CE/SC 10110-20110: Planet Earth

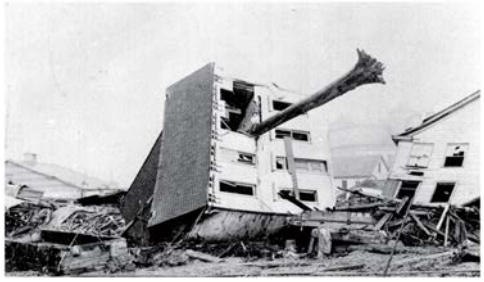
Streams and Floods

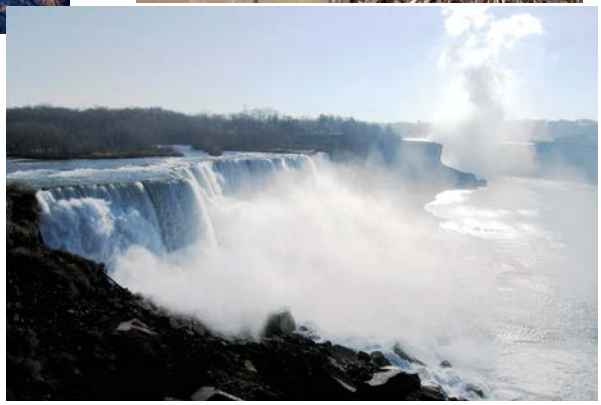
Earth

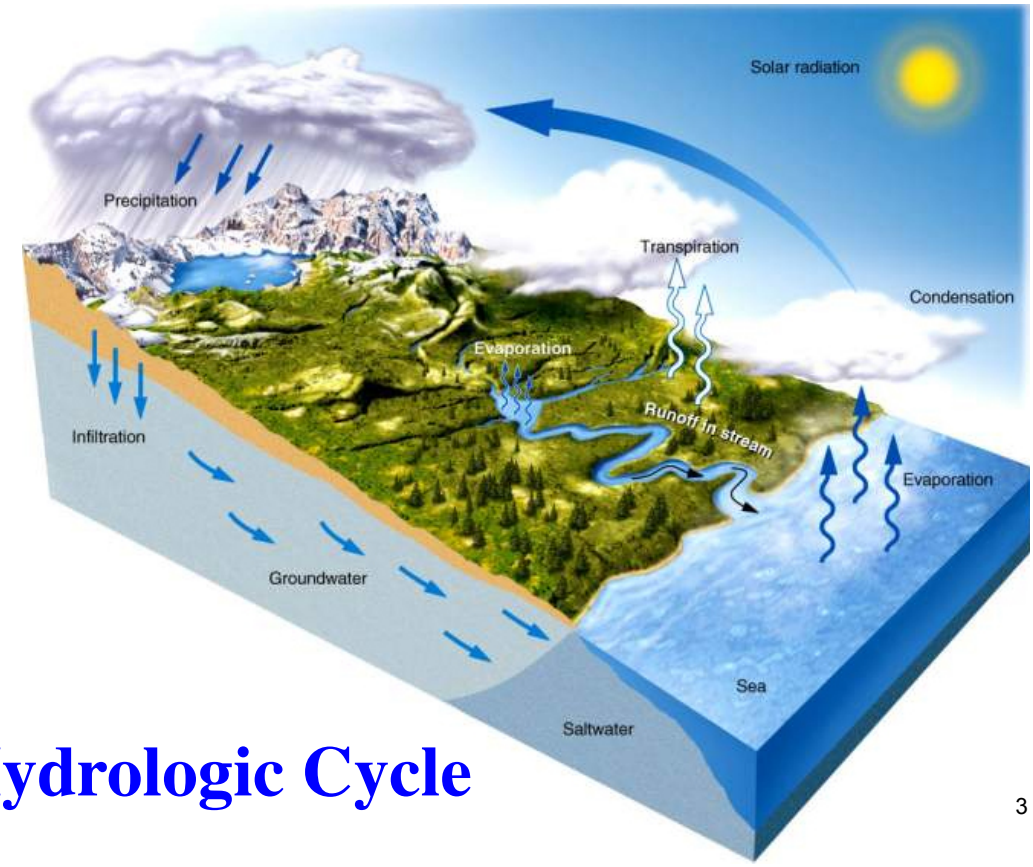
Portrait of a Planet
Fifth Edition

Chapter 17

Stream Runoff – Draining the Land







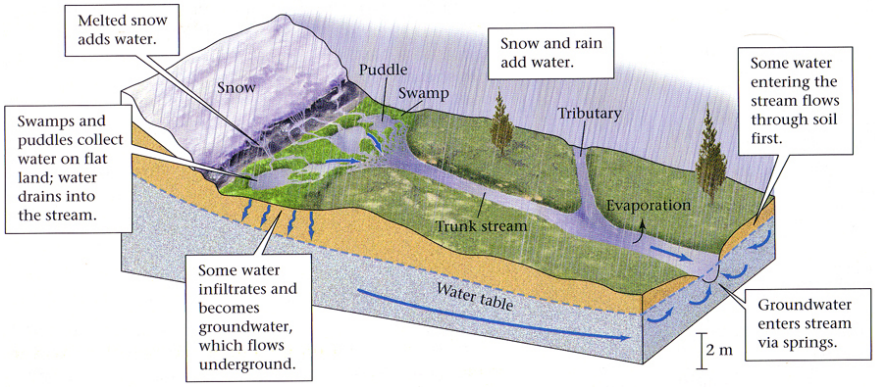
Hydrologic Cycle

Rivers & Streams: Basics

River = big stream!
Reach = any segment along the length of the stream.
Meander = curving reach.

Sheetwash: unchanneled sheet of water, especially in deserts (no vegetation).

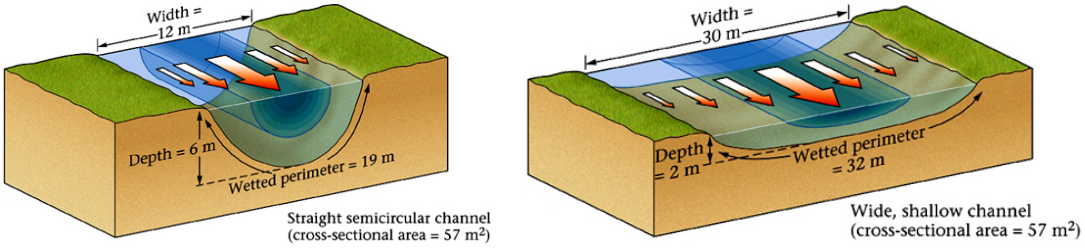
Channel flow – in a channel! This is where a river/stream is *most* of the time. Deepest part of the channel = ***Thalweg***.

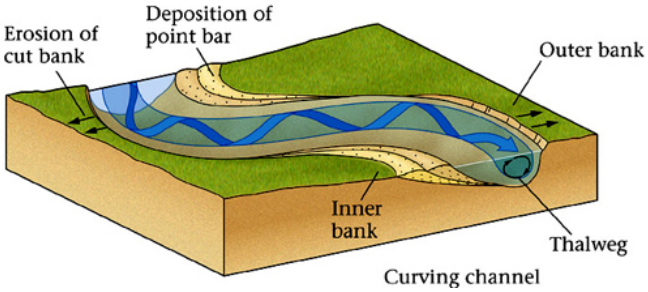


Rivers & Streams: Basics

Types of Runoff: Depends on surface roughness and flow velocity.

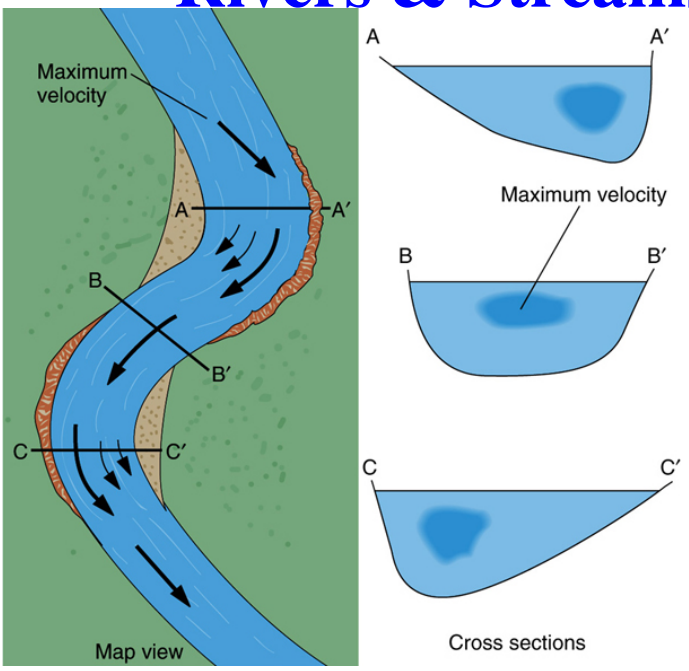
Laminar: water moves slowly along a smooth channel, following straight, parallel lines, follows slope of containing boundary. More friction in wider, shallower streams





In a curved channel, the fastest and deepest flow shifts towards the outer edge of the stream (over the ***THALWEG***). The water follows a spiral path - surface water flows faster toward the outer bank, water deeper down must flow toward the inner bank to replace the surface water.

