

# MODULE 1: LANDSCAPES, CATCHMENT BASINS AND CHANNEL MORPHOLOGY<sup>1</sup>

## Introduction

"Streams, rivers and groundwater flow pathways are the plumbing of continents. Water coalesces and flows downhill in surface and subsurface channels in response to precipitation patterns and the complex nature of the long (geologic time) and short (decadal) term processes that determine the biophysical form of landscapes that produce runoff (catchment basins). Uplift of mountain ranges, caused by continental drift and volcanism, is continually countered by erosion and deposition (sedimentation) mediated by the forces of wind and water" (Stanford 1996). This interplay of flowing water and geological processes produces a diverse array of biophysical areas that can be arranged in a hierarchy of spatial scales. Plants and animals are distributed in relation to these biophysical gradients. For example, certain species of aquatic insects reside only in cold, rocky environments of cascading headwater streams in the high mountains. Often the first task of anyone who intends to study the biota of a given region is to determine the appropriate spatial scale of study to answer the question at hand. It is the purpose of this laboratory to examine some of the features of landscapes, catchment basins and channel morphology using topographic maps. These features allow biologists to put studies of the biota into context of larger-scale features and suggest avenues of study with regard to the biota. Exercises in this laboratory have been modified from those in Wetzel and Likens (1991), Stanford (1996) and Bisson and Montgomery (1996).

In each of the exercises below, be sure to use comparable measuring units. Metric units are the preferred scientific units, but you will notice that the United States Geological Survey (USGS) maps provided give many measurements in English units (feet, miles etc.). Be sure to convert to common metric units when needed. Also when calculating ratios, such as sinuosity, measurements must be in the same units. Examine the maps and notice that different maps use different scales. Notice the contour lines, associated elevation units and symbols. Much of the information that we gather from the topographic maps can now be gathered electronically using Geographic Information Systems (GIS); however, we will use simple methods to estimate these features.

Work in groups of three or four persons. Each person should turn in their own data sheets at the end of the laboratory.

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<sup>1</sup>Last modified 8/22/2005

## Exercise 1: Catchment basin size & stream order

Boundaries of catchment basins (also called watersheds and drainage basins in American terminology) are determined from surface features of topographic maps, field surveys or aerial photographs. Each stream from the smallest (small, high elevation streams) to large rivers (e.g., Mississippi) has a catchment basin. Thus, the catchment basin of a large river is made up of a nested hierarchy of smaller and smaller subbasins, just as the water flowing in the river comes from a nested hierarchy of many smaller streams. Moreover, you can determine basin characteristics upstream of any point in a particular stream, not just above its mouth. Surface water and shallow subsurface water flow downhill from topographic divides (highest elevations) to lower elevations. However, it is important to remember that deep, subsurface flows (e.g., groundwater) often cross these divides, and thus often does not flow in the same way as surface water. In this laboratory we will examine topographic features that influence flow of surface and shallow subsurface water.

The streams within any catchment basin can be organized in a number of different manners. One widely used method in the United States is the Horton-Strahler method (Horton 1945, Strahler 1952). In this method each headwater or “finger-tip” tributary is designated as a first order stream. Two first-order tributaries combine to produce a second-order stream, two second-order tributaries combine to produce a third-order and so on. When a stream of a smaller order combines with a stream of larger order the order of the larger stream is not changed. When determining stream order, intermittent streams (those that do not flow continually) are usually not included. Typically, intermittent streams are indicated with dashed blue lines (as opposed to solid blue lines indicating permanent streams). As we will discover in lecture, biological assemblages are often correlated with stream order.

Label the order of each stream and trace the outline of the basin(s). Water flows perpendicular to contour lines (elevation lines). Draw the basin boundaries by following the ridge tops which appear on topographic maps as downhill pointing V-shaped crenulations. The boundary should be perpendicular to the contour lines it intersects. The tops of mountains are often marked as dots or “x’s” and usually are enclosed within a contour line. Trace the basin boundary onto the graph paper provided and estimate the area of the basin(s). [Estimate the area ( $\text{km}^2$ ) of a small square on the graph paper and then count the squares.]

