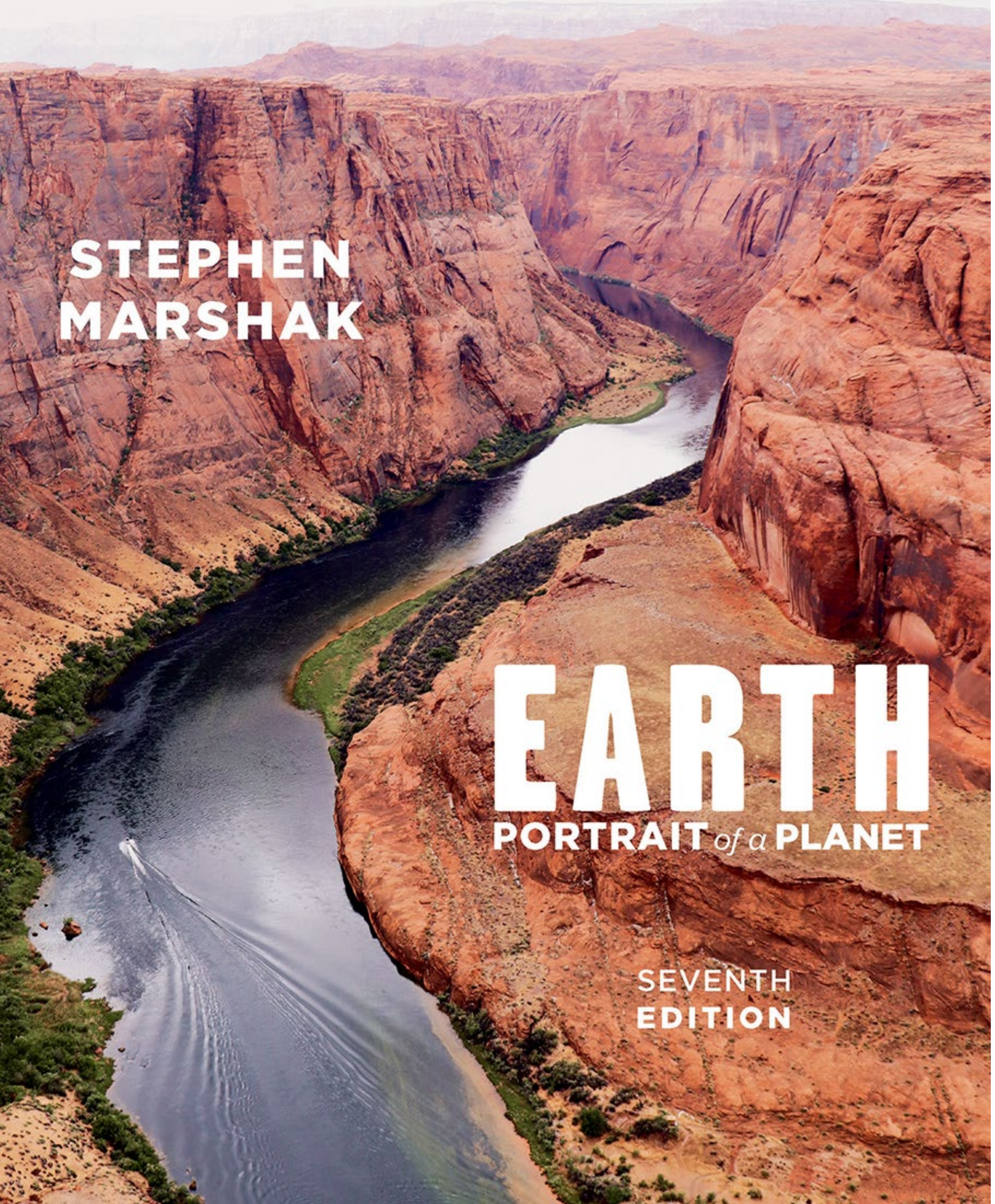


Chapter 17

Streams and Floods: The Geology of Running Water

Hydrologic Cycle

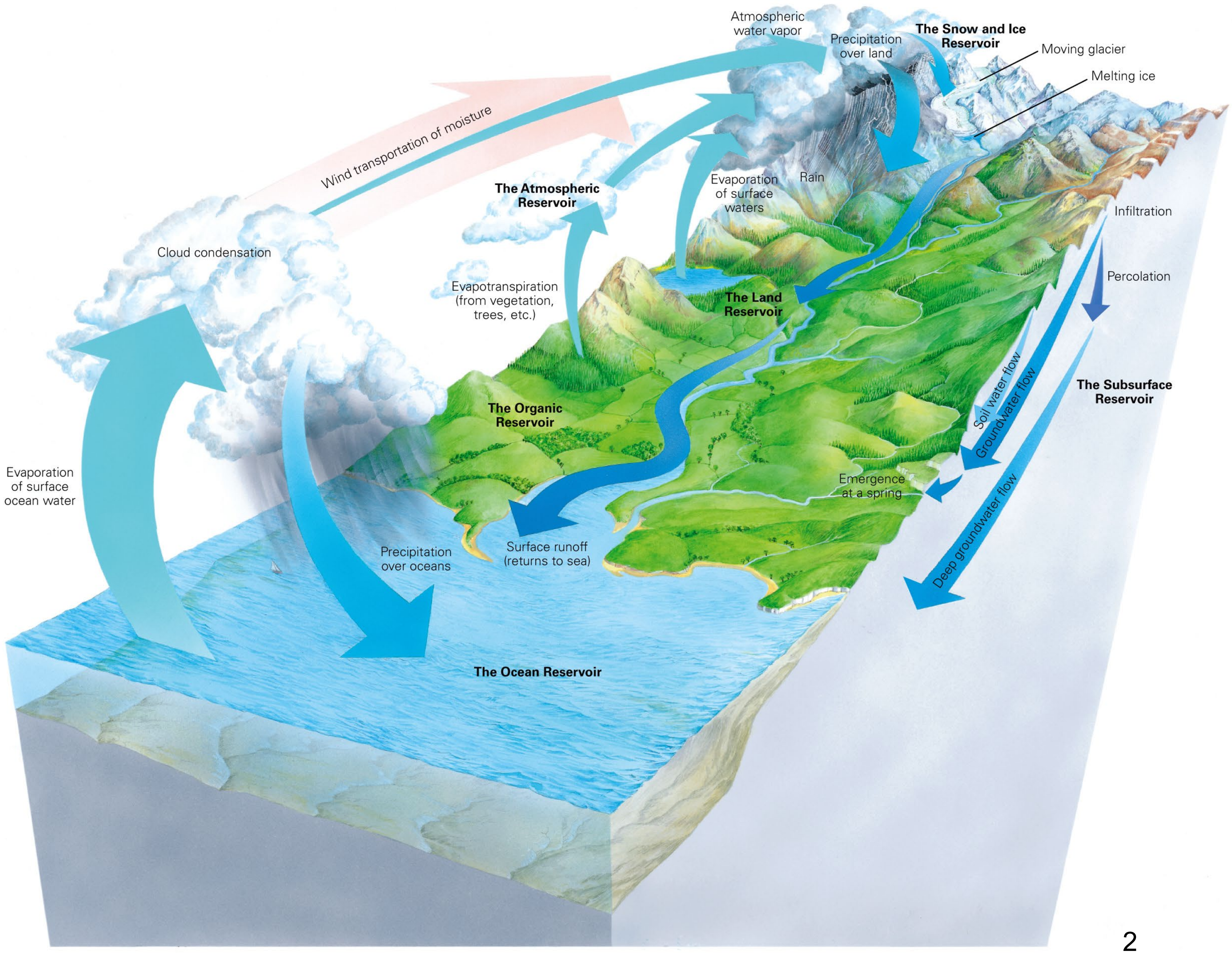


TABLE F.2 Major Water Reservoirs of the Earth

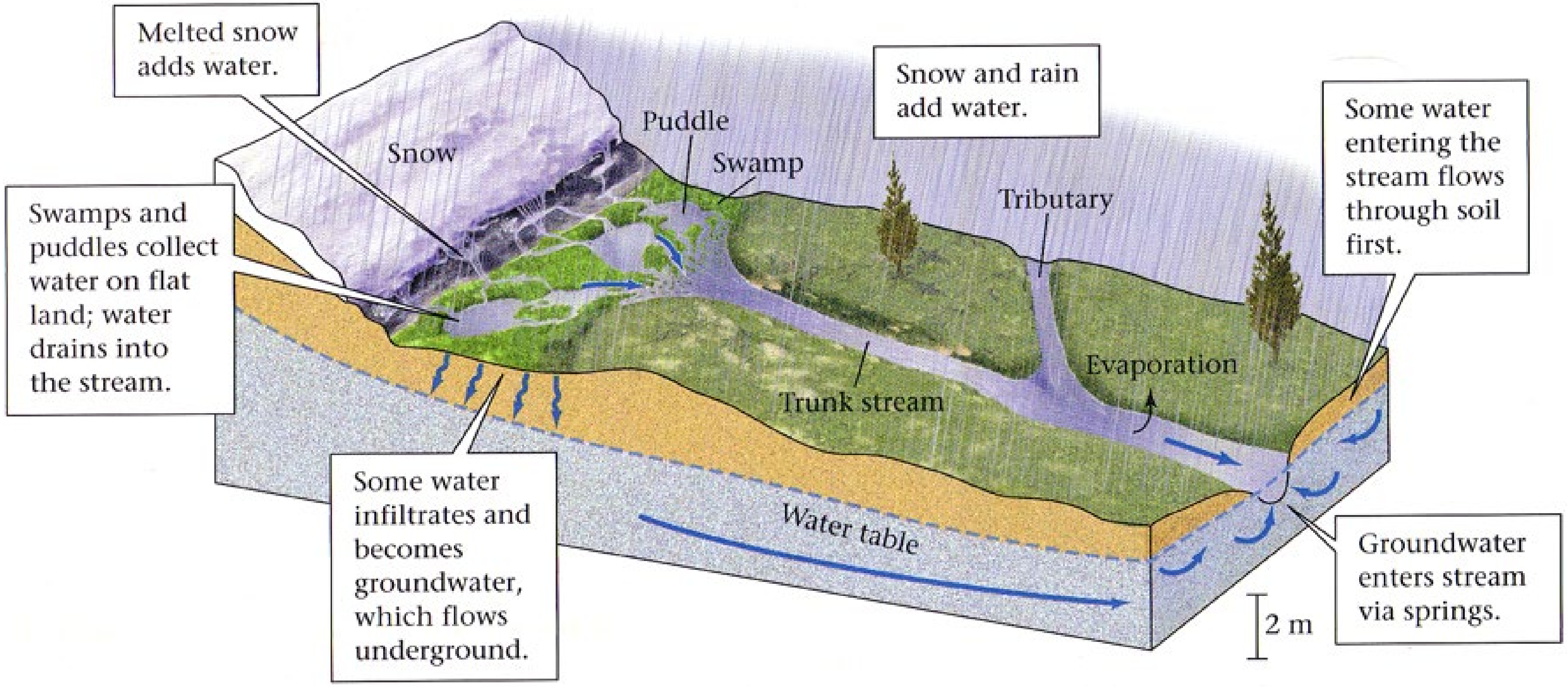
H_2O Reservoir	Volume (km^3)	% of Total Water	% of Fresh Water
Oceans and seas	1,338,000,000	96.5	–
Glaciers, ice caps, snow	24,064,000	2.05	68.7
Saline groundwater	12,870,000	0.76	–
Fresh groundwater	10,500,000	0.94	30.1
Permafrost	300,000	0.022	0.86
Freshwater lakes	91,000	0.007	0.26
Salt lakes	85,400	0.006	–
Soil moisture	16,500	0.001	0.05
Atmosphere	12,900	0.001	0.04
Swamps	11,470	0.0008	0.03
Rivers and streams	2,120	0.0002	00.006
Living organisms	1,120	0.0001	00.003

Source: Data from P. H. Gleick, *Encyclopedia of Climate and Weather* (New York: Oxford University Press, 1996).

Rivers & Streams: Basics

Stream = body of running water that flows in a channel
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

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

Natural Levee: natural sediment built up adjacent to channel that resists floods.

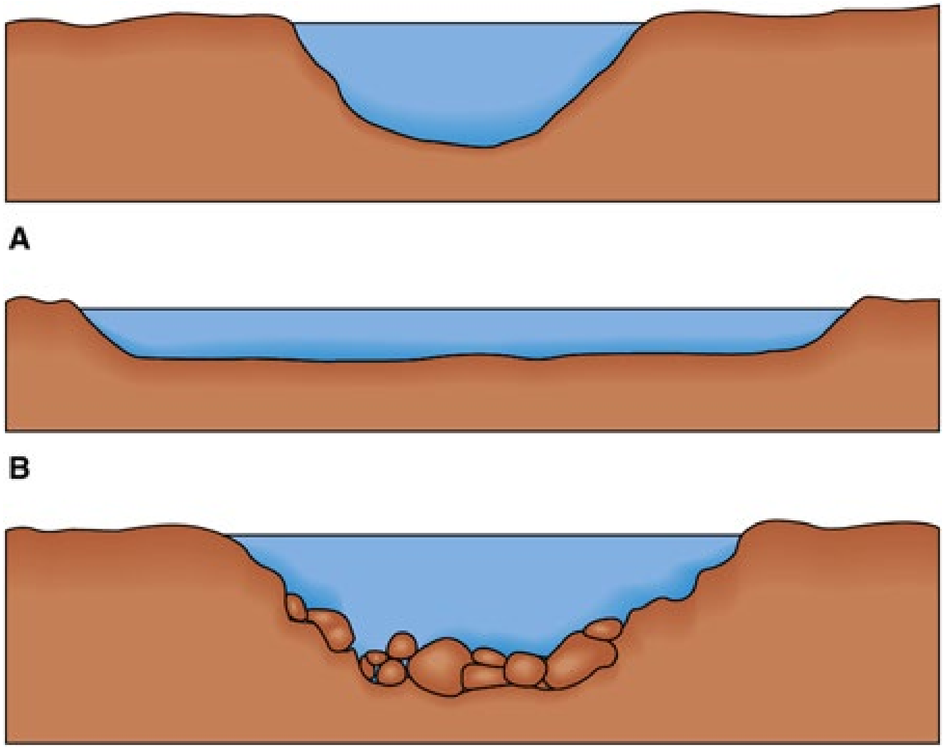
Banks: sides of river channel

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

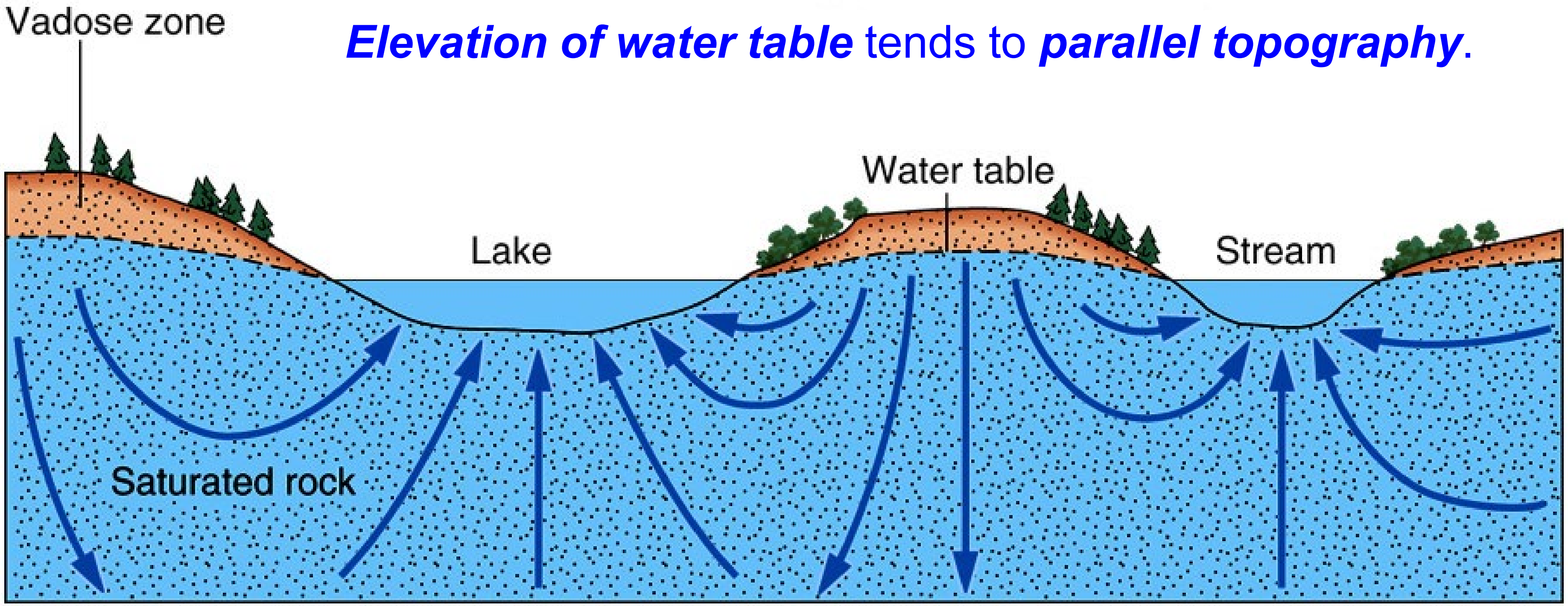
Water Table: Surface that is the contact between saturated and unsaturated zones.

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.

Elevation of water table tends to ***parallel topography***.

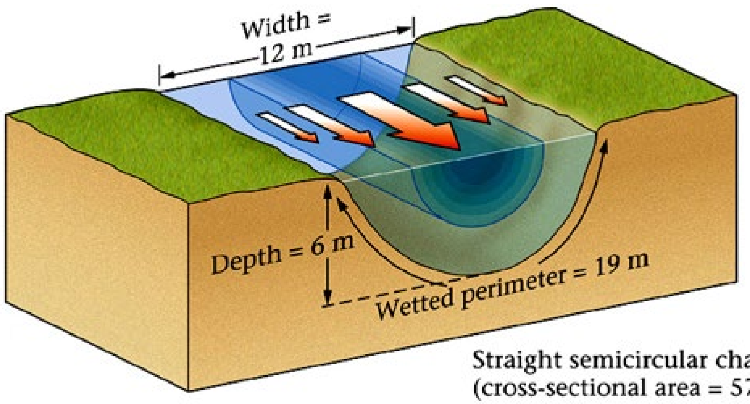


The ***water table*** comes to the ***surface*** at **springs**, **edges of streams**, & **lakes**.

