Length (m) __________
Total Stream Length (km) __________

12. Calculate the sub-basin area for Whiskey Run, upstream from control point C:
    a. Square meters:
    b. Hectares:
    c. Square km:
    d. Square mi:
    e. Acres:

13. Calculate the drainage density (total stream length / basin area) for the entire Mingo Creek basin (km^{-1})

14. What is the highest stream order attained in the entire Mingo basin?

15. Calculate the drainage density (total stream length / basin area) for the Whiskey Run sub-basin (km^{-1})

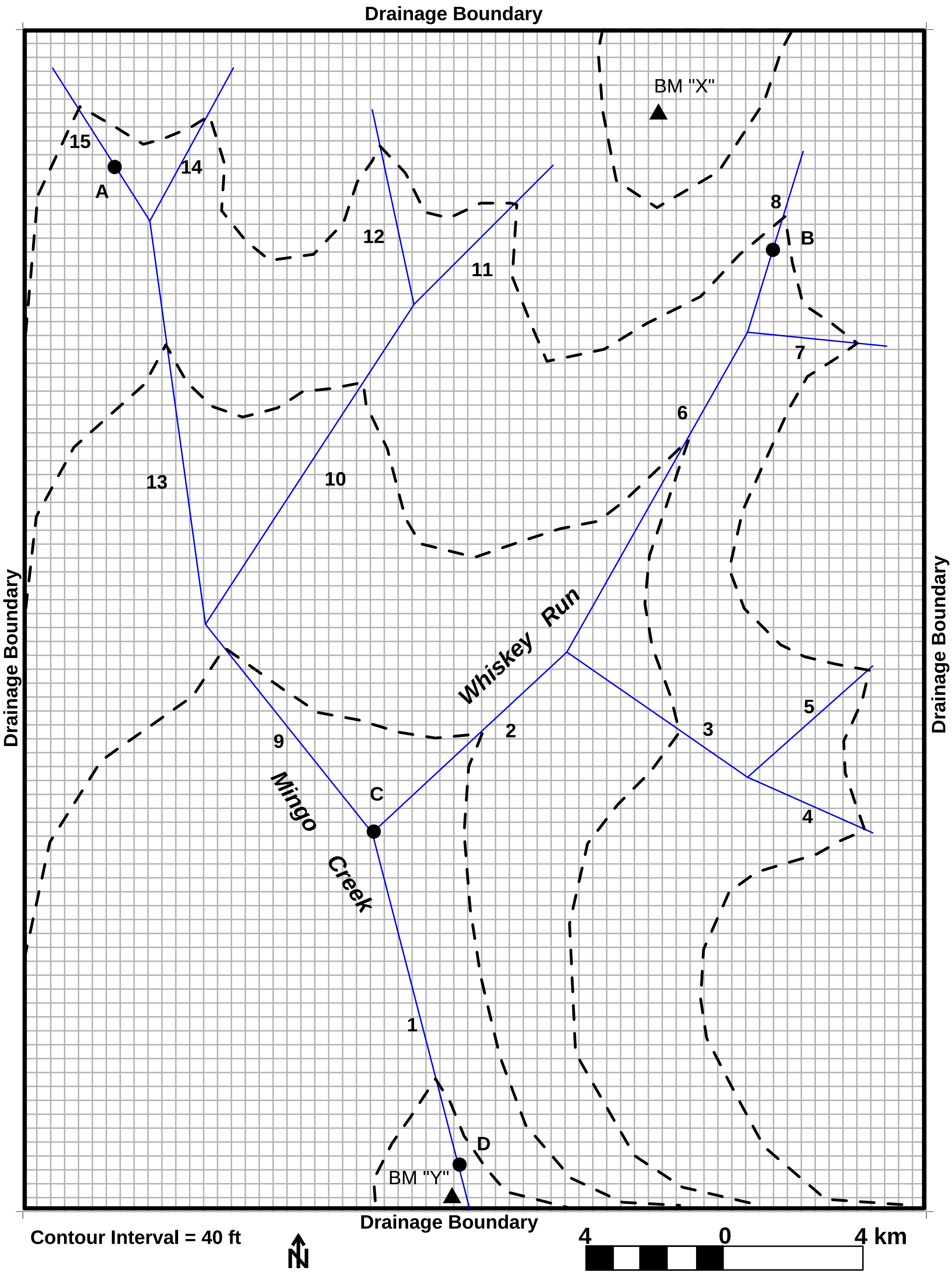
16. What is the highest stream order attained in the Whiskey Run sub-basin?