Be sure to turn your map in with stream order labeled. Also, determine the characteristics listed on the next page for your basin(s). Record the data in Table 1.

Determine the following characteristics for each basin:

**Basin length** (km) = Straight-line distance from the mouth of the stream a point on the basin divide. The line should be roughly parallel to the stream.

**Stream (main channel) length** (km) = The length of the stream from the mouth to the end of the “blue line.” Includes all the “wiggles.” This actually can be a problem. For example, the smaller the scale of the map (a smaller area in greater detail), the more “wiggles” and the longer the stream length. This occurs because the length of an intricately sinuous line tends to increase as it is measured more accurately. This has prompted people that use maps to try to develop measurements that do not have this problem. For example, fractal stream length is a measure of stream length that is standardized.

**Total stream length** (km) = The length of all the streams in the basin. Use the **stream (main channel) length** from above.

**Drainage basin area** (km<sup>2</sup>) = Total area of the basin.

**Drainage density** (km/km<sup>2</sup>) = Total stream length (total stream (main channel length)) divided by area of the drainage basin.

**Mean stream slope** (dimensionless) = Average channel slope is one factor that controls water velocity.

Slope = (Elevation at source - elevation at the mouth)/stream length (use stream (main channel length)).

**Mean basin slope** (dimensionless) = An index of the slope of the basin which influences surface runoff and is related to drainage density and basin relief. It is computed from the difference in stream-bed altitude at point 10% (E10) and 85% (E85) of the basin length. Use the equation:

Slope = (E85 - E10)/0.75\*Basin length

**Sinuosity ratio** (dimensionless) = The ratio of stream length to straight line, down-valley distance (straight line from beginning of the stream to its mouth). This is a measure of the “wiggleness” of a stream. If the channel makes broad-scale changes in direction, the straight line, down-valley distance should be computed separately for the different segments.

Record the data in Data Table 1.

## Exercise 2: Stream reach classification

Valley segments, stream reaches, and channel geomorphic units are three hierarchically nested subdivisions of the drainage networks (Frissell et al. 1986) that were determined in Exercise 1. These features are of a smaller spatial scale than those determined in Exercise 1. There are several reasons why biologists classify and measure such features. One may be to determine changes how biotic assemblages correlate with the features. A second may be to group sampling sites into physical units for purposes of comparisons. There is no universally accepted method; however, we will focus on the Montgomery and Buffington (1993) classification for valley segments and stream reaches and the Hawkins et al. (1993) classification for channel units. Exercises relating to channel units will be carried out in the field during another laboratory. Figure 1 represents the classification from Montgomery and Buffington. Tables 1 and 2 provide definitions and characteristics (from Bisson and Montgomery 1996).

In this exercise, we will classify the reaches of streams using a simple classification based on observations from topographic maps. This exercise is in the spirit of the Montgomery and Buffington (1993) classification; however, full classification would require aerial photographs and/or field reconnaissance. Another method that is becoming popular was developed by Rosgen (1994). This method is complex and uses some characteristics that we will examine in this and other laboratories, but also uses other measures not examined.

Select a stream from the smaller-scale (1:24,000) topographic maps. Use a stream for which you can locate both headwaters and mouth. The topographic maps that are provided are adjacent to one another, so the end (or beginning) of your stream may be on another map. [To put the stream in context, locate it on the larger-scale (1:250,000) topographic map.] Using the smaller-scale topographic map, construct a longitudinal profile of the channel beginning at the mouth of the stream and working toward the headwaters. Using a ruler (or string as in Exercise 1), measure the distance of the stream channel. In Data Table 2 record the elevation and distance from the mouth each time a contour line intersects the channel. Plot the longitudinal profile of the stream (x-axis = distance from the mouth; y-axis = elevation) with the stream source nearest the vertical axis. Turn this profile in at the end of class.

