Streams & Flooding

- Stream Discharge
- Drainage Networks
- Erosion, Transport and Deposition
- Flooding & Flooding Hazards
Stream Discharge

~75% of precipitation falls directly back to the oceans. The remaining 25% falls on the land surface.

Water that falls on the land surface moves downslope (under the influence of gravity) in thin sheets of water in a process known as overland flow.

Eventually overland flow discharges into discrete channels. A *stream* is any size channelized body of running water (small creeks to giant rivers).
Stream discharge is the term used to describe the volume of water moving through a channel (commonly ft$^3$/s or m$^3$/s).

This discharge of a river can be measured with the following equation:

\[
\text{Discharge (m}^3/\text{sec}) = W_c \text{ (m)} \cdot D_c \text{ (m)} \cdot V_s \text{ (m/sec)}
\]

\[
= A_c \text{ (m}^2) \cdot V_s \text{ (m/sec)}
\]

Burt Carter, Georgia Southwestern State University
A stream **hydrograph** is a plot that shows the stream discharge versus time.

The stream hydrograph shows that there is a *lag time* between precipitation events and changes in stream discharge.
The *lag time* is due to the amount of time it takes for water to flow across the landscape (*overland flow* and stream flow) and accumulate in a channel.

The *lag time* will also be a function of the distance between the where the rain occurred and where the *stream discharge* is being measured.
Natural surfaces permit infiltration of precipitation. Urbanization results in resurfacing where natural surface is replaced with artificial surfaces that do not absorb precipitation.

The lag time in stream discharge after precipitation may decrease and result in the possibility of flooding.
This *hydrograph* shows spikes in stream discharge due to precipitation (darker blue) events superimposed on a baseline discharge (light blue).

*Groundwater baseflow* represents the discharge of groundwater into a stream. Note that the baseflow is fairly continuous and is independent of the sporadic input of water from other sources (e.g., precipitation).

*Baseflow* conditions permit the stream to maintain a minimum flow throughout the year and is critical to maintaining stream ecosystems.
Climate is an important parameter regarding the interaction between streams and groundwater.

In regions with abundant precipitation where water infiltrates water into the subsurface, the water table may be higher than the stream channel (A). This type of stream is known as a *gaining stream*.

In more arid environments, the stream water may flow into the groundwater system (B). This type of stream is known as a *losing stream*.
Drainage Networks and Basins

As a stream flows downhill, it merges with other streams. The smaller of the two merging streams is known as a *tributary*. A branching network of streams known as a *drainage system* forms where the merging tributaries form progressively larger streams.

The bottom image shows a tributary network on the surface of Mars.
The upper part of the drainage system is called the *headwaters* (sometimes called the *source*).

One important characteristic of a drainage system is the large number of *tributaries* in the *headwaters*.

The lower part of the drainage system where it empties into an ocean or lake is known as the *mouth*. 
Headwater tributaries are found in narrow, steep valleys.

As the stream gets closer to the mouth, the river and the valley that it occupies becomes wider and the steepness of the channel decreases.

One characteristic of a mature stream (after it has exited the headwaters) is the development of tight S-shaped curves known as meanders.
The *stream gradient* is the grade or the drop in elevation of a stream (as a ratio) and is usually expressed as feet/mile or m/km.

Generally, streams have a steeper slope or higher gradient at the headwaters and a higher water velocity. Toward the mouth of a stream, there is a lower gradient and lower water velocity.
Individual drainage systems can be separated from one another by a topographic feature such as a mountain ridge known as a *drainage divide*.

Precipitation that falls on different sides of the *drainage divide* will enter different drainage systems.
The map shows the major *drainage divides* in North America. These divides represent drainage networks that terminate in different oceans (or the Great Basin).

A large scale example is the *Continental Divide* that separates drainage networks that terminate in the Pacific from the rest of the continent.
A **watershed** (drainage basin or catchment) is the area of land where water from precipitation converges to a single point where it may exit the basin to the ocean. In the continental US, there are 2,110 watersheds.

Drainage basins are separated from one another by topographic features (geographical barriers) such as a mountains.
This map shows the major watersheds in North America.
The Mississippi River has the world's fourth largest watershed (3,220,000 km²). It is found in 32 U.S. states and two Canadian provinces and empties into the Gulf of Mexico. 40% of the landmass of the continental United States is covered by the Mississippi watershed.

