Stream Hydrology

- **Watershed**
  - Area that contributes water to a point on a stream
  - Scale is user-defined
  - Other names:
    - Catchment
    - Drainage basin

<table>
<thead>
<tr>
<th>Order</th>
<th>Number</th>
<th>Average length (km)</th>
<th>Total length (km)</th>
<th>Mean drainage area (km²)</th>
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<tbody>
<tr>
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<td>1,570,000</td>
<td>1.6</td>
<td>2,510,000</td>
<td>2.6</td>
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<tr>
<td>2</td>
<td>550,000</td>
<td>3.3</td>
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<td>3</td>
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<td>8.8</td>
<td>0790,000</td>
<td>67</td>
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<tr>
<td>4</td>
<td>180,000</td>
<td>19</td>
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<td>4,200</td>
<td>45</td>
<td>190,000</td>
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<td>950</td>
<td>102</td>
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<td>41</td>
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<td>9</td>
<td>8</td>
<td>1,240</td>
<td>9,900</td>
<td>68,000</td>
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<tr>
<td>10</td>
<td>1</td>
<td>2,800</td>
<td>2,800</td>
<td>3,240,000</td>
</tr>
</tbody>
</table>

Of the approximately 5,200,000 total river kilometers in the contiguous United States, nearly half are first order, and the total for first- to third-order combined is just over 85%. Examples of large rivers include the Allegheny (seventh order), the Ohio (eighth order), the Columbia (ninth order), and the Mississippi (tenth order).
Basics of watershed hydrology

- **Inputs** of water
  - Precipitation (Rain, Snow)

- **Outputs** of water
  - Evaporation
  - Transpiration
  - Stream Runoff

Inputs = Output
- Runoff = Precipitation – ET

Runoff – The amount of water that makes is delivered by precipitation over the watershed into the river
- the **AMOUNT of water per unit area**

How fast does precipitation get into stream?
Runoff varies across the globe

Discharge (Q) = the volume of water moving through a stream channel over a given time interval = **volumetric** flow rate
Units of L^3/T (e.g., m^3/sec, gallons/day, acre-feet/yr)

**Hydrograph** -- time series record of streamflow at a stream cross-section: discharge plotted against time

The way runoff is actually calculated:
Runoff = Q / Area
= m^3 month^-1 / km^3 = cm/month
What controls the shape of the hydrograph?

- How fast the precipitation gets to the stream channel
  - The type of precipitation
  - The pathways of flow from the land to the stream.

Pathways and Rate of runoff

- (1) lithology and soils -- infiltration to groundwater vs. overland flow
- (2) topography -- how fast overland flow occurs
- (3) vegetative cover (type & extent) and ET
- (4) type of precipitation (rain vs. snow)
- (5) size of watershed
In most simple view, Runoff = Precipitation – Evapotranspiration

High summer precip but low runoff in this forested watershed

High summer precip but much evaporation in this desert watershed

Note that these hydrographs have different shapes, i.e., seasonal patterns of runoff. Why is this important?

• Humans modify watershed land surfaces to change the pathways of precipitation runoff and therefore hydrograph shapes.

Example of Urbanization on hydrograph
**Discharge vs. Velocity**

2 specific terms and one general term

- **Discharge** = streamflow = how much water moving down the channel = *volumetric* flow rate
  
  - Units: \( Q = \text{L}^3/\text{T} \)
  
  - (e.g., m³/sec, gallons/day, acre-feet/yr)

- **Current velocity** = how fast water molecule is moving at a point = *linear* flow rate
  
  - Units: \( U \) (or \( V \)) = L/T
  
  - (e.g., m/s)

- “Flow” = \( Q \) or \( U \) !!!!

**How do we measure discharge (\( Q \))?**

Example: Garden hose filling a bucket

\[
Q = A \times U
\]

\[
\text{m}^3/\text{s} \times \text{m}^2 \times \text{m/s}
\]

- How do we get the “area” of a river cross section? \( A = \text{W} \times \text{D} \)
  
  - \( Q = \text{W} \times \text{D} \times U \)

  So, we need the average width, the average depth and the average \( U \).

  How do we do this?

- Divide river into a large number of “cells” and measure the width, depth, and velocity (at 60% of depth in each), multiply and add them up.

  (We’ll come back to the 60% of depth part)
What is the relationship between average U and Q?

- In the stream below, how do velocity (U) and discharge (Q) change from the pool to the riffle?