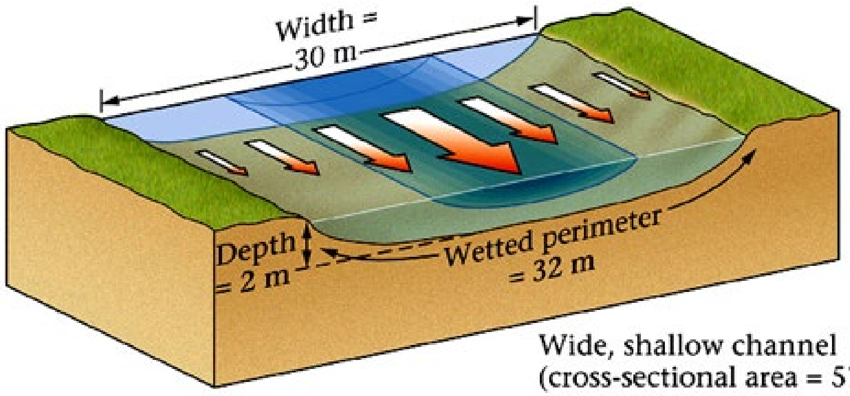
Rivers & Streams: Basics

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

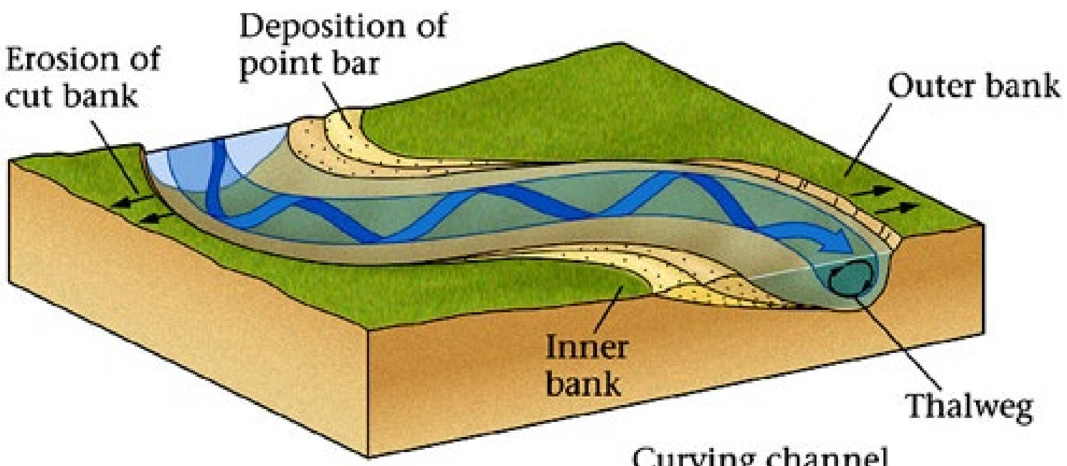
Laminar: water moves slowly along a smooth channel, following straight, parallel lines, follows slope of containing boundary. More friction in wider, shallower streams



Straight semicircular channel
(cross-sectional area = 57 m^2)



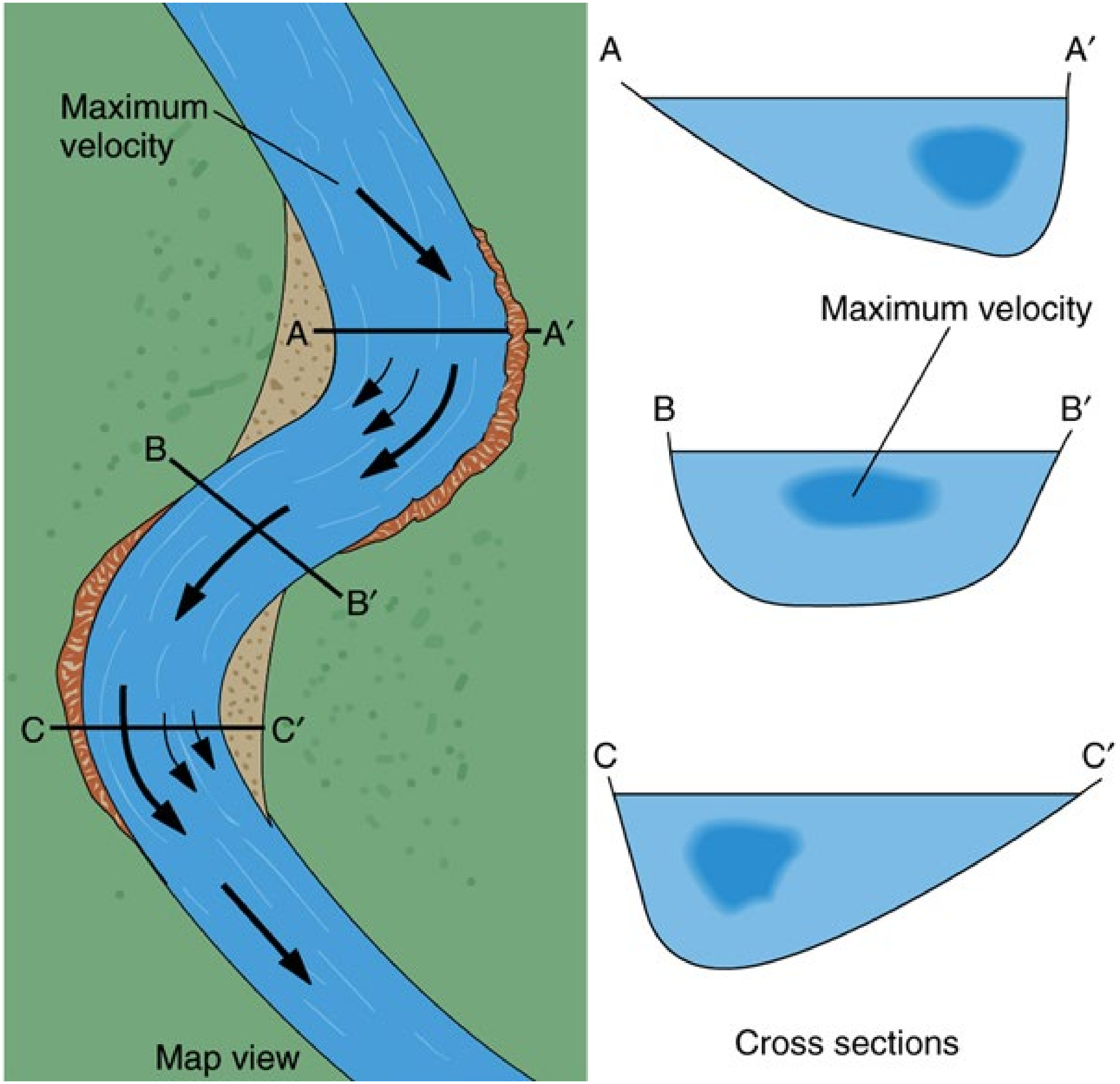
Wide, shallow channel
(cross-sectional area = 57 m^2)



Curving channel

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



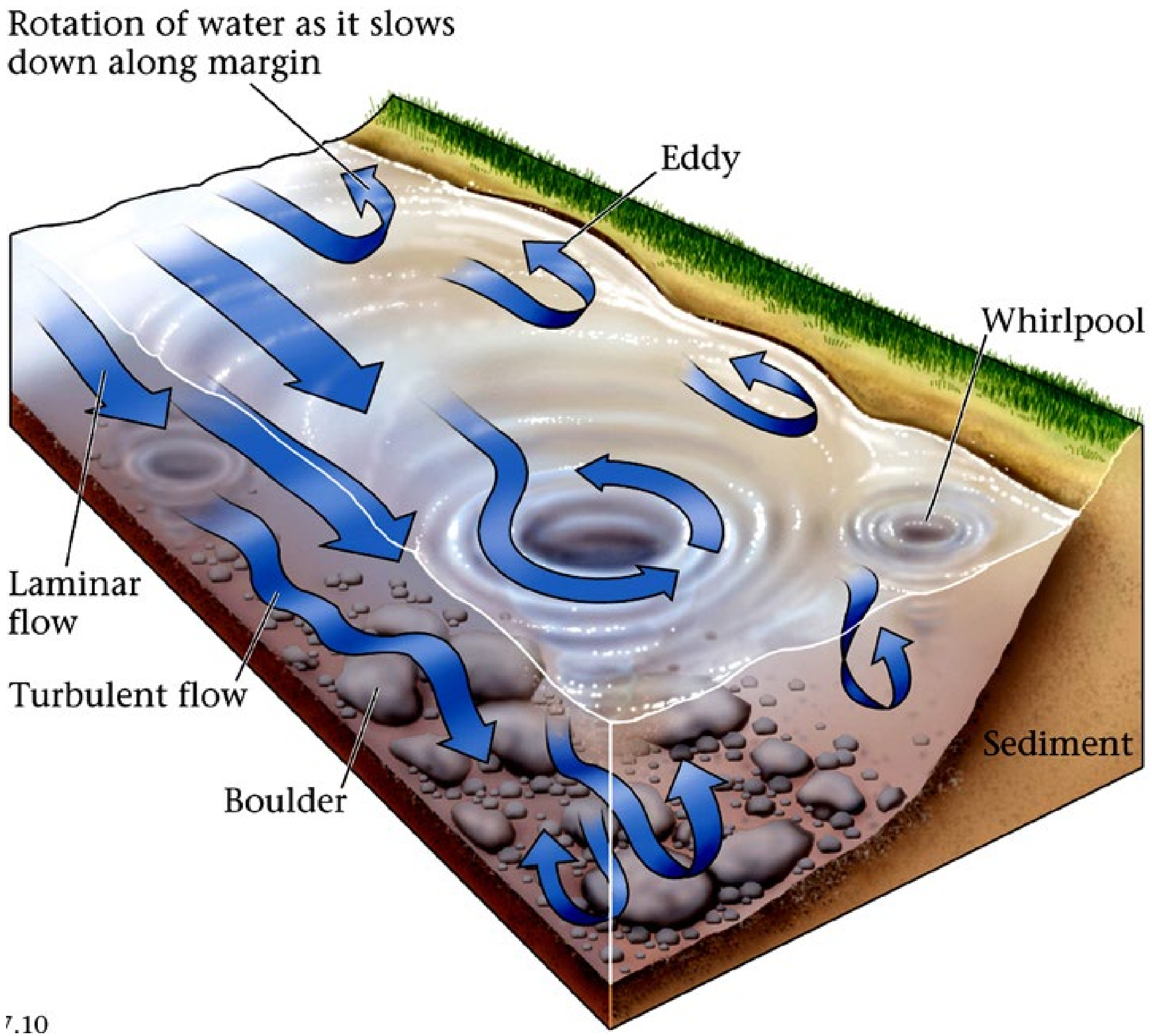
Velocity changes with:

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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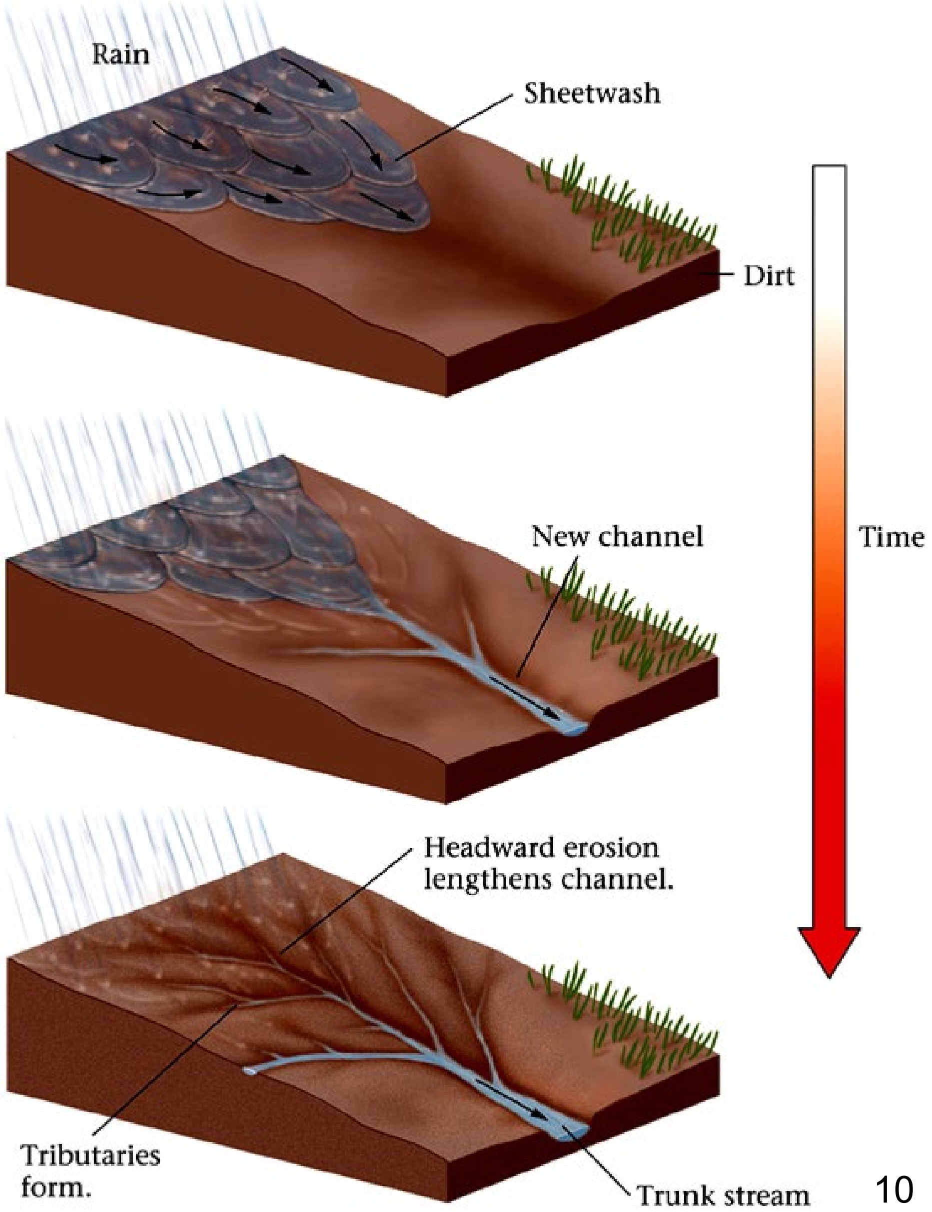
Streams & Drainage Networks

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

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

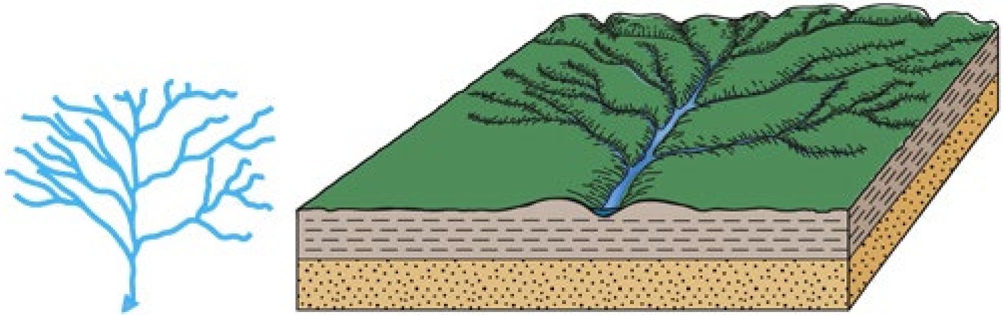
Together, these tributaries form a ***drainage network***.

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



Streams & Drainage Networks

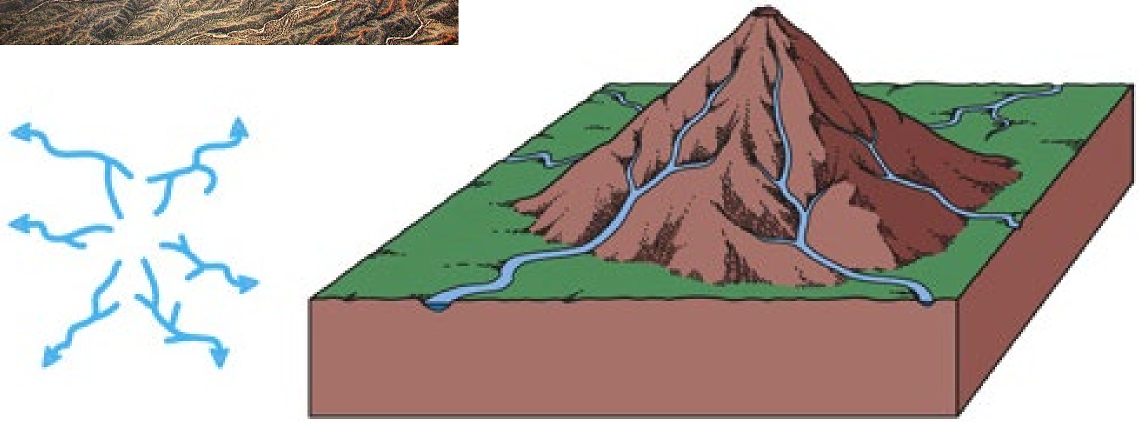
Patterns produced depend strongly on the nature of the *bedrock* (homogeneous vs. heterogeneous vs. faulted/ jointed).



A Dendritic

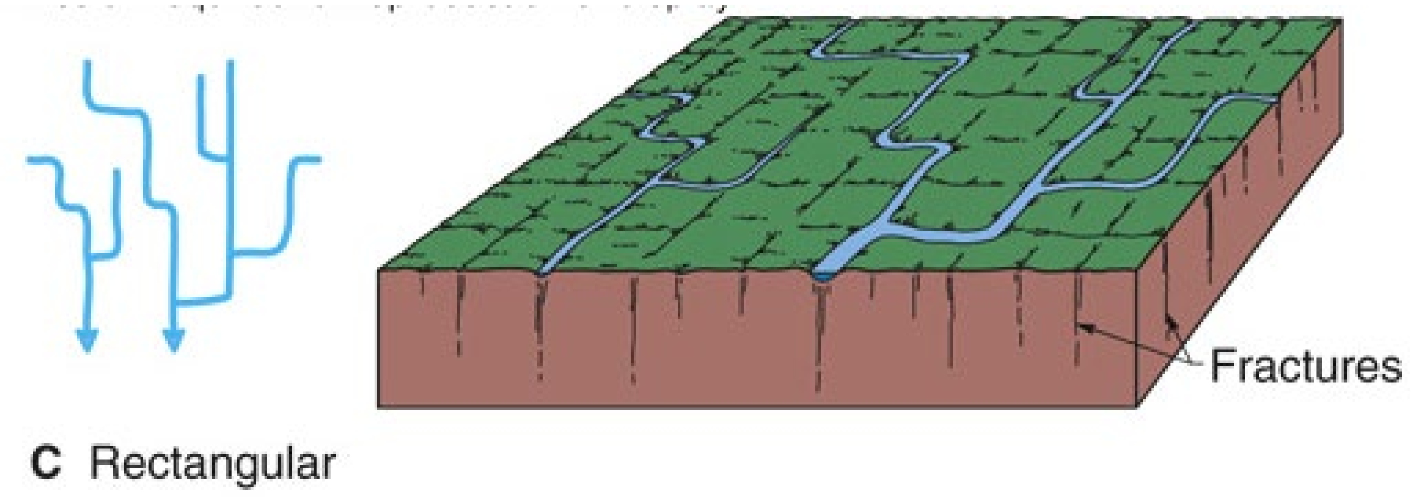
Dendritic: homogeneous bedrock (igneous, metamorphic **or** sedimentary with horizontal bedding). Not heavily faulted or jointed.

Radial: volcanoes and domes.



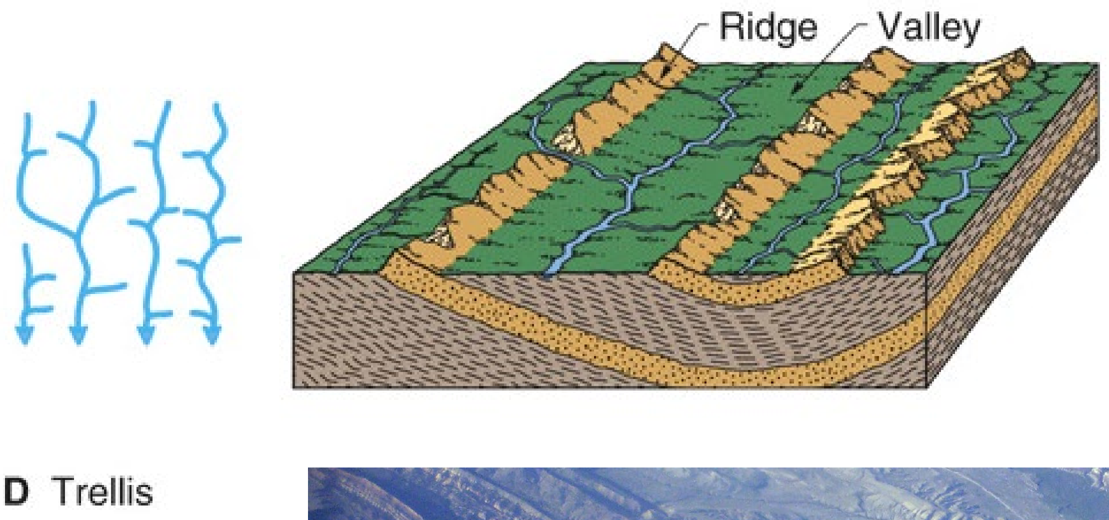
B Radial

Streams & Drainage Networks

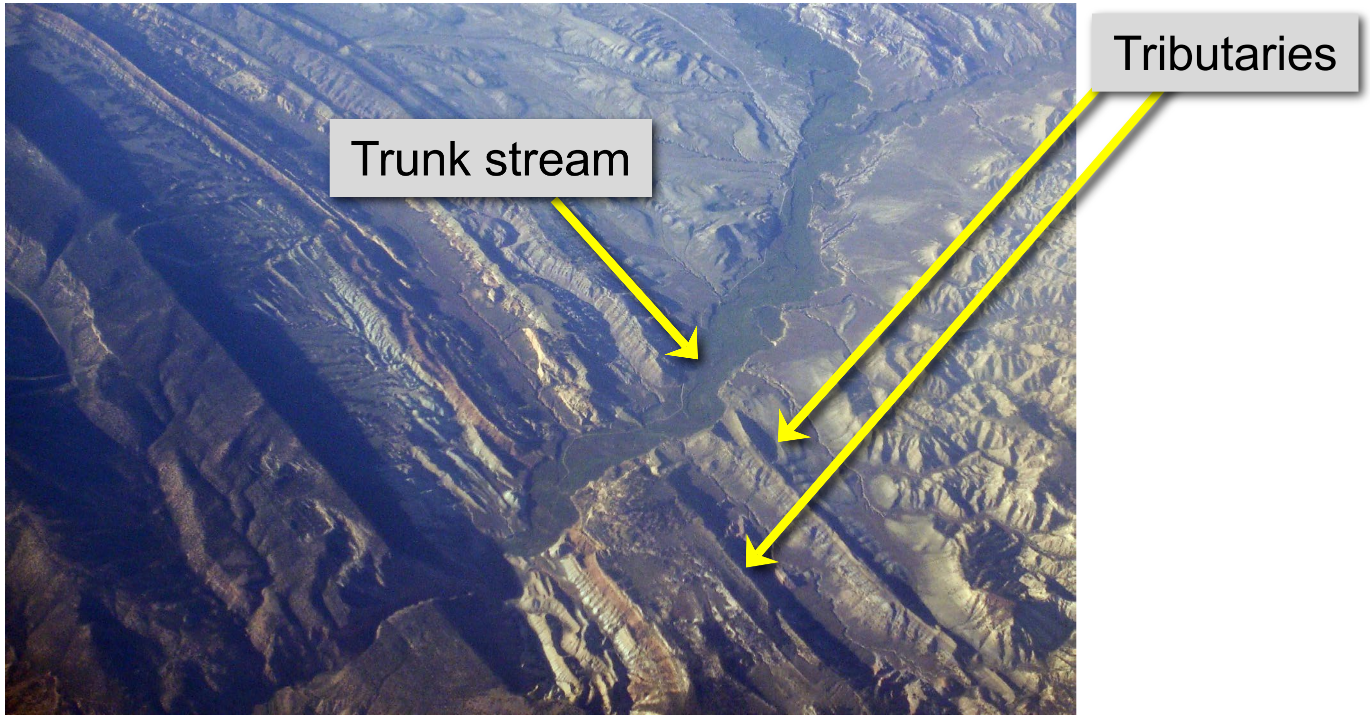


Rectangular: Faulted/jointed bedrock. Square patterns. 90-degree turns are common and streams enter each other at right angles.