Any precipitation that falls in the Mississippi watershed will move into one of the river’s tributaries, eventually enter the Mississippi River and finally discharge into the Gulf of Mexico.
### Some of the World’s Largest Rivers

<table>
<thead>
<tr>
<th>River</th>
<th>Drainage Area km²</th>
<th>Ave. Discharge m³/sec.</th>
<th>Sediment Load (tons/year)</th>
</tr>
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<tbody>
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</tr>
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<td>4,014,500</td>
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Differences in the major rivers are due to climate and local geology.
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Note the Congo and Mississippi have about the same size drainage basin. Why is the discharge of the Congo so much greater?

The Congo basin is in a wet tropical climate compared to the Mississippi.
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Note that the Amazon has a much larger drainage basin and discharge than the Ganges/Brahmaputra rivers. Why does the Ganges/Brahmaputra have much larger sediment load than the Amazon?

- The Ganges/Brahmaputra Rivers transport much more sediment since it drains the Himalaya Mountains.
Stream Erosion, Transport and Deposition

Fastest flow is usually toward the center of the channel - related to frictional resistance along the sides of the channel.

With straight channels the fastest water is in the center of the stream.

Fastest water is on the outside of a river-bend, slower on the inside.
Since the highest velocity water flow is on the outside of a bend in the channel, *erosion* occurs on the outer bank of the bend. The lowest velocity occurs on inside bank where *deposition* of sediment occurs. **Point bars** are deposits that form on the inside curve of meanders, where the water velocity is lower. **Meanders** are S-shape curves that are the result of erosion and deposition on opposite banks of a river.
Meandering Streams

Point bars accumulate on the inside and erosion occurs on the outside of river bends, causing the channel to *migrate*. The ultimate effect is for the river to *abandon* the channel - forming an *oxbow lake*.

*Meanders* are characteristic of mature streams with a low gradient. Much of the erosion of the stream is in a lateral sense.
Note that the previous channels of the river can be seen in this meander.
The top image shows a map of the Mississippi River’s channels (produced in 1944). Below is a satellite image of the same region. The modern river channel is superimposed on channels from 1880, 1820, 1765 and prehistoric channels. An oxbow lake remains from 1785 channel.

In the 20th century, the rate of change on the Mississippi slowed due to engineering to maintain towns, farms, roads and shipping routes. Levees now prevent the river from changing its course so often.
Erosion on the outer bank of a meandering stream.

Now you know what side of the river to build your home.
If the *stream gradient* is high, streams may also cut downward into the channel forming deep canyons. This is most common when the gradient is large (mountainous region) or the region is experiencing tectonic uplift (ex. Colorado Plateau).
When a stream empties into a lake or ocean, the *gradient* drops to zero. *Base level* is the concept that describes the lowest level that a stream can erode.

Oceans represent the ultimate *base level* but a lake may represent a temporary or local *base level*.
Generally, river *gradients* decrease from the headwaters to the mouth. As the gradient becomes less steep (the channel gets closer to the base level), there is less downcutting of the stream.

The stream may put more of its erosive power into lateral forces forming *meanders* and wide river valleys.
Sediment Transport and Deposition

1) **Dissolved load** - transport of ions and chemicals in solution - responsible for the saltiness of the sea.

2) **Suspended Load** - typically the largest load - clays, silt and fine sand. This material settles out when the river slows (settling velocity) usually in an ocean or lake.

3) **Bed Load** - the material that is transported along the river bed - rolling, sliding and saltation - where the particles bounce or skip along the river bed.

**Mississippi River:**

- 26% Dissolved
- 67% Suspended
- 7% Bed load
Prior to 1900, the Mississippi River transported ~400 million metric tons of sediment per year. This has decreased to ~145 million metric tons per year. The reduction in sediment transported by Mississippi River is the result of engineering modification of the Mississippi and its tributaries.

The image shows the discharge of the suspended load of the Mississippi River into the Gulf of Mexico.
Saltation is one of the processes for the transport of the bed load where particles are either plucked out of the bed by the force of the water or are knocked out by landing grains.