Visually locate any inflections in slope (abrupt changes in slope) on the stream profile and indicate these on your map using small arrows. If inflection points occur compute from your graph (or from Table 2) the channel length of each segment separated by the inflection points. If no real inflection point occurs, determine the length of the entire channel. Compute the mean stream slope for each segment according to the formula from Exercise 1. Using Figure 2, classify each segment as "Strongly Confined", "Moderately Confined" or "Unconfined" based on the shape of the contour lines. Record these data in Data Table 3. Using the characteristics of slope and channel confinement from your table, determine the stream reach classification(s) that could be appropriate for each segment based on the information given in Table 2.

## Literature cited

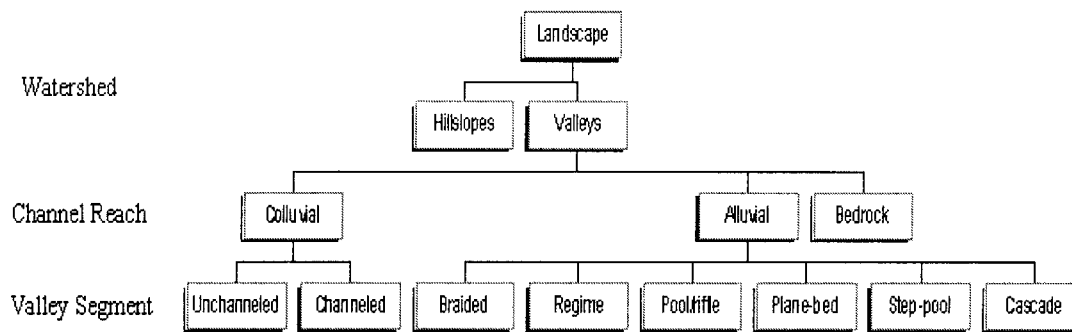
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- Strahler, A.N. 1952. Hypsometric (area-altitude) analysis of erosional topography. *Bull. Geol. Soc. Amer.* 63: 1117-1142.
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**Table 1.** Descriptions of valley segment and stream reach types. Taken from Bisson and Montgomery (1996).

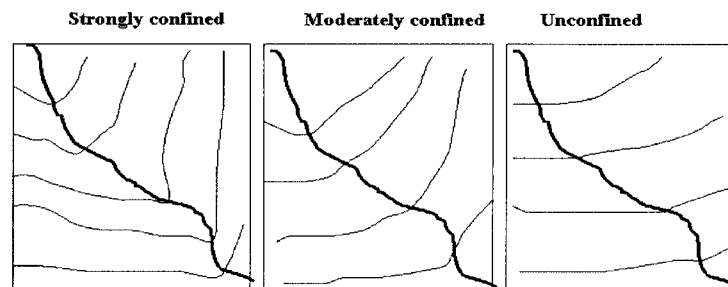
- I. **Colluvial Valleys:** Valleys where eroded sediment and organic matter accumulate. Sediments are flushed out by periodic floods of debris in steep headwater valleys or in low-gradient landscapes by expansion of the alluvial channel.
  - A. **Unchanneled:** Headwater valley segments lacking recognizable stream channels.
  - B. **Channeled:** Low-order streams immediately downslope from unchanneled colluvial valleys.
  