Streams & Drainage Networks



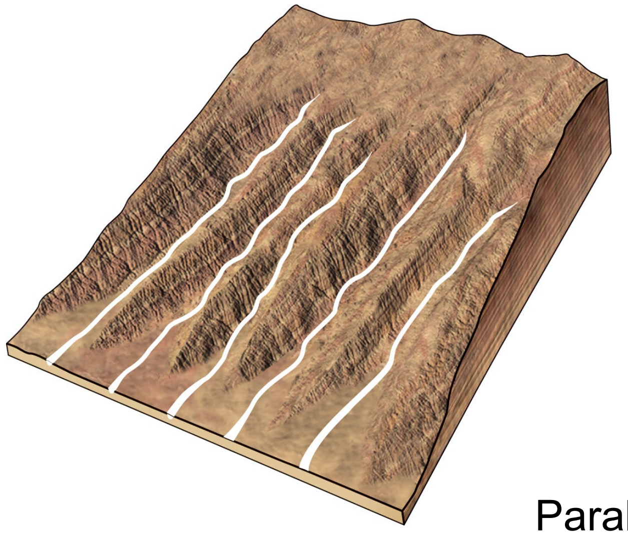
Trellis: Dipping beds of sedimentary rocks of alternating resistance to erosion (e.g., alternating limestone and sandstone).



Streams & Drainage Networks

Parallel: On a uniform, fairly steep slope, several streams with parallel courses develop simultaneously. Typically form on the sides of steep escarpments of weak substrate.

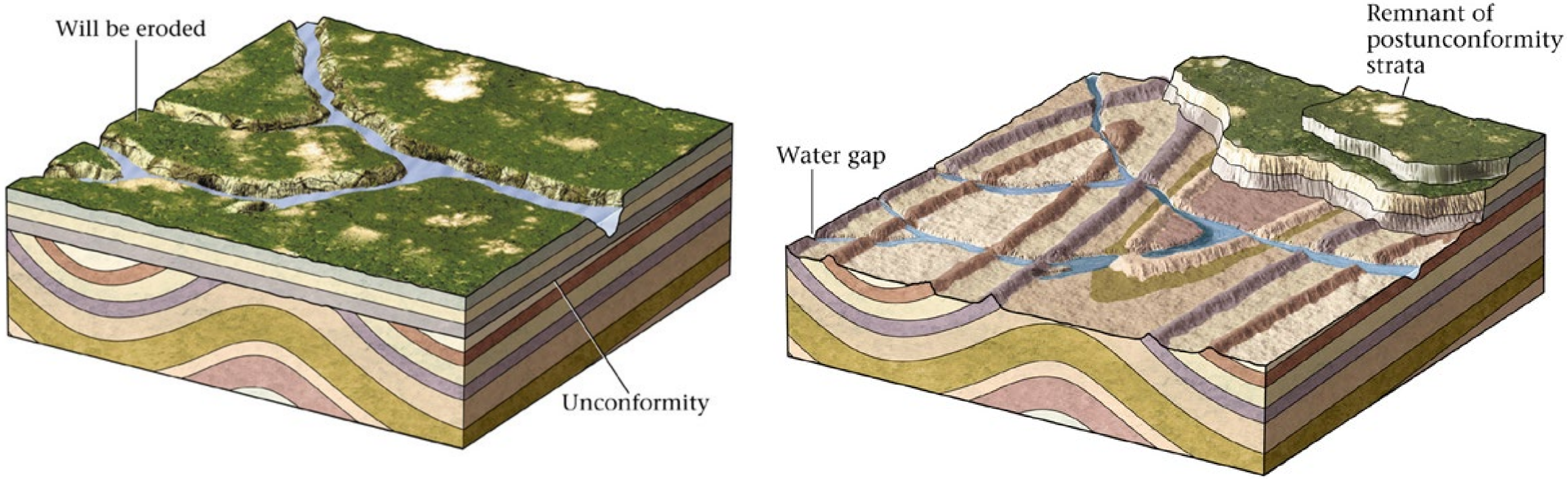
If the weak substrate has no sediment on top of it, it is called ***badlands topography***.



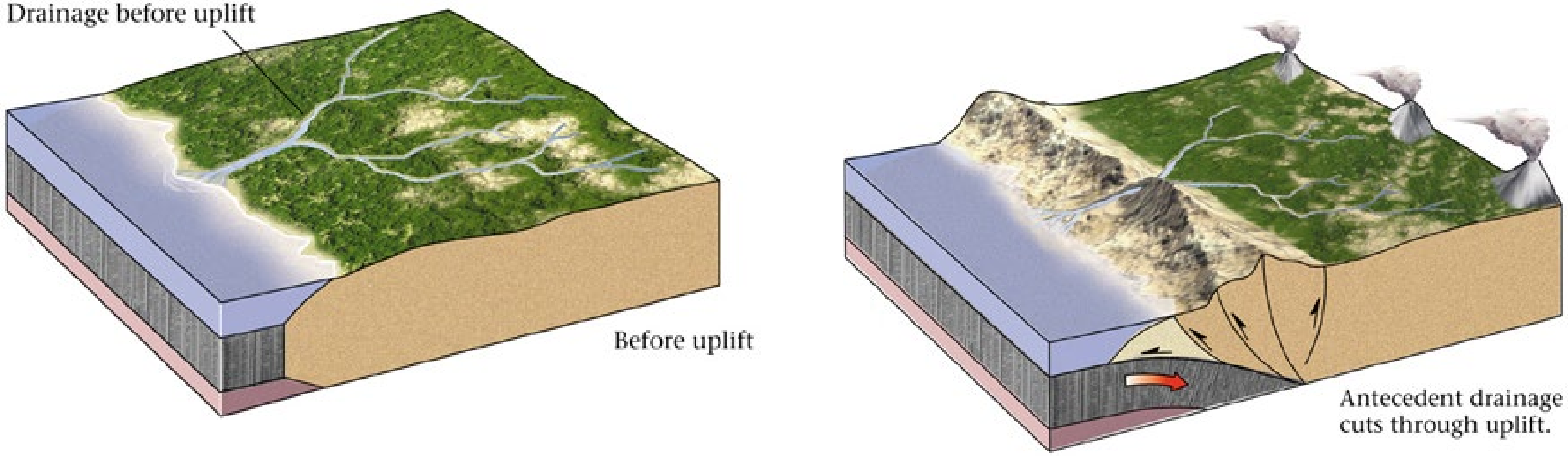
Parallel

Streams & Drainage Networks

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



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

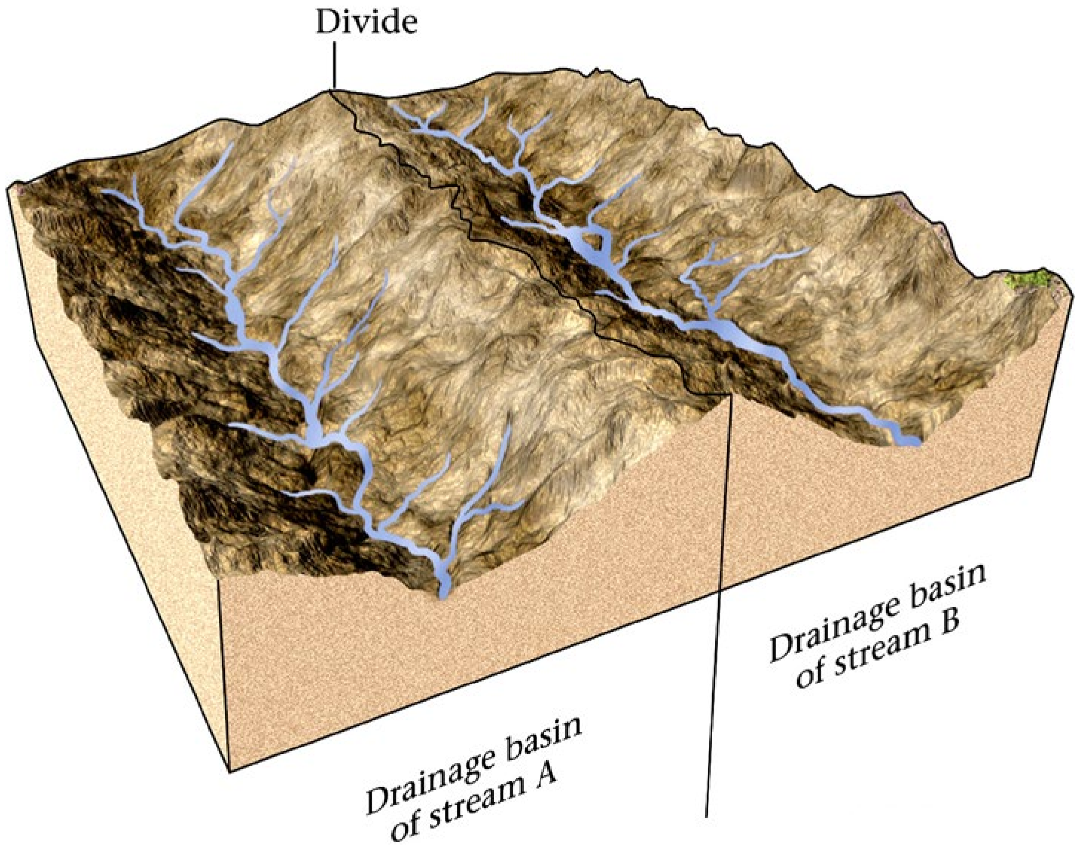


Streams & Drainage Networks

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).

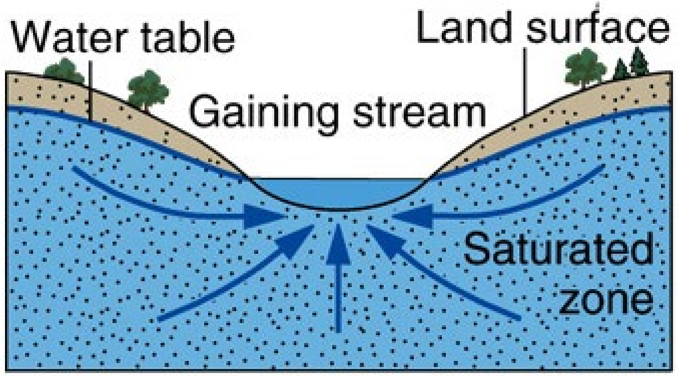
Streams & Drainage Networks

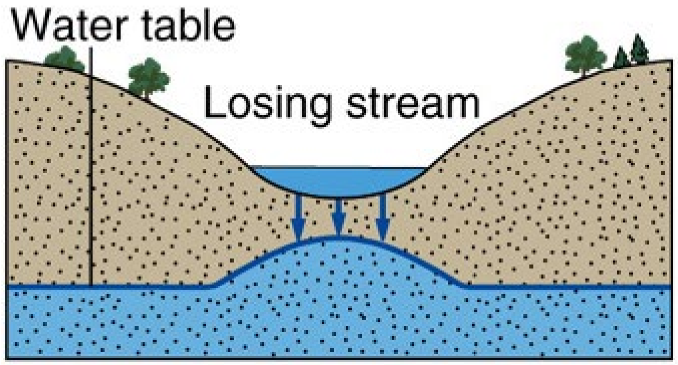
The Amazon Watershed

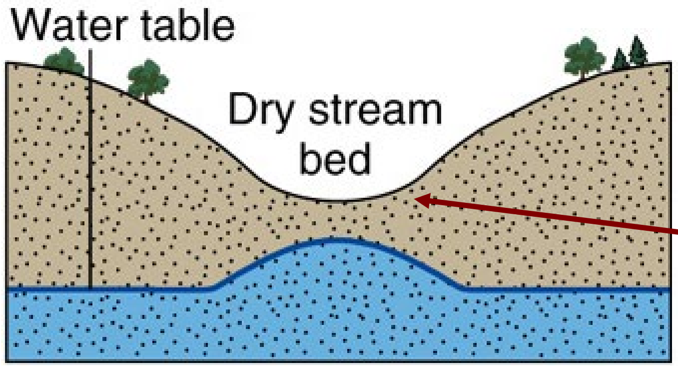
Permanent streams are defined by water flowing all year. These streams are common where there is abundant rainfall, groundwater discharge, and low rates of evaporation.

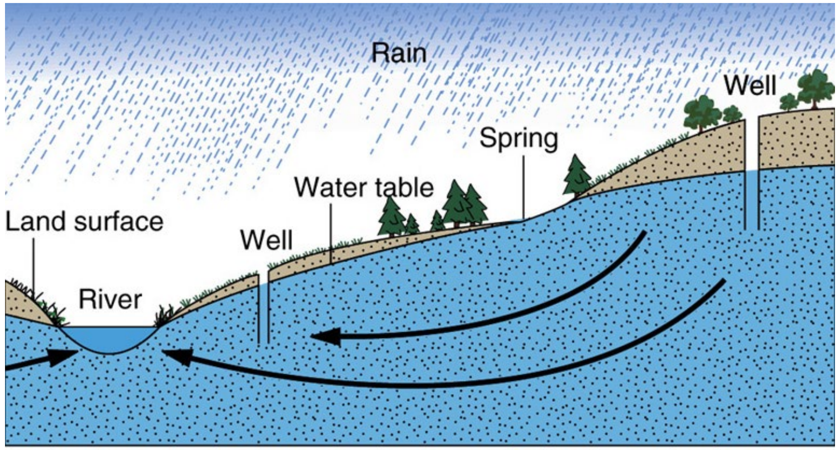
Permanent and Ephemeral Streams

Permanent Streams.

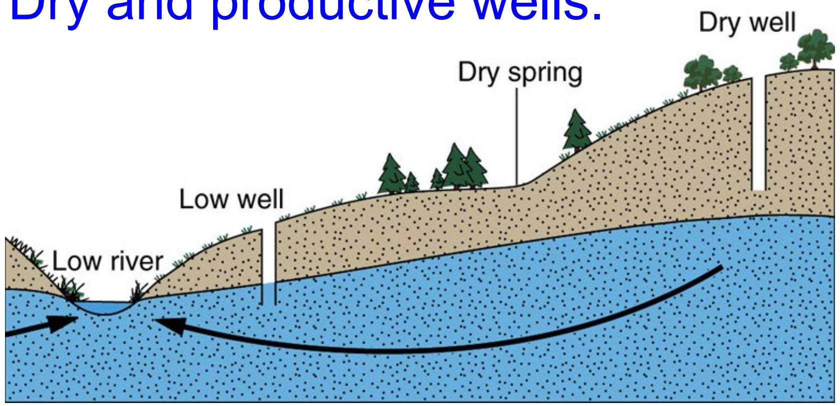








Dry and productive wells.

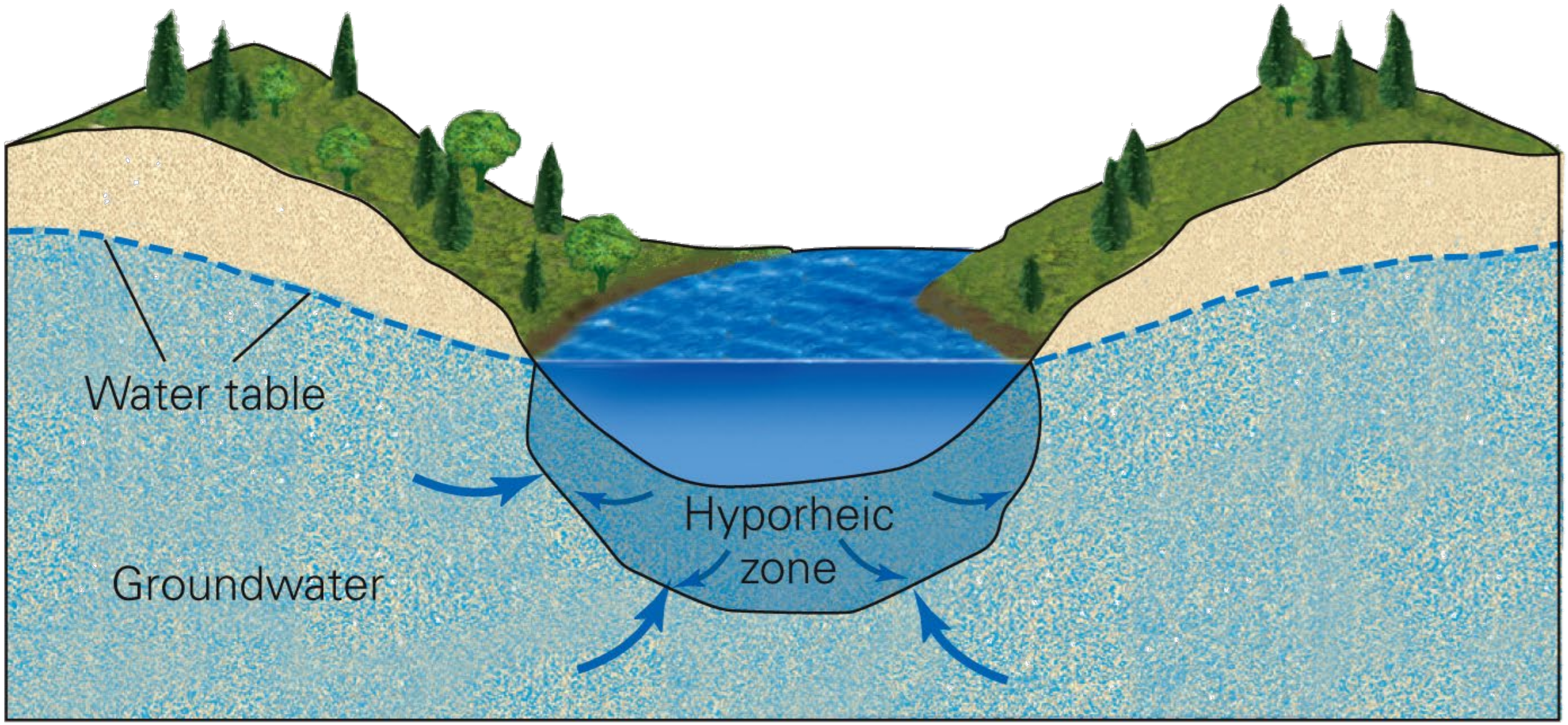


Water table depth can vary seasonally – springs can dry up during dry season

Dry wash or **Wadi**.