Is the discharge different? Why?
Is the velocity different? Why?

Consider 3 different channel geometries below. How does U change between them for a given Q?

- Let Q = 10 m³/s. We know … continuity of flow:
  \[
  Q_1 = Q_2 = Q_3 \\
  Q = A \cdot U (= W \cdot D \cdot U)
  \]

  **Riffle** (wide, shallow, fast)
  \[
  \text{X-sec} \\
  A = 10 \text{ m}^2 \\
  U = ___ \\
  U = 10 \text{ m}^3/\text{s} / 10 \text{ m}^2 = 1 \text{ m/s}
  \]

  **Pool** (wide, deep, slow)
  \[
  \text{X-sec} \\
  A = 50 \text{ m}^2 \\
  U = ___ \\
  U = 10 \text{ m}^3/\text{s} / 50 \text{ m}^2 = 0.2 \text{ m/s}
  \]

  **Chute** (narrow, deep, fast)
  \[
  \text{X-sec} \\
  A = 5 \text{ m}^2 \\
  U = ___ \\
  U = 10 \text{ m}^3/\text{s} / 5 \text{ m}^2 = 2 \text{ m/s}
  \]
**Why is current velocity (U) important ecologically?**

1. this generates the force organisms “feel”
   - Faster velocities = more "erosional force"
2. erosional force on sediment (i.e., habitat)
   - (faster flows --> remove larger particles)
3. delivery of nutrients, gases, food; removal of wastes

**Is current velocity same everywhere in stream?**

- Is wind velocity the same over the surface of the Earth?

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**Is current velocity same everywhere in stream?**

Why or why not?

Friction!
As water encounters solid surface
[deck of cards]
Why is velocity “zero” at solid surface interface?
→ **No-slip condition** (velocity = 0 at boundary)

**Where is there friction in a stream?**

- bed
- banks
- Atmosphere

What would a Vertical Velocity Profile look like for Fig. B?
Shape of the velocity distribution (from bed to surface) is logarithmic (ideally):

- Average U in a stream cross-section = 0.6 depth of stream
- Can calculate U at all depths from surface to the bottom

This vertical change in velocity creates shear stress on the bottom – the force exerted as one “layer” of water moves past another. The loss of velocity near the bed translates this force onto the bed (“wall”). It is proportional to the velocity gradient (how fast velocity changes vertically from the bed).

How does velocity affect an object projecting off the bed into the flow?

Shear stress ($\tau$) = the force per unit area on the streambed or object on the streambed

Shear stress ($\tau$) is proportional to velocity gradient, which is measured as the change in velocity ($\Delta U$) divided by the change in depth ($\Delta y$)

So, an organism on the streambed experiences a force that is proportional to the change in velocity from its ventral surface to its dorsal surface.

$$\tau \sim \frac{\Delta U}{\Delta y}$$
Shear Stress $\sim \frac{\Delta U}{\Delta y}$

[Measure how fast velocity changes with depth]

Which of the following have the greater $\frac{\Delta U}{\Delta y}$?

- For same $\Delta y$, which has greater $\Delta U$?

Take home – the faster velocity changes above the bed surface, the higher the shear stress.

Physical forces acting on benthic organisms

1) Shear stress ($\tau$)
   $\tau \sim \frac{\Delta U}{\Delta y}$

2) Lift
   Upward force caused by pressure difference created in vertical dimension ($\Delta U$ vertical, i.e. $U_{max} - U_{min}$)

3) Form Drag
   Force caused by pressure difference in longitudinal direction ($\Delta U$ longi), influenced by body’s shape – examples?

4) Skin Friction Drag
   Drag due to friction between moving water and surface of object (mucus reduces)
For this benthic insect, where is the greatest lift?

How does it prevent being lifted from bed?

How do stream organisms reduce form drag forces?

- Fusiform (torpedo) shape to minimize flow separation (see Fig. above)
- Reduce skin friction drag?
  - mucus secretions, etc.

What near-bed velocities (Umax) do benthic organisms experience???

Theory – use logarithmic relationship in Fig. 2.8, which shows that velocity right at the bed is very low, and benthic organisms are very small (maybe few mm height). Can they "avoid" high velocities by being very near the bed?
* True for non-turbulent flows in smooth beds where water molecules move in parallel

* But turbulence is the norm in rough beds
  - Turbulence occurs when the inertial force of moving water exceeds the cohesive force among molecules, causing "random" movement
  - something breaks up flow coherence (obstacle in water)