17. Calculate the Basin Ruggedness for the Mingo Creek basin (drainage density x basin relief) (km^{-1} * km)

18. Plot the follow X-Y Graphs based on your data:
    a. Gradient (Y axis) vs. Stream Order (X axis)
    b. Stream Length (Y axis) vs. Stream Order (X axis)

Part 2. Thinking Questions… to follow in separate handout

Topographic Map of the Mingo Creek Drainage



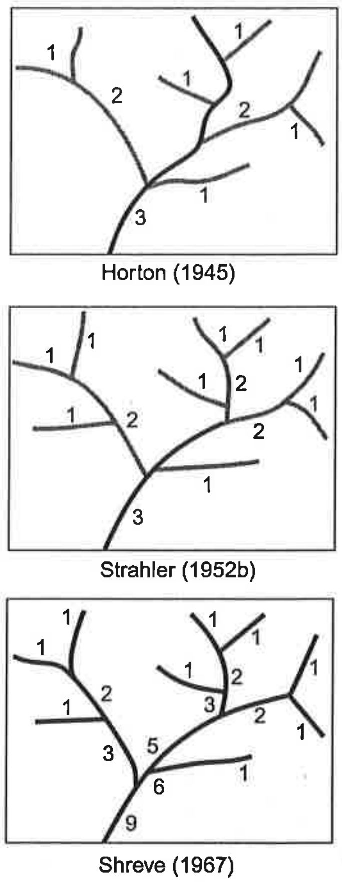


Figure 5.21 Methods of ordering streams within a drainage basin.

statistical relationships that hold for a large number of basins. Two general types of numbers have been used to describe basin morphometry or network characteristics (Strahler 1957, 1964, 1968). **Linear scale** measurements allow size comparisons of topographic units. The parameters may include the length of streams of any order, the relief, the length of the basin perimeter, and other measurements. The second type of measurement consists of **dimensionless numbers,** often derived as ratios of length parameters, that permit comparisons of basins or networks. Length ratios, bifurcation ratios, and relief ratios are common examples. Table 5.2 shows the most commonly used linear, areal, and relief equations, but numerous others have been derived from them.

Linear Morphometric Relationships The establishment of stream ordering led Horton to realize that certain linear parameters of the basin are proportionately related to the stream order and that these could be expressed as basic relationships of the drainage composition. Much of linear morphometry is a function of the **bifurcation ratio (R_b),** which is defined as the ratio of the number of streams of a given order to the number in the next higher order (using Strahler ordering). The bifurcation ratio allows rapid estimates of the number of streams of any given order and the total number of streams within the basin. Although the ratio value will not be constant between each set of adjacent orders, its variation from order to order will be small, and a mean value can be used. Also, as Horton pointed out, the number of streams in the second-highest order is a good approximation of R_b. When geology is reasonably homogeneous throughout a basin, R_b values usually range from 3.0 to 5.0.

The **length ratio (R_L),** similar in context to the bifurcation ratio, is the ratio of the average length of streams of a given order to those of the next higher order. The length ratio can be used to determine the average length of streams in an unmeasured given order (L_o) and their total length. The combined length of all streams in a given basin is simply the sum of the lengths in each order. For most basin networks, stream lengths of different orders plot as a straight line on semilogarithmic paper (fig. 5.22), as do stream numbers. The relationships between stream order and the number and length of segments in that order have been repeatedly verified and are now firmly established (Schumm 1956; Chorley 1957; Morisawa 1962; and many others).

Areal Morphometric Relationships The equity among linear elements within a drainage system suggests that areal components should also possess a consistent morphometry, because dimensional area is simply the product of linear factors. The fundamental unit of areal elements is the area contained within the basin of any given order (A_o). It encompasses all the area that provides runoff to streams of the given order, including all the areas of tributary basins of a lower order as well as interfluve regions. Schumm (1956) demonstrated (fig. 5.23) that basin areas, like stream numbers and lengths, are related to stream order in a geometric series.

Although area by itself is an important independent variable (Murphey et al. 1977), it has also been employed to manifest a variety of other parameters (see table 5.2), each of which has a particular significance in basin geomorphology, especially in regard to the collection of rainfall and concentration of runoff. Numerous studies have been successful in formulating relationships between basin area and discharge. One of the more important areal factors is **drainage density (D),** which is essentially the average length of streams per unit area and as such reflects the spacing of the drainageways. Drainage density reflects the interaction between geology and climate. As these two factors vary from region to region, large variations in D can be expected (table 5.3). In general, resistant surface materials and those with high infiltration capacities exhibit widely spaced streams, consequently yielding low D. As resistance or surface permeability decreases, runoff is usually accentuated by the development of a greater number of more closely spaced channels; thus D tends to be higher. As a rule of thumb, where geology and slope angles are the same, humid regions develop thick vegetal cover that increases resistance and