Ephemeral Stream

Permanent and Ephemeral Streams



Hyporheic zone: surface/groundwater exchange

Discharge & Turbulence

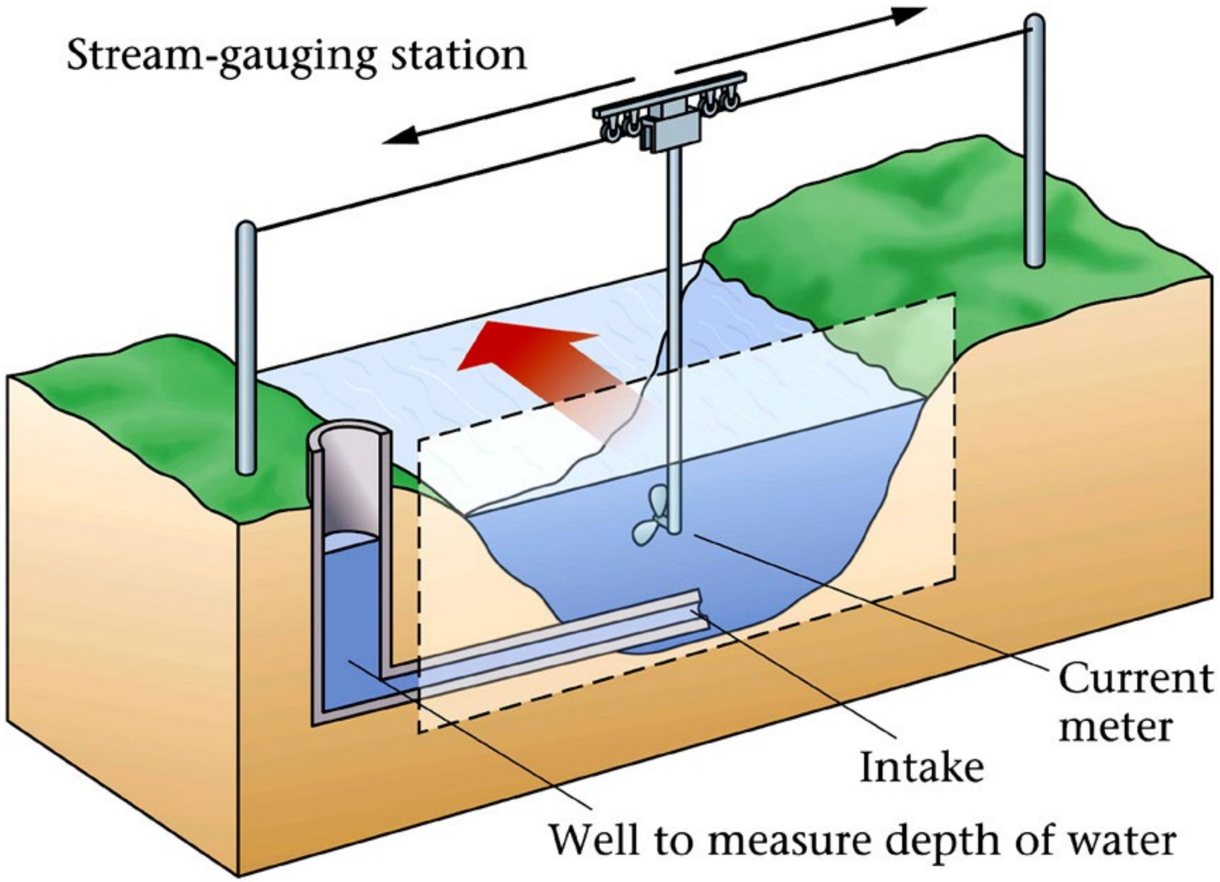
Discharge: volume of water flowing through a given point in a stream in unit time.

Discharge = A_c x v_a

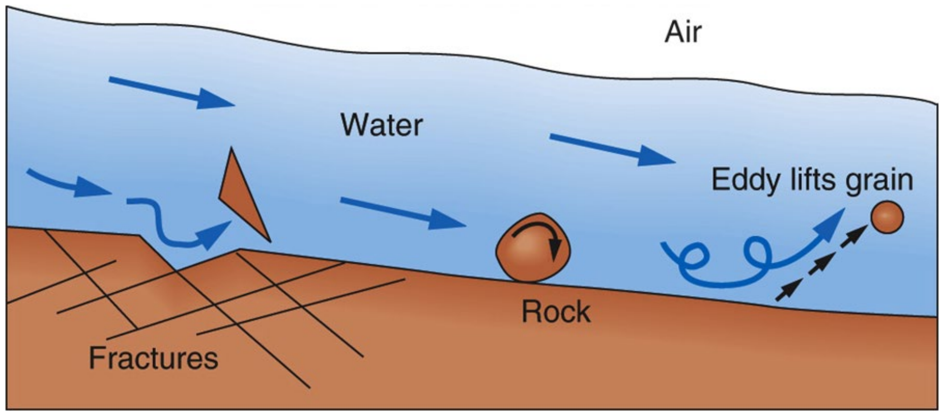
A_c = stream cross section.
v_a = average velocity of water downstream.

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



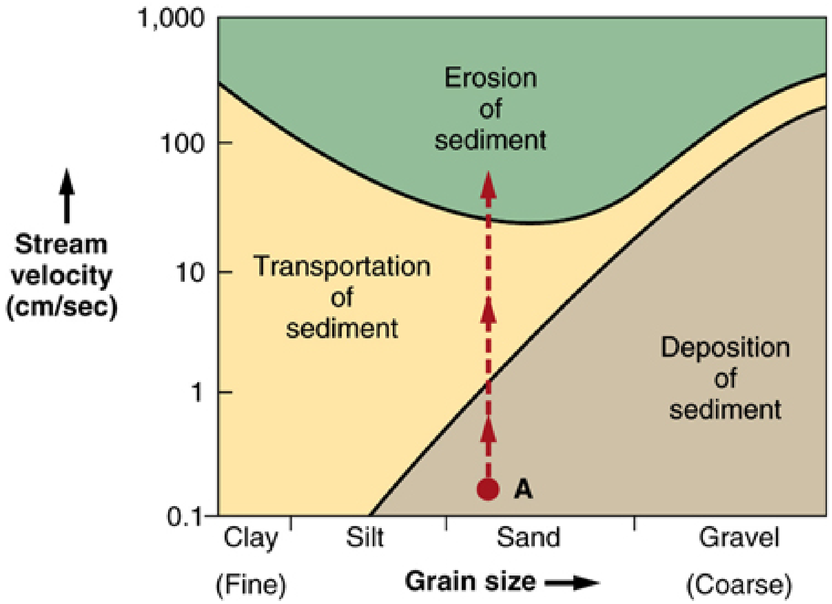
Stream erosion occurs in four ways:

Dissolution: water dissolves soluble components;

Scouring: removal of loose fragments;

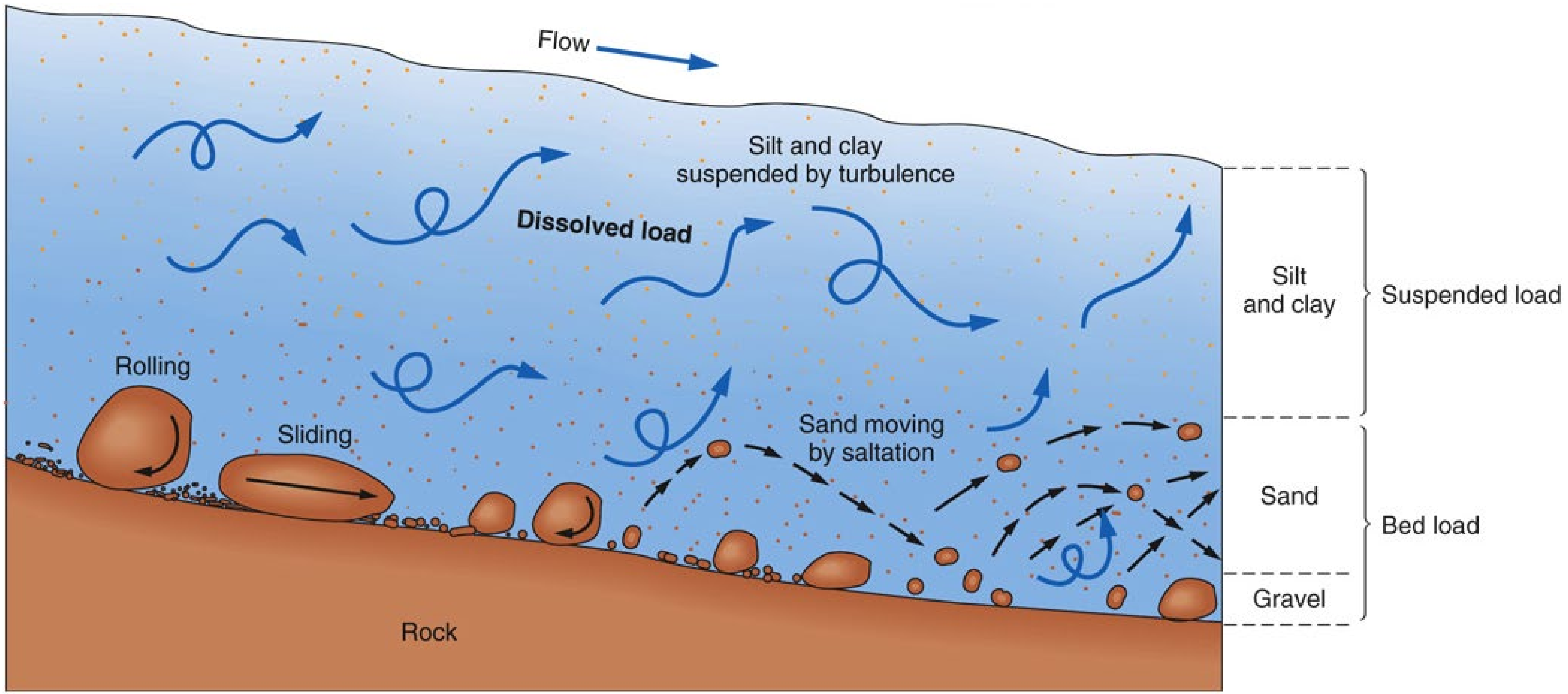
Breaking & Lifting: pressure of flowing water can break rock fragments off the channel floor and walls. Flow can also cause clasts to rise/lift off the floor.;

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



Stream Transport/Erosion

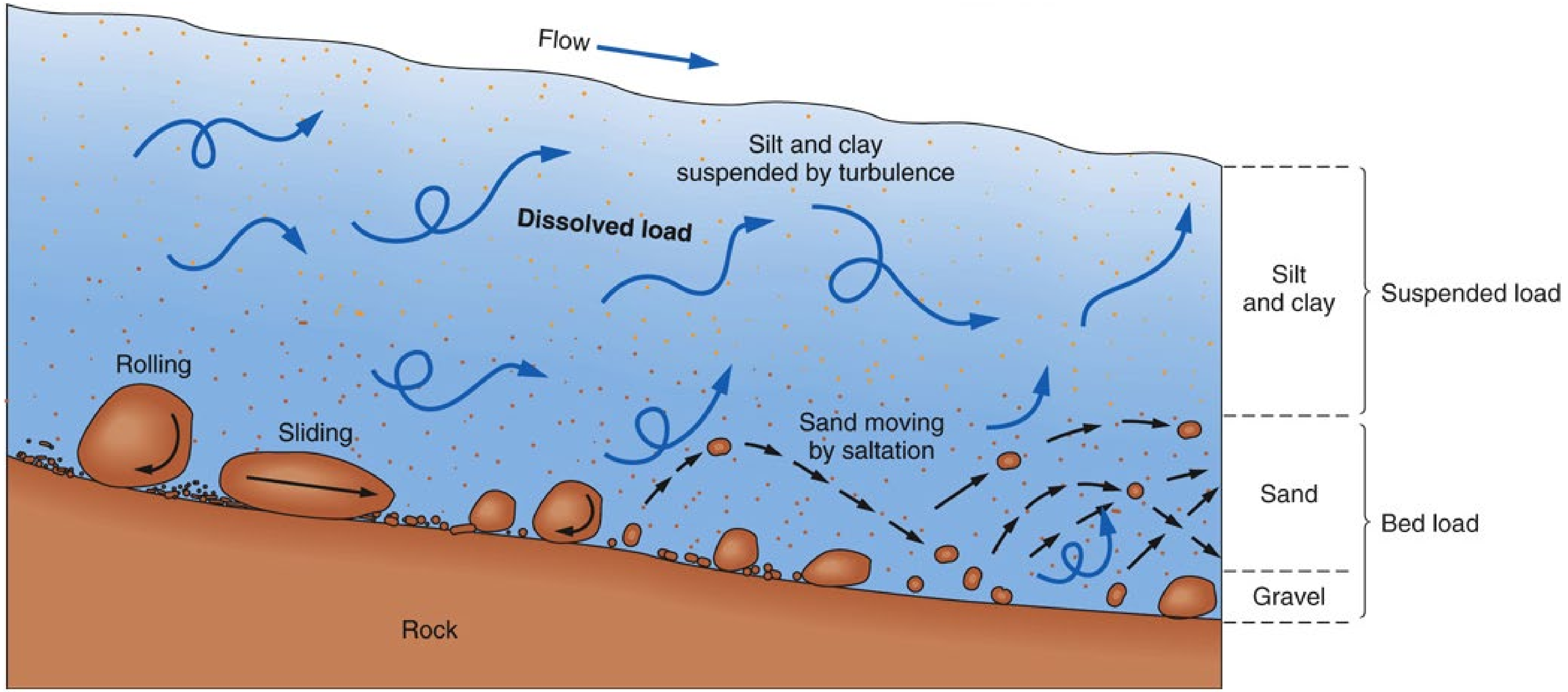
Stream Load: ***total material*** that the river is carrying.



Dissolved Load: ions in solution.

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

Stream Transport/Erosion



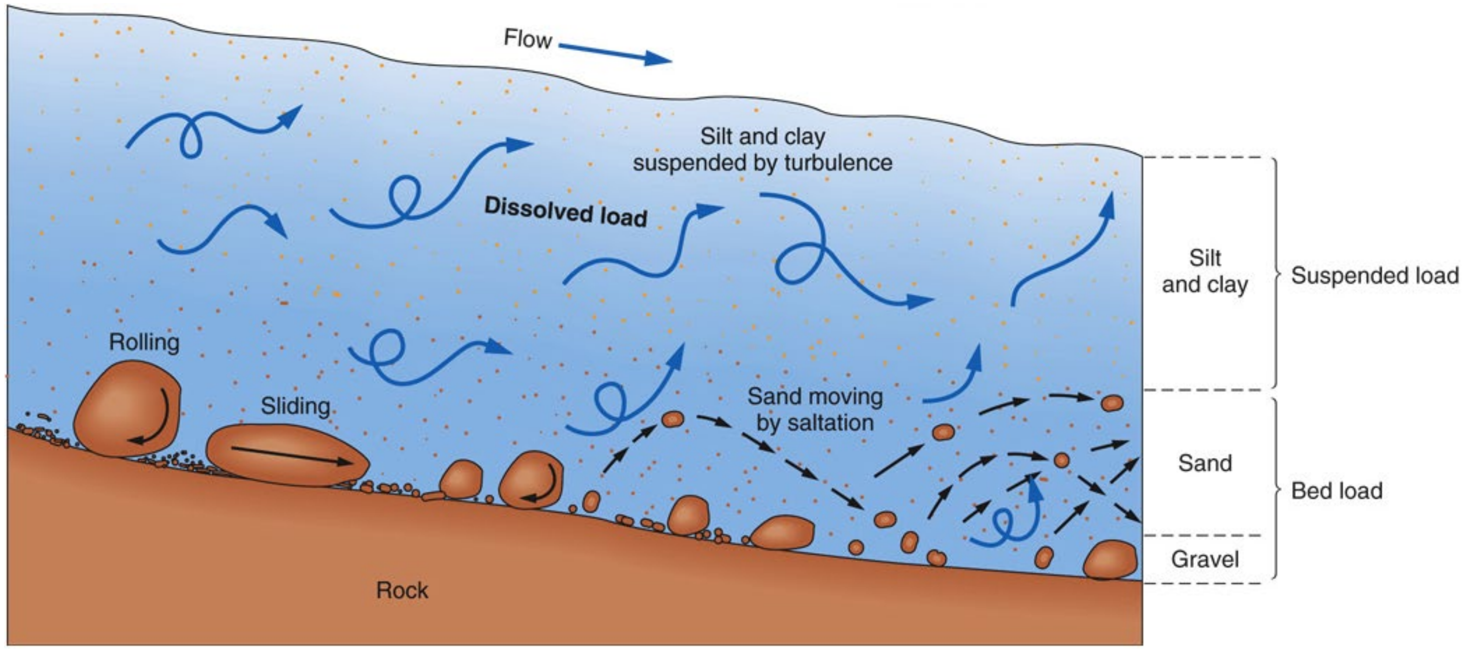
Suspended Load: typically clay and silt. Remain suspended because stream velocity exceeds the settling velocity of the particles.

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.

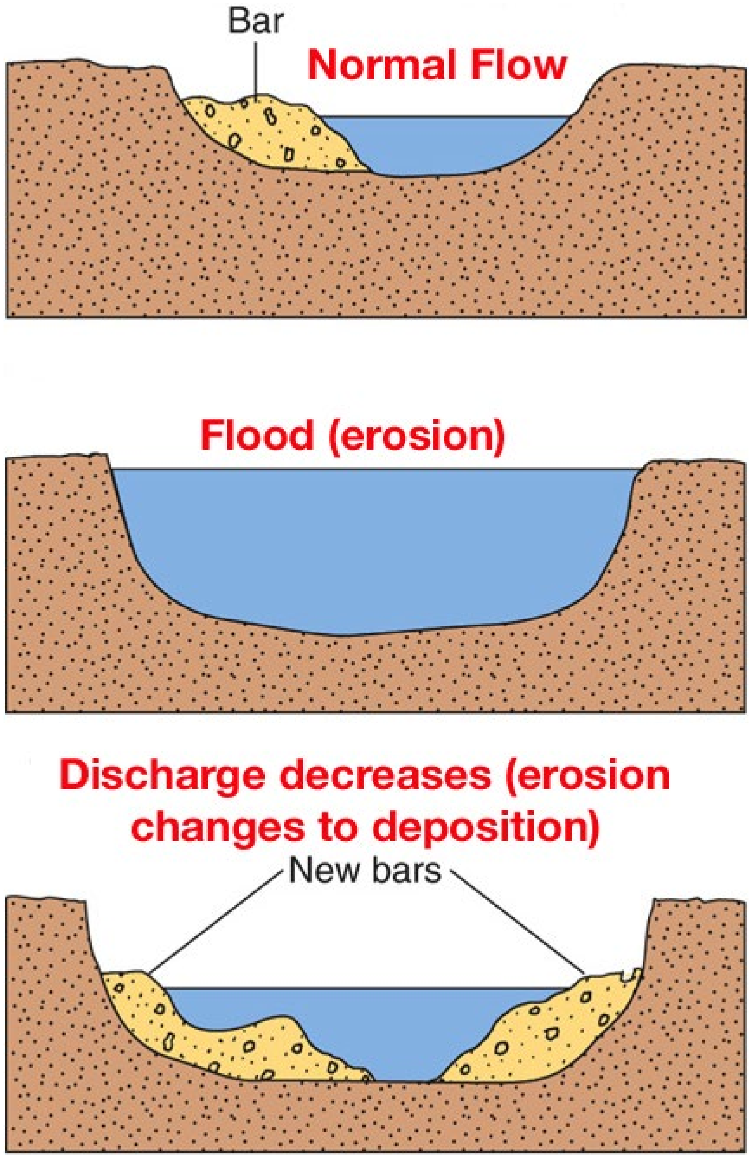
The channel widens.

The stream gradient decreases.

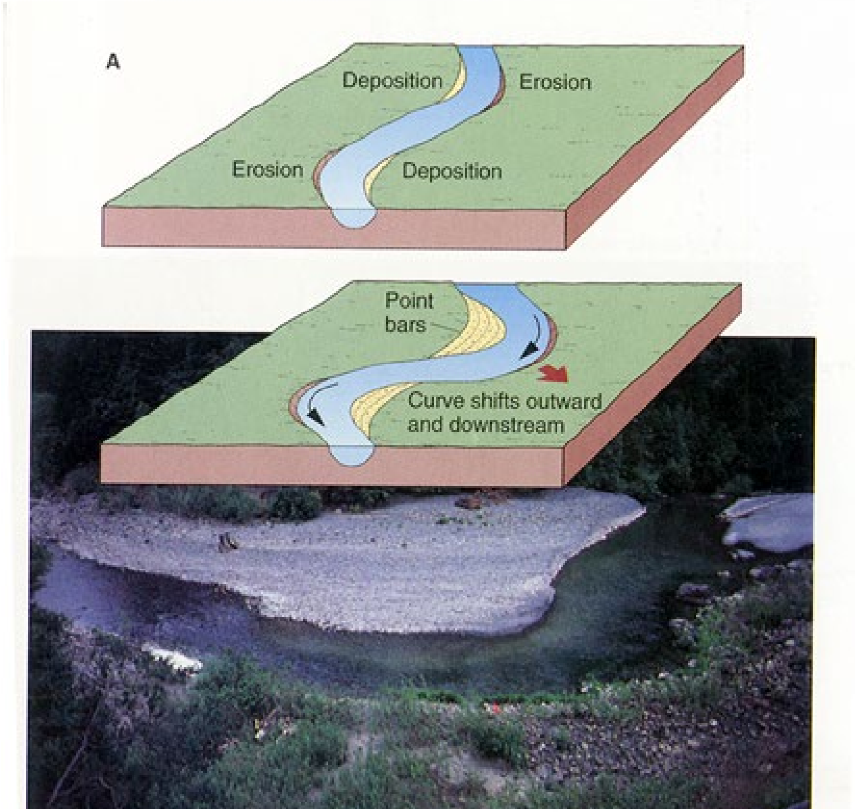
Discharge decreases due to evaporation, infiltration, or removal for irrigation.