Saltation is also a process in wind (aeolian) erosion.
The sediment on in a river bed is evidence of the bed load of a stream.
Deposition of Stream Sediments

*Alluvium* is the term used for sediment deposited by a stream. *Hydraulic sorting* occurs as stream velocity drops (where all of the material is suspended), larger particles drop out, then smaller and so on. This has the effect of sorting the sediments by *size* and *density* - important to placer gold mining.

![Poorly Sorted Sediment](image1.png) ![Well Sorted Sediment](image2.png)
Hydraulic sorting results in bar deposits that are composed of boulders and large gravel due to high water velocity (due to high gradient). Further downstream where the gradient and water velocity is lower, bar deposits become finer (sands and clay).

A tube or jar of sediment demonstrates the easily demonstrates the hydraulic sorting of alluvium where the coarser particles are at the bottom and fine upwards.
Deltas form at the mouth of a stream where it terminates in a lake or ocean. When the gradient and velocity drop, sediment is deposited in the ocean or in a lake.
Deltas are dynamic structures and change rapidly with time.

The top image shows how Mississippi River delta has changed its location in the last 4600 years.
*Hydraulic sorting* results in different size particles being deposited in different locations on the delta. The brown colors represent coarser sand and silt particles falling out of suspension. The light blue colors represent finer clay particles that settle further offshore in a less energetic environment.
Alluvial fans form at the mouth of a stream where it empties into a valley. When the gradient and water velocity drop, sediment is deposited in a fan-shaped structure on the valley floor. **Alluvial fans** form in arid regions in a terrestrial setting.
Alluvial fans and deltas are similar structures, and differ mainly by being deposited either above or below water.
As a river approaches base level and creates meanders, wide valleys are formed. Deposition on the valley floor builds a broad flat plain known as a floodplain.

When a river floods, the floodplain is the first area to be flooded. Floodplains are an important ecosystem. Floodplains store water during a flood and are an integral part of the drainage system.
Flooding and Flood Hazards

*Flood stage* is the height of the river when it overflows its banks.

The amount of flooding is often termed as the height of the river above *flood stage*. The example in the figure shows the level at 10 ft. and 20 ft. above *flood stage*. 

Adapted from USGS
Another way to quantify flooding is by river discharge. Since the calculation of discharge involves the height of the river, there is a direct relationship between discharge and stage.

\[
\text{Discharge} = W_c \times D_c \times V_s
\]

The USGS maintains a network of >9500 river gauges that continuously measure discharge - discharge and other data are available in real time over the internet. These data are used to monitor rivers and predict flooding.
Flooding is dependent upon weather events. The National Weather Service monitors weather and issues flood and other weather warnings based on current weather conditions.

Local news organizations get their data from the NWS to issue flood and other weather warnings.
Due to the random occurrence of weather events, predictions about flooding (in the medium- and long-term) are based on statistical probabilities. Projections about major floods are based on historical discharge data over a long period of time.

The figure shows a typical plot relating the probability/frequency of maximum discharge to the recurrence interval and percent probability.
Recurrence intervals are statistical in nature and a 100-year flood does not occur every 100 years. A 100-year flood has a 1% probability of occurring.

Note that low-discharge events are more numerous and have a higher probability of occurrence. Progressively larger discharges (floods) have longer recurrence intervals.

Stephen Nelson, Tulane University
Natural Factors that Affect Flooding

1. *Nature of precipitation events.* Potential for flooding increases with intensity and duration of precipitation.
   A. Spring and summer floods are commonly associated with intense rainfall associated with thunderstorms.
   B. Large regional floods can be produced by less intense precipitation over a long period of time.
   C. Snowmelt may cause large floods during the spring.

2. *Ground conditions.* *Infiltration capacity* is the ability of the ground to absorb water. Infiltration capacity is affected by:
   A. Slope - steeper slopes have lower *infiltration capacities*.
   B. Nature of the surface - some surface materials have an inherently lower *infiltration capacity* (asphalt, clay, etc.).
   C. Water content - water saturated soil has a lower *infiltration capacity*.

3. *Vegetation cover* - vegetation reduces the volume of overland flow by absorbing water and restricting the flow of water.