Rivers & Streams: Basics



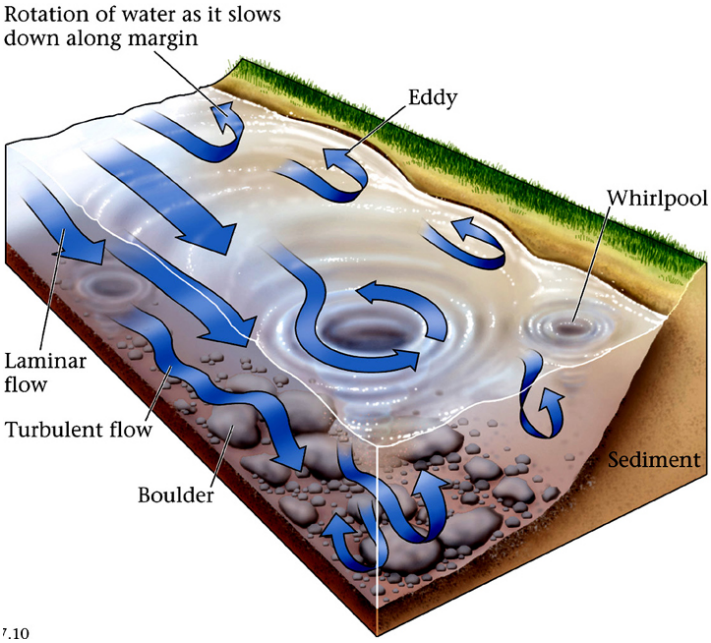
Velocity changes with:

Depth of channel.

River "bendiness" – fastest on outside of curves – further to travel.

Rivers & Streams: Basics

Turbulent: water moves along an erratic path, deflected by the sides and bed of the channel (and obstructions) with the formation of eddies and swirls (shearing motion).



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Rivers & Streams: Basics

Flood Plain: flat area adjacent to the river channel that periodically floods. Fertile soil.

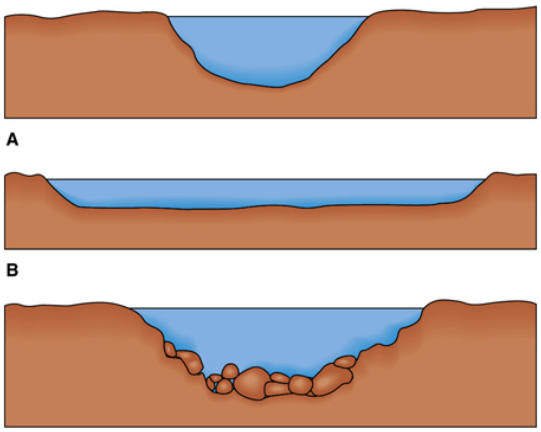
Natural Levee: natural sediment build up that resists floods.

Banks: sides of river channel

Channel: where the water flows during non-flood stages.

Stream Velocity: moderate ~5 km/h; flood >25 km/h.Velocity is a function of:

- **Stream gradient**: vertical distance/ horizontal distance. Given as m/km or %.
- **Frictional resistance**: shape of channel, perimeter roughness.



Rivers & Streams: Basics

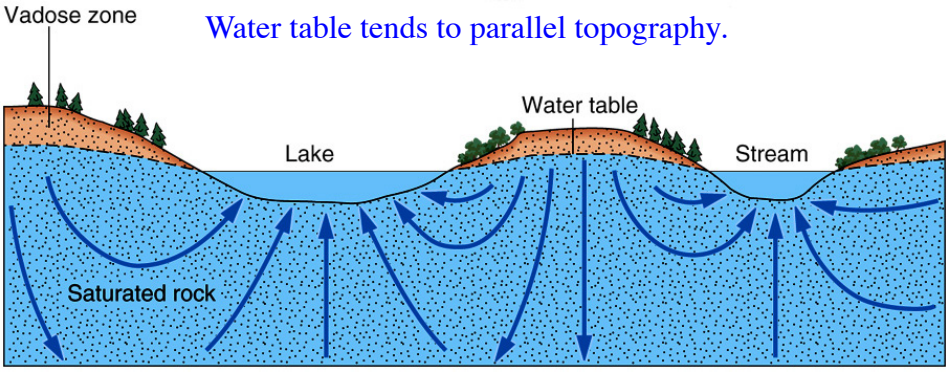
Water Table: Surface that is the contact between saturated and unsaturated zones.

Humid Regions: cm to m below surface;

Arid Regions: 10s of meters below surface.

Springs are where the water table and the ground surface intersect.

Water table tends to parallel topography.



The water table comes to the surface at springs, edges of streams, & lakes.

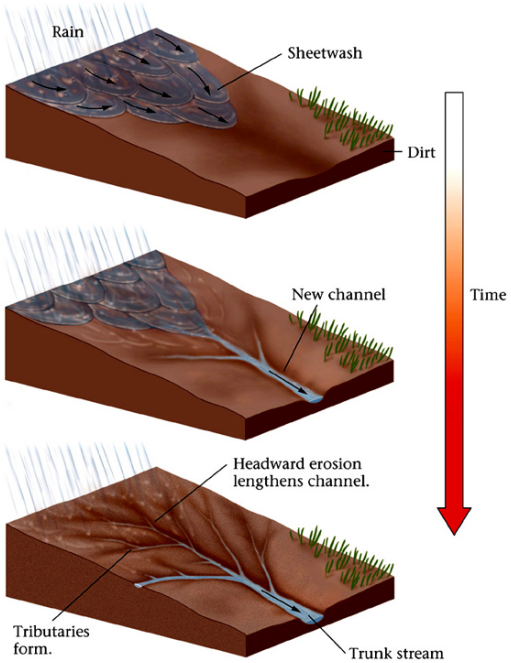
Streams & Drainage Networks

Streams begin as ***sheetwash***. Heterogeneities in the surface promote channel formation through ***downcutting***.

Tributaries: smaller streams joining the main or **trunk** stream.

Together, these form a ***drainage network***.

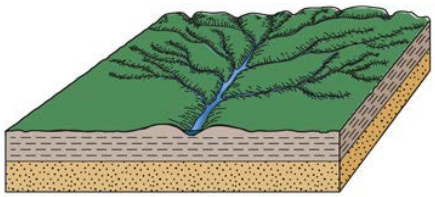
Stream migrates upstream through **headward erosion** - flow is more intense at the entry to the channel.



Streams & Drainage Networks

Patterns produced depend strongly on the nature of the *bedrock* (homogeneous vs. heterogeneous vs. faulted/ jointed).

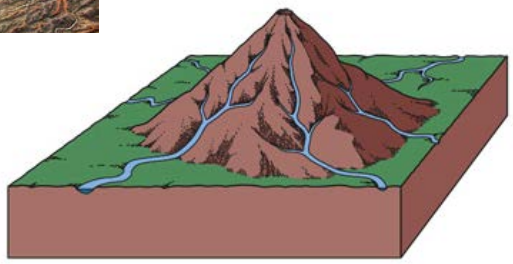
A Dendritic



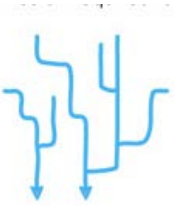
Dendritic: homogeneous bedrock (igneous, metamorphic **or** sedimentary with horizontal bedding). Not heavily faulted or jointed.

Radial: volcanoes and domes.

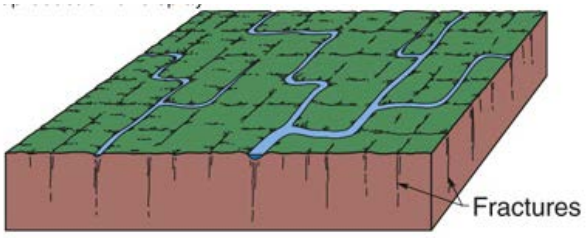
B Radial



Streams & Drainage Networks

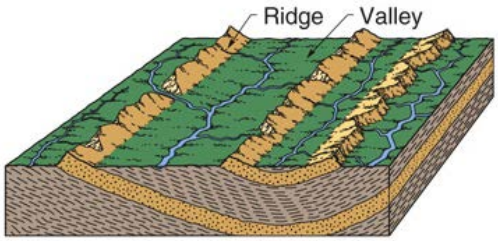


C Rectangular



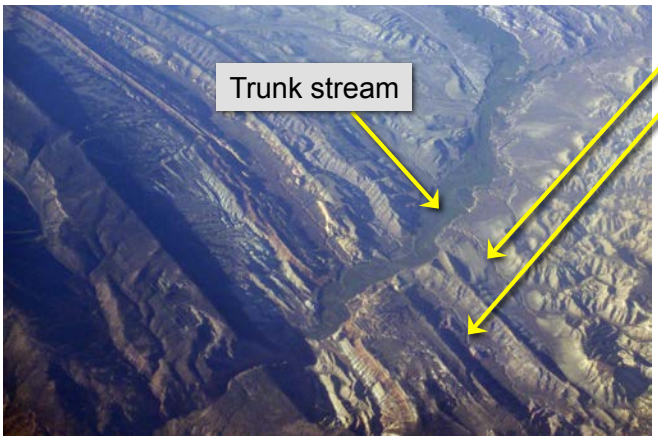
Rectangular: Faulted/jointed bedrock. Square patterns. 90-degree turns are common and streams enter each other at right angles.

Streams & Drainage Networks



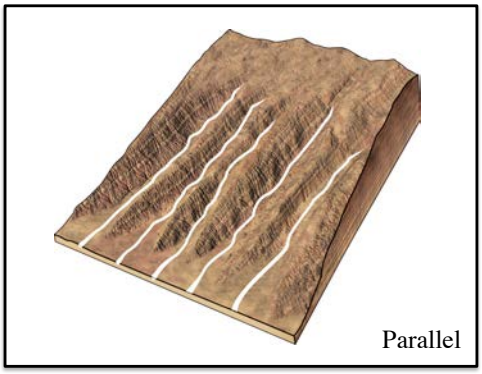
Trellis: Dipping beds of sedimentary rocks of alternating resistance to erosion (e.g., alternating limestone and sandstone).