Of obstructions.

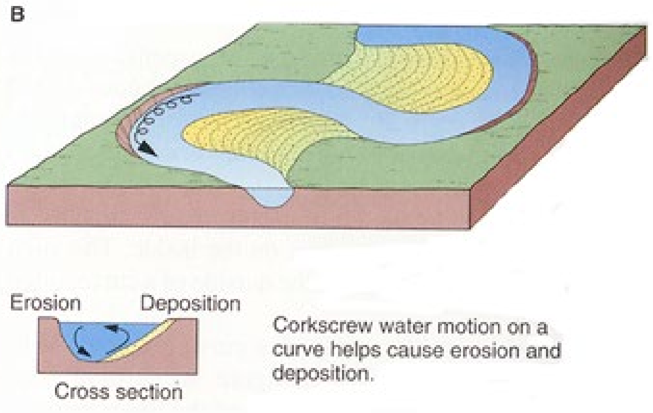
Along the banks and in the middle of a stream due to channel widening.

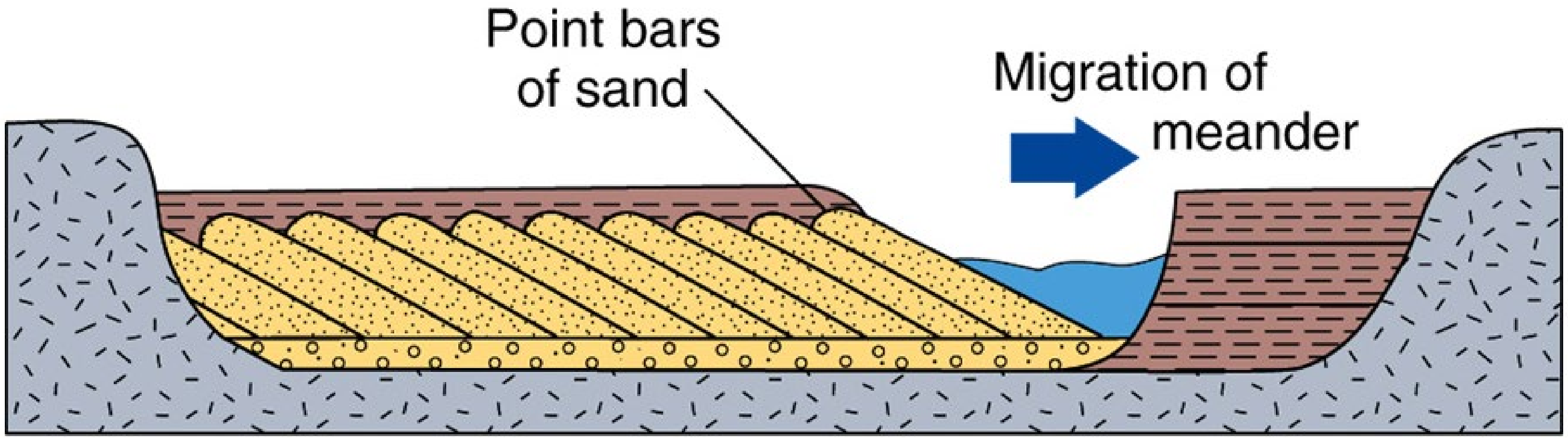


Fluvial Deposition



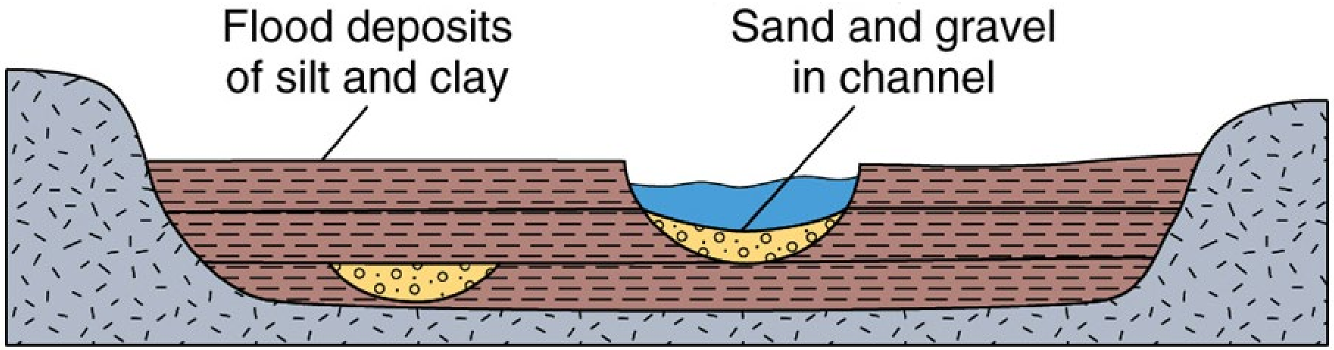
Point Bars





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).

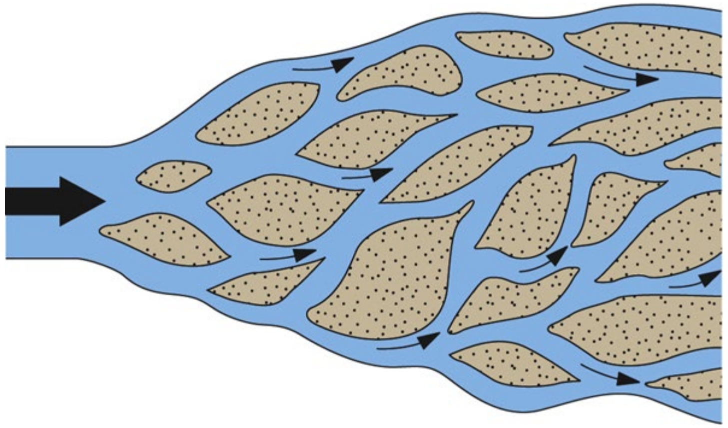


Channel "wanders" in the flood plain taking the "path of least resistance".

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***.

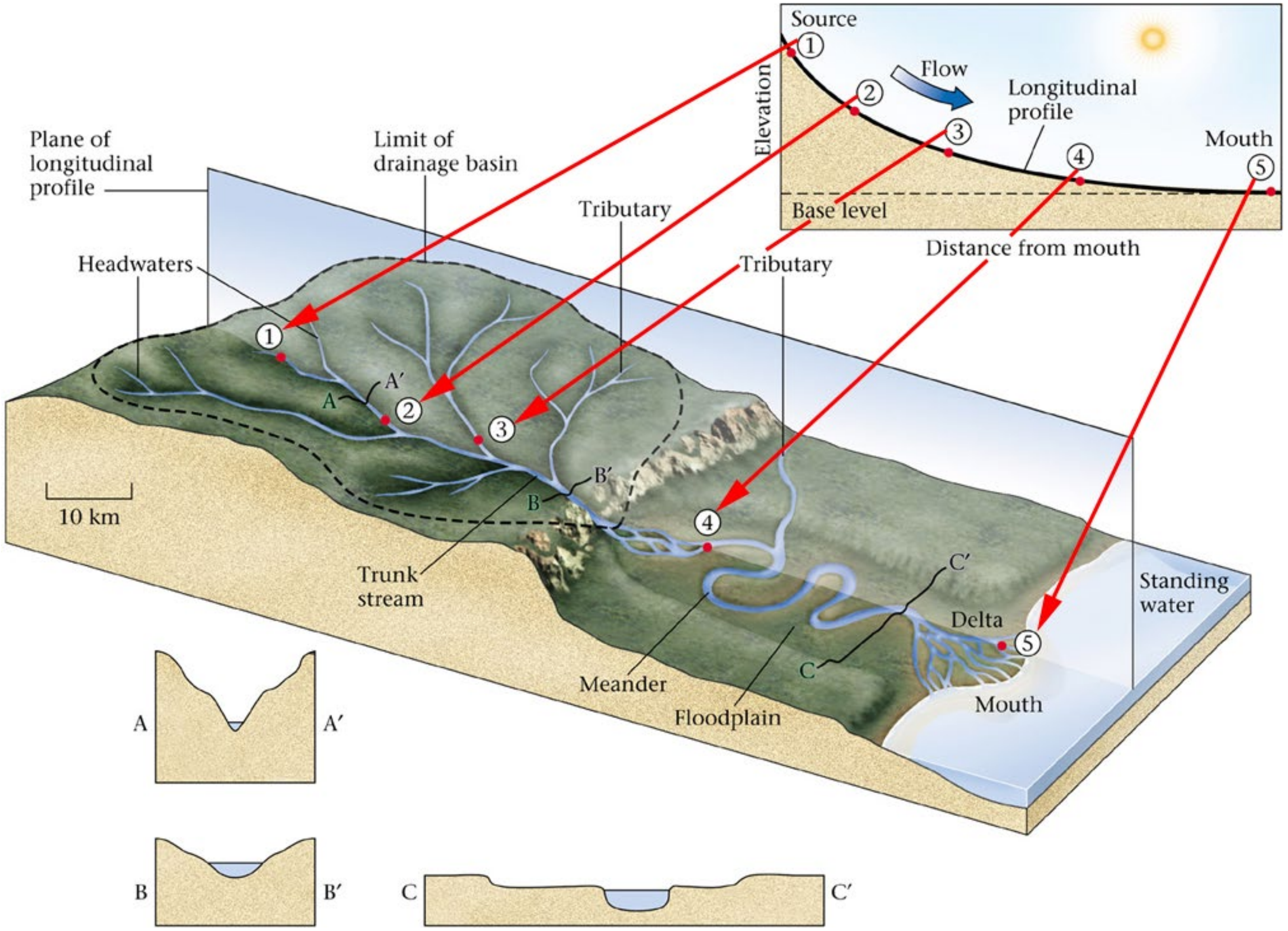
Fluvial Deposition

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

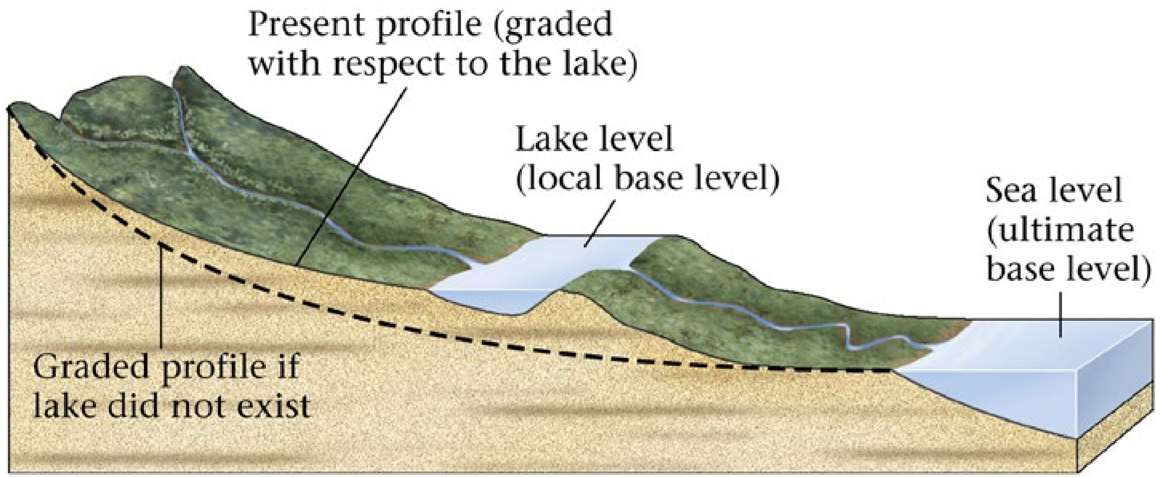


Typically headwaters are in highlands, gradient is high, channel is narrow and confined.

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



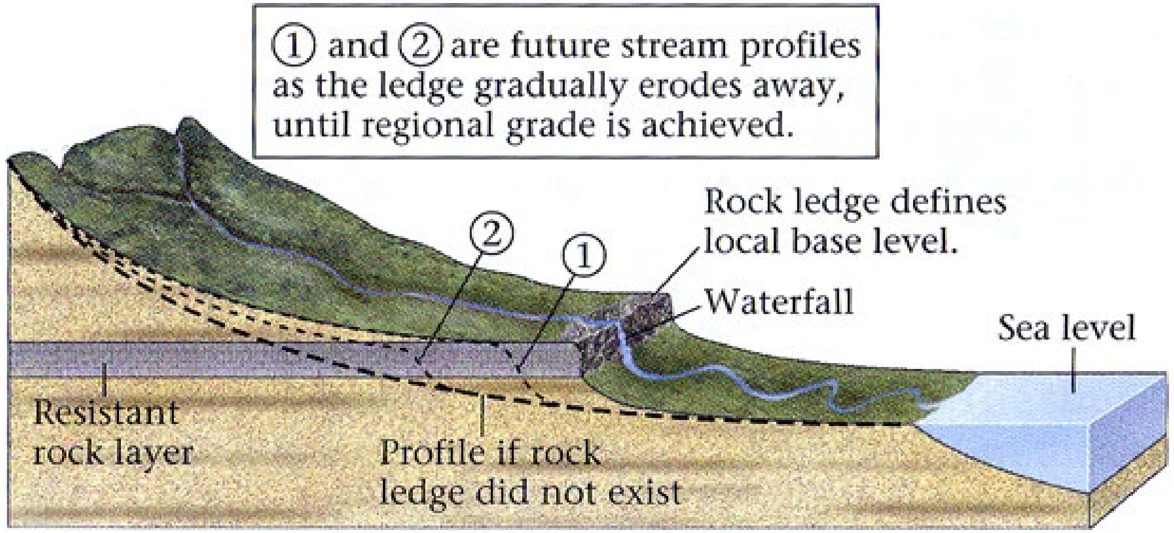
Young streams – irregular with rapids and waterfalls = "**ungraded**".

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).

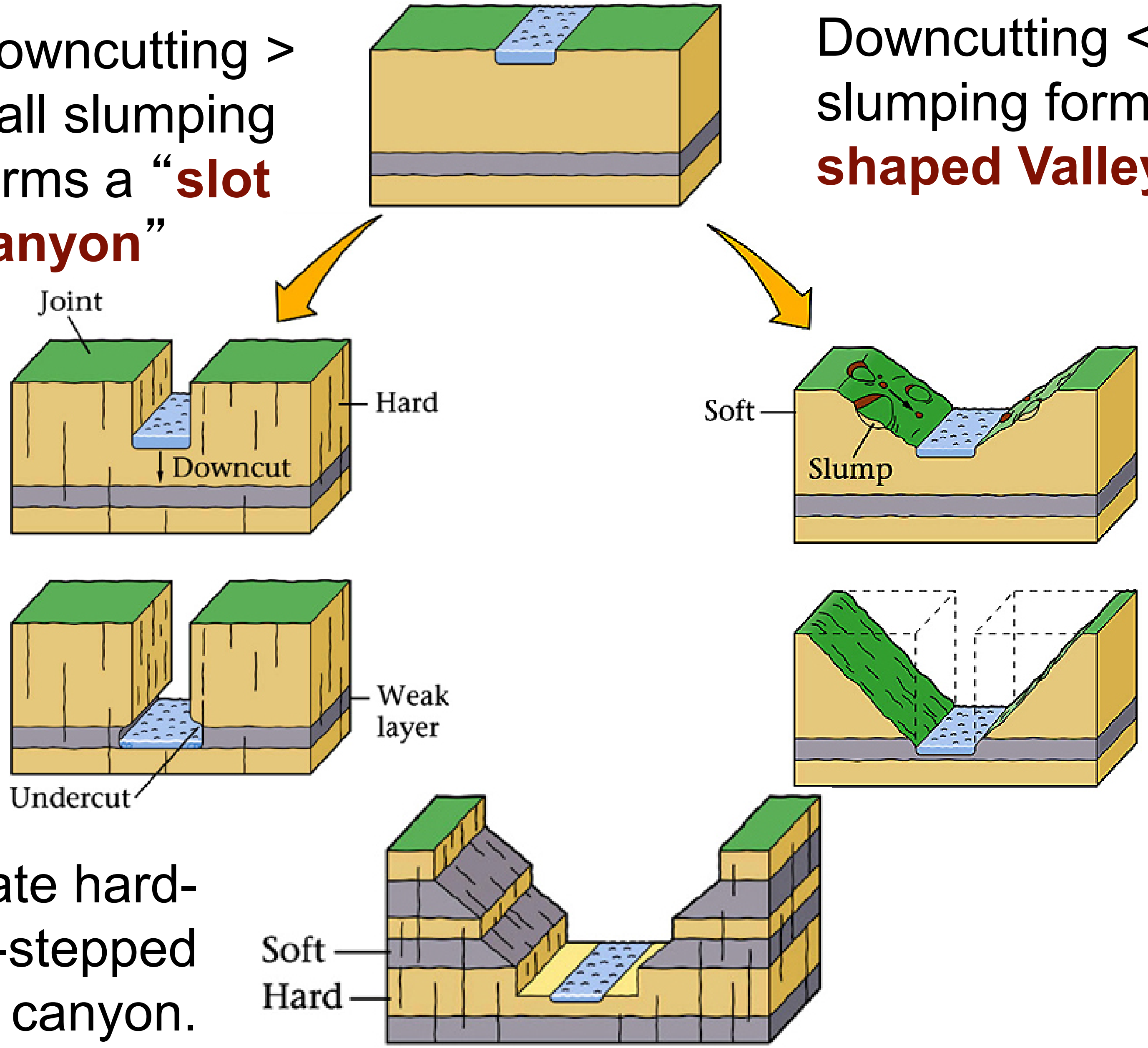


Valleys and Canyons

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

Downcutting > wall slumping forms a "**slot canyon**"

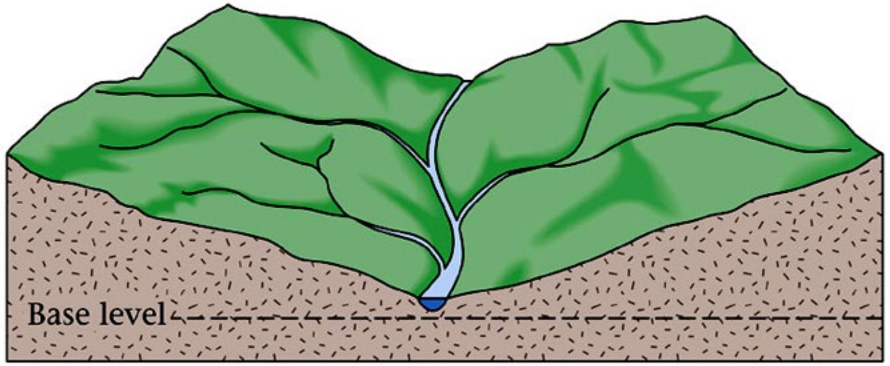
Downcutting < wall slumping forms a "**V-shaped Valley**"

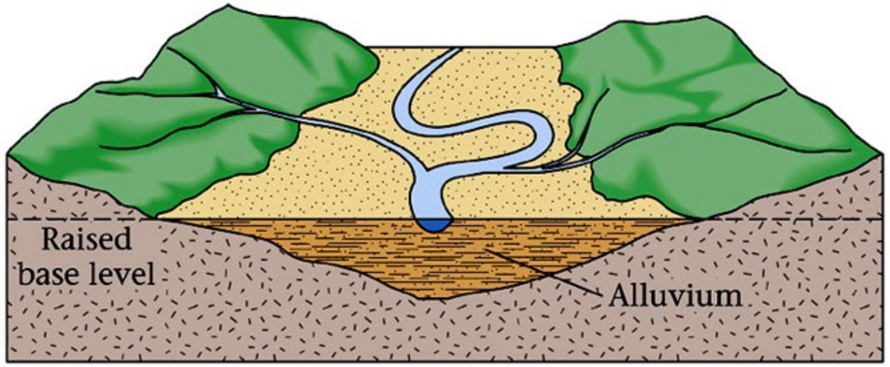


Downcutting through alternate hard-soft layers produces a stair-stepped canyon.