- II. **Alluvial Valleys:** Valleys that are supplied with sediment from upstream sources and the streams within them are capable of moving and sorting the sediments at erratic intervals. They are often the most common type of valley segment in most landscapes.
  - A. **Cascade Reaches:** The steepest alluvial channels. Majority of water tumbles over and around boulders. The large substrata size prevents substrata mobilization during typical flows.
  - B. **Step-Pool Reaches:** Boulders and logs form a series of steps alternating with pools. Step-pool reaches tend to be straight and have high gradients, coarse substrata, and small width to depth ratios.
  - C. **Plane-Bed Reaches:** Long, relatively straight channels of uniform depth. They are intermediate in gradient between cascade and step-pool reaches and pool-riffle reaches. The absence of channel-spanning structures or significant constrictions by streambanks inhibits the development of pools.
  - D. **Pool-Riffle Reaches:** This type is commonly associated with small to mid-sized streams and is very prevalent in alluvial valleys of low to moderate gradient. These reaches tend to have lower gradient than the three previous reach types and are characterized by undulating stream beds (intermediate sinuosity) that form riffles (cross-over points from bars to pools) and pools (low points in the channel bed) associated with gravel bars (high points in the channel bed).
  - E. **Regime Reaches:** Low gradient, meandering channels (high sinuosity) with predominantly sand substrata. They occur in higher order channels within unconstrained valley segments.
  - F. **Braided Reaches:** These reaches occur in high-order streams and are characterized by numerous gravel and sand bars. The active channel is wide relative to adjacent unbraided sections.
  
- III. **Bedrock Valleys:** These valleys have little fill material and usually possess confined channels and lack an alluvial bed.

Table 2. Characteristics of different types of stream reaches (modified from Bisson and Montgomery (1996)).

	<b>Colluvial</b>	<b>Bedrock</b>	<b>Cascade</b>	<b>Step-Pool</b>	<b>Plane-bed</b>	<b>Pool-riffle</b>	<b>Regime</b>	<b>Braided</b>
<b>Predominant bed material</b>	Variable	Bedrock	Boulder	Cobble/boulder	Gravel/cobble	Gravel	Sand	Variable
<b>Bedform pattern</b>	Variable	Variable	None	Oscillates vertically	None	Oscillates laterally	Multilayered	Oscillates laterally
<b>Dominant roughness elements</b>	Boulders, large woody debris	Streambed, banks	Boulders, banks	Steps & pools, boulders, large woody debris, banks	Boulders, cobbles, banks	Bars & pools, boulders & cobbles, large woody debris, sinuosity, banks	Sinuosity, dunes, ripples & bars, banks	Bars & pools
<b>Typical slope (%)</b>	> 20	Variable	8 - 30	4 - 8	1 - 4	0.1 - 2	< 0.1	< 3
<b>Typical confinement</b>	Strongly confined	Strongly confined	Strongly confined	Moderately confined	Variable	Unconfined	Unconfined	Unconfined
<b>Pool spacing (channel widths)</b>	Variable	Variable	< 1	1 - 4	None	5 - 7	5 - 7	Variable



**Figure 1.** Hierarchical subdivision of watersheds into valley segments and stream reaches (modified from Bisson and Montgomery (1996)).



**Figure 2.** Appearance of strongly confined, moderately confined, and unconfined channels on topographic maps (modified from Bisson and Montgomery (1996)).

### Data Table 1

	Basin 1	Basin 2
Stream Name		
Basin Length (km)		
Stream (Main Channel) Length (km)		
Total Stream Length (km)		
Drainage Basin Area (km <sup>2</sup> )		
Drainage Density (km/km <sup>2</sup> )		
Mean Stream Slope		
Mean Basin Slope		
Sinuosity		
Main Channel Stream Order (at the “bottom” of the basin)		



### Data Table 3: Stream \_\_\_\_\_

	Segment 1	Segment 2	Segment 3
Segment Stream Length			
Segment slope			
Segment confinement			
Stream Reach Classification (from Table 2)			

#### Assignment:

By next laboratory period each student should turn in the following:

Exercise 1: Turn in completed Data Table 1.

Exercise 2: Turn in completed Data Tables 2 & 3 and the graph of the longitudinal profile.

Answer the following questions in about 1 paragraph:

1. What other factors (either natural or man-made) might influence the large-scale features that we have examined in this laboratory?
2. What things might cause inaccuracies in the results of this laboratory?