D Trellis



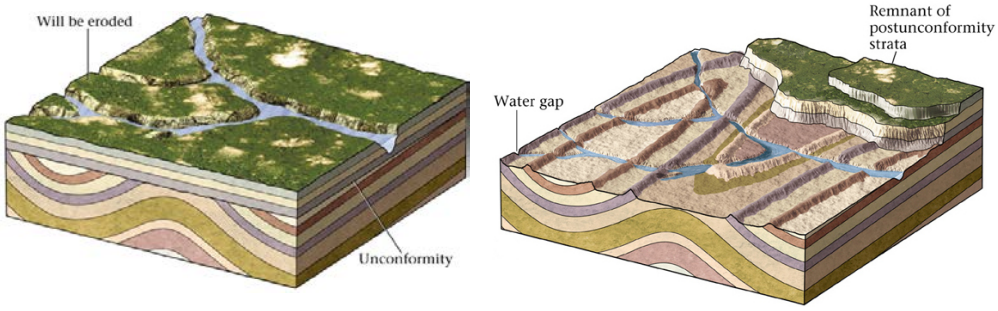
Streams & Drainage Networks

Parallel: On a uniform, fairly steep slope, several streams with parallel courses develop simultaneously. Typically form on on the sides of steep escarpments of weak substrate. If the weak substrate has no sediment on top of it, it is called ***badlands topography***.

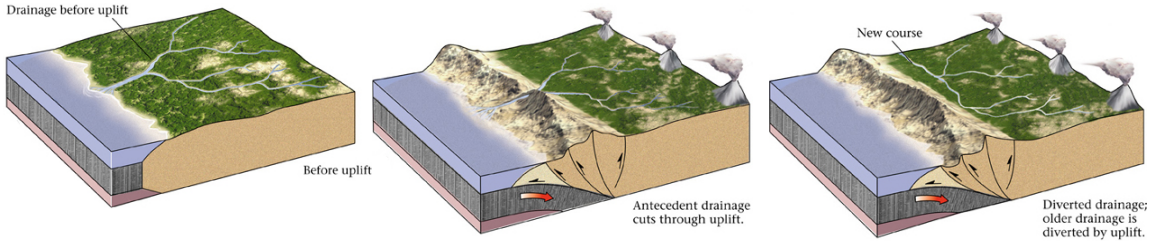


Streams & Drainage Networks

Superposed Streams: erode through an unconformity but maintain the drainage pattern.



Antecedent Streams: stream maintains its flow pattern during tectonic activity.

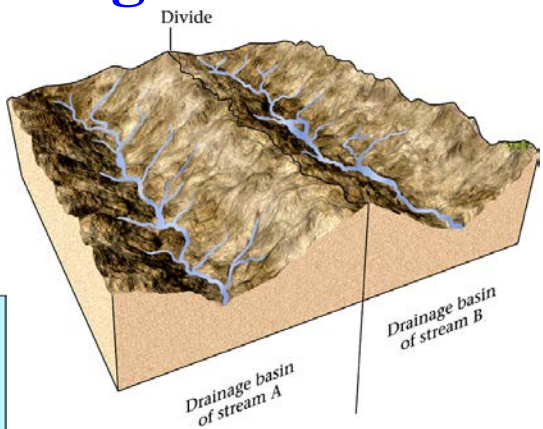


Streams & Drainage Networks

Headwater: beginning of the streams, high elevations in the drainage basin.

Mouth: where the river enters a larger body of water (ocean, lake, etc.).

Divide: high area that separates drainage basins.



Drainage Basin: An area in which all runoff flows into a single stream (e.g., Mississippi River and on more local scale).

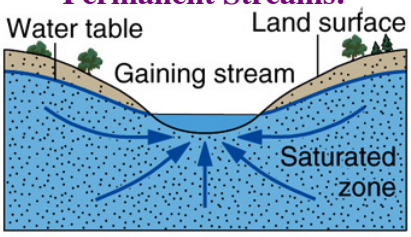
Streams & Drainage Networks

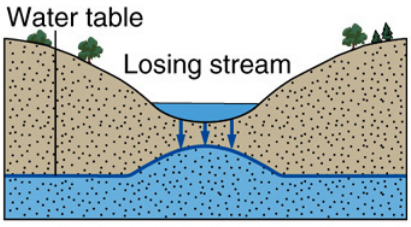
The Amazon Watershed

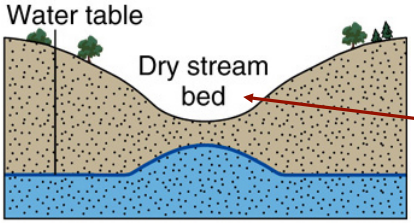
Permanent streams are defined by water flowing all year. These streams are common where there is abundant rainfall, groundwater discharge, and low rates of evaporation.

Permanent and Ephemeral Streams

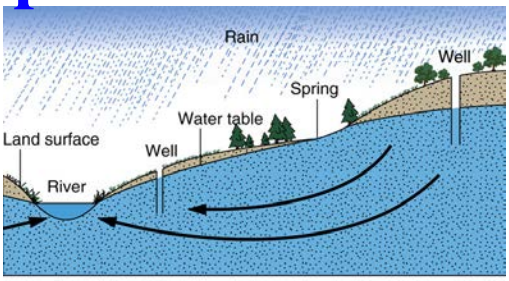
Permanent Streams.



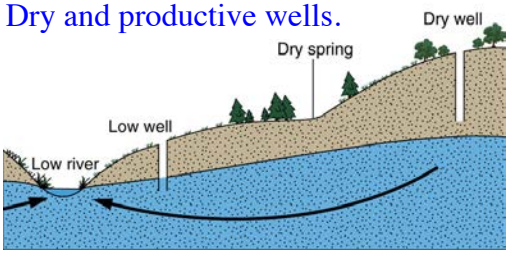




Ephemeral Stream



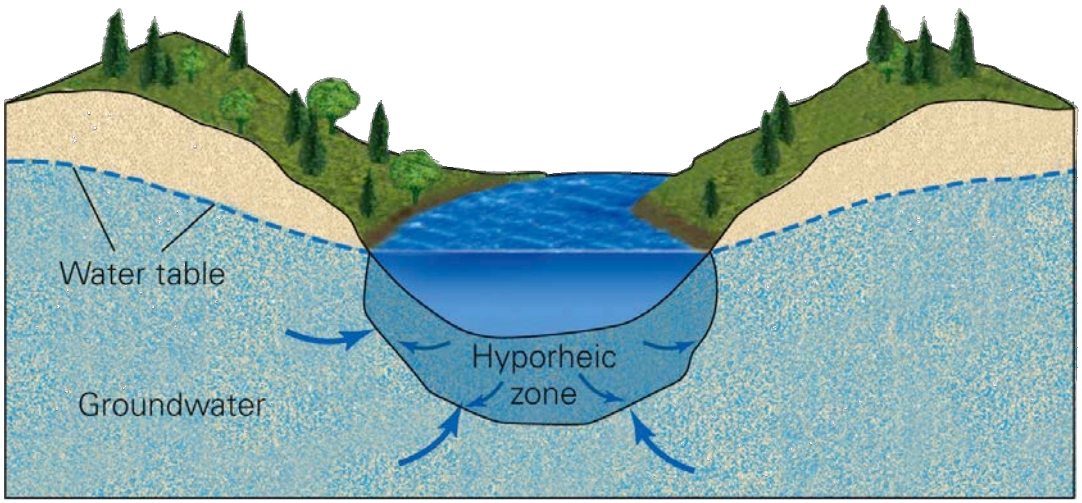
Dry and productive wells.



Water table depth can vary seasonally – springs can dry up during dry season

Dry wash or **Wadi**.

Permanent and Ephemeral Streams



Hyporheic zone: surface/groundwater exchange

Discharge & Turbulence

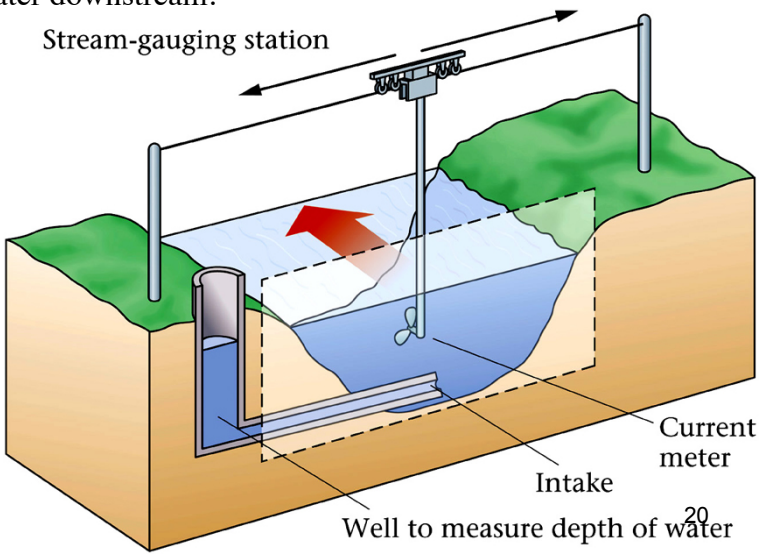
Discharge: volume of water flowing through a given point in a stream in unit time.

$$\text{Discharge} = A_c \times v_a$$

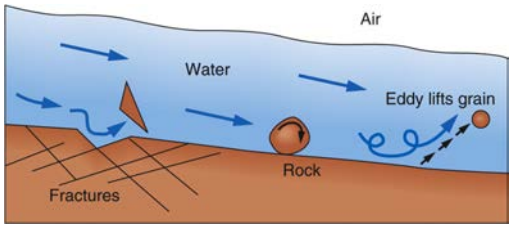
A_c = stream cross section.
v_a = average velocity of water downstream.

Measured at a Stream-Gauging Station.

Discharge can increase downstream in temperate climate because of impact from tributaries and groundwater. In arid climates it may decrease due to infiltration and evaporation.



Stream Erosion



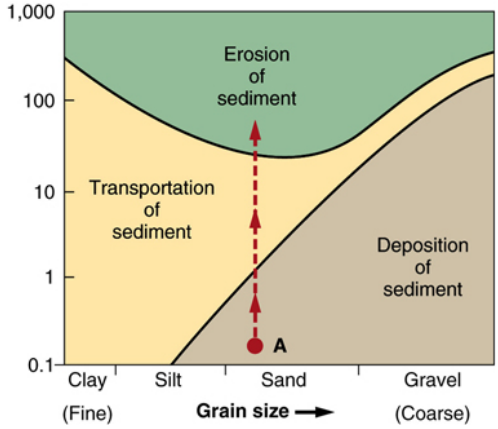
Stream erosion occurs in four ways:

Dissolution: water dissolves soluble components;

Scouring: removal of loose fragments;

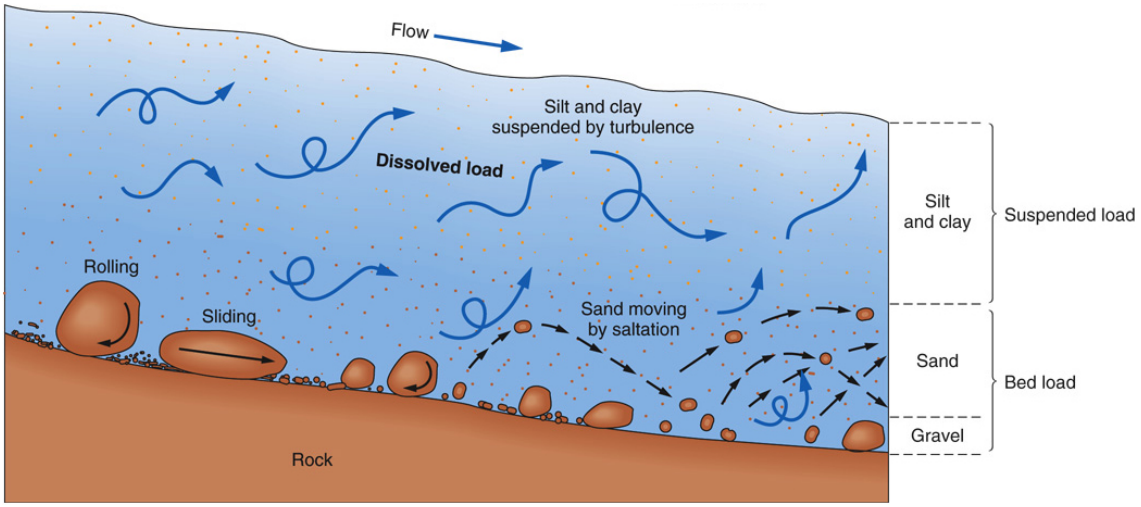
Breaking & Lifting: pressure of flowing water can break rock fragments off the channel floor and walls. Flow can also cause clasts to rise/lift off the floor.;

Abrasion: equivalent of sand-blasting - can form ***potholes***.



Stream Transport/Erosion

Stream Load: total material that the river is carrying.

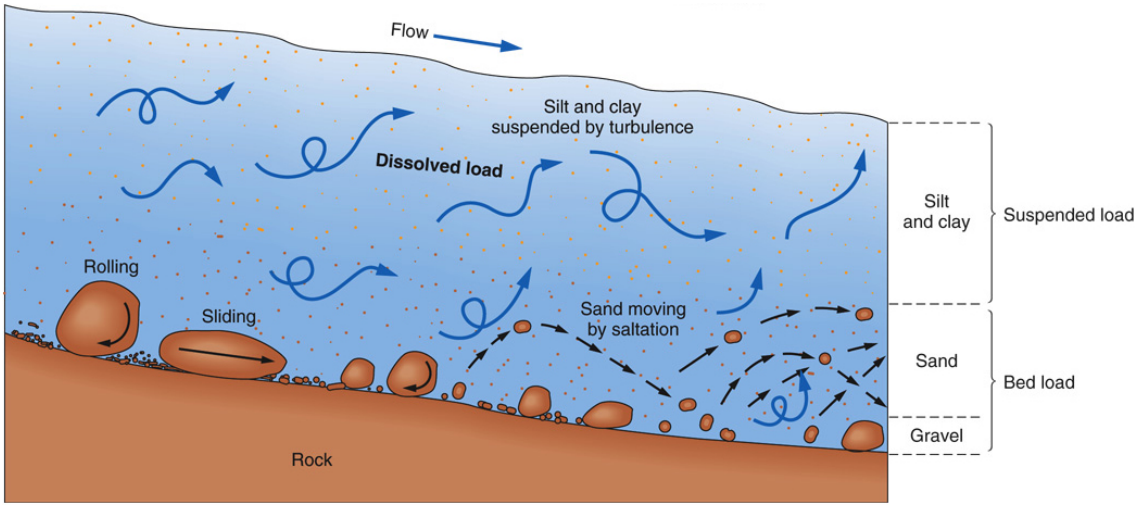


Dissolved Load: ions in solution.

Clastic Load: clasts of sediment being moved by the river.

Stream Transport/Erosion

Clastic Load: Suspended & Bed Loads.



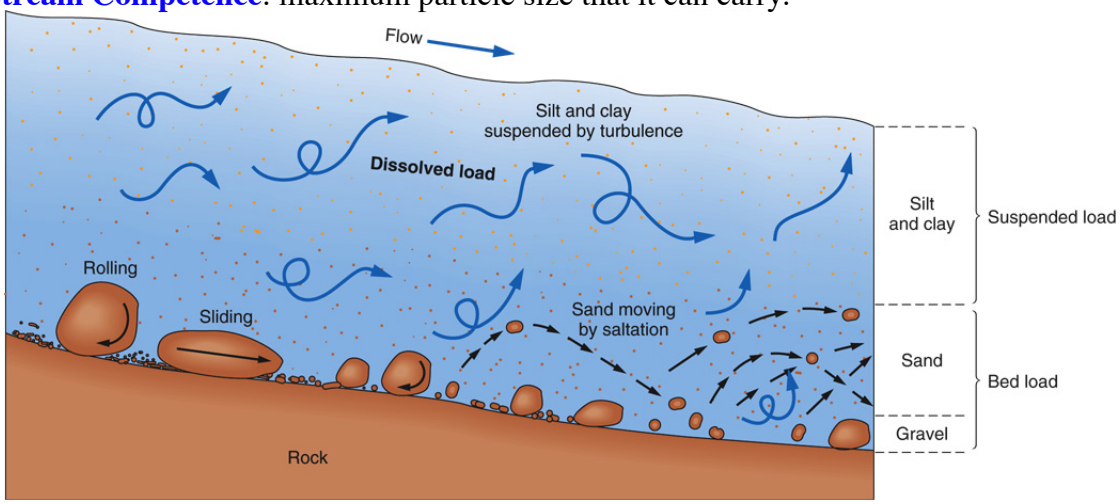
Suspended Load: typically clay and silt. Remain suspended because stream velocity exceeds the settling velocity of the particles.

Bed Load: grains rolling along the stream bed because stream velocity is less than the settling velocity of these particles. Typically sand and gravel.

Stream Transport/Erosion

Stream Capacity: Maximum load stream can carry. Streams are rarely loaded to capacity because weathering & erosion are slow processes.

Stream Competence: maximum particle size that it can carry.



Traction: grains rolling/sliding along.

Saltation: "hopping" grains because size is too large for continuous suspension. Typically falling grains dislodge more grains (transfer of kinetic energy).

Fluvial Deposition

Fluvial deposits or ***alluvium*** form when stream velocity drops below settling velocity because:

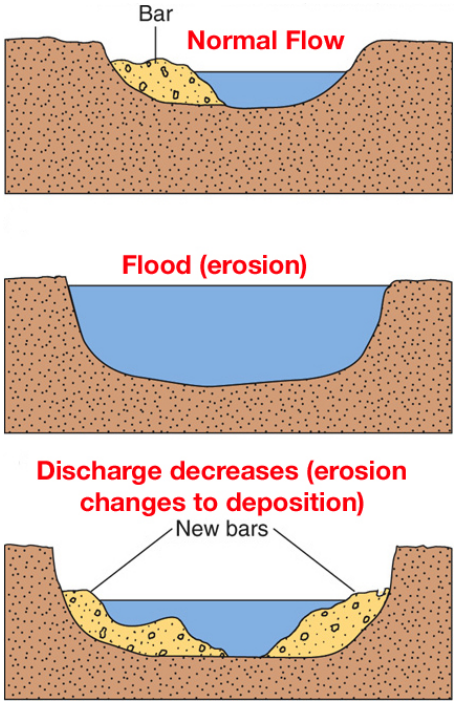
A stream enters a standing body of water.
The channel widens.

The stream gradient decreases.

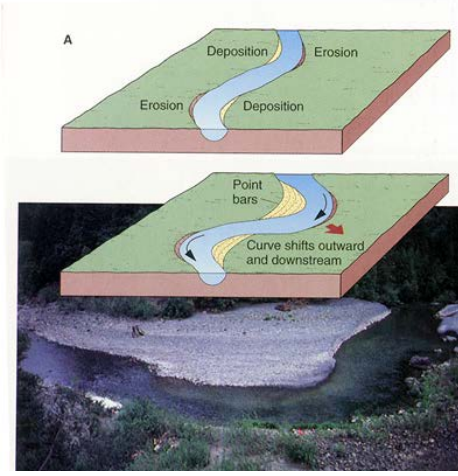
Discharge decreases due to evaporation, infiltration, or removal for irrigation.

Of obstructions.

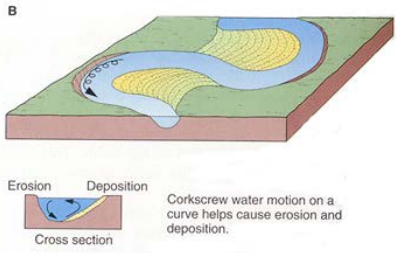
Along the banks and in the middle of a stream due to channel widening.

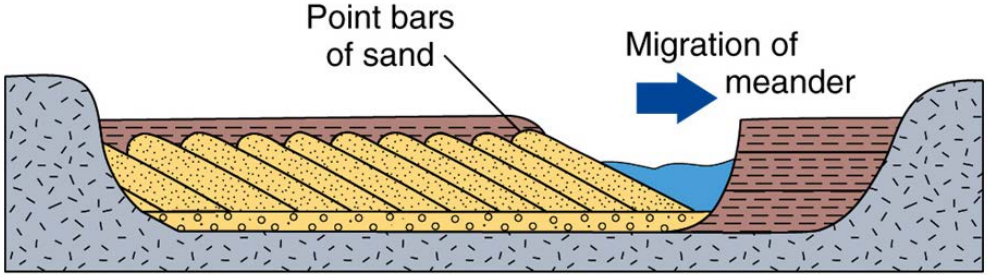


Fluvial Deposition



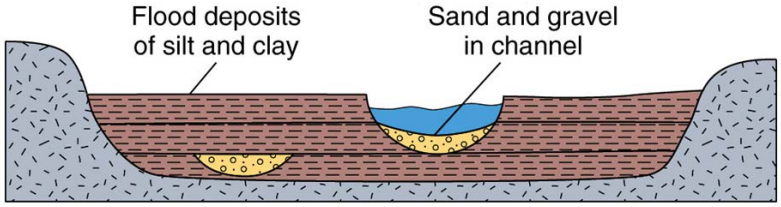
Point Bars





Fluvial Deposition

Flood Plain: flat area outside of the channel. Velocity drops once water has spilled out of the channel and deposits fine sediments (muds/silts).

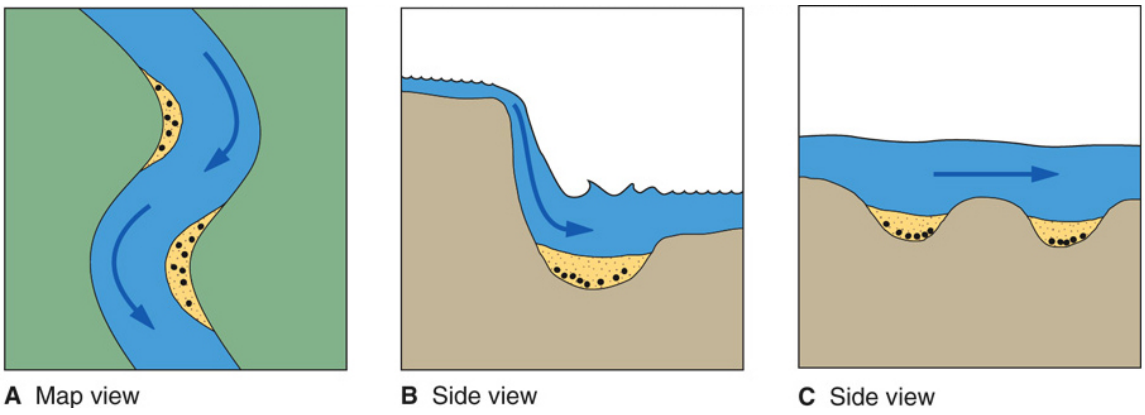


Channel "wanders" in the flood plain taking the "path of least resistance".

Yazoo Streams: tributary streams that run in the floodplain parallel to the main river. They are blocked from joining the main river by ***natural levees***.

Fluvial Deposition

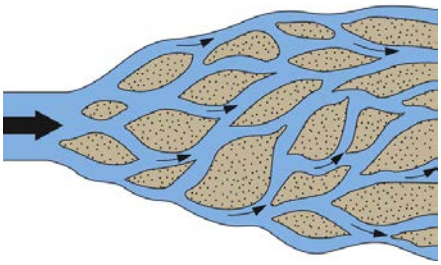
Economic Aspects



Heavy minerals deposited in rivers where velocity is low.

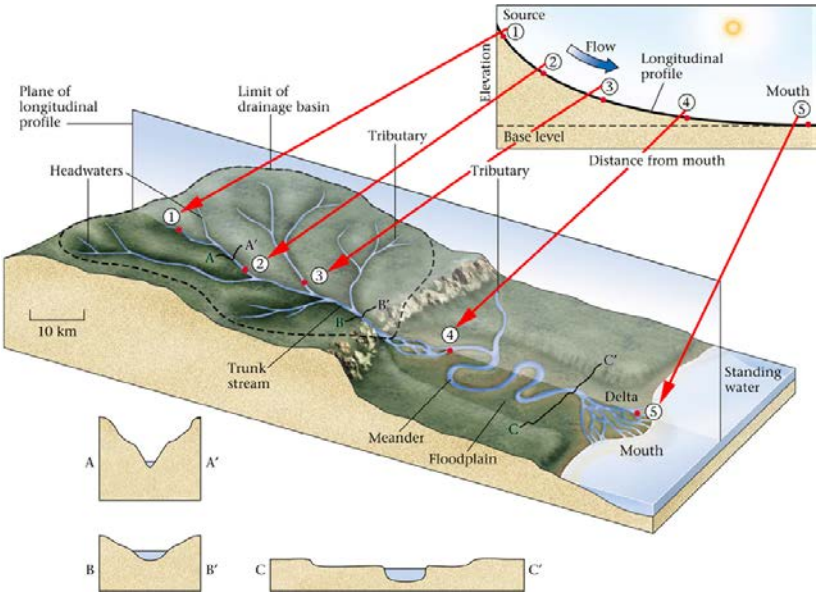
Fluvial Deposition

Braided Streams: sediment load has exceeded stream capacity. Stream divides into numerous strands weaving between elongate mounds of sand and gravel.



Alluvial Fans: Form when a constrained channel becomes unconstrained – velocity decreases and coarser grains get deposited. Typically form when rivers emerge from a mountain range.

River Profiles and Base Level

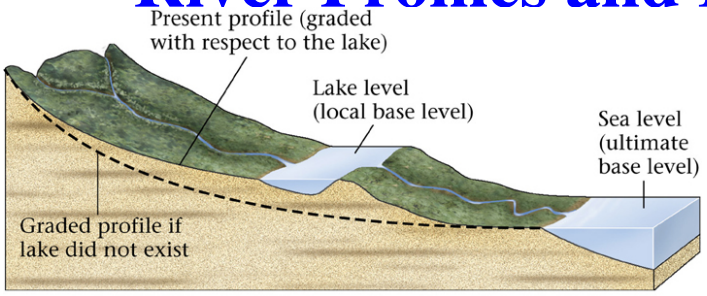


Typically headwaters are in highlands, gradient is high, channel is narrow and confined.

As river flows towards the mouth, gradient decreases, discharge increases, channel increases in size and is less constrained (i.e., floodplain increases).

Obstructions eventually smoothed out. Erosion changes from vertical to lateral from the upper to lower parts of the ***longitudinal profile***.

River Profiles and Base Level



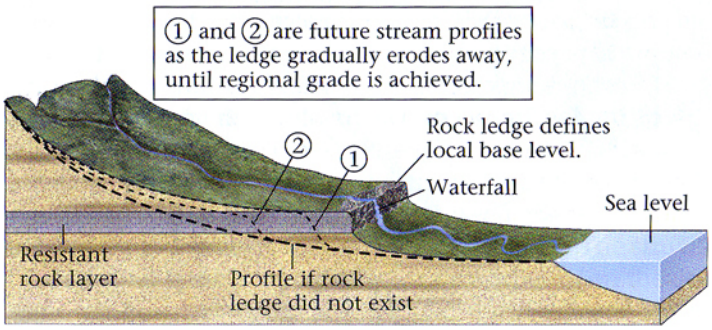
Young streams – irregular with rapids and waterfalls = "**ungraded**".

As stream smooths its longitudinal profile to concave-up shape, it becomes "**graded**".

Streams attain the longitudinal "concave-up" profile over time.

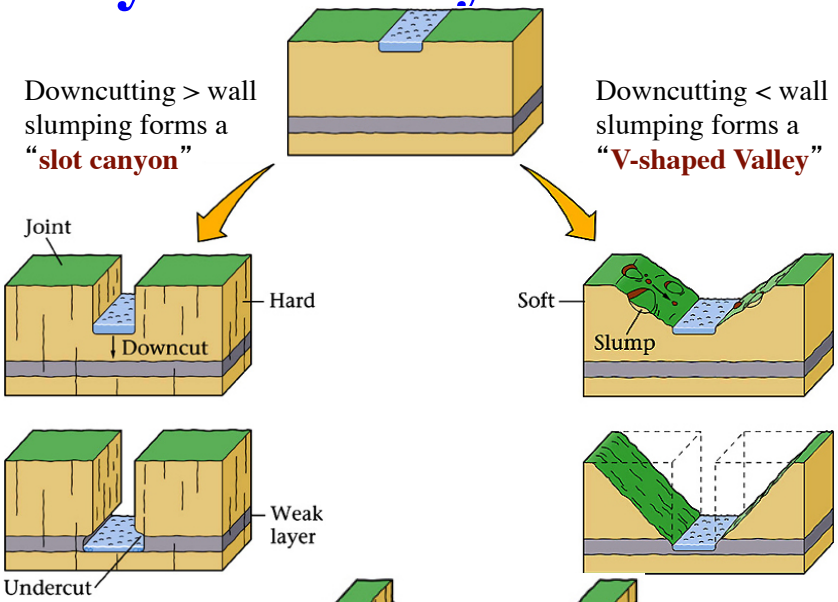
A graded stream is one that can carry all the sediment that has been supplied to it.

This can be interrupted by a dam – changes base level, changes stream grade, and modifies sediment movement. Sediment builds up behind the dam – downstream is then "sediment-starved" (i.e., Colorado River, Grand Canyon).

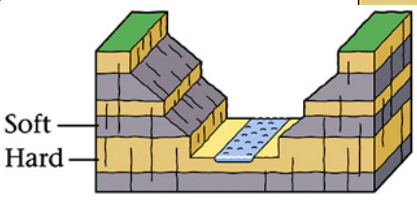


Valleys and Canyons

Whether a stream produces a canyon or valley depends upon rate of downcutting and the competence of the rocks forming the valley walls.

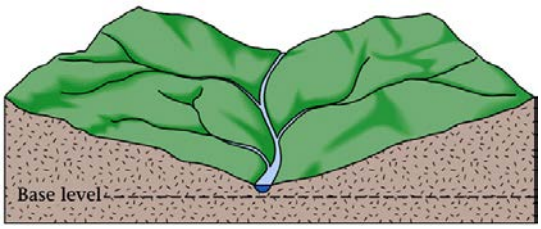


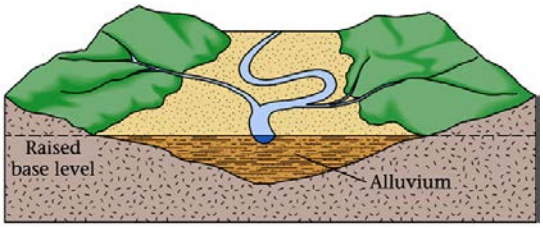
Downcutting through alternate hard-soft layers produces a stair-stepped canyon.



Valleys and Canyons

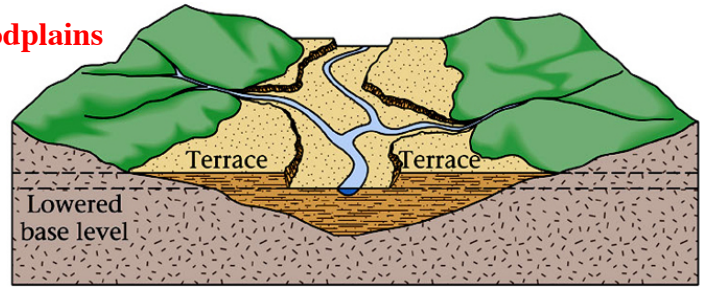
Vertical erosion means the valley floor is generally free of alluvium.
Alluvium is deposited when base-level is reached or it rises.





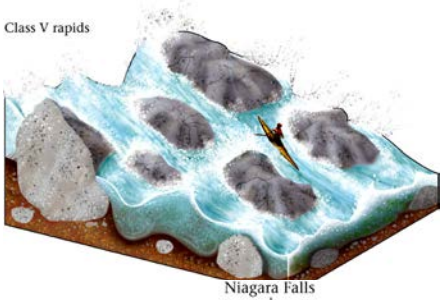
If base level drops and/or uplift occurs, streams cuts alluvium and forms "**stream terraces**".

Raised floodplains

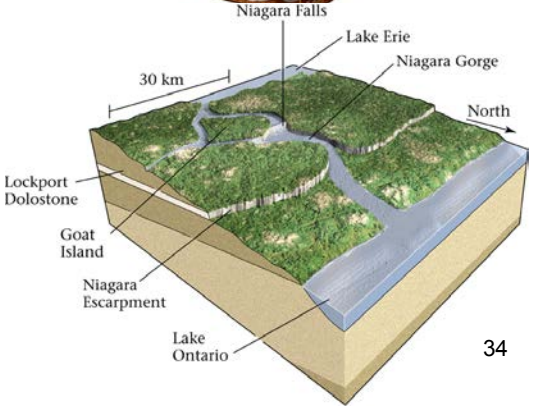


Rapids and Waterfalls

Rapids: form where the stream flow is constricted - passing over large blacks, narrowing of the channel. This creates turbulence.

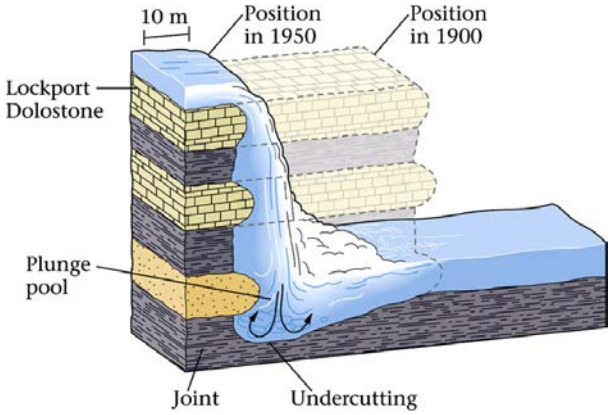


Waterfalls: escarpments (elevated sections), sometimes caused by a change in base level, faulting, variations in rock type, are removed by erosion and migrate upstream (e.g., Niagara Falls).

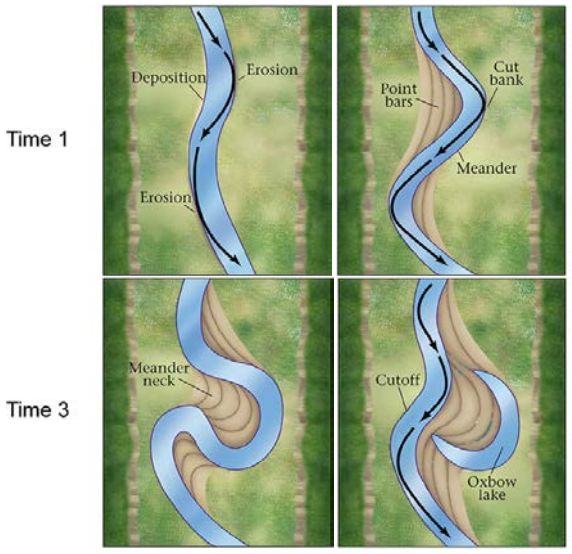


Rapids and Waterfalls

Niagara Falls: water moves from Lake Erie to Lake Ontario. Drops over a 55 m ledge of hard Silurian dolostone, which is on top of weak shale.
Undercutting by the water as it falls (forming a **plunge pool**) cause migration.



Meanders



Develop on the floodplain as river changes from vertical to lateral erosion - it "wanders" over the floodplain.
Eventually meanders are cut off and **ox-bow lakes** form.

Natural Levees

Meandering streams occupy only a small part of the floodplain, which is typically bounded by eroded bluffs. During floods, the entire floodplain may be immersed. **Natural levees** are sand ridges that parallel the channel.

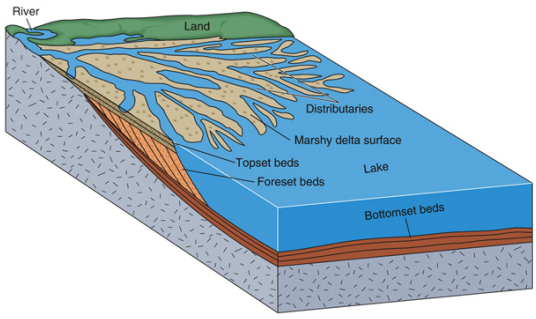
Deltas

Form when river enters a body of water and velocity decreases (e.g., Mississippi). The shape is dominated by the river and is a function of:

Sediment supply, shifting of river mouth.

Waves and currents in the body of water.

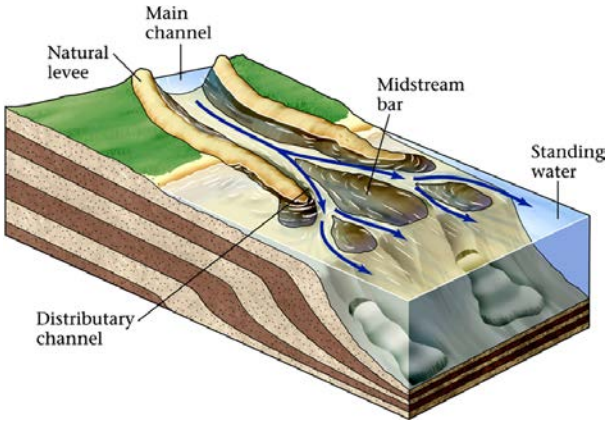
Tides.

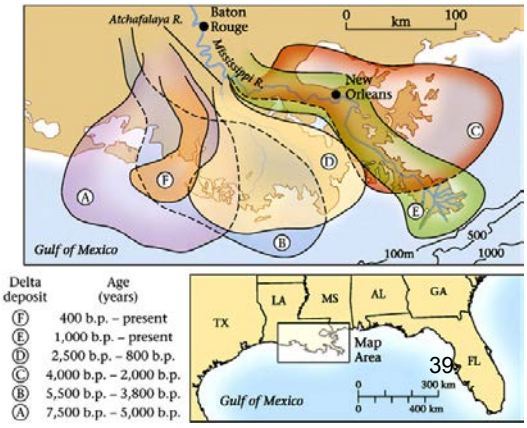


On top of a delta, the stream divides into a fan of distributary channels.

Deltas

Sediment deposition builds out the toe of the delta and reduces the gradient. Eventually, the river cannot flow in this channel - the natural levee is topped upstream and the river makes a new path to the sea. This process = **avulsion**.



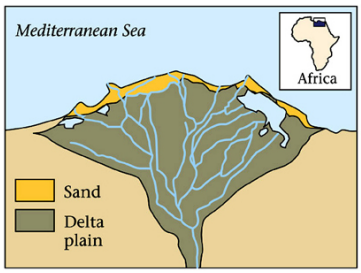


Deltas

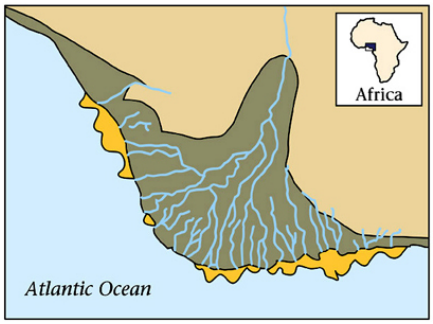
Abandoned delta lobes, starved of sediment, slowly compact, dewater, and subside. Abandoned delta lobes are eventually submerged. Subsidence is a problem for cities built on deltas. Subsidence near (or below) sea level magnifies flooding risks. New Orleans is a prime example.

Deltas

Shape of delta controlled by interplay of river discharge and offshore currents.

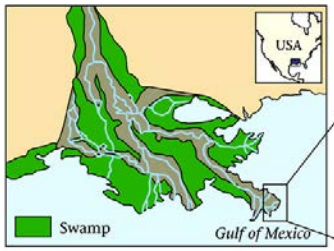


Strong offshore currents do not allow the delta to push into the sea.



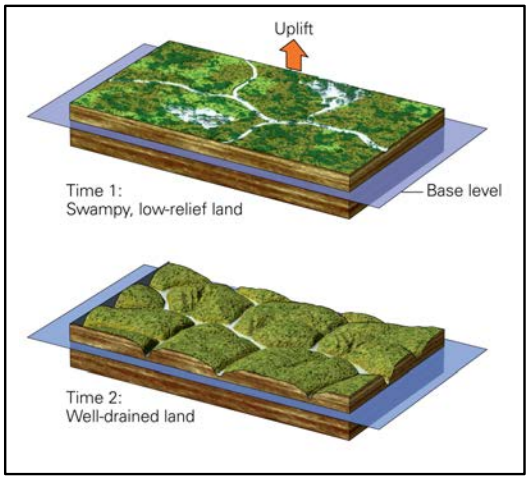
Deltas named by the Greeks after the Nile Delta - it is an upside down Δ.

Birds Foot Delta

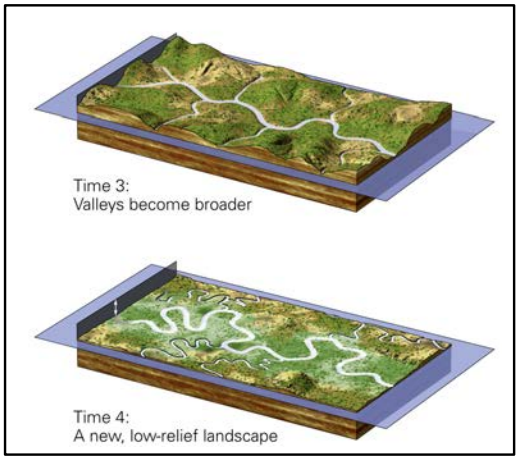


Weak offshore currents.

The Evolution of Drainage: Beveling Topography

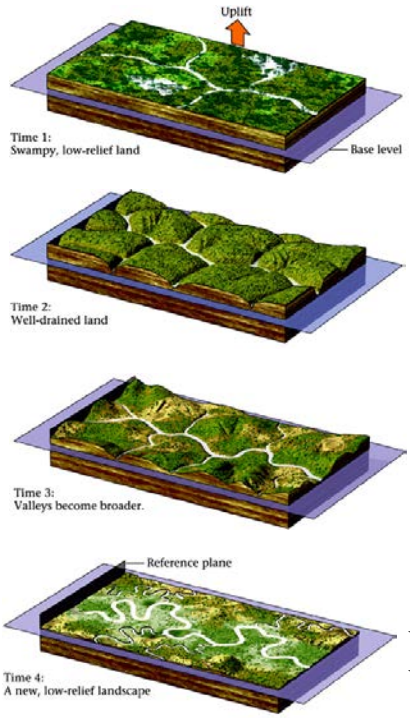


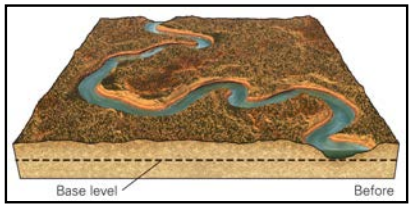
When base level drops, a new equilibrium is slowly established as streams cut into the former surface, valleys widen, and hills erode. Eventually, the landscape is eroded to the new base level.

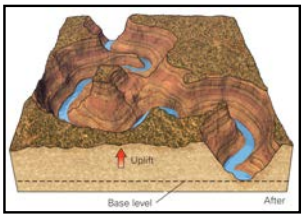


Stream Rejuvenation

Caused by uplift and/or base level drop. Can also cause ***incised meanders***.



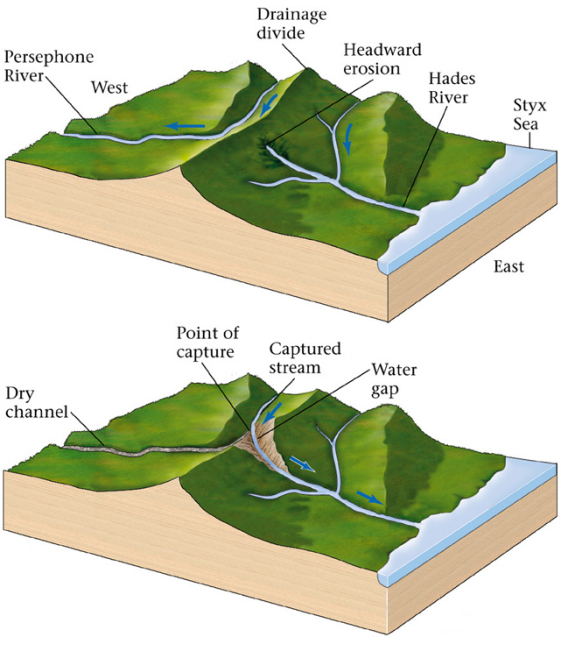


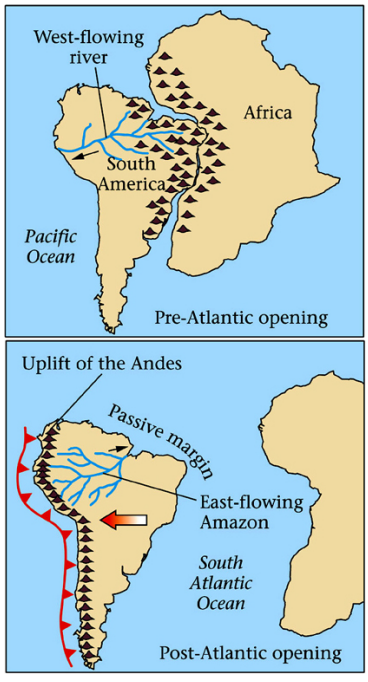


What are the causes of uplift?
What are the causes of base-level drop?

Stream Piracy

Headward erosion allows one stream to "capture" another.
Can cause a drainage reversal (e.g., the Amazon).





Floods

Floods happen:

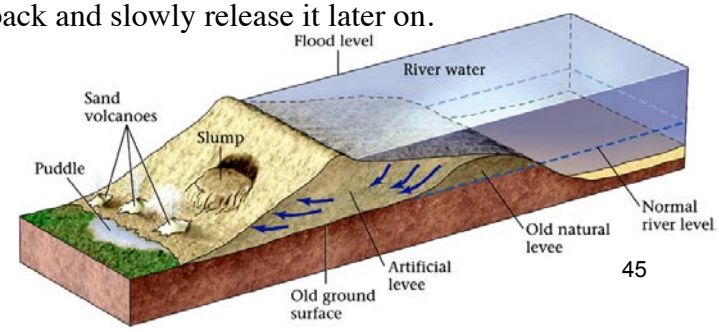
1. During abrupt, heavy rains (water falls faster than it can infiltrate);
2. After long periods of continuous rain (ground is saturated);
3. Heavy snows melt after winter;
4. When an artificial or natural dam breaks.

What flood control measures can you name?

Flash Floods: floodwaters rise so quickly it may be impossible to escape from their path.

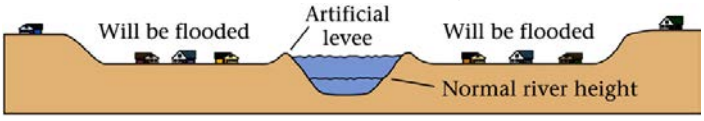
Artificial Levees: man-made (mud, sand, concrete). Built along the Mississippi after a major flood (1927 Mississippi Flood Control Act). Dams also built along tributaries to hold flood water back and slowly release it later on.

Insufficient to stem the 1993 floods - they were topped and undermined.

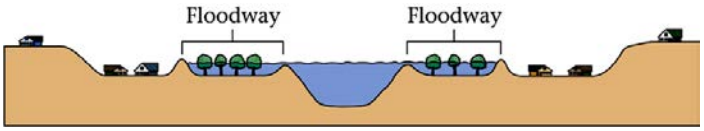


Floods

Artificial levees can be counter-productive. They keep the water in the channel and as it goes downstream, the flood level rises higher than it normally would.



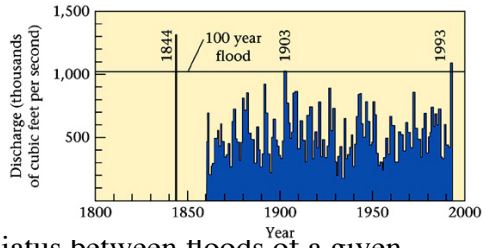
Other flood control measures: wetlands (nature's sponges), floodways (areas kept clear of building and development as they will be inundated during flood to reduce the volume of water in the channel), move levees further away so they don't have to be so high.



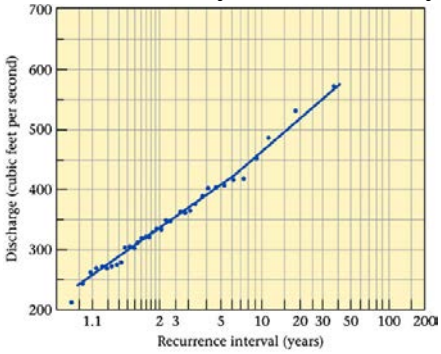
Floods

River data 10-30 years used. Largest discharge is given a *rank* of "1", the second largest "2", etc.

$$\text{Annual Probability of Flooding} = \frac{1}{\text{Recurrence Interval}}$$



Flood Recurrence Interval (R): Average time hiatus between floods of a given size (e.g., 100 years flood occurs *on average* every 100 years. However, you can have two 100 year floods in 2 years!

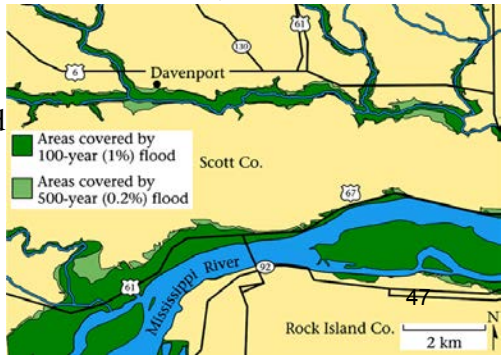


Flood of 1% probability = 100 year flood.

$$R = \frac{(n + 1)}{m}$$

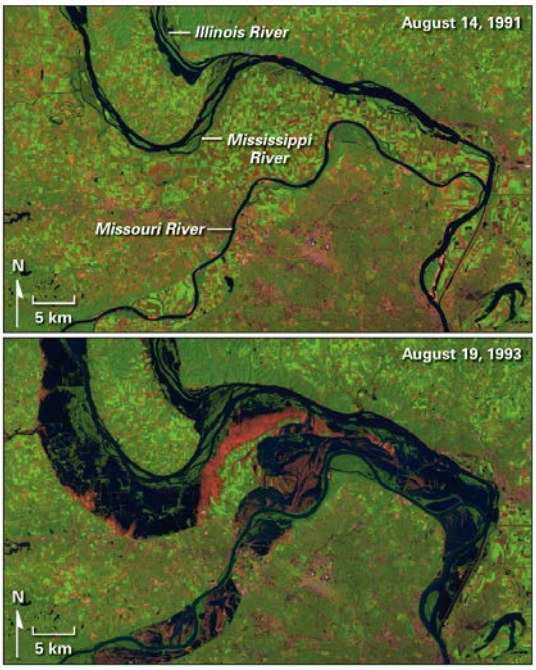
n = total number of years for which there is a record; **m** = rank.

Use these data to create "flood hazard maps" for urban planning.



Raging Waters: Floods

Case History of a Seasonal Flood: the Mississippi and Missouri Rivers, 1993



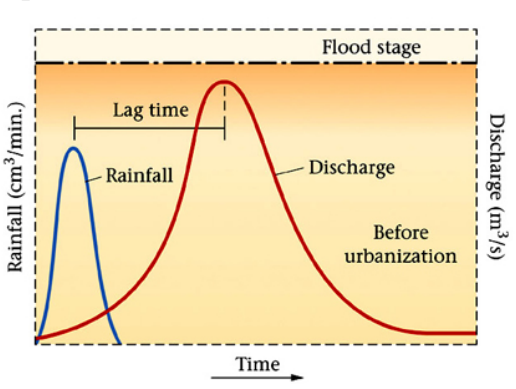
In the spring of 1993, the jet stream moved over the midwestern United States. This trapped moist humid air from the Gulf of Mexico and rain fell in great abundance. In July of 1993, floodwaters invaded large areas. Flooding lasted 79 days, covering 40,000 square miles. The toll was enormous: 50 people died, 55,000 homes were destroyed, and the damage totaled $12 billion.

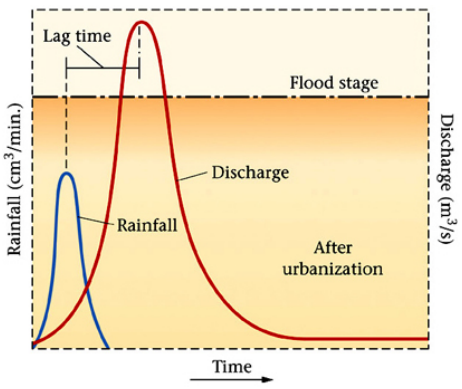
Rivers: A Vanishing Resource?

Pollution: from raw sewage, storm drain water in urban areas, spilled oil, industrial waste, excess fertilizers, animal waste, general trash. Can destroy or radically alter ecosystems and make rivers off-limits.

Dam Construction: alters river ecosystems by decreasing water and sediment/ nutrient flow downstream. Positive side - irrigation for agriculture, hydroelectric (clean) power.

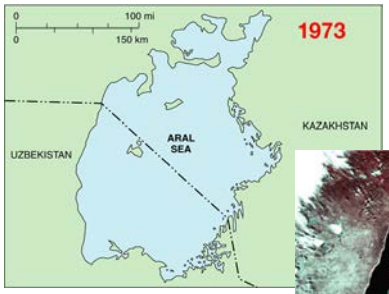
Urbanization: Increases run-off and peak discharge amounts due to concrete/tarmac (prevents infiltration).

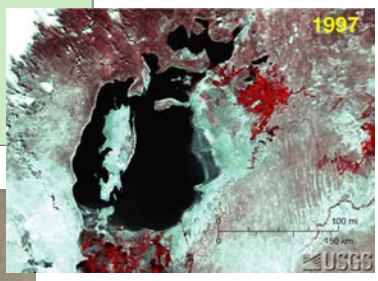




Rivers: A Vanishing Resource?

Overuse: water taken out of rivers can mean none reaches downstream (e.g., Aral Sea in Central Asia).





Summary

Hydrologic Cycle.

The Basics: River, Reach, Meander, Sheetwash, Chanel Flow, Thalweg, Laminar Flow, Turbulent Flow, Flood Plain, Natural Levee, Banks, Channel. Strem Velocity, Water Table, Springs.

Streams & Drainage Networks: Downcutting, Tributaries, Headward Erosion, Dendritic, Radial, Rectangular, Trellis, Superposed Streams, Antecedent Streams, Headwater, Mouth, Divide, Drainage Basin.

Permanent & Ephemeral Streams: Dry Wash (Wadi), Dry & Productive Wells.

Discharge & Turbulence.

Stream Erosion: Dissolution, Scouring, Breaking & Lifting, Abrasion.

Stream Transport: Stream Load, Dissolved Load, Clastic Load, Suspended Load, Bed Load, Stream Capacity, Stream Competence, Traction, Saltation.

Fluvial Deposition: Alluvium, Bars, Point Bars, Flood Plain, Yazoo Streams, Deltas, Economic Aspects, Braided Streams, Alluvial Fans.

River Profiles & Base Level: Longitudinal Profile, Local & Ultimate Base Level, Ungraded & Graded Streams.

Valleys & Canyons: Slot Canyon, V-shaped Valley, Stream Terraces.

Rapids & Waterfalls: Plunge Pool, Niagara Falls.

Summary (cont.)

Meanders: Yazoo Streams, Ox-Bow Lakes.

Deltas: Avulsion, Distributaries, Topset-Foreset-Bottomset Beds, Natural Levee, Bird-Foot Delta.

Stream Rejuvenation: Incised meanders.

Stream Piracy: Headward Erosion, Stream Capture.

Floods: Causes, Flash Floods, Artificial Levees, Undermining of Levees, Other Flood Control Measures, Flood Recurrence Interval, Flood Hazard Maps.

Vanishing Rivers: Pollution, Dam Construction, Urbanization, Overuse.