Valleys and Canyons

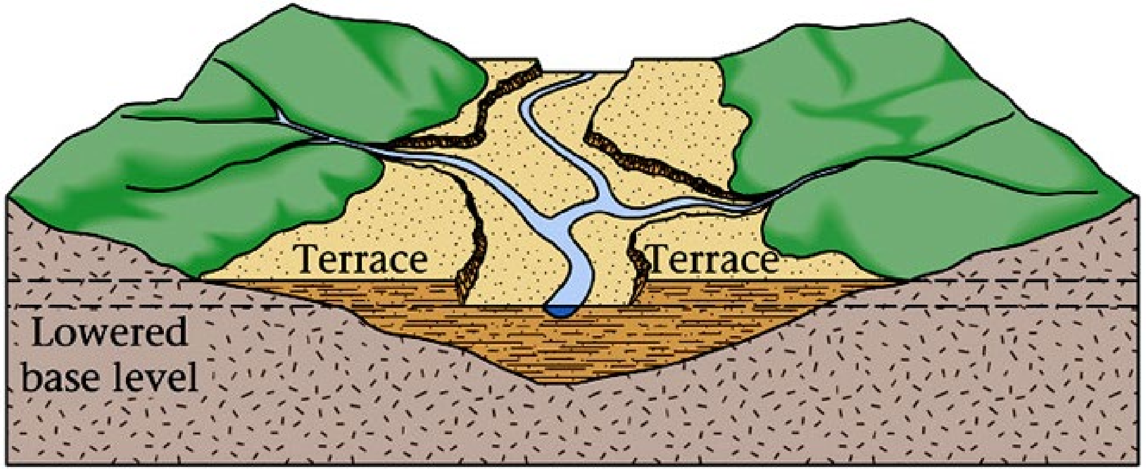
Vertical erosion means the valley floor is generally free of alluvium.
Alluvium is deposited when base-level is reached or it rises.





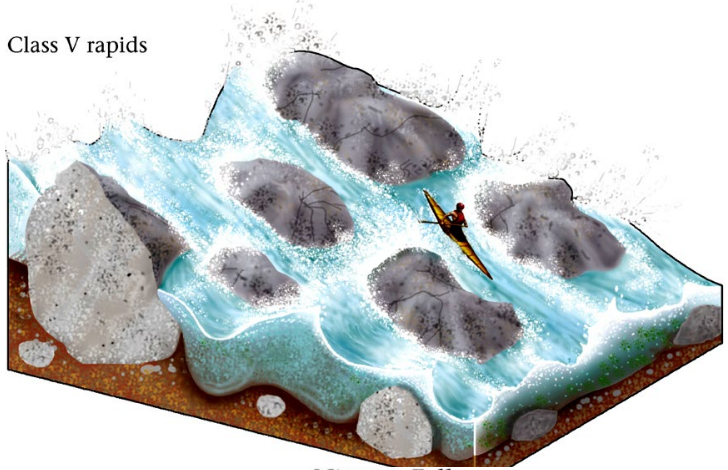
If base level drops and/or uplift occurs, streams cuts alluvium and forms "**stream terraces**".

Raised floodplains

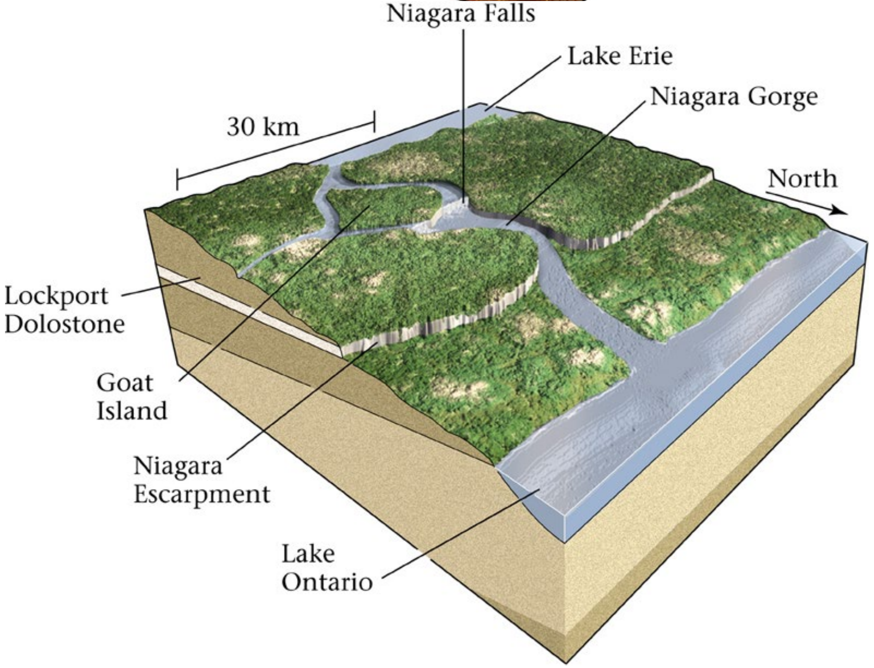


Rapids and Waterfalls

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

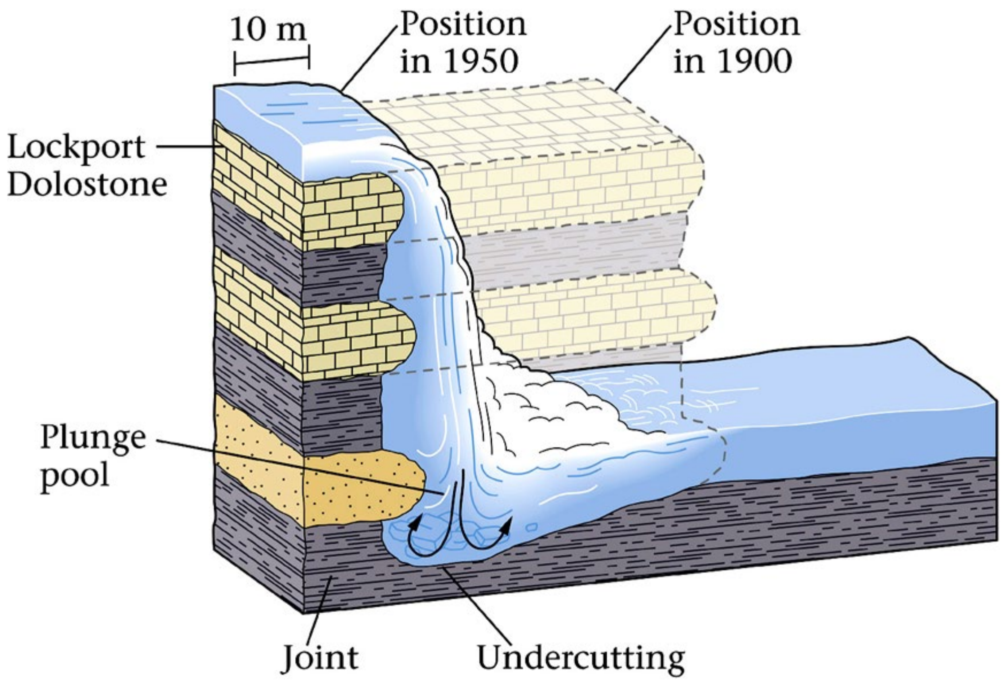


Waterfalls: escarpments (elevated sections), sometimes caused by a change in base level, faulting, variations in rock type, are removed by erosion and migrate upstream (e.g., Niagara Falls).



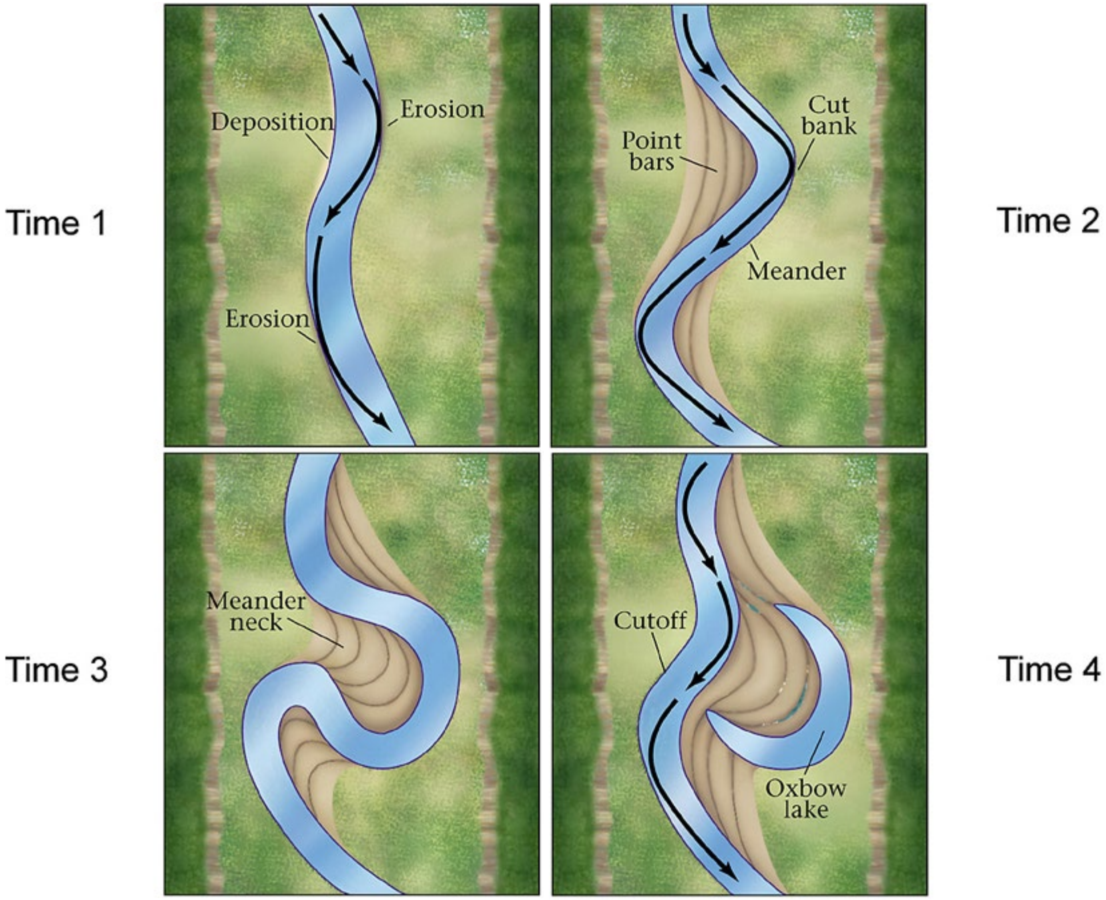
Rapids and Waterfalls

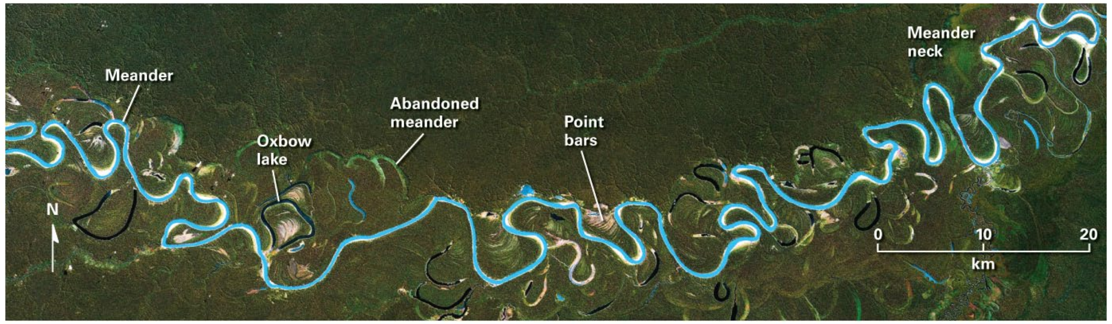
Niagara Falls: water moves from Lake Erie to Lake Ontario. Drops over a 55 m ledge of hard Silurian dolostone, which is on top of weak shale.
Undercutting by the water as it falls (forming a **plunge pool**) cause migration.



Meanders

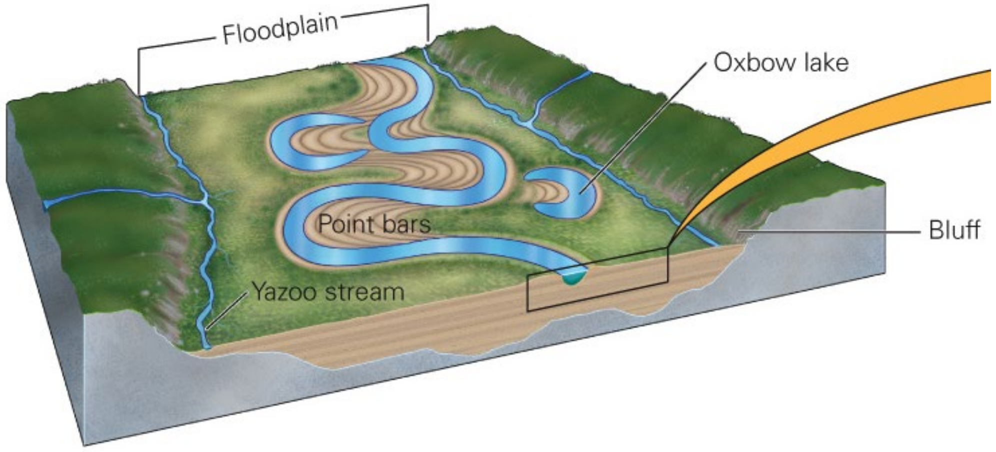
Develop on the floodplain as river changes from vertical to lateral erosion - it “wanders” over the floodplain. Eventually meanders are cut off and **ox-bow lakes** form.

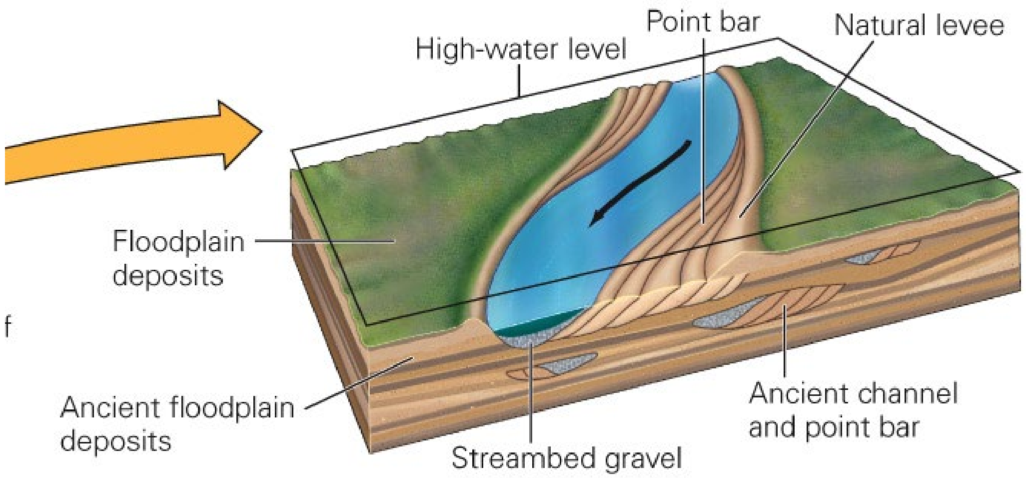




Natural Levees

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.





Avulsion = process of abandoning a river channel and forming a new one.

Deltas

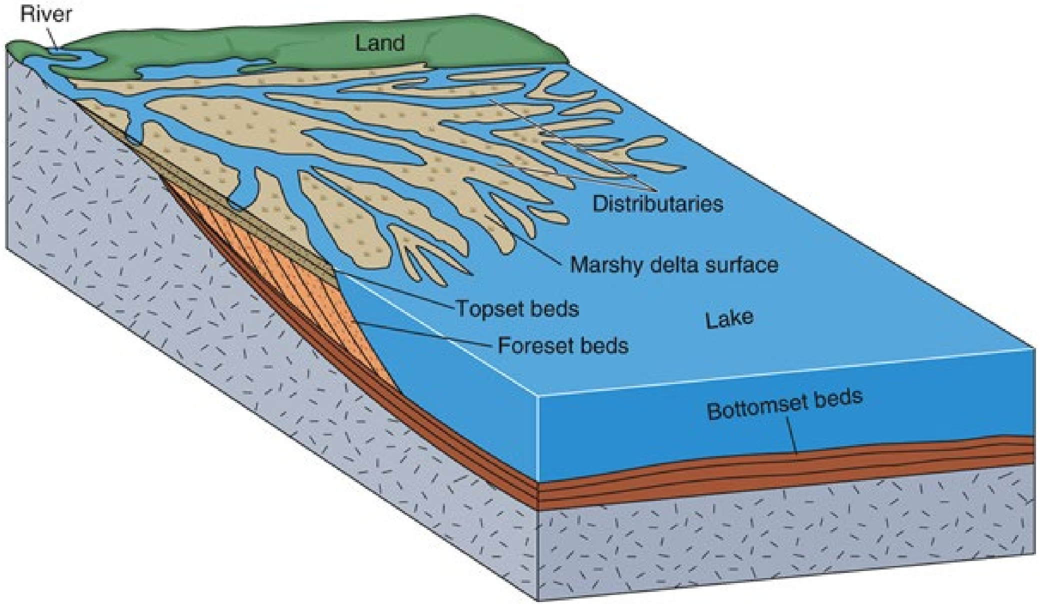
Form when river enters a body of water and velocity decreases (e.g., Mississippi).

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.

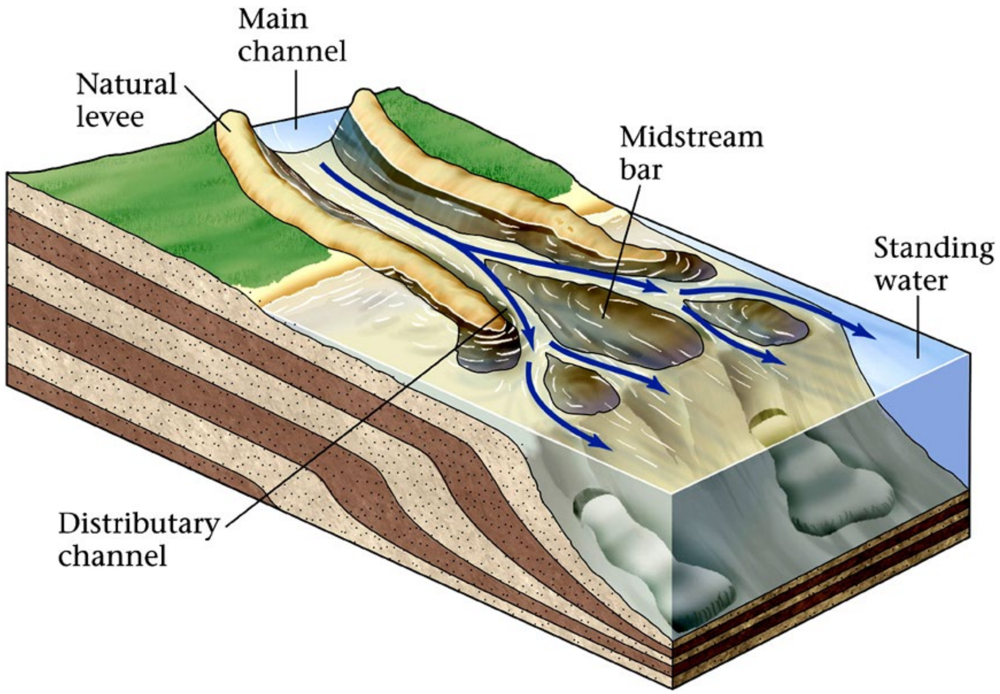
Tides.

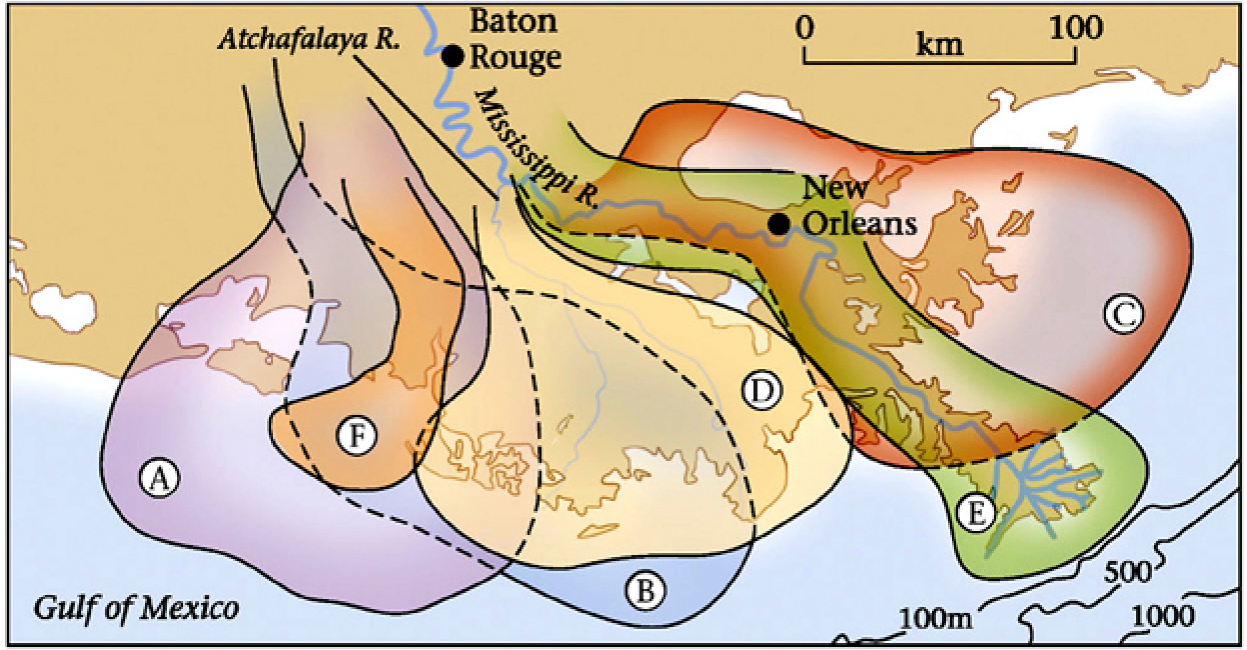


On top of a delta, the stream divides into a fan of ***distributary*** channels.