Table 5.2 Common Morphometric Relationships

Linear Morphometry	
Stream number in each order (N_o)	$N_o = R_b^{s-o}$
Total stream numbers in basin (N)	$N = \frac{R_b^s - 1}{R_b - 1}$
Average stream length	$\bar{L}_o = \bar{L}_1 R_L^{o-1}$
Total stream length	$L_o = \bar{L}_1 R_b^{s-1}\left(\frac{u^s - 1}{u - 1}\right)$ where $u = R_L / R_B$
Bifurcation ratio	$R_b = N_o / N_{o+1}$
Length ratio	$R_L = \bar{L}_o / L_{o+1}$
Length of overland flow	$l_o = \frac{1}{2D}$
Areal Morphometry	
Stream areas in each order	$\bar{A}_o = \bar{A}_1 R_a^{o-1}$
Length-area	$L = 1.4A^{0.6}$
Basin shape	$R_F = \frac{A_o}{L_b^2}$
Drainage density	$D = \frac{\Sigma L}{A}$
Stream frequency	$F_s = \frac{N}{A}$
Constant of channel maintenance	$C = \frac{1}{D}$
Relief Morphometry	
Relief ratio	$R_h = H/L_o$
Relative relief	$R_{hp} = H/p$
Relative basin height	$y = h/H$
Relative basin area	$x = a/A$
Ruggedness number (Melton 1957)	$R = DH$

s = order of master stream, o = any given stream order, H = basin relief, P = basin perimeter.
(Adapted from Strahler 1958)

infiltration, thereby resulting in a lower drainage density than would otherwise be expected in arid basins. Thus, drainage density not only reflects the geologic framework, but may serve as a useful parameter in climatic geomorphology (Daniel 1981). Methods for the rapid estimation of drainage density have been devised (McCoy 1971; Mark 1974; Richards 1979; Bauer 1980).

Drainage density has also been used as an independent variable in the framing of other morphometric parameters. For example, the **constant of channel maintenance** and the length of overland flow (see table 5.2) both utilize a reciprocal relationship with density to demonstrate the link between factors that control surface erosion and those that describe the drainage net (Schumm 1956). The constant of channel maintenance indicates the minimum area required for the development and maintenance of a channel; that is, the ratio represents the amount of basin area needed to maintain one linear unit of channel length. As Schumm (1956, p. 607) points out, this relationship requires that drainage networks develop in an orderly way because the meter-by-meter growth of a drainage system is possible only if sufficient area is available to maintain the expanding channels.

Relief Morphometric Relationships

The third group of parameters shown in table 5.2 indicates the vertical dimension of a drainage basin; it includes factors of gradient and elevation. Like stream numbers, length, and area, the average slope of stream segments in any order approximates a geometric series in which the first term is the mean slope of the first-order streams. This relationship is reasonably valid as long as the geologic framework is homogeneous. Channel slopes and surface slopes are closely akin to the parameters for length. Horton suggested, for example, that the length of overland flow as a function of only the drainage density is at best an approximation because overland flow also depends on slope parameters.

As relief refers to elevation differences between two points, slopes that connect the points are the integral factors affecting the flow of runoff. The most useful relief parameters are the **maximum basin relief** (highest elevation on the basin divide minus the elevation of the mouth of the trunk river) and the **divide-averaged relief** (the average divide elevation minus the mouth elevation). The **relief ratio** (Schumm 1956), the maximum basin relief divided by the longest horizontal distance of the basin measured parallel to the major stream, indicates the overall steepness of the basin.

A different relief relationship is found by **hypsometric analysis** (Strahler 1952b), which relates elevation and basin area. As figure 5.24A shows, the basin is assumed to have vertical sides rising from a horizontal plane passing through the basin mouth and under the entire basin. Essentially, a hypsometric analysis reveals how much of the basin occurs within cross-sectional segments bounded by specified elevations. The relative height (y) is the ratio of the height (h) of a given contour above the horizontal datum plane to the total relief (H). The relative area (x) equals the ratio a/A, where a is the area of the basin above the given contour and A is the total basin area. The hypsometric curve (fig. 5.24B) represents the plot of the relationship between y and x and simply indicates the distribution of mass above the datum. The form of the curve is produced by the **hypsometric integral (HI),** which expresses, as a percentage, the volume of the original basin that remains. In natural basins most HI values range from 20 to 80%, higher values indicating that large areas of the original basin have not been altered into slopes. Although