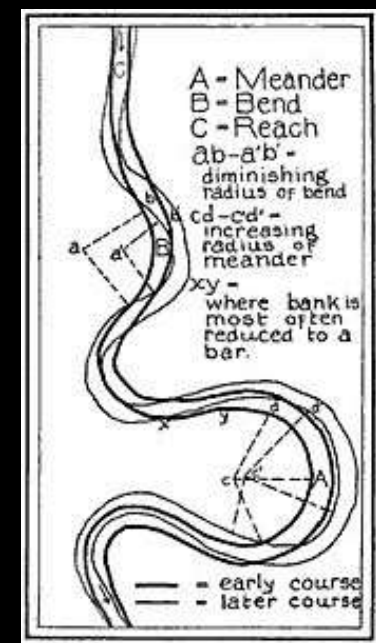
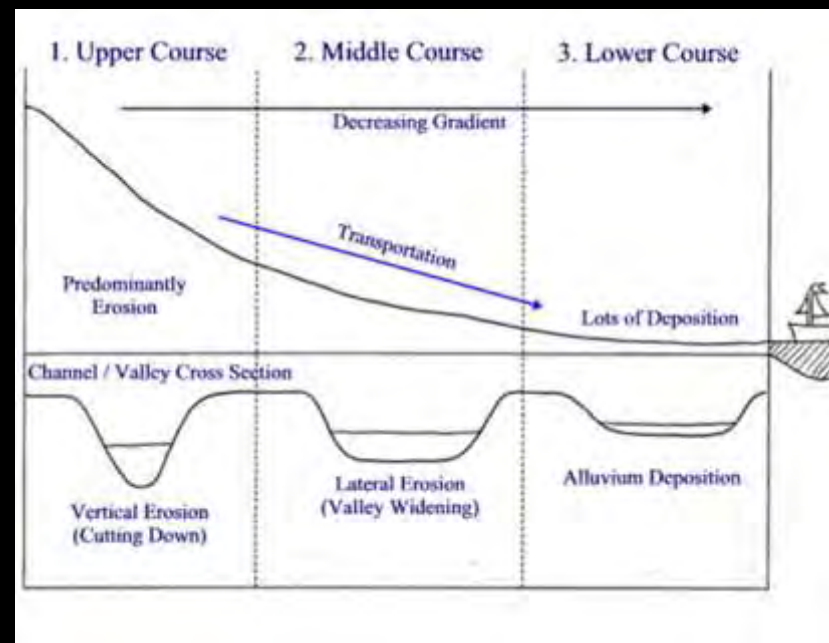
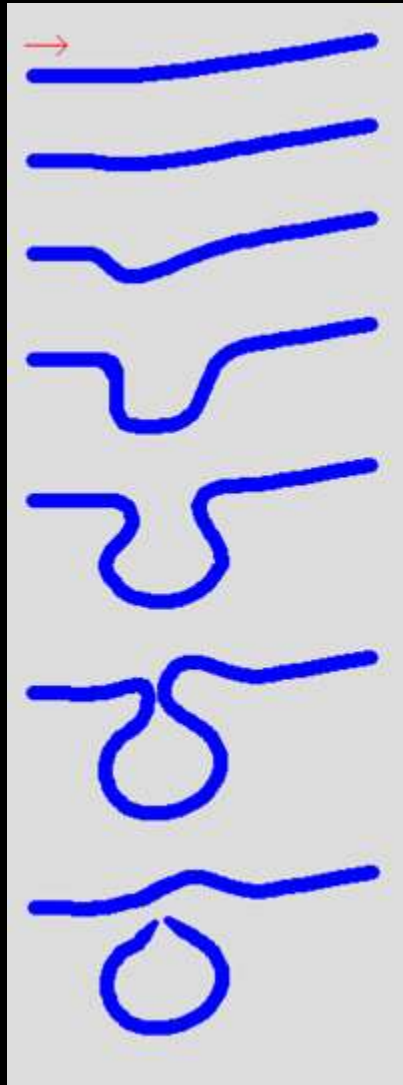


River Process: the Fluvial System and Hydrology

Kevin M. Anderson, Ph.D.

Austin Water - Center for Environmental Research



Sinuosity is inversely proportional to slope

Luna Leopold (October 8, 1915 – 2006)

He was a leading U.S. geomorphologist and hydrologist, and son of Aldo Leopold. He received a B.S. in Civil Engineering from the University of Wisconsin, Madison in 1936; an M.S. in Physics-Meteorology from the University of California, Los Angeles in 1944; and a Ph.D. in Geology from Harvard University in 1950.

Leopold is widely known in his primary field for his multitude of work in fluvial geomorphology and for the classic book, *Fluvial Processes in Geomorphology*, that he wrote with Gordon Wolman and John Miller.

“Water is the most critical resource issue of our lifetime and our children’s lifetime. The health of our waters is the principal measure of how we live on the land.”

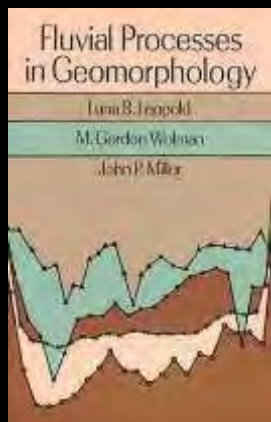
Leopold, Luna B. (1994, reprinted 2006). *A View of the River*. Harvard University Press; New Ed edition.

Leopold, Luna B. (1997). *Water, Rivers and Creeks*. University Science Books.

Leopold, L. (1977). “A Reverence for Rivers”. *Geology*. 5:429-430.

Leopold, Luna B., (1974). *Water: A Primer*. W.H Freeman Co.

Leopold, Luna B.; Wolman, M. Gordon; and Miller, John P. (1964, reprinted 1995). *Fluvial Processes in Geomorphology*. Dover Publications.



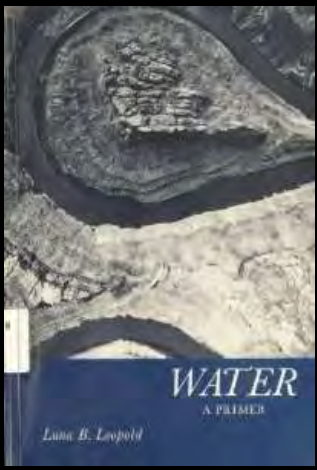
“A Reverence for Rivers”

Speaking of the Persians who dominated Asia Minor in the 5th century B.C., Herodotus said, “They never defile a river with the secretions of their bodies, nor even wash their hands in one; nor will they allow others to do so, as they have a great reverence for rivers.” It is the last phrase that deserves our attention.

The river is like an organism; it is internally self-adjusting. It is also resilient and can absorb changes imposed upon it, but not without limit. The limit beyond which a river cannot adjust is well illustrated by some of the effects of our national program of channelization, in which we have already dredged, straightened, channelled, revetted, trained, and “improved” more than 16,500 miles of river channels in the United States, quite apart from the thousands of reservoirs already built.....

Man’s engineering capabilities are nearly limitless. Our economic views are too insensitive to be the only criteria for judging the health of the river organism. What is needed is a gentler basis for perceiving the effects of our engineering capabilities. This more humble view of our relation to the hydrologic system requires a modicum of reverence for rivers. [Leopold 1977]

The Virtual Luna Leopold Project
<http://eps.berkeley.edu/people/lunaleopold/>



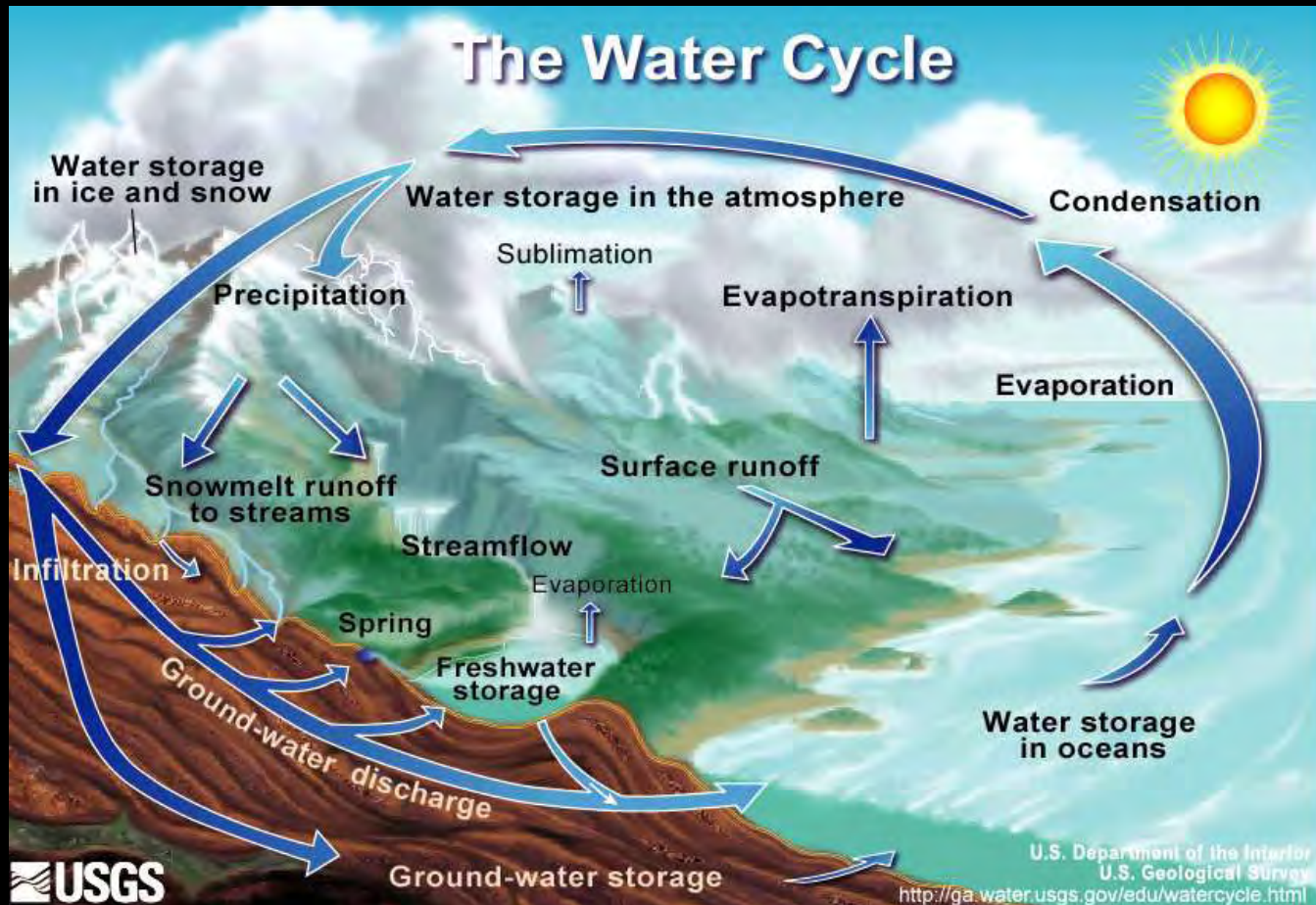
Luna B. Leopold
2005 GRA Lifetime Achievement Award

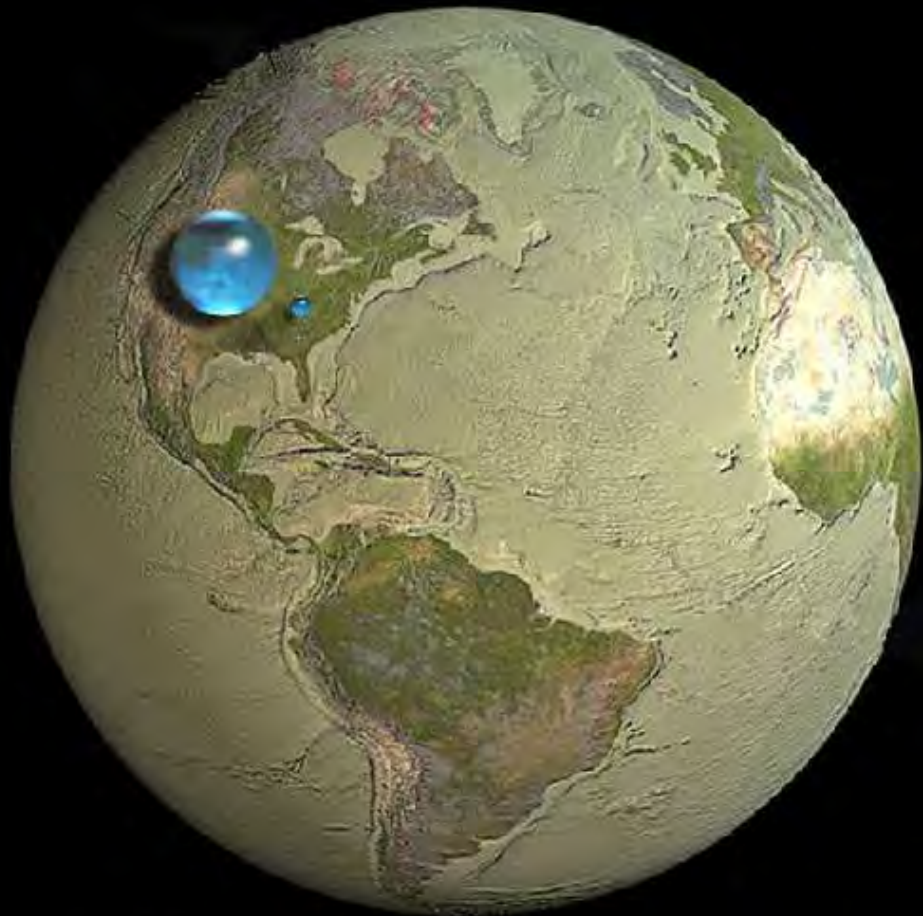


A river is a body of water flowing along a natural channel. It is a part of the water cycle.

Fluvial is a term used in geography and Earth science to refer to the processes associated with rivers and streams and the deposits and landforms created by them.

Water evaporates from water bodies such as rivers, lakes and seas, and from plants and trees. The water vapor rises, cools and condenses to form clouds. Rain falls from the clouds. The rain water is intercepted by plants, seeps into the ground before reaching surface streams, or runs off the land surface into streams and rivers. The rivers enter lakes or seas. The water cycle is then repeated.





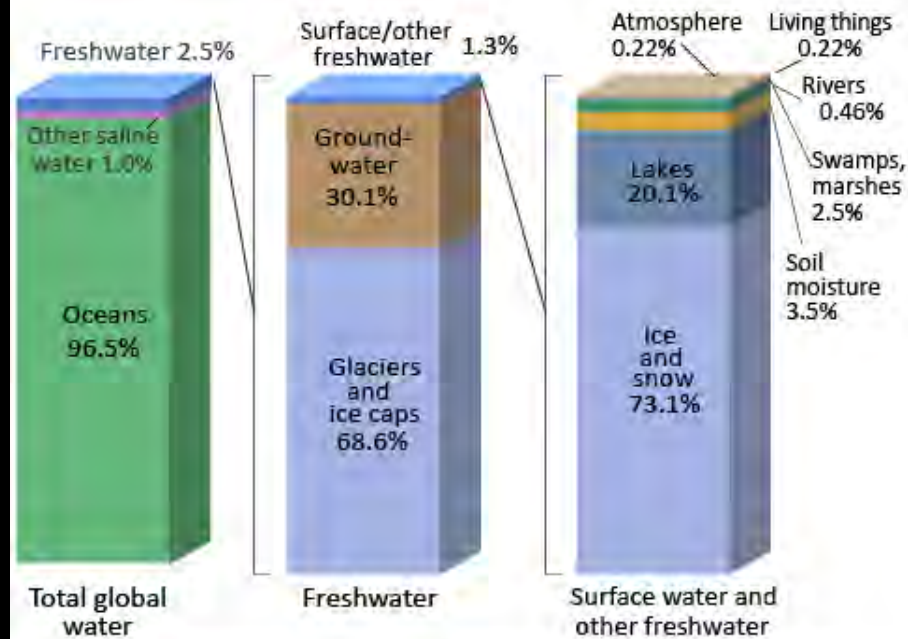
Water in, on, and above the Earth



- Liquid fresh water
- Freshwater lakes and rivers

Howard Perlman, USGS
 Jack Cook, Adam Nieman
 Data: Igor Shiklomanov, 1993

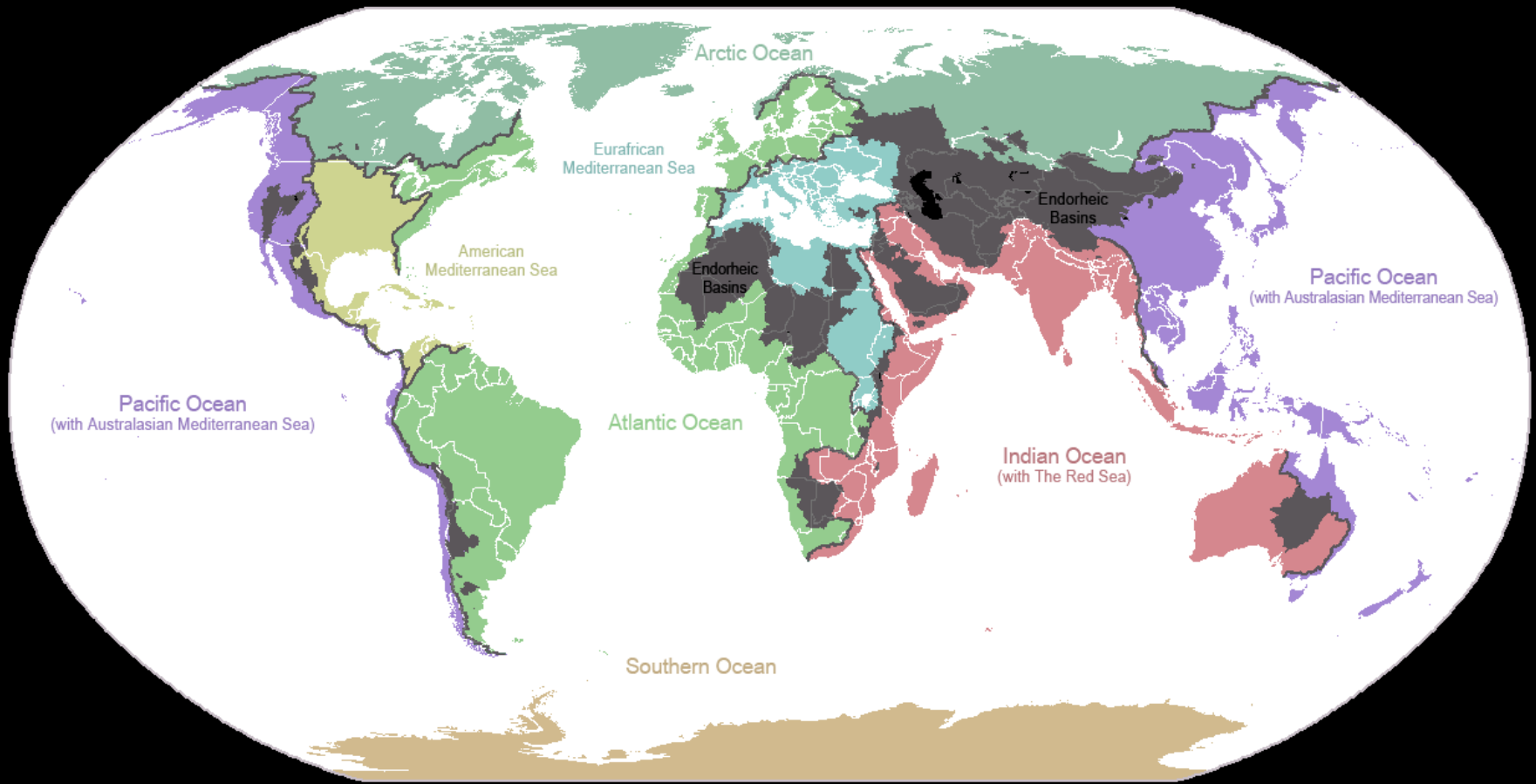
Where is Earth's Water?



Source: Igor Shiklomanov's chapter "World fresh water resources" in Peter H. Gleick (editor), 1993, *Water in Crisis: A Guide to the World's Fresh Water Resources*. (Numbers are rounded).

Spheres showing:

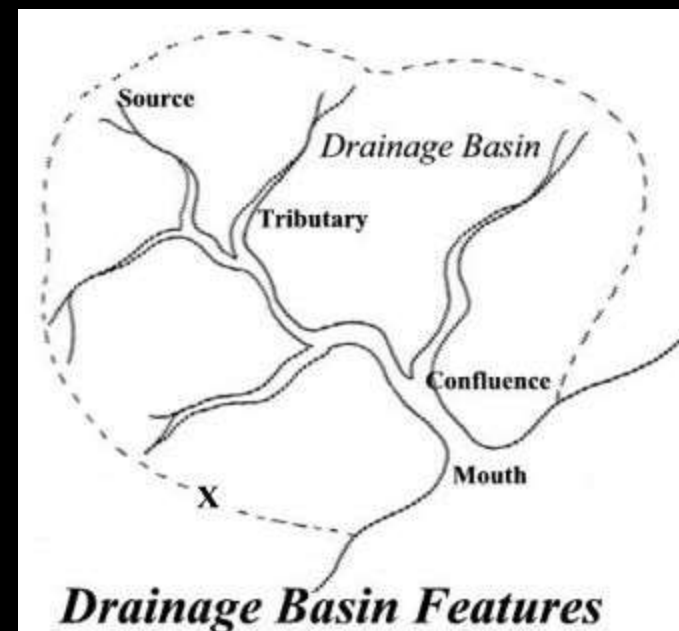
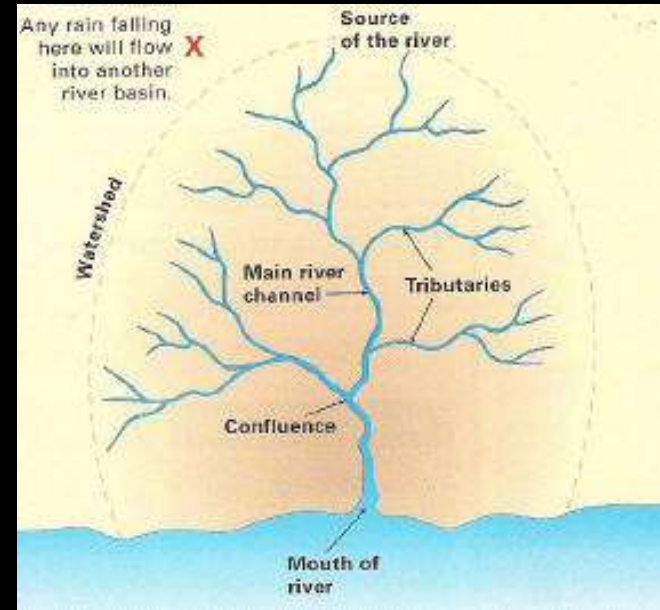
- (1) All water (sphere over western U.S., 860 miles in diameter)
- (2) Fresh liquid water in the ground, lakes, swamps, and rivers (sphere over Kentucky, 169.5 miles in diameter)
- (3) Fresh-water lakes and rivers (sphere over Georgia, 34.9 miles in diameter).



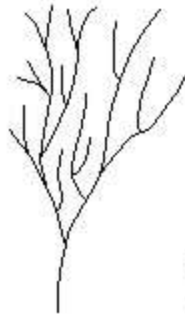
Watersheds vs. Drainage Basin/Catchment Area

A watershed (US usage) or drainage basin/catchment area (British usage) is an area of land which is drained by a river and its tributaries. In British usage, a watershed is the boundary separating one drainage basin from another. It usually follows the ridge or crest of a hill or mountain.

River starts at the source or headwaters, flows along its course and ends or drains into a lake or sea.

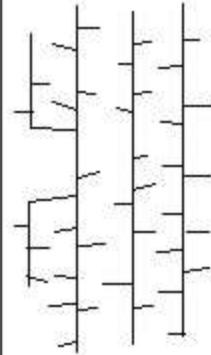


Drainage Patterns



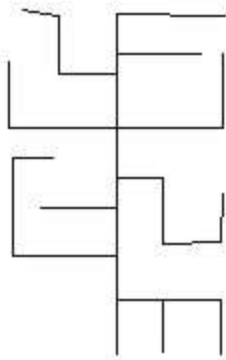
DENDRITIC – tributaries meet at low angles and branch in random, tree-like pattern. Form on roughly planar surfaces of consistently erodable rocks or sediment.

**FLINT/CHATTAHOOCHEE/
APALACHICOLA SYSTEM**



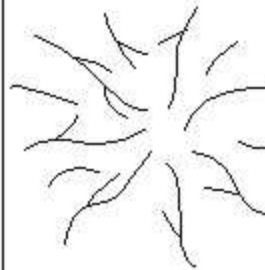
TRELLIS – Short tributaries meet long trunk streams at near right angles. Few connections between trunks. Form on folded or tilted sedimentary rocks of different resistances to erosion.

POTOMAC SYSTEM



RECTANGULAR – Straight tributaries meet straight trunk streams. Bends approximate right angles. Form on faulted or otherwise fractured bedrock. (**ANGULAR** drainage is similar but bends/junctions are at some angle other than 90°).

**COTTONWOOD CREEK,
UTAH (ANGULAR DRAINAGE)**



RADIAL – Flow outward from a well-defined central point. Form on volcanoes and other round uplifts of the land.

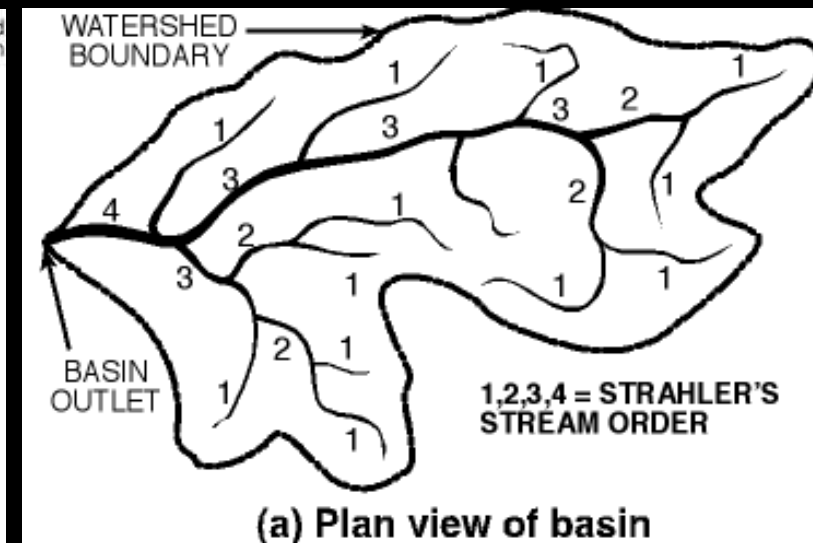
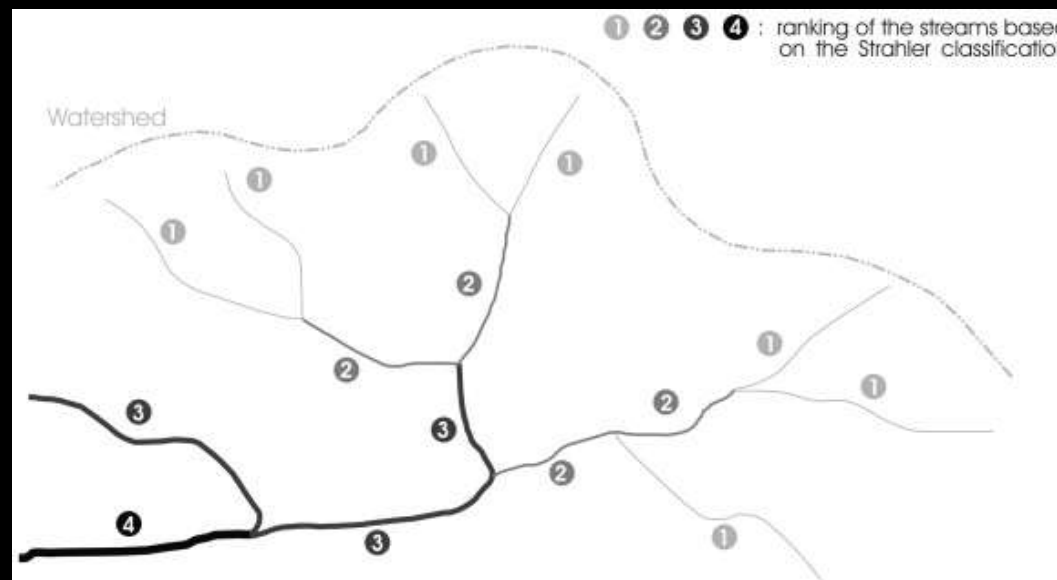
**DRY VALLEYS ON NORTH
MENAN BUTTE, IDAHO**

Strahler number or Horton–Strahler number

a mathematical tree with a numerical measure of its branching complexity.

These numbers were first developed in hydrology by Robert E. Horton (1945) and Arthur Newell Strahler (1952, 1957) in this application, they are referred to as the Strahler stream order and are used to define stream size based on a hierarchy of tributaries.

They also arise in the analysis of hierarchical biological structures such as (biological) trees and animal respiratory and circulatory systems, in register allocation for compilation of high level programming languages and in the analysis of social networks.



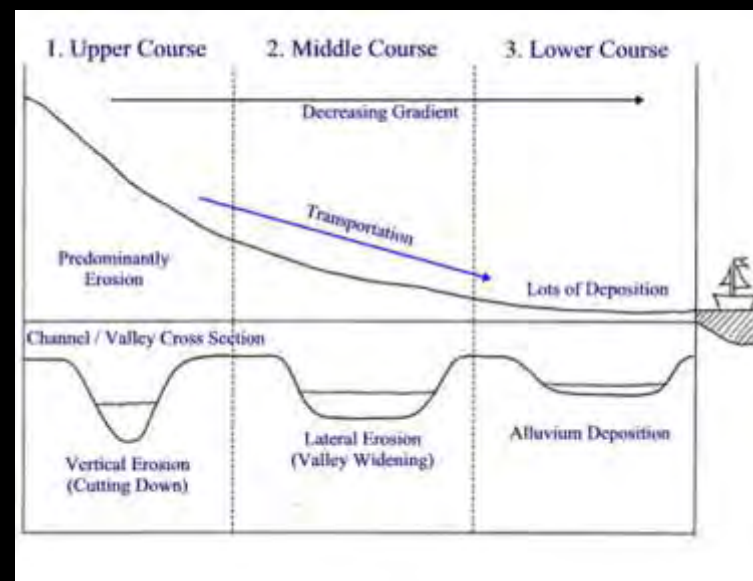
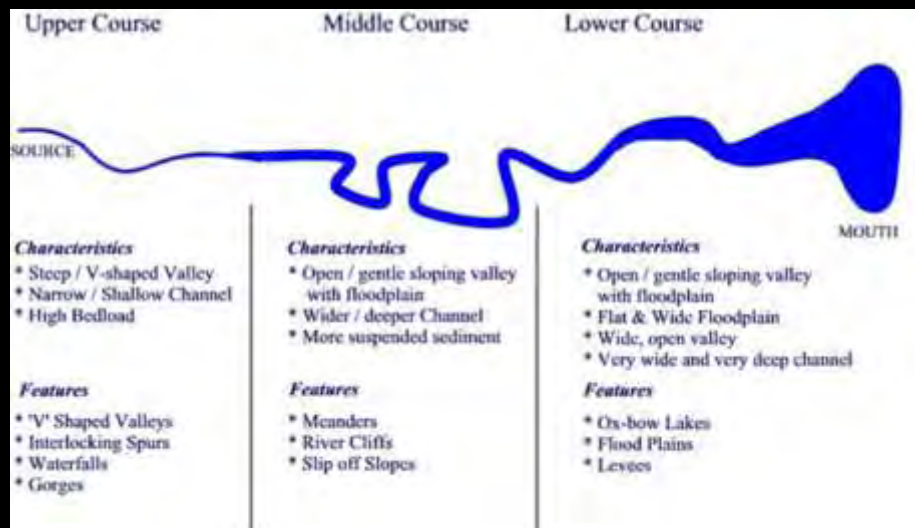
The Life of a River – William Morris Davis (1850 - 1934)

An American geographer, geologist, geomorphologist, and meteorologist, often called the "father of American geography".

His most influential scientific contribution was the cycle of erosion, first defined around 1884, which was a model of how rivers create landforms. His cycle of erosion suggests that (larger) rivers have three main sections: upper course, middle course, and lower course - each of which has distinct landforms and other properties associated with it.



“The Life of a River” - He viewed the river system as having a life of its own. “Its youthful headwaters are steep and rugged. It rushes toward the sea, eroding bed and bank on its way. In its central part, it is mature, winding sedately through wide valleys adjusted to its duty of transporting water and sediment. Near its mouth it has reached, in its old age, a nearly level plain through which it wanders in a somewhat aimless course toward final extinction as it joins the ocean that had provided the sustaining waters through its whole life span.”



The Upper Course - Youthful Headwaters



The Upper Course - The Speed of Flowing Water

The velocity of a river is the speed at which water flows along it. The velocity will change along the course of any river, and is determined by factors such as the gradient (how steeply the river is losing height), the volume of water, the shape of the river channel and the amount of friction created by the bed, rocks and plants.

Gradient of river - the steeper the slope, the faster the flow.

River Competence - Rivers and streams carry sediment that ranges in size from clay (smallest) to boulders (biggest). The "competence" of a river or stream refers to the largest particles that a river can transport.

Hydrologists use the term channel efficiency to describe the river's ability to transport bedload and discharge.

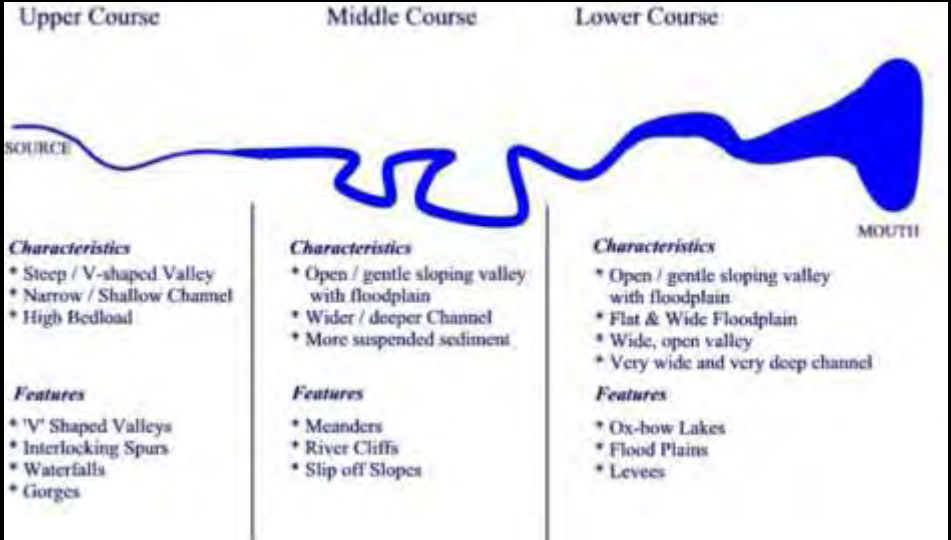


Photo source: V Vannet on www.geographyphotos.com

The Upper Course - Youthful Headwaters

Wetted perimeter refers to the wetted length of bed and bank. Larger wetted perimeter (banks and bed in contact with water), the river has to overcome more friction and is slowed down.

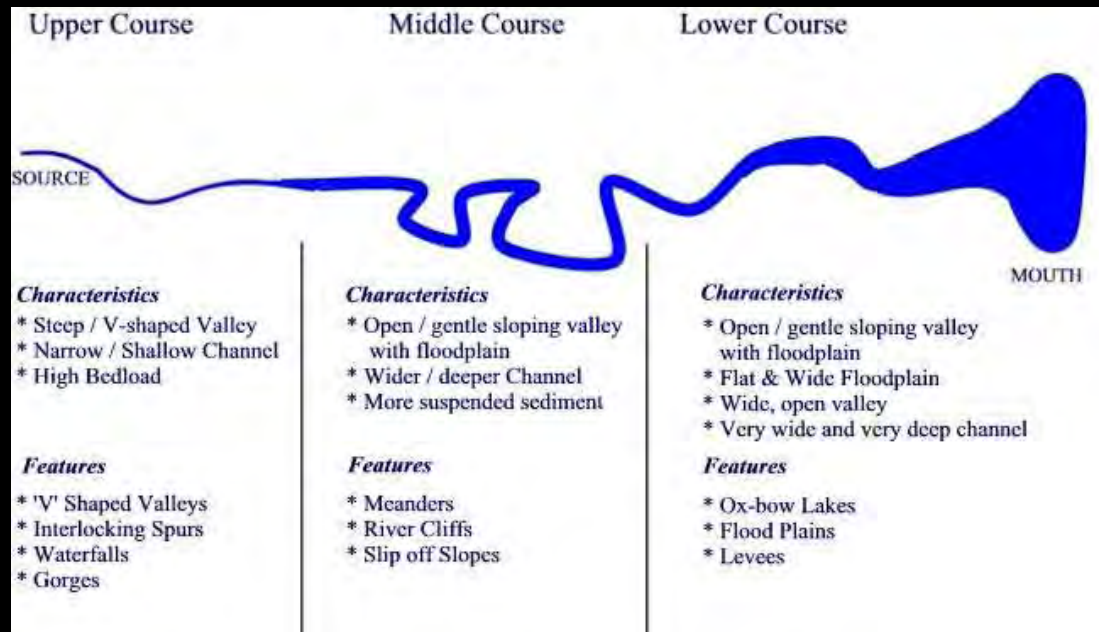
Smooth semi-circular channels are the most efficient channels and are located more often further downstream.

Roughness in the channel, which describes the quantity of large and angular bedload increases the wetted perimeter. Large bedload creates turbulent inefficient flow in the channel. The channel in the upper course is more often shallow and punctuated with large angular bedload. The rougher the channel, the slower is the flow, because the water has to overcome the friction of the river bed and banks.

As a consequence it has low channel efficiency and therefore the quantity of transported bedload is lower.

The quantity of bedload that a river able to transport is known as capacity.

Capacity of a river increases downstream.



“DOWNSTREAM CHANGE OF VELOCITY IN RIVERS”

AMERICAN JOURNAL OF SCIENCE, VOL. 251, AUGUST 1953, PP. 606-624

LUNA B. LEOPOLD

Because river slope generally decreases in a downstream direction, it is generally supposed that velocity of flow also decreases downstream.

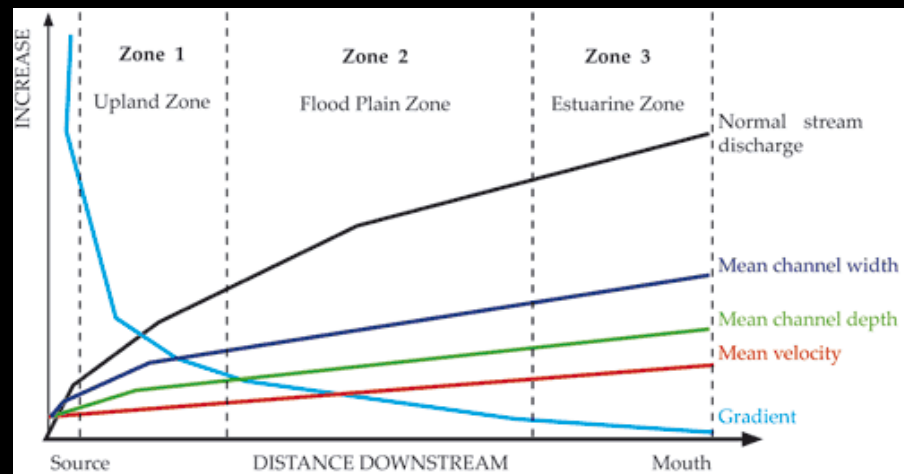
Analysis of some of the large number of velocity measurements made at stream-gaging stations demonstrates that mean velocity generally tends to increase downstream.

Although there are many reaches in nearly all rivers where mean velocity decreases downstream, the general tendency for conservation or for downstream increase was found in all data studied.

Computations of bed velocity indicate that this parameter also tends to increase downstream.

Near the streambed, shear in the vertical profile of velocity (rate of decrease of velocity with depth) tends to decrease downstream.

This downvalley decrease of shear implies decreasing competence downstream.



The Upper Course - Rapids

Rapids are most commonly found in the upper course of the river and form as a result of the river cutting down rapidly in a localized section of the river.

The main characteristics of rapids are distinctly steeper gradients marked by steps in the channel and high turbulence, which is the result of large bedload in the channel or steps.

It is common that rapids form over different bands of geology that vary in resistance or where the river is transporting large more resistant bedload.

The velocity of the river is noticeably faster at rapids but not efficient in its flow. Due to the roughness of the channel, flow is turbulent and known as white water.

This white water is thrown up and characterized by eddy currents.



The Upper Course - Erosion

River erosion is the gradual removal of rock material from the river banks and bed.

There are four types of erosion within the river.

1. Hydraulic action refers to the force of the water flow against the banks and bed. Sometimes the bank becomes over saturated and just slumps into the river.

2. Abrasion refers to the way in which the suspended load, transported by the flow collides with the bed and bank. This is sometimes anecdotally referred to as the 'sandpaper effect'.

3. Solution is the chemical reaction between carbon acid in the water and mineral elements in the rock.

4. Attrition is unique because it directly relates to erosion of bedload rather than the bed and bank. Attrition takes place through small collisions between bedload material.

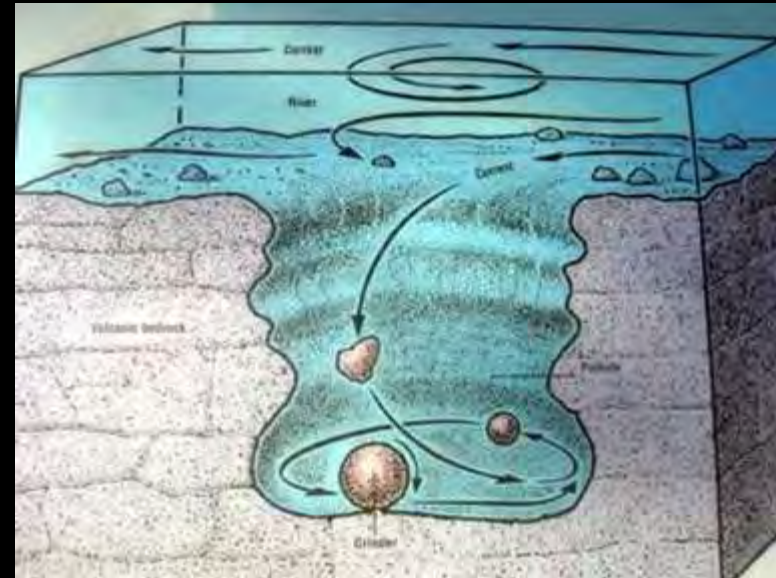
Abrasion, hydraulic action and solution all erode the bed and banks of the river, hence deepening and widening the river.



Erosional Features

Potholes: Circular depressions on the river bed

- Formed by abrasion
- Most effective in flood conditions
- Pebbles which are trapped in hollows on the river bed are swirled about in turbulent/ fast flowing water
- Tenaja in intermittent Western streams – Ernst Tenaja, Big Bend



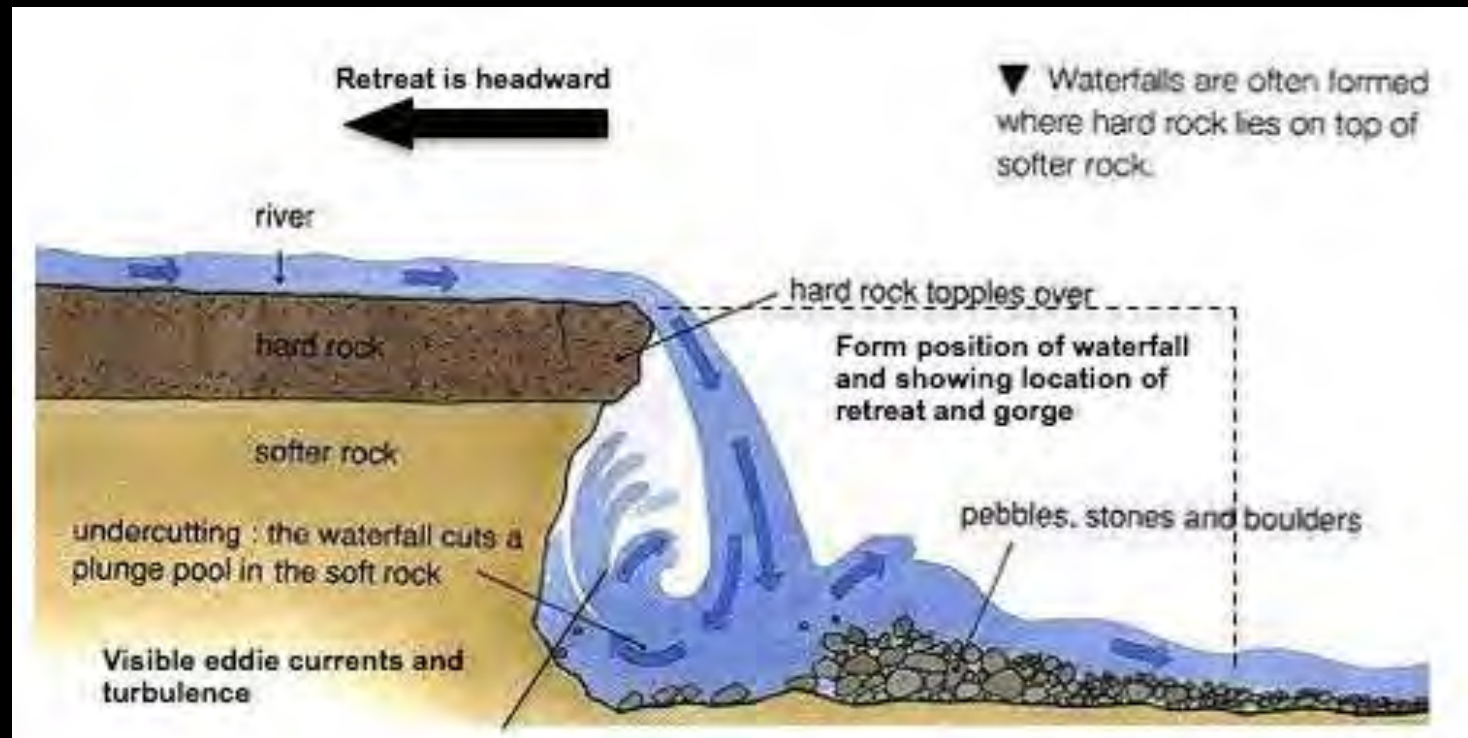


Ernst Tenaja, Big Bend

Waterfalls

Waterfalls like rapids form mainly in the upper course as a result of differentiated erosion. If the river channel flows across different bands of geology with varying resistance, then the softer less resistant rock will be eroded faster creating a step in the river.

The hydraulic action of the water enlarges this step over time creating the waterfall.



Plunge pools: A large depression at the foot of a waterfall

Due to the force of the water a deep plunge pool forms at the base of the waterfall. Turbulent flow with eddy currents and splashback undercut the cap of resistant rock headwardly, until the undercut is significant enough for the rock above to collapse under its own weight. This leaves angular resistant bedload in the plunge pool, which will combine with hydraulic action to further deepen and undercut through the process of abrasion.



Other Waterfall Forms

Waterfalls form when the channel crosses a fault line where tectonic processes have lifted or folded the rock. Waterfalls then tower over the resulting step in the rock.

This can be seen at the Gullfoss falls in Iceland. The Gullfoss is a 2-tiered waterfall with a total height of 32m (105ft). Also known as the Golden Falls, the Gullfoss is part of the Hvítá river.



Knickpoint

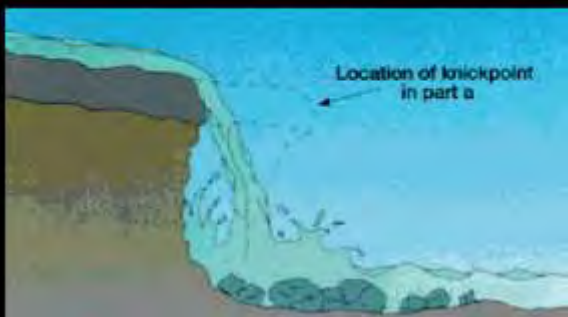
A knickpoint is a term in geomorphology to describe a location in a river or channel where there is a sharp change in channel slope, such as a waterfall or lake, resulting from differential rates of erosion above and below the knickpoint.

Knick Point Retreat

Undercutting



Collapse

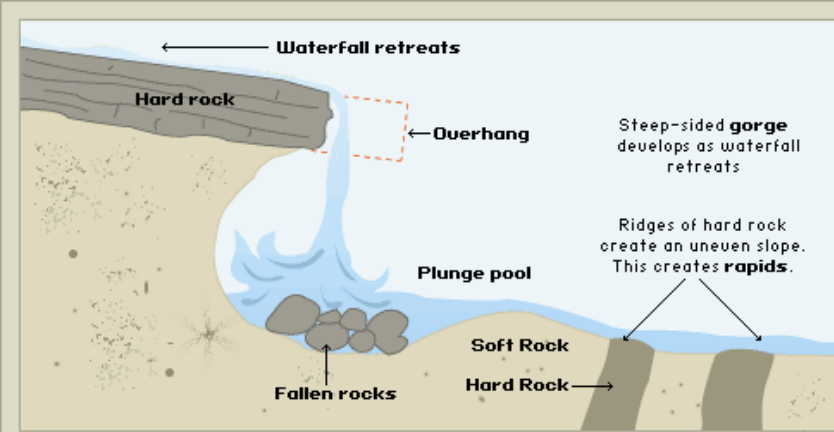


River Gorges

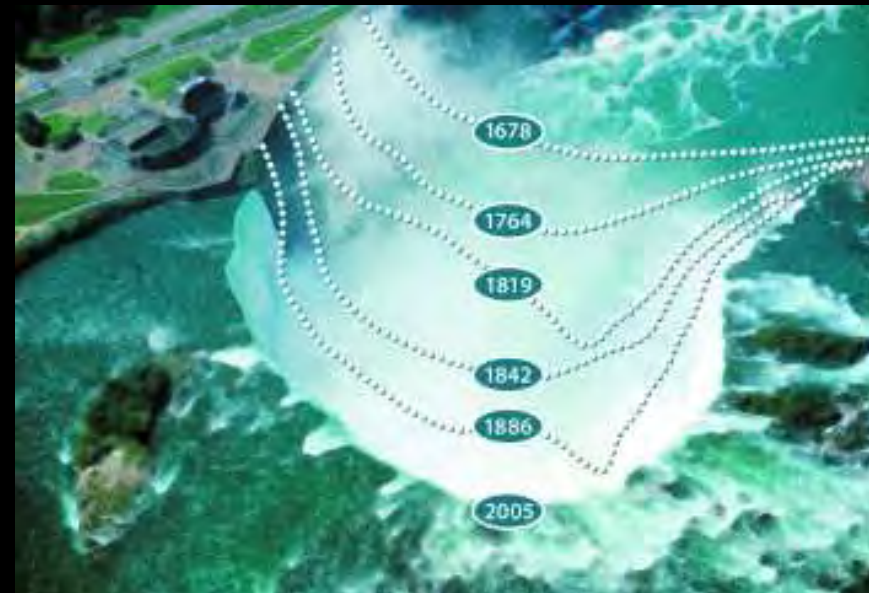
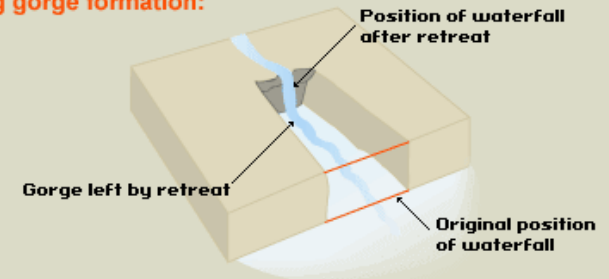
River valleys which are steep sided, deep and narrow

Over time the waterfall becomes higher and retreats upstream.

As the waterfall retreats a deep gorge with steep U-faced sides forms down the length of the river and marks the length of retreat.



Block diagram showing gorge formation:

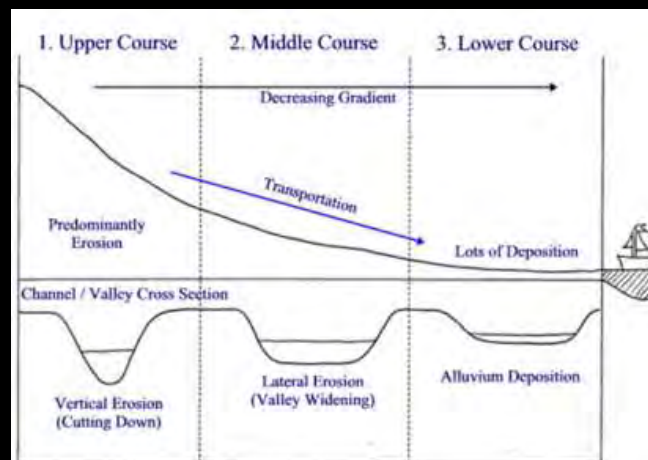


The Middle Course – its duty of transporting water and sediment

Erosion → Transportation → Deposition



Sinuosity is inversely proportional to slope



Transportation

When a river erodes the eroded material becomes the river's load and the river will then transport this load through its course until it deposits the load. There are a few different ways that a river will transport load depending on how much energy the river has and how big the load is.

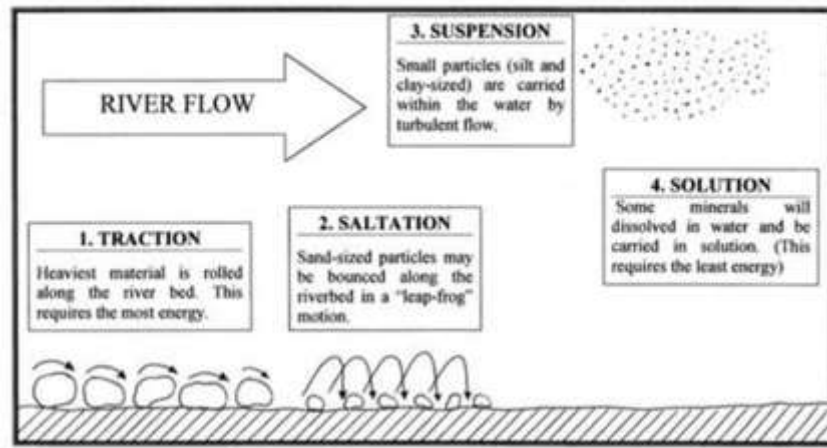
1. The largest of particles such as boulders are transported by traction. These particles are rolled along the bed of the river, eroding the bed and the particles in the process, because the river doesn't have enough energy to move these large particles in any other way.

2. Slightly smaller particles, such as pebbles and gravel, are transported by saltation. This is where the load bounces along the bed of the river because the river has enough energy to lift the particles off the bed but the particles are too heavy to travel by suspension.

3. Fine particles like clay and silt are transported in suspension, they are suspended in the water. Most of a river's load is transported by suspension.

4. Solution is a special method of transportation. This is where particles are dissolved into the water so only rocks that are soluble, such as limestone or chalk, can be transported in solution.

River Processes: Transportation



Capacity & Competence

Rivers can only carry so much load depending on their energy. The maximum volume of load that a river can carry at a specific point in its course is called the river's capacity. The biggest sized particle that a river could carry at a specific point is called the river's competence.

Deposition

To transport load a river needs to have energy so when a river loses energy it is forced to deposit its load. There's several reasons why a river could lose energy. If the river's discharge is reduced then the river will lose energy because it isn't flowing as quickly anymore. This could happen because of a lack of precipitation or an increase in evaporation. Increased human use of a river could also reduce its discharge forcing it deposit its load.

If the gradient of the river's course flattens out, the river will deposit its load because it will be travelling a lot slower. When a river meets the sea a river will deposit its load because the gradient is generally reduced at sea level and the sea will absorb a lot of energy.

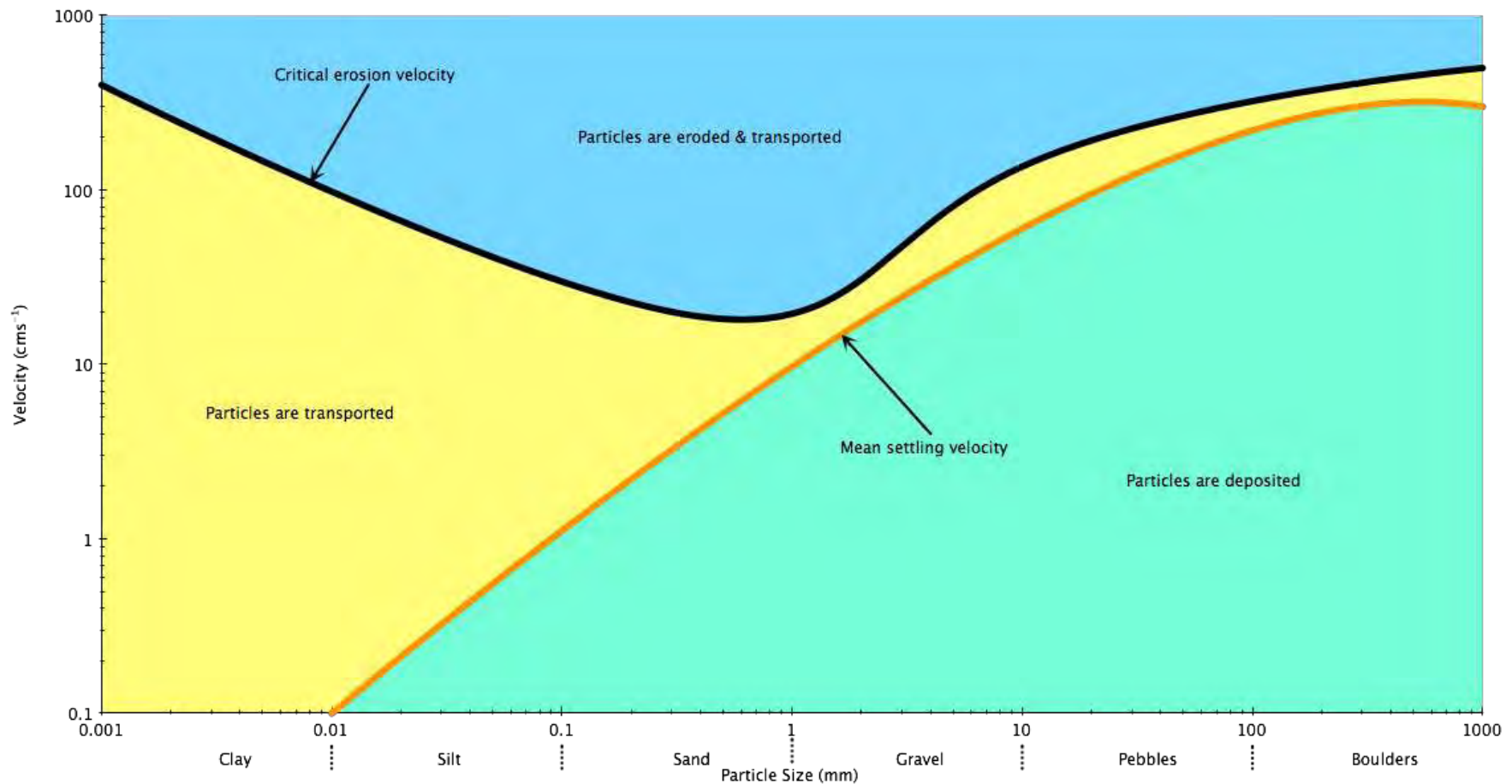


Hjulstrom Curve

For each grain size there is a specific velocity at which the grains start to move, called entrainment velocity.

However the grains will continue to be transported even if the velocity falls below the entrainment velocity due to the reduced (or removed) friction between the grains and the river bed. Eventually the velocity will fall low enough for the grains to be deposited.

This is shown by the Hjulstrom curve.



Deposition and Channel Patterns

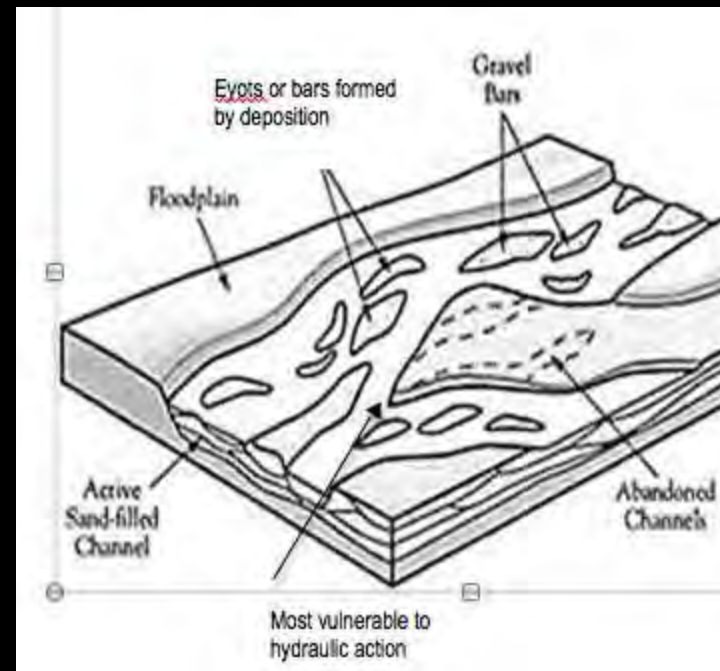
Braided channels are dominated by multiple channels (braids) and sediment bars (eyots).

This unique channel characteristic develops due to changes in velocity and discharge.

This occurs as part of its typical river regime.

During periods of increased discharge, the capacity of the river to transport sediment increases and eyots become eroded.

The competence of the river to transport larger bedload also increases. The braids widen and merge.



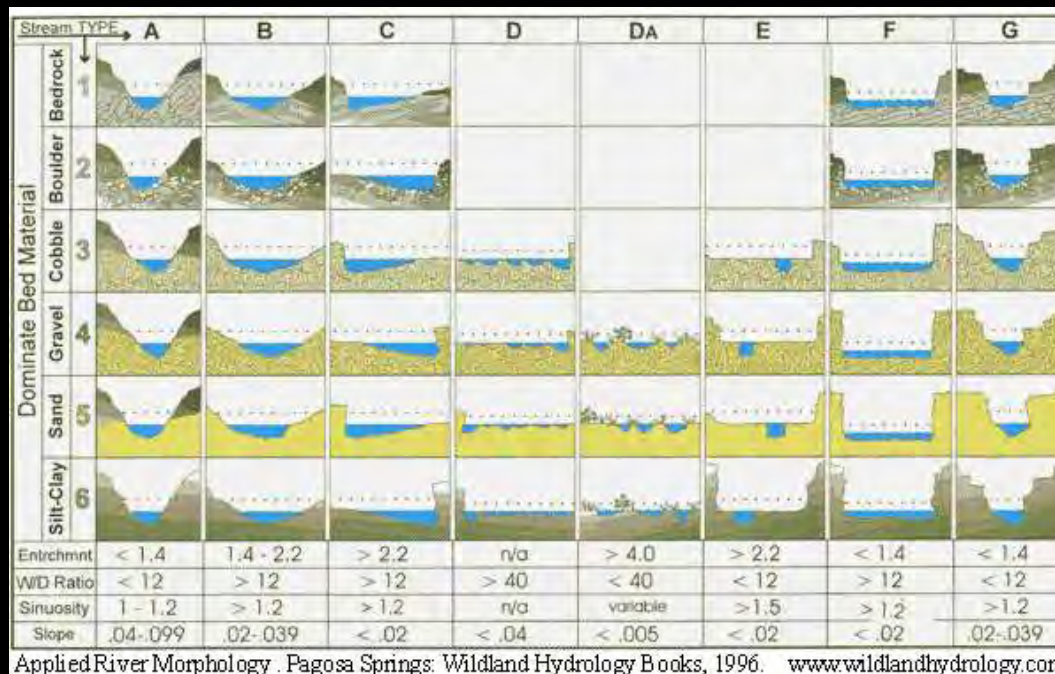
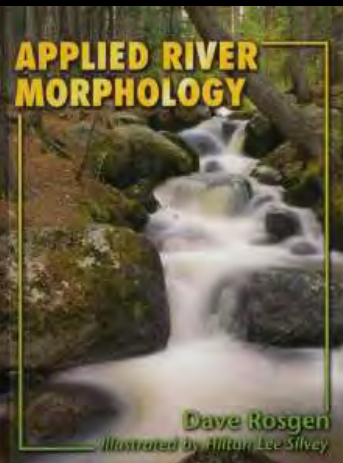
River Morphology

Dave Rosgen, a former hydrologist with the U.S. Forest Service and now Principal Hydrologist of Wildland Hydrology Consultants.

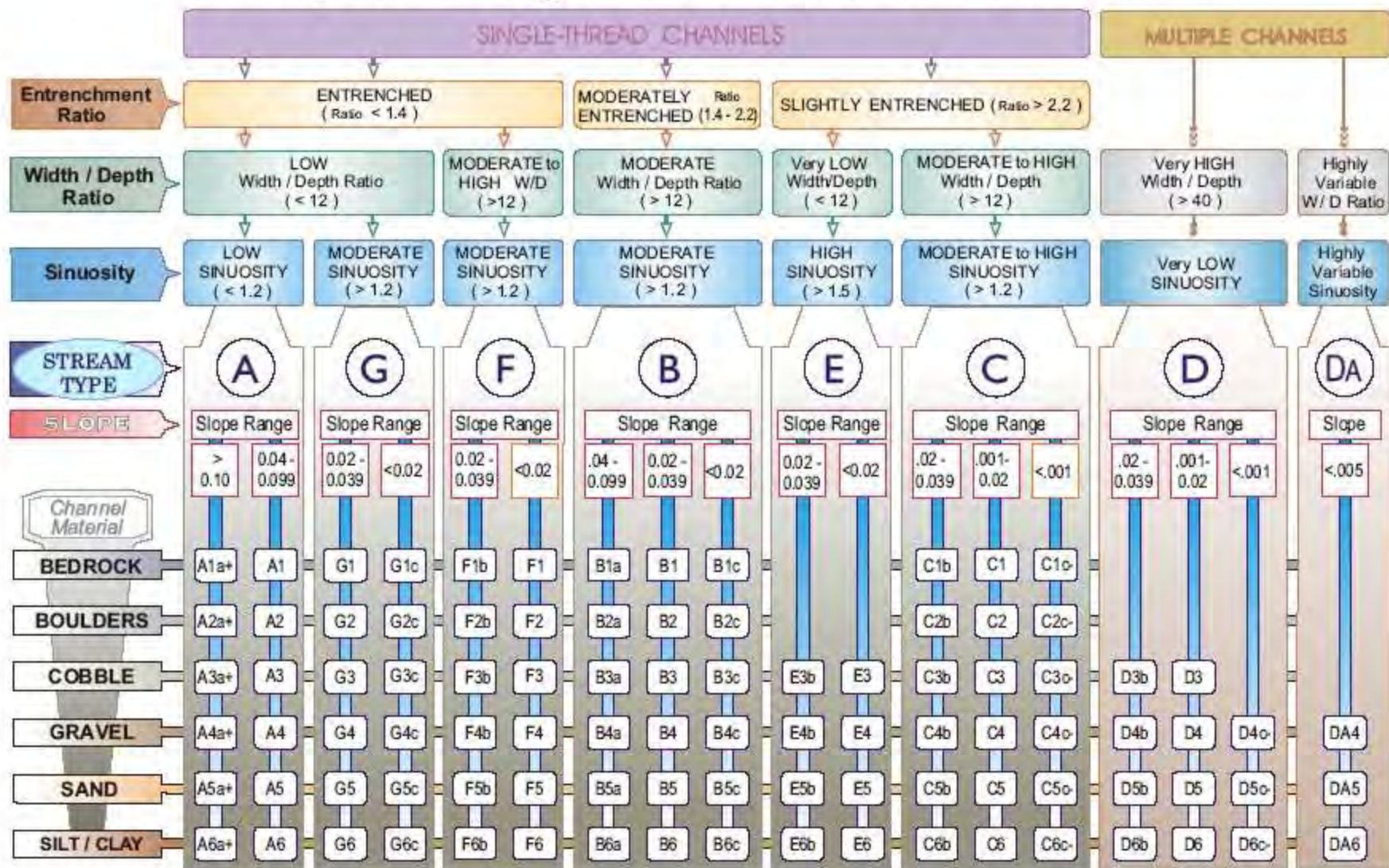
Rosgen's system is based on the notion that the most effective classification system is one based on objective, quantifiable criteria that are readily observable and measurable in the field.

The objective of classifying streams on the basis of channel morphology is to set categories of discrete stream types so that consistent, reproducible descriptions and assessments of condition and potential can be developed.

Since the procedure relies on morphology, it is not readily apparent that the system is process based. However, the classification system is grounded in the basic morphological-process relations of fluvial systems.



The Key to the Rosgen Classification of Natural Rivers

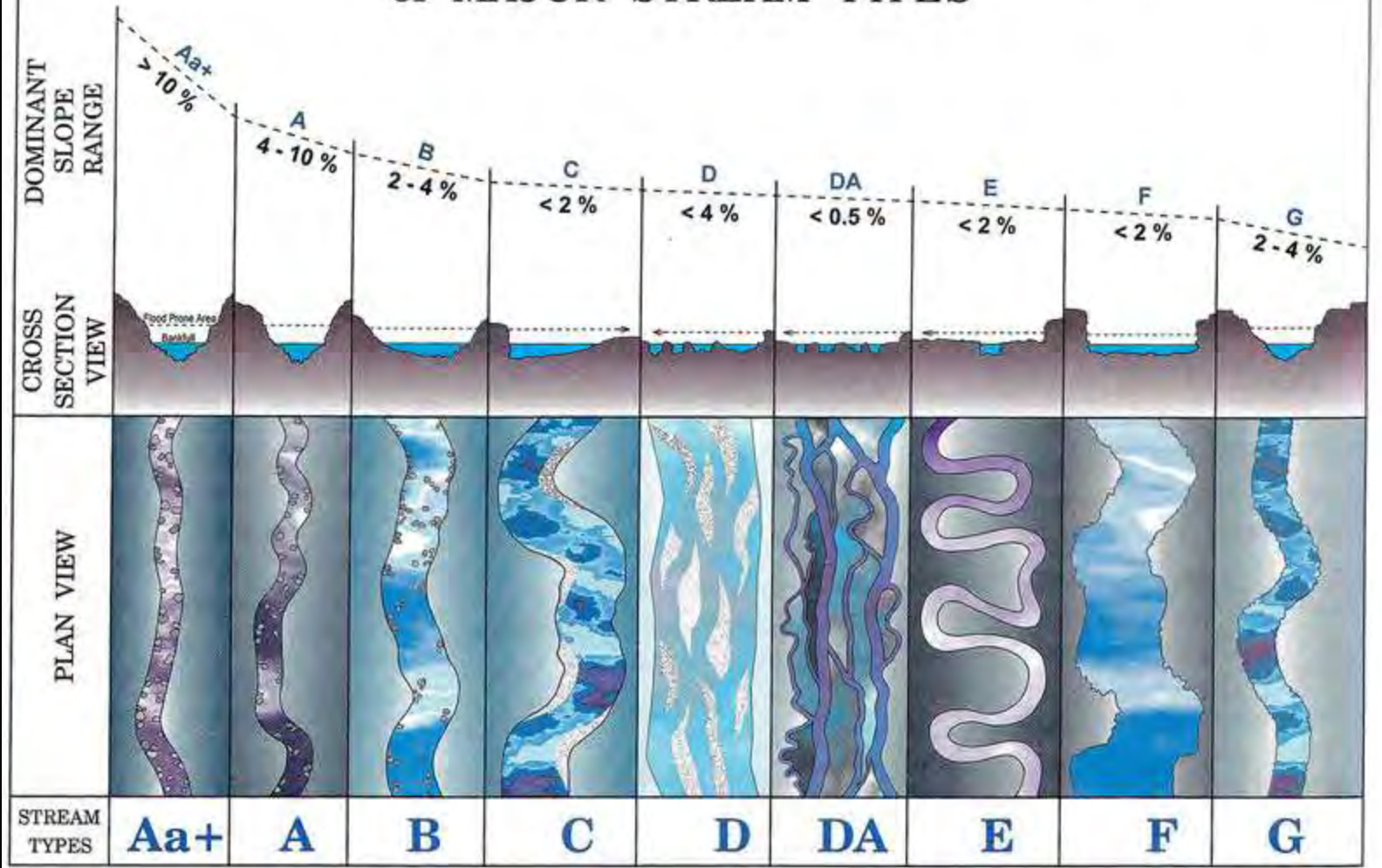


KEY to the **ROSGEN** CLASSIFICATION of NATURAL RIVERS.

As a function of the "continuum of physical variables" within stream

reaches, values of **Entrenchment** and **Sinuosity** ratios can vary by +/- 0.2 units; while values for **Width / Depth** ratios can vary by +/- 2.0 units.

LONGITUDINAL, CROSS-SECTIONAL and PLAN VIEWS of MAJOR STREAM TYPES

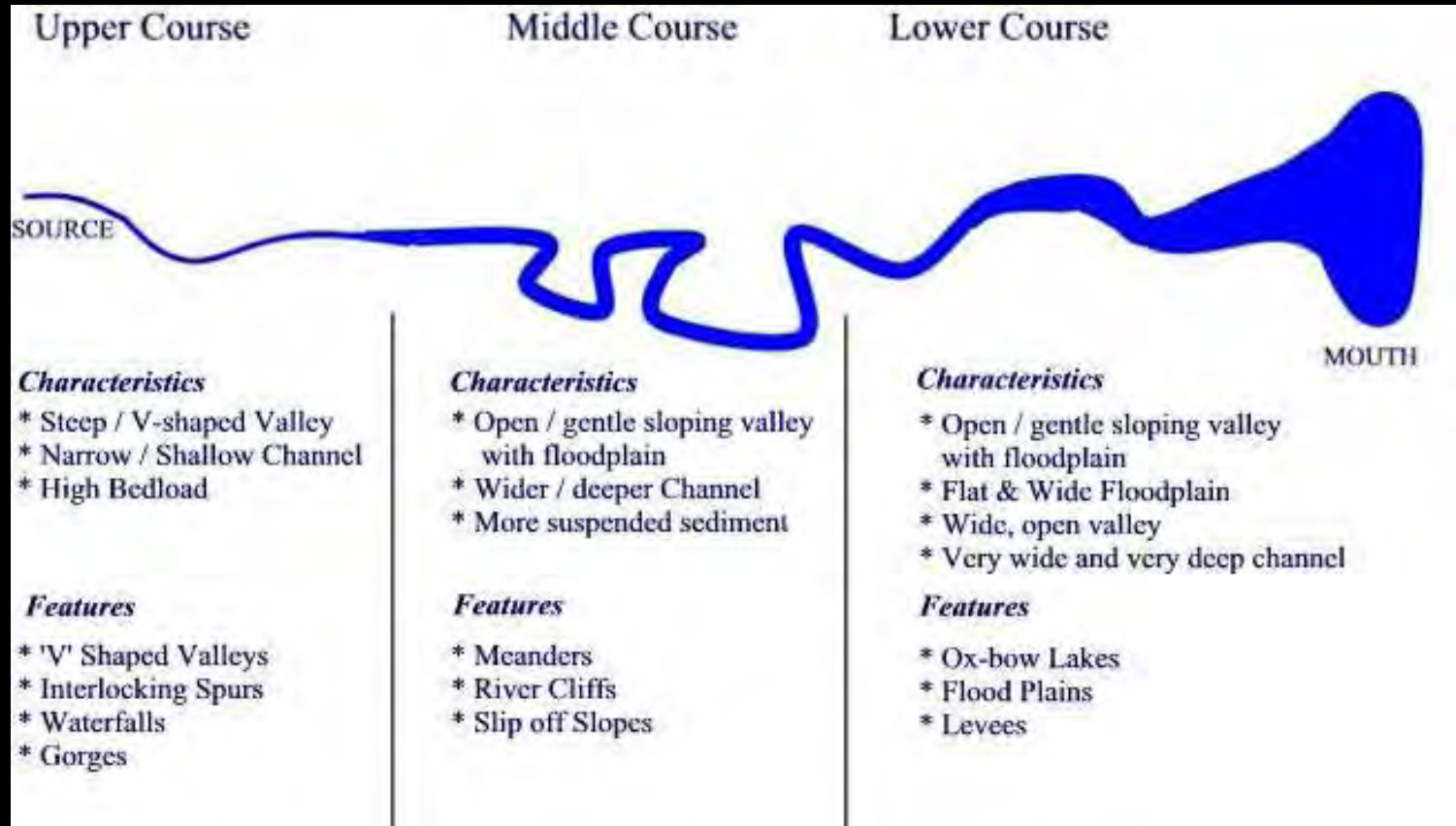


sinuosity is inversely proportional to slope

Middle Course - Wandering Sedately

Fluvial Process

Sinuosity is inversely proportional to slope



Fluvial Process

The helical flow of water plays an important role in the formation of meanders, especially in the developing river cliffs and slip-off slopes.

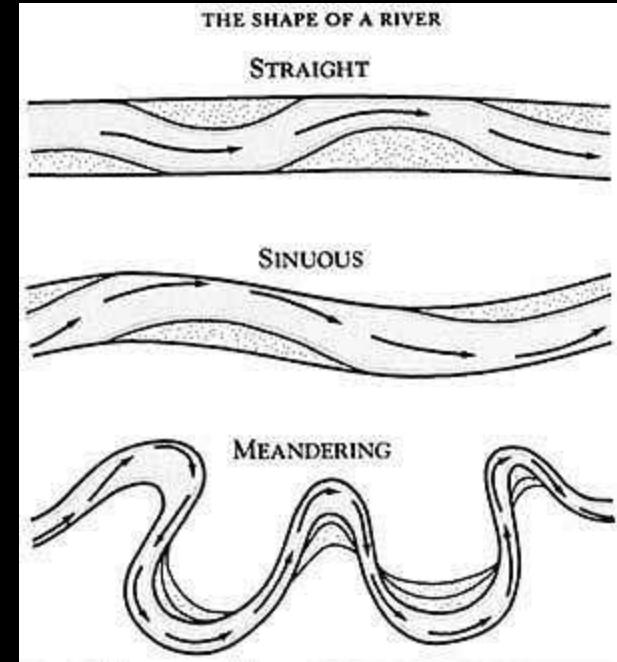
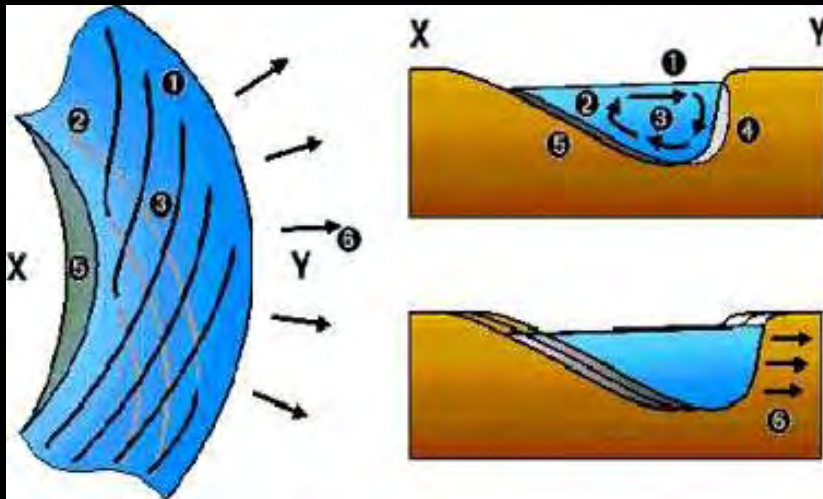
Higher velocity chutes within a stream tend to be driven to the outside of a meander seen at point 1.

On the outside of the meander, the surface of the water has a tendency to be slightly higher because it has gained momentum and acceleration, in the same way as centrifugal force works.

Here, the flow is forced down the outer bank which results in the scouring of the bank and bed.

It returns to the surface toward the inside of the meander where flow is less turbulent, seen at point 2.

This flow across the channel is known as the secondary cell. This can be seen in the diagram below.



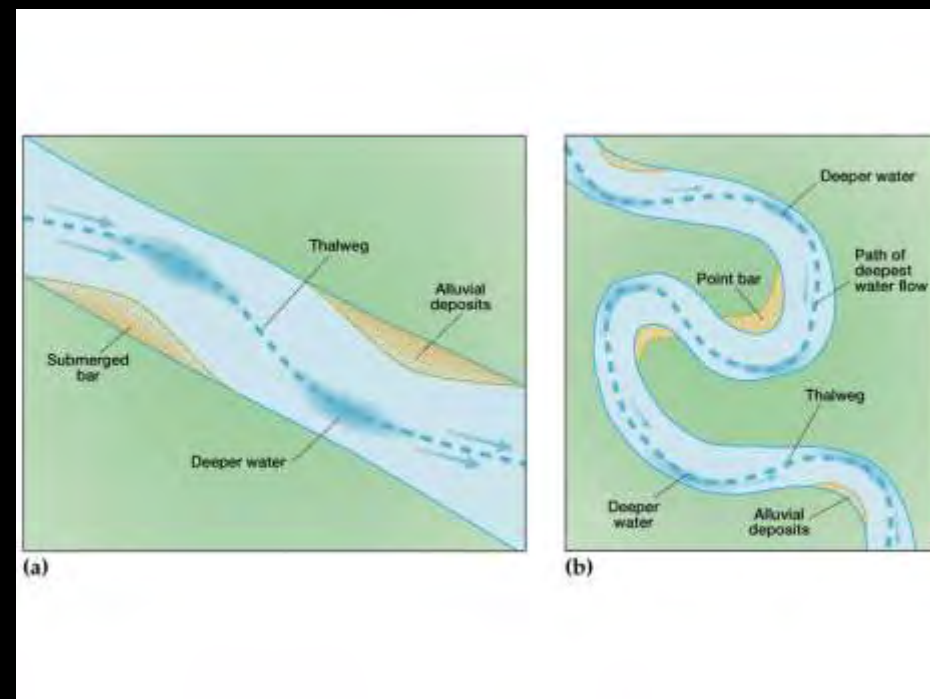
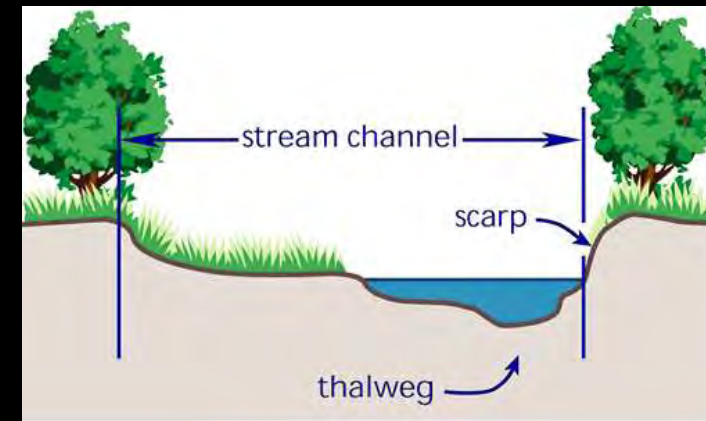
Thalweg

In hydrological and fluvial landforms, the thalweg is a line drawn to join the lowest points along the entire length of a stream bed or valley in its downward slope, defining its deepest channel.

The thalweg thus marks the natural direction (the profile) of a watercourse.

The thalweg is almost always the line of fastest flow in any river.

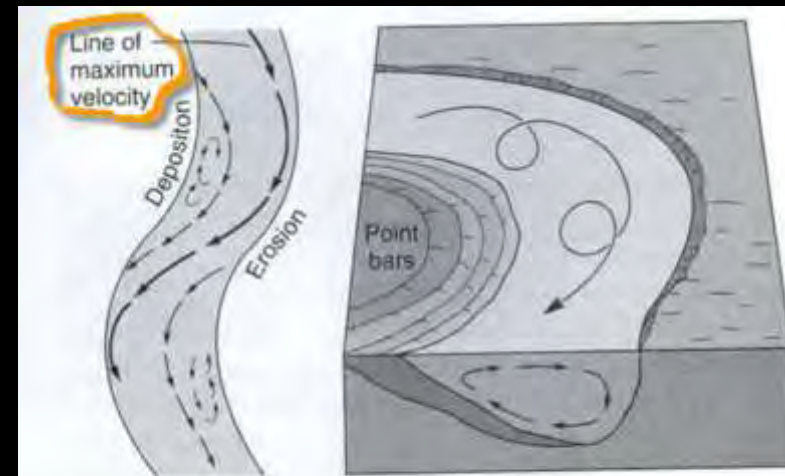
The word derives from German "Talweg" meaning "valley way".



A Meander

- The helical flow continues to erode the outside of the bend and deepens the pool.
- At the same time it redistributes scoured material and deposits it on the slip-off slope and riffle section.
- This continuous process cause meanders to migrate and contract at their neck.
- Overtime the meander neck becomes narrower until the river cuts directly through, forming a channel cut-off and incipient ox-bow.
- This leaves meander scars on the floodplain that simply mark the old channel.

Sinuosity is inversely proportional to slope



Helical flow in a meander.

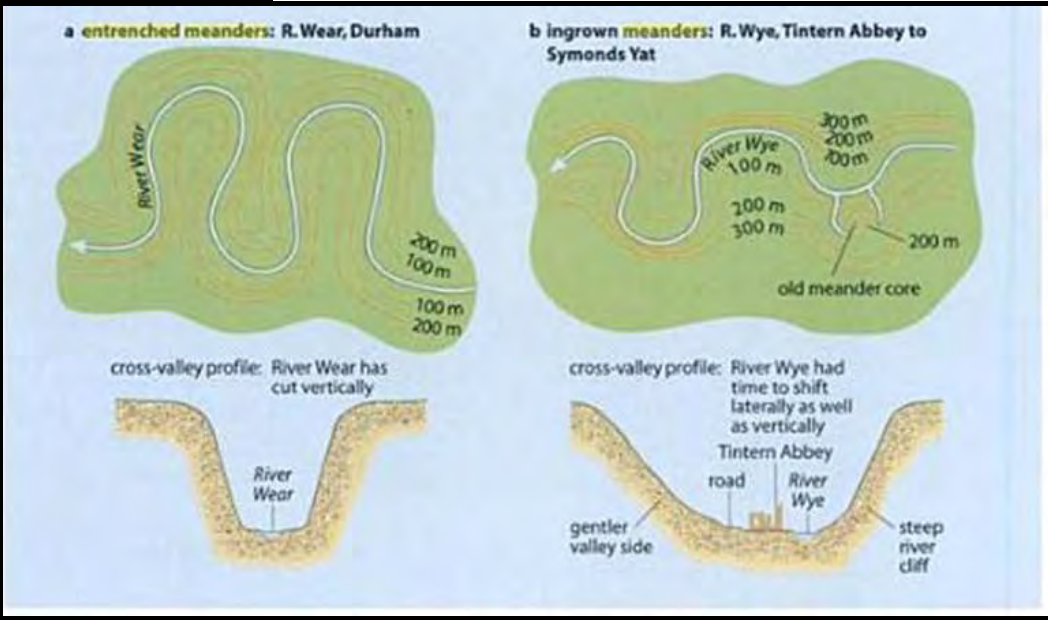
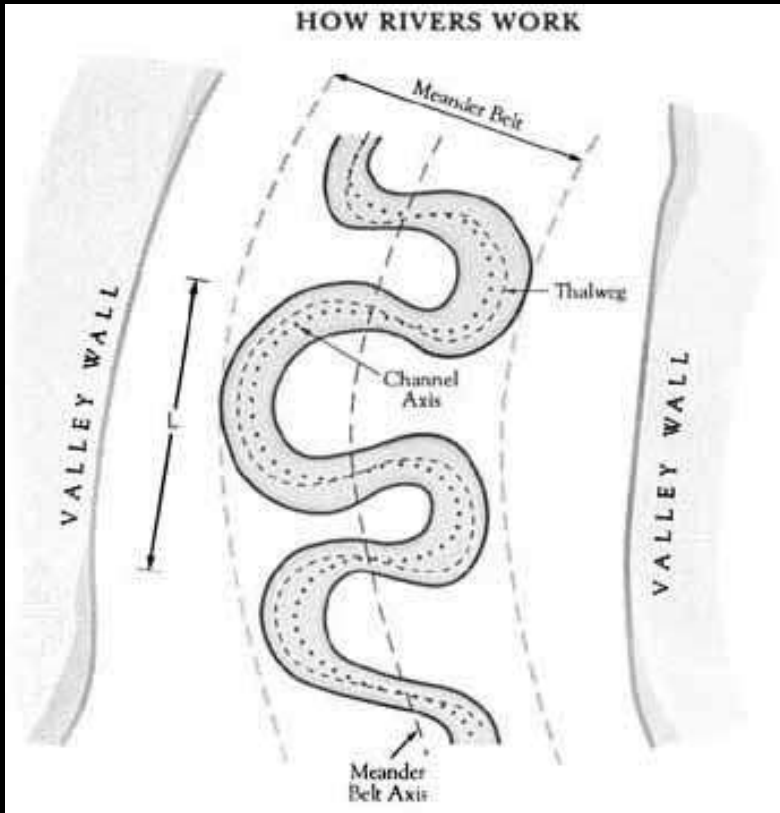
Meanders , Again

Meanders are loop-like bends in a river.

The water flows round the meander in a spiral manner.

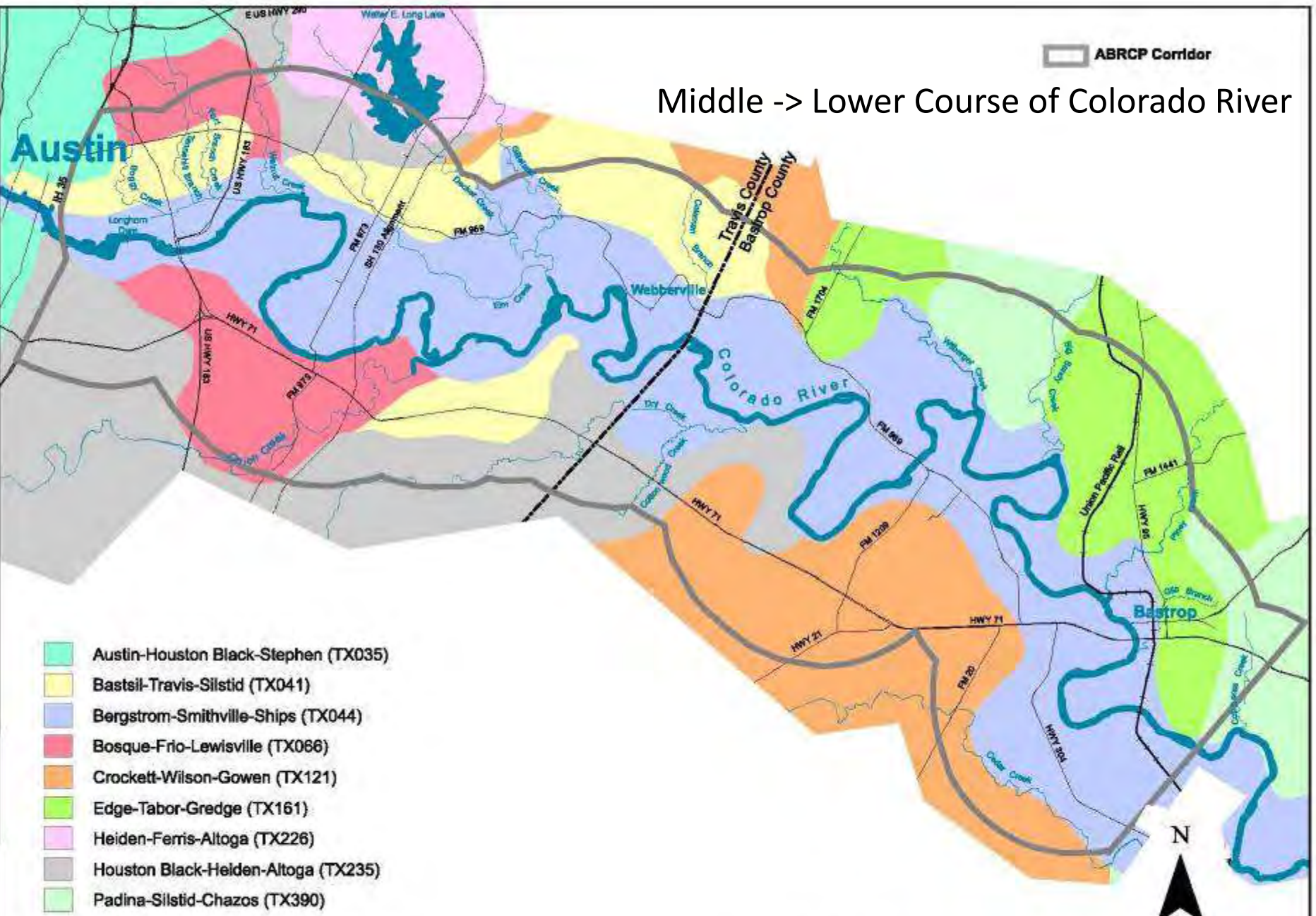
This causes erosion to take place on the outer bank and deposition on the inner bank.

Gradually, a steep river cliff is formed on the outer bank, making it concave in shape. On the inner bank, deposition of alluvial materials produces a gentle slip-off slope and the bank takes on a convex shape.



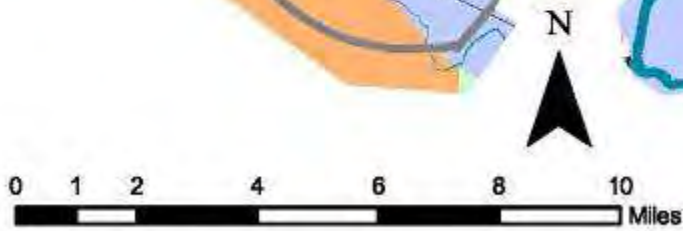
Middle -> Lower Course of Colorado River

ABRCP Corridor



- Austin-Houston Black-Stephen (TX035)
- Bastil-Travis-Silstid (TX041)
- Bergstrom-Smithville-Ships (TX044)
- Bosque-Frio-Lewisville (TX066)
- Crockett-Wilson-Gowen (TX121)
- Edge-Tabor-Gredge (TX161)
- Heiden-Ferris-Altoga (TX226)
- Houston Black-Heiden-Altoga (TX235)
- Padina-Silstid-Chazos (TX390)

STATSGO (State Soil Geographic Database)





Old Mining Pit

2003



2006



80 feet

130 feet

Breach

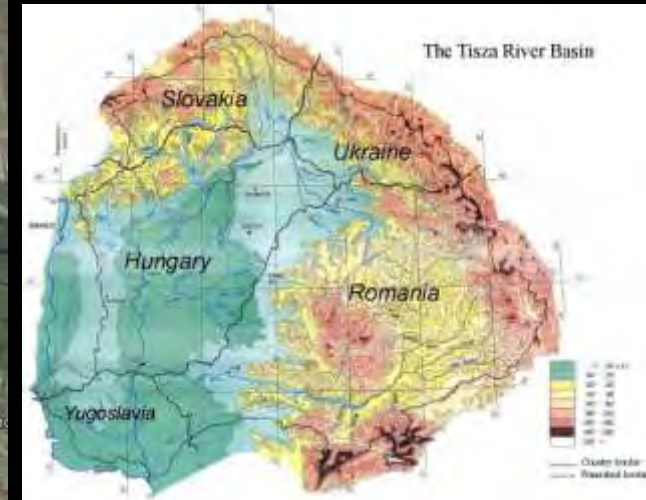
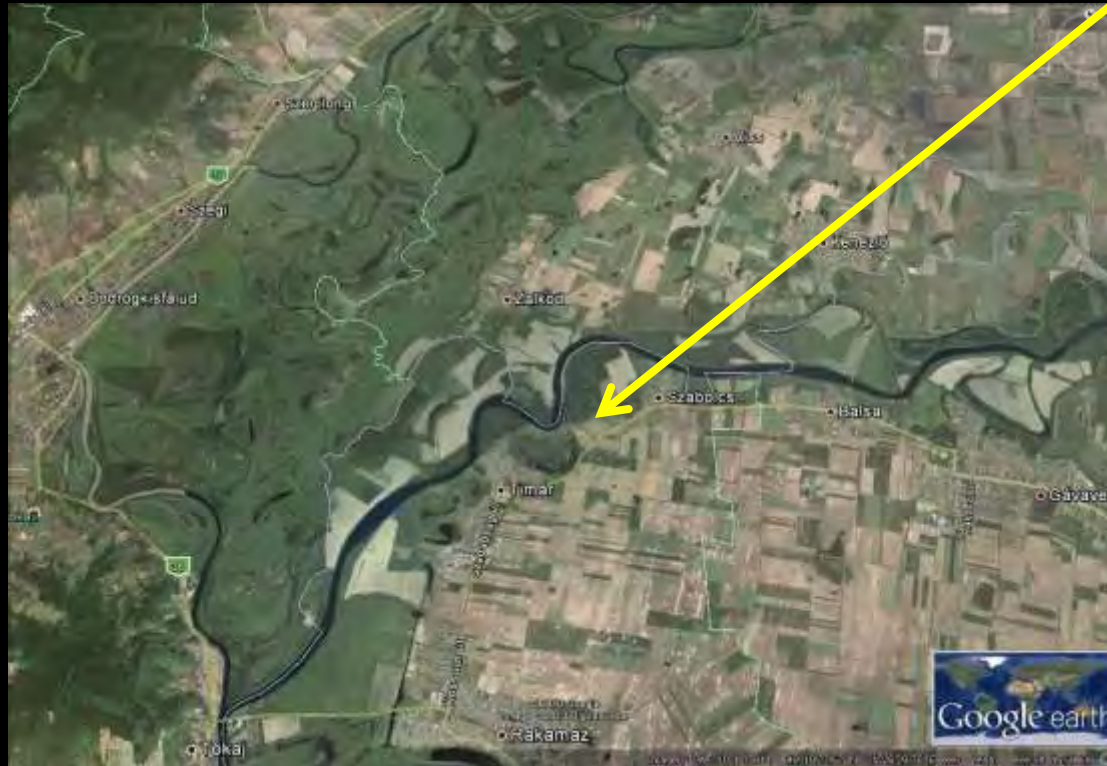
Mining Pit

2006

Oxbow Lake

An oxbow lake is a crescent-shaped lake formed on a river when a meander has been cut through and abandoned.

When a river meanders in very big loops, the outer bank is so rapidly eroded that the river cuts through the narrow neck of the meander. The river then flows straight through the channel. When deposition seals off the cut-off from the river channel, an oxbow lake is formed. It may silt up and eventually dry up.



The Bodrogek lowland region between the Bodrog and Tisza rivers is separated from the area up north by yet another river called Latorca. The southern part belongs to Hungary and the upper Bodrogek is on the other side of the border in Slovakia. Now a cross-border UN Ramsar Wetland of International Importance

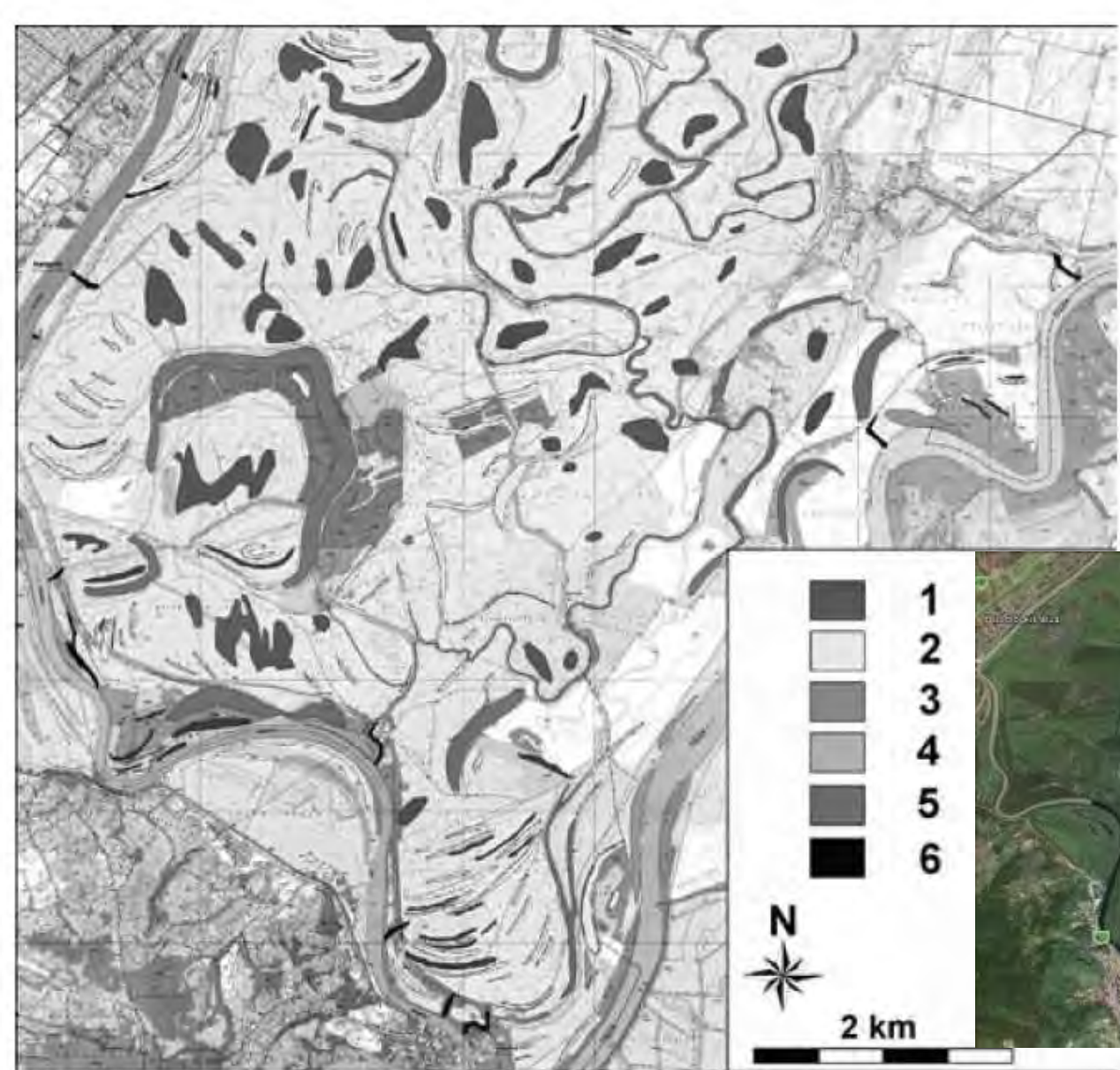
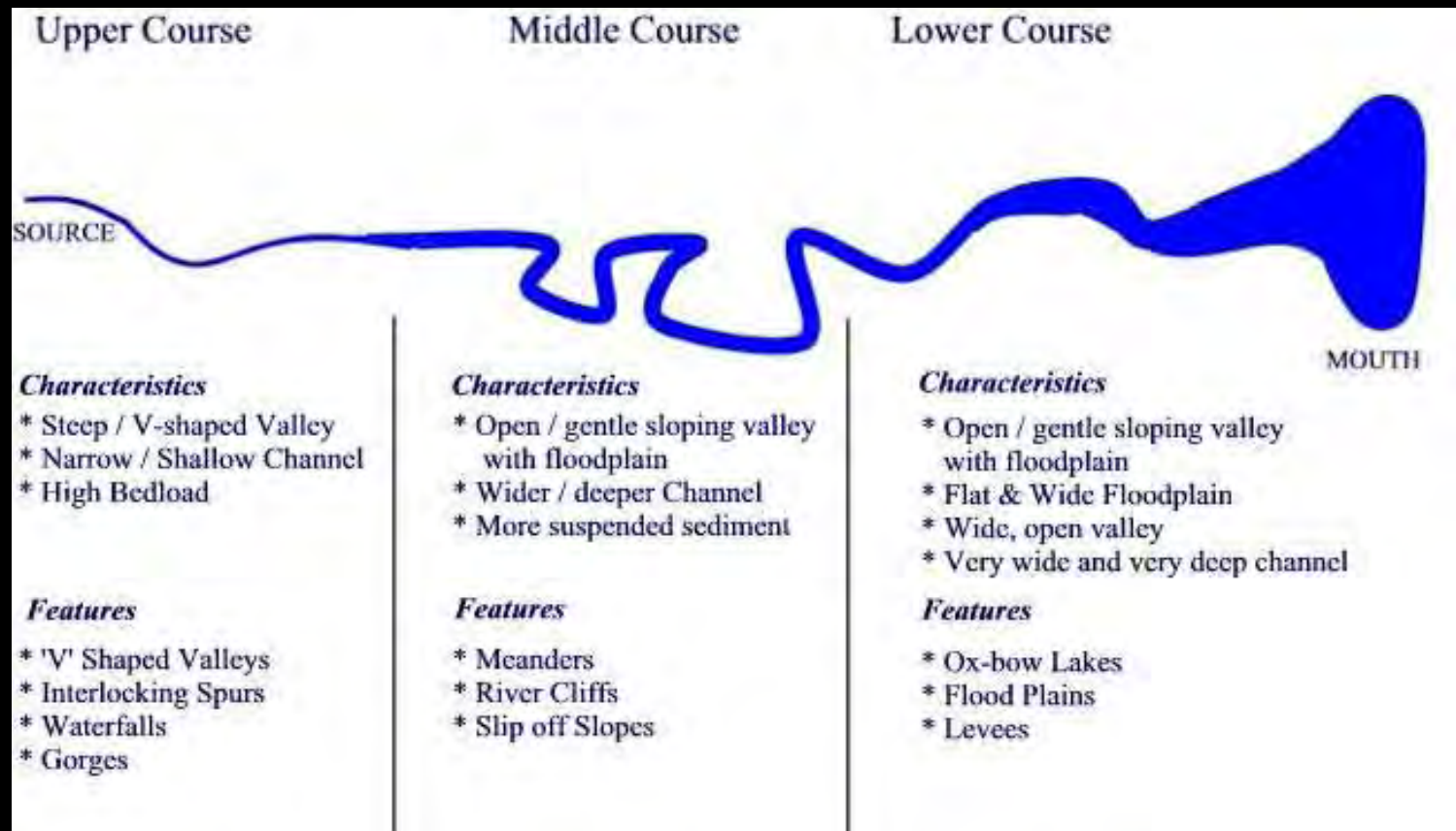


FIG. 2 - Landforms of the SW Bodrogek (In: Szabó & *alii*, 2004). 1: fluvial ridge, 2: swale, 3: abandoned cut-offs, 4: present natural levee, 5: backswamps, 6: (remnants of) one-time flood-plain ditches.

The Lower Course – Old Age Wandering and Deposition



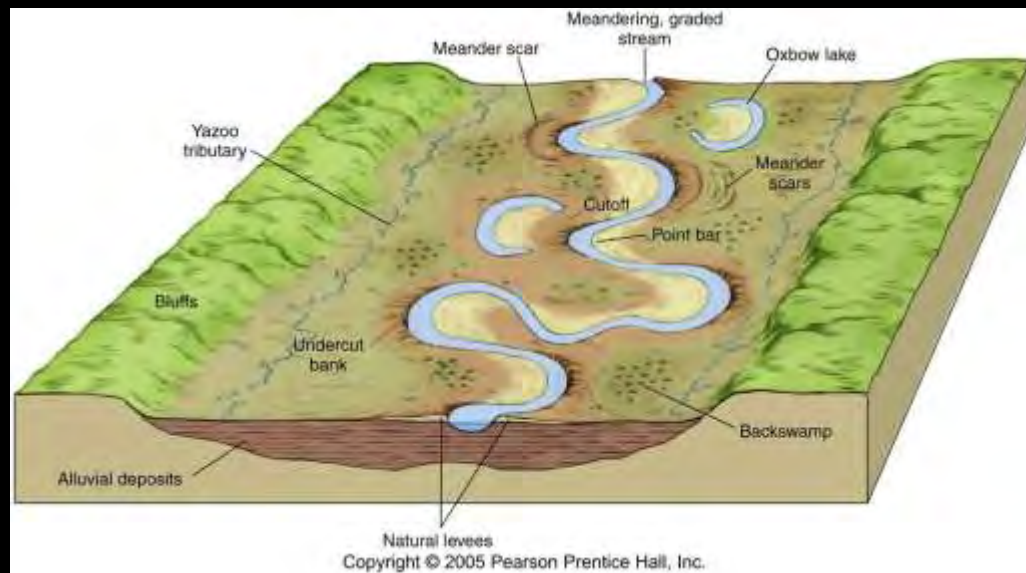
Floodplains and Levees

A floodplain is a low-lying plain on both sides of a river that has repeatedly overflowed its banks and flooded the surrounding areas.