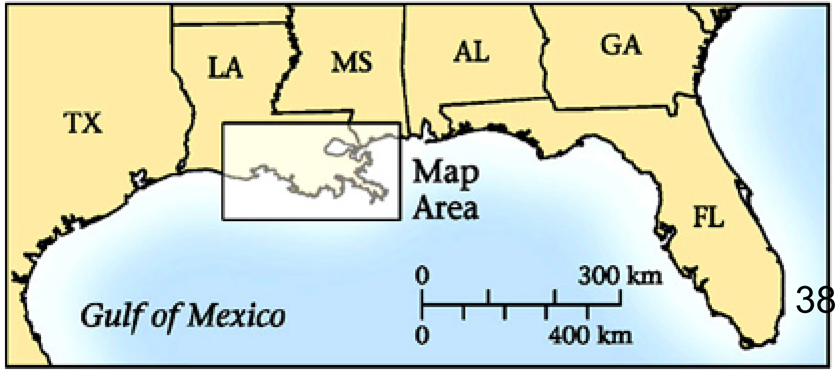
Deltas

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.



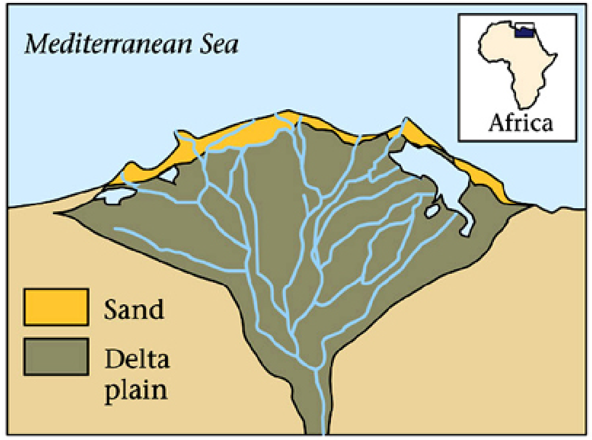


Delta deposit	Age (years)
F	400 b.p. – present
E	1,000 b.p. – present
D	2,500 b.p. – 800 b.p.
C	4,000 b.p. – 2,000 b.p.
B	5,500 b.p. – 3,800 b.p.
A	7,500 b.p. – 5,000 b.p.



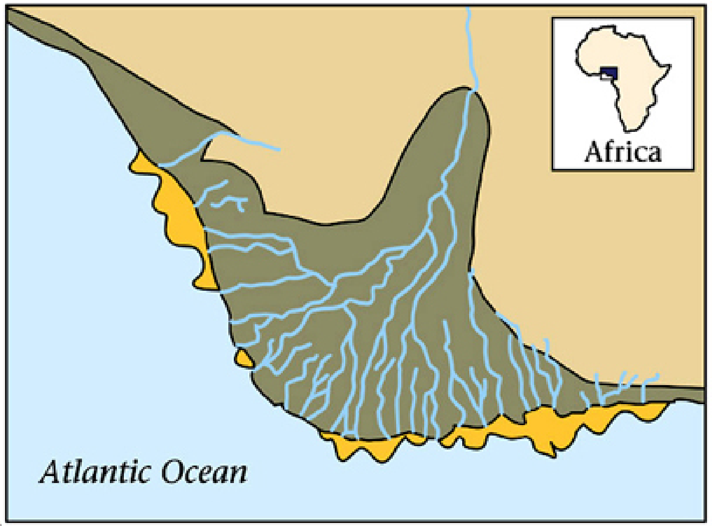
Deltas

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

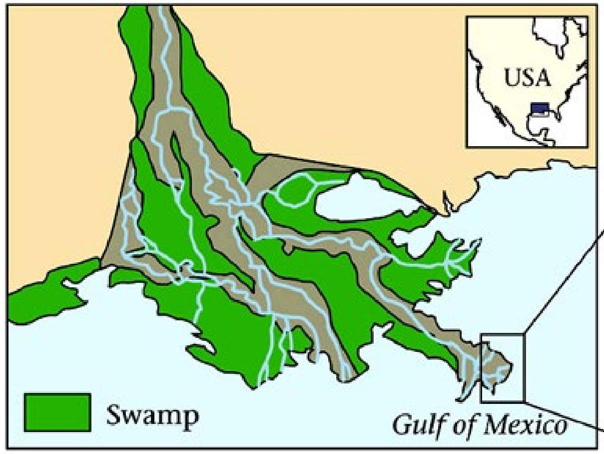


Deltas named by the Greeks after the Nile Delta - it is an upside down Δ.

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



Birds Foot Delta

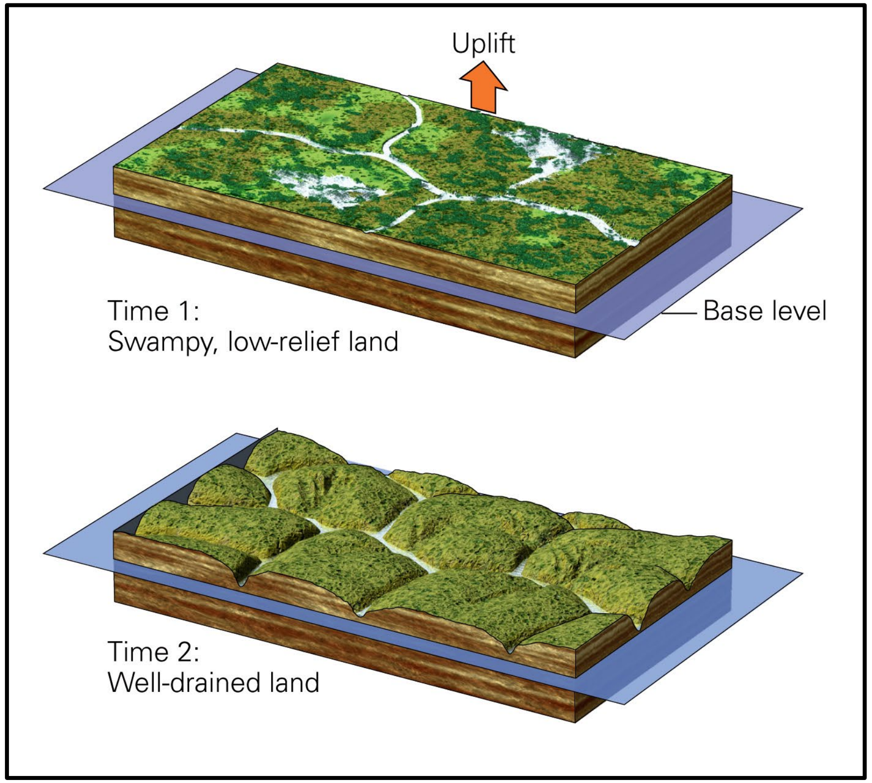


Weak offshore currents.

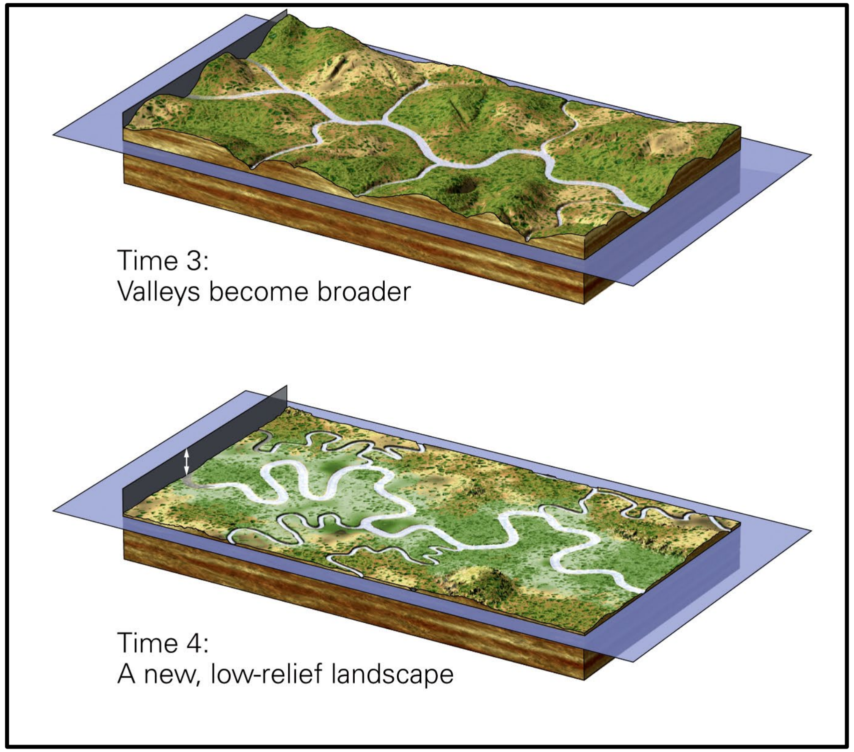
Deltas

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.

The Evolution of Drainage: Beveling Topography



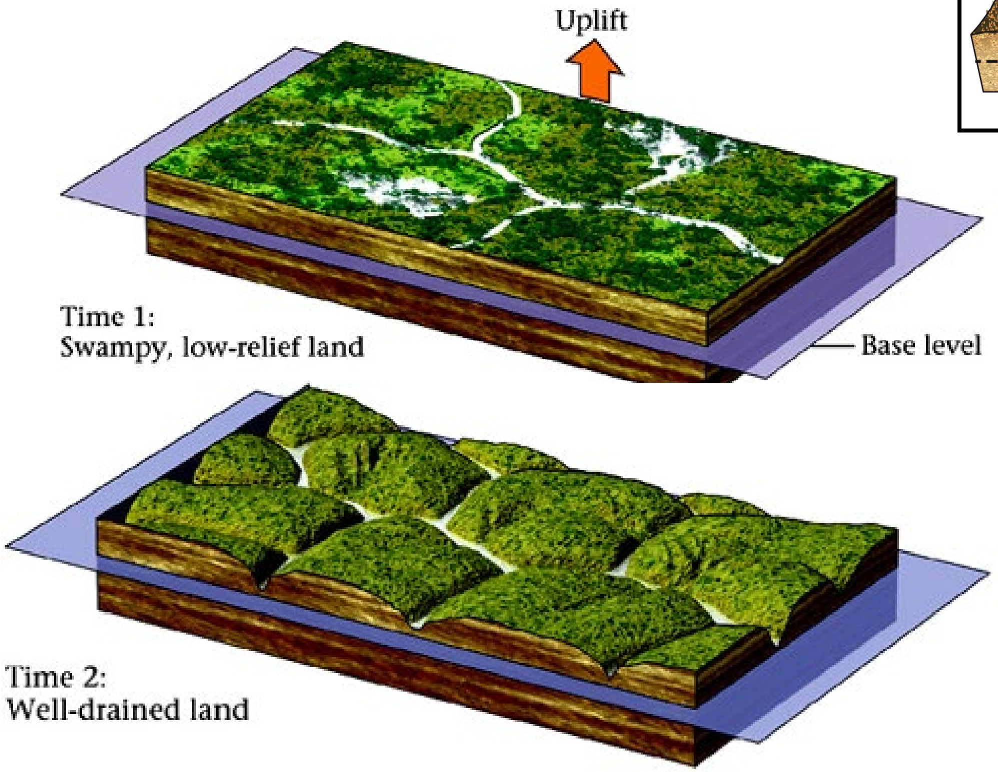
When base level drops, a new equilibrium is slowly established as streams cut into the former surface, valleys widen, and hills erode. Eventually, the landscape is eroded to the new base level.

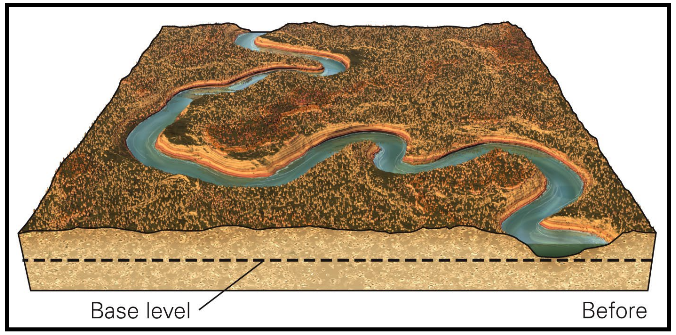


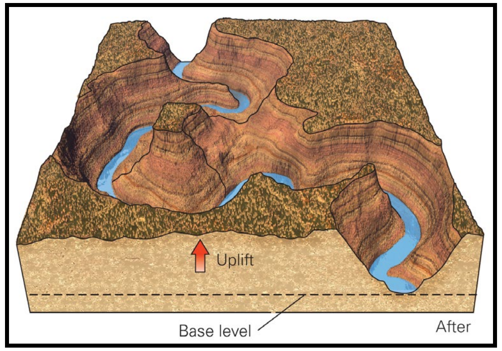
Stream Rejuvenation

Caused by uplift and/or base level drop.

Can also cause ***incised meanders***.







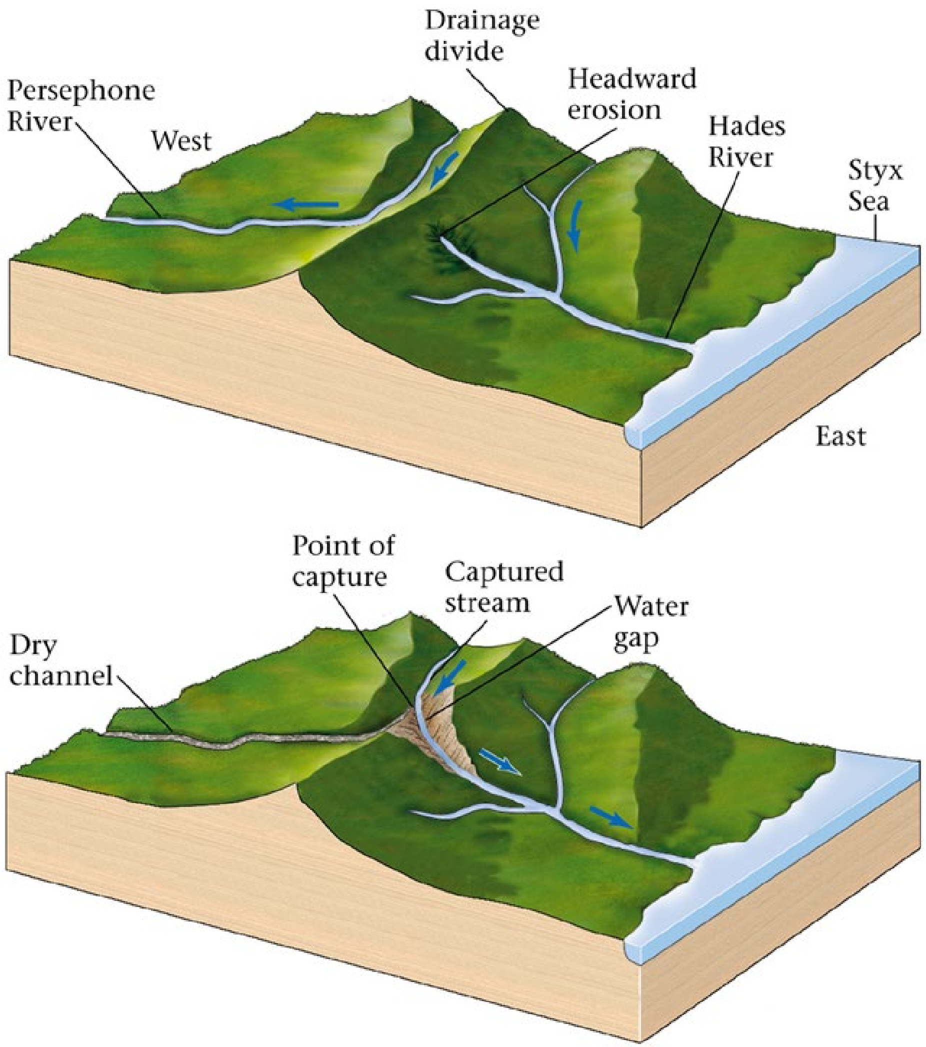
What are the causes of uplift?
What are the causes of base-level drop?

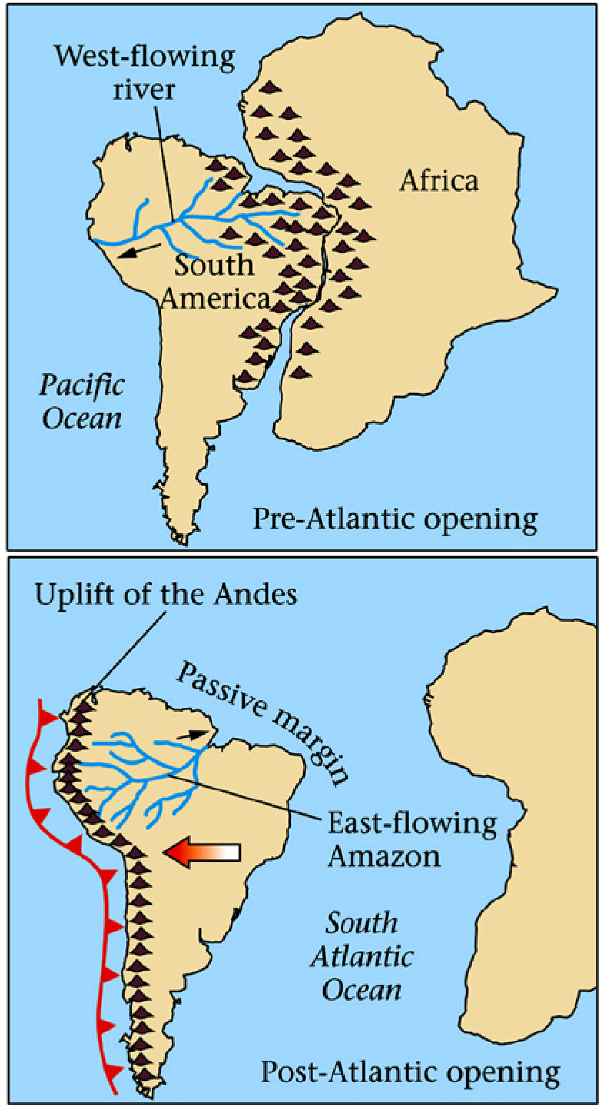
TABLE F.1 Causes of Uplift and Subsidence

Causes of Uplift
• **Thickening of the crust.** At convergent and collisional boundaries, compression causes the crust to shorten horizontally (by development of folds, faults, and foliations) and thicken in the vertical direction. Because of isostasy (see Chapter 11), lithosphere with thickened crust floats relatively higher on the asthenosphere, with the result that the surface of the crust in mountain belts rises. Intrusion or extrusion of igneous rocks thickens the crust or builds volcanoes on top of the surface, and also can cause uplift.
• **Heating of the lithosphere.** Heating decreases the thickness and density of lithosphere, so to maintain isostatic equilibrium, lithosphere floats higher.
• **Rebound due to unloading.** Removal of a heavy load (such as a glacier or mountain) from the surface causes the Earth's surface to rise in a manner similar to the way a trampoline's surface rises when you step off it.
• **Delamination.** If dense lithospheric mantle separates from the base of the plate and sinks into the mantle, the surface of the lithosphere rises. The effect resembles the consequence of unloading ballast from a ship.
Causes of Subsidence
• **Thinning of the crust due to stretching.** In rifts, where the crust undergoes horizontal stretching, the axis of the rift drops down by slip on normal faults.
• **Cooling of the lithosphere.** Cooling thickens the lithospheric mantle and makes it denser, so to maintain isostatic equilibrium, the lithosphere sinks down and its surface lies at a lower elevation.
• **Sinking due to loading.** Where a heavy load (such as a glacier or volcano) forms on the Earth's surface, the lithosphere warps downward, somewhat like the surface of a trampoline warps down when you stand on it.

Stream Piracy

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





Raging Waters: Floods

- Floodwaters are devastating to people and property. Discharge and velocity increase and flow spills out of the stream channel, immersing adjacent land. Water scours floodplains, altering the landscape and destroying structures.

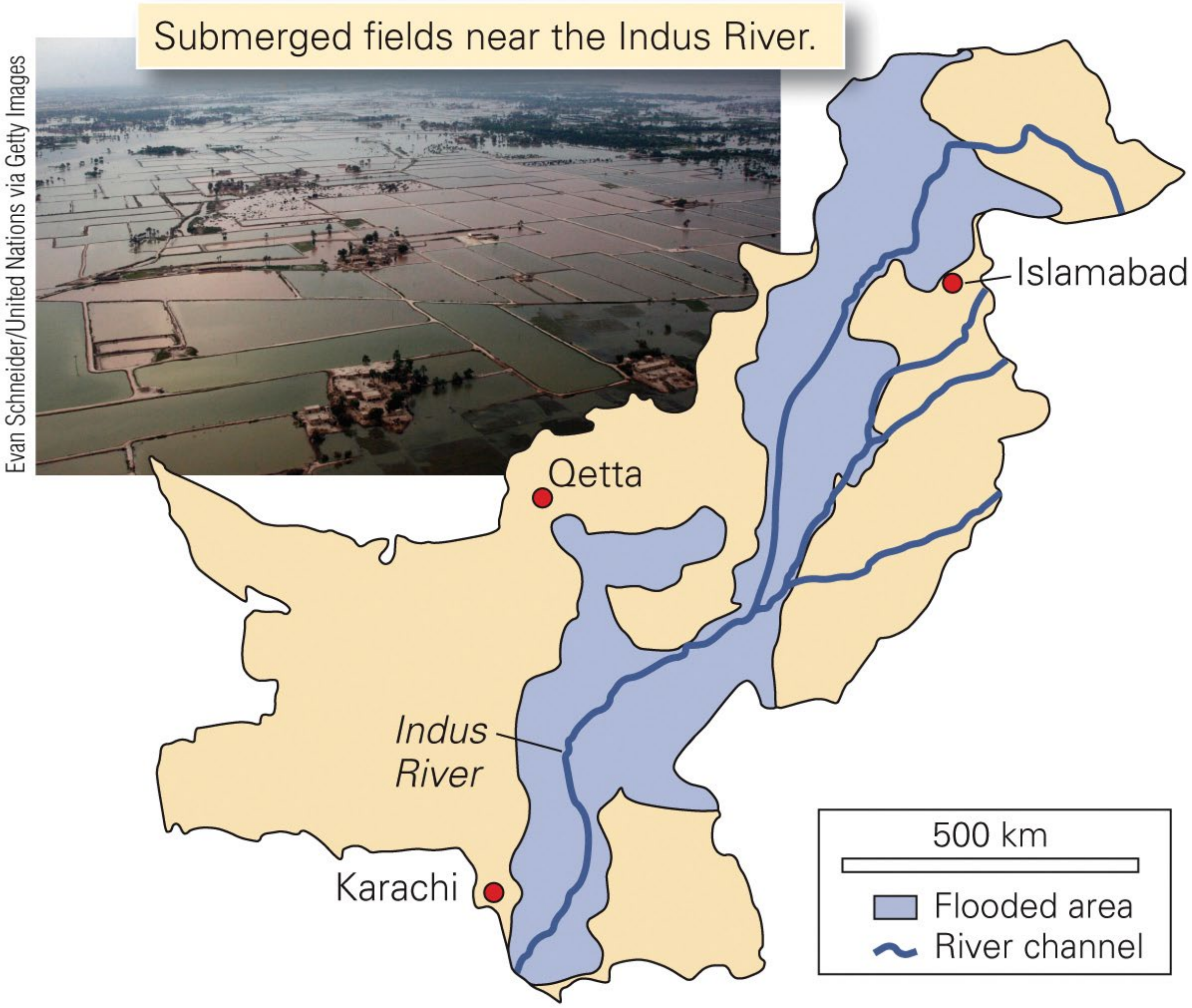
Stephen Marshak

Sigit Pamungkas/Newscom

Mike Hollingshead/Getty Images

Raging Waters: Seasonal Floods

- Seasonal floods take time—hours or days—allowing for evacuation. Still, so many people live in floodplain and delta-plain settings that losses are still gigantic. Seasonal floods recur on an annual basis. Monsoons, the tropical rains of the Indian subcontinent, generate long periods of rain and severe flooding. In 1990, a monsoon killed 100,000 people in Bangladesh.



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.

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

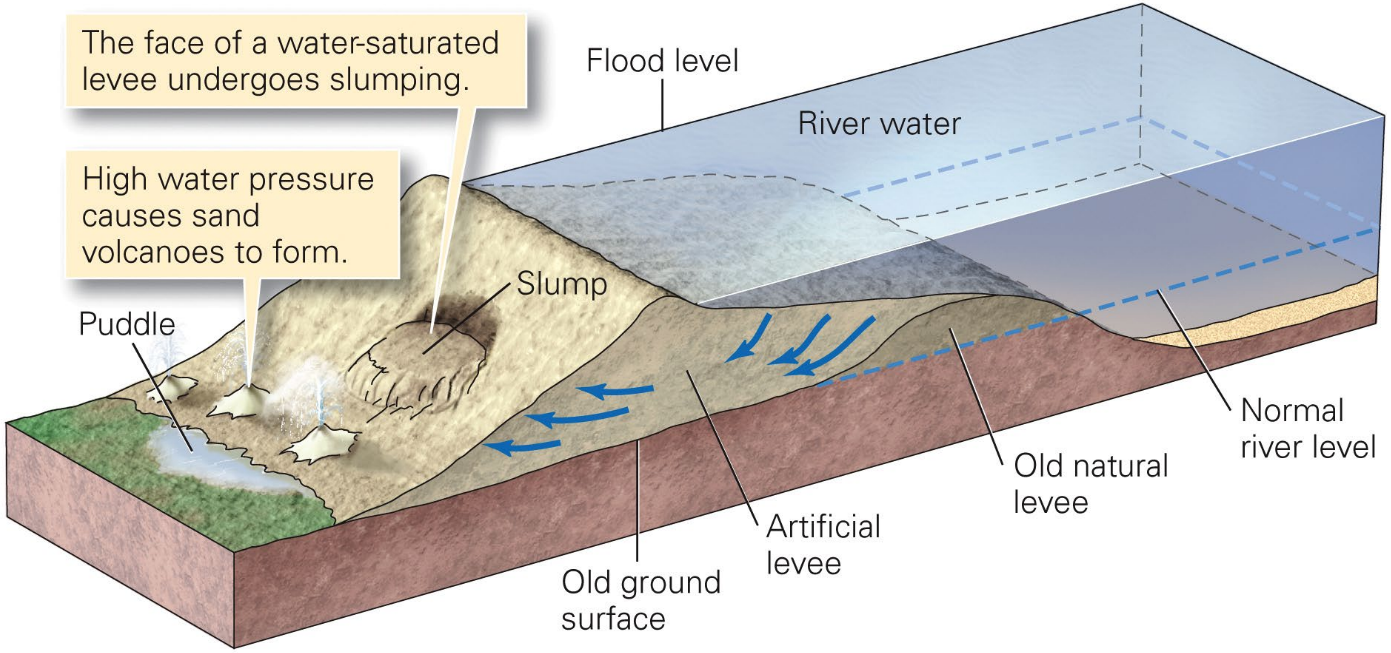
What flood control measures can you name?

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.

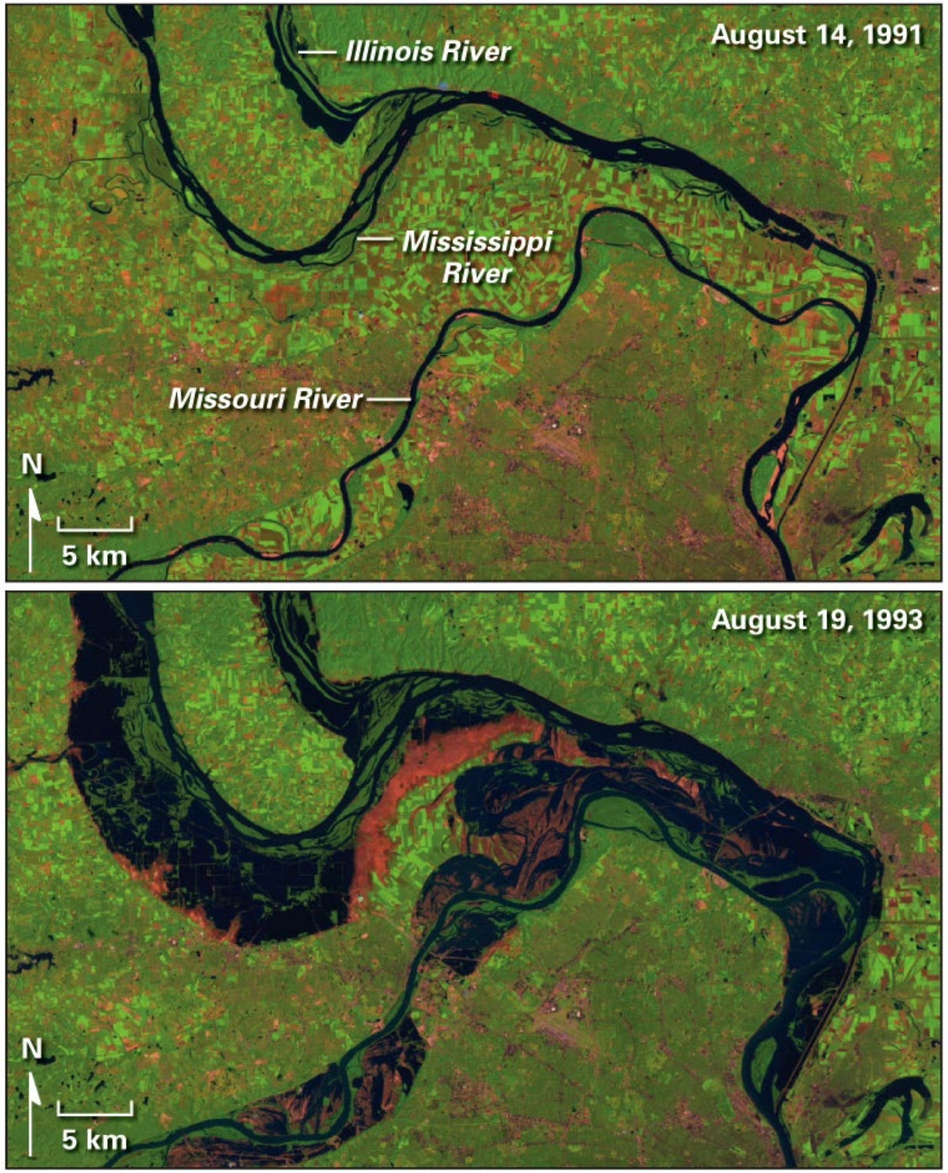
Living with Floods – 1

- Flood control is expensive and sometimes futile. Dams hold water back from trunk streams. Artificial levees and flood walls increase channel volume and transmit intensified flooding downstream. Levees are sometimes overtopped or undermined.

Stephen Marshak



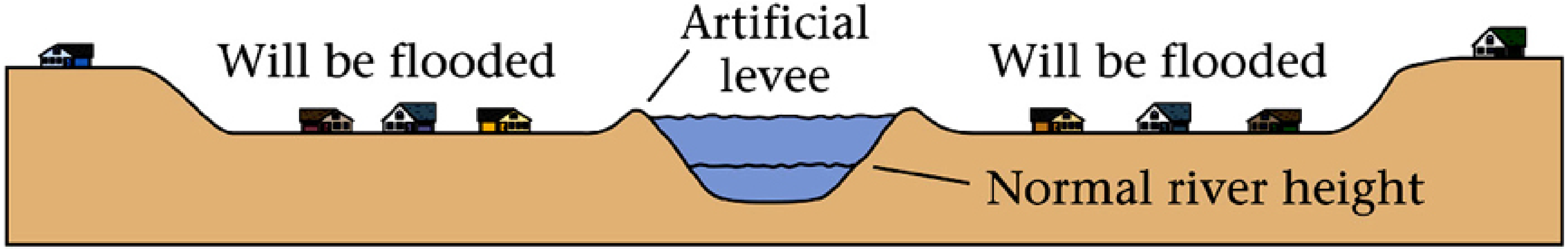
Case History of a Seasonal Flood: the Mississippi and Missouri Rivers, 1993



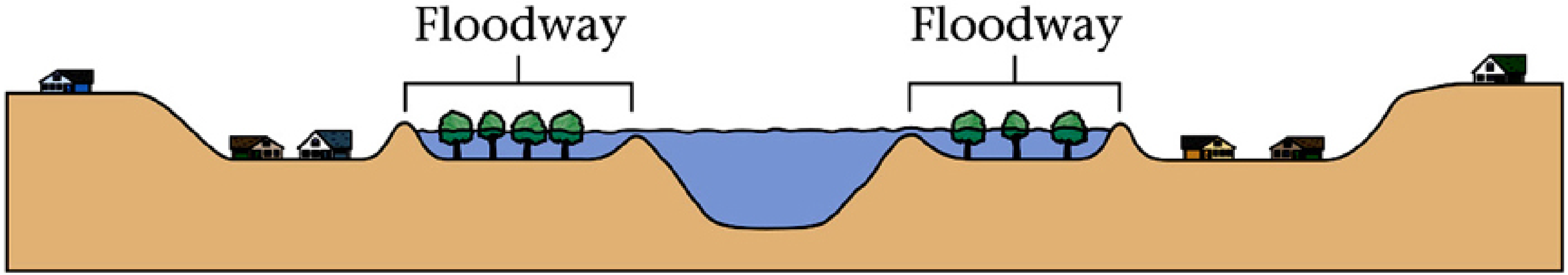
In the spring of 1993, the jet stream moved over the midwestern United States. This trapped moist humid air from the Gulf of Mexico and rain fell in great abundance. In July of 1993, floodwaters invaded large areas. Flooding lasted 79 days, covering 40,000 square miles. The toll was enormous: 50 people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

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.

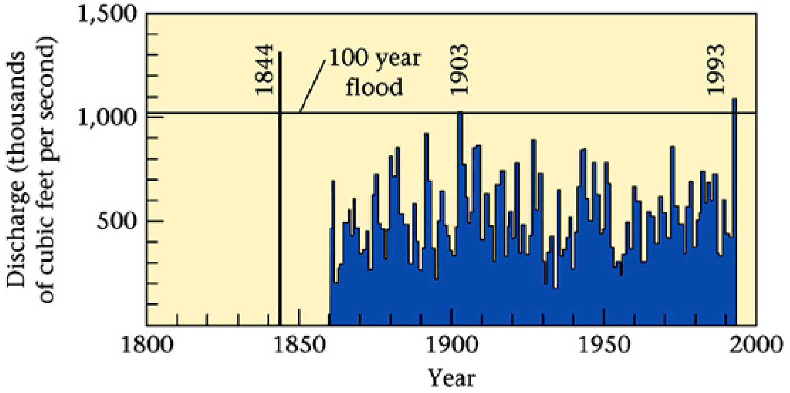


Floods

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

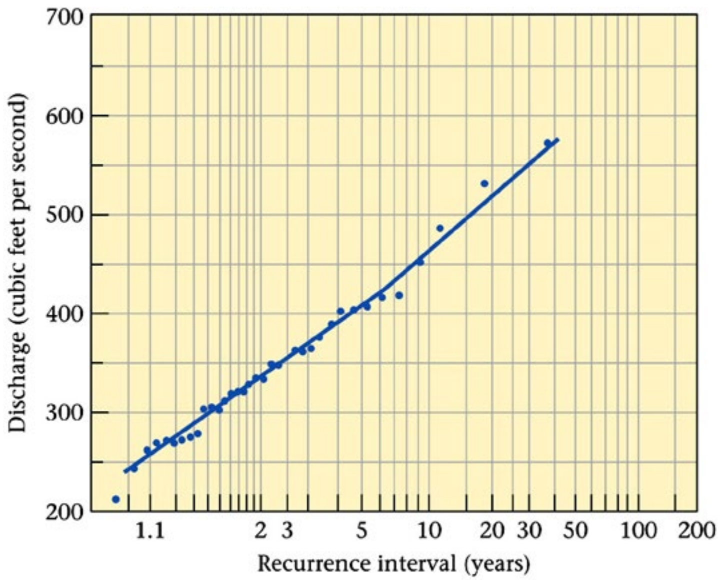
$$R = \frac{(n + 1)}{m}$$

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



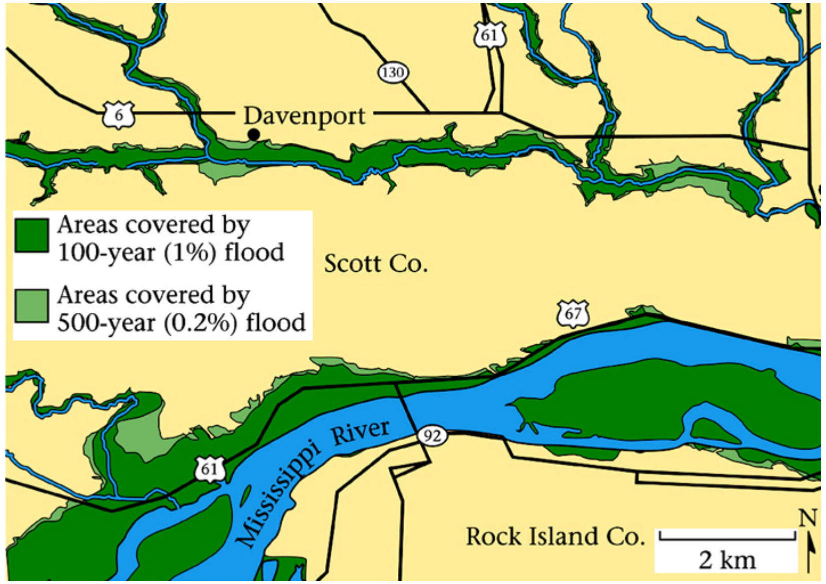
Flood Recurrence Interval (R): Average time hiatus between floods of a given size (e.g., 100 years flood occurs *on average* every 100 years).

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



Flood of 1% probability = 100 year flood.

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

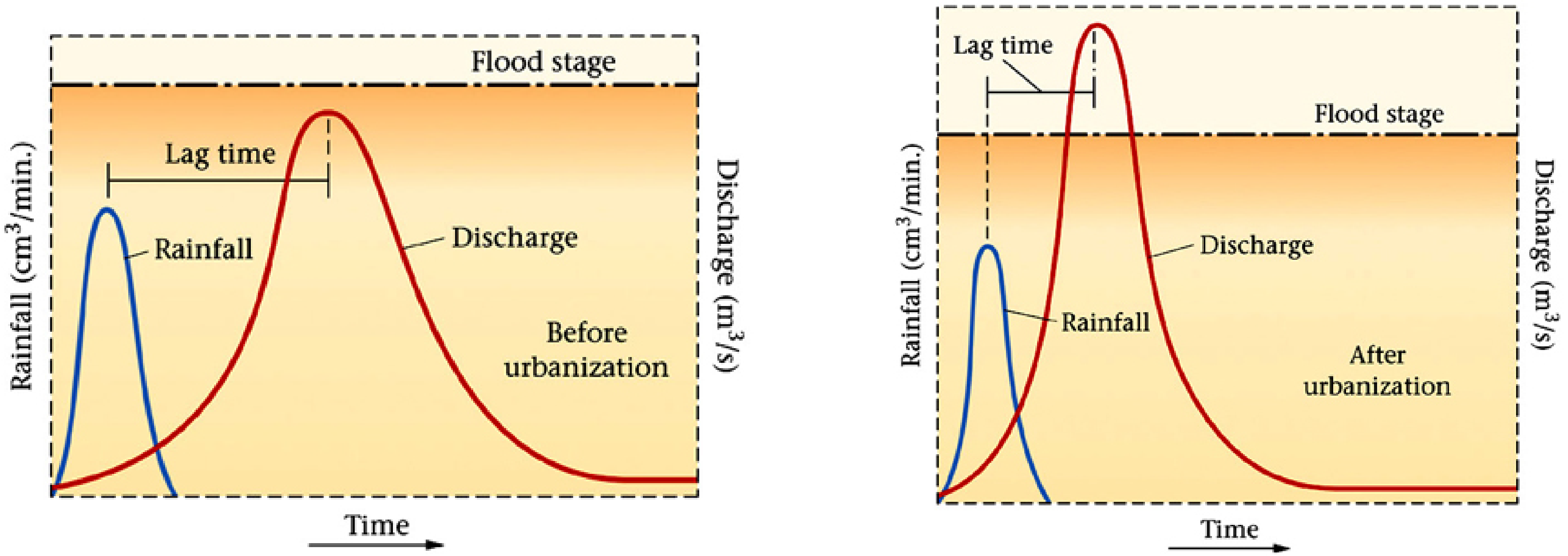


Rivers: A Vanishing Resource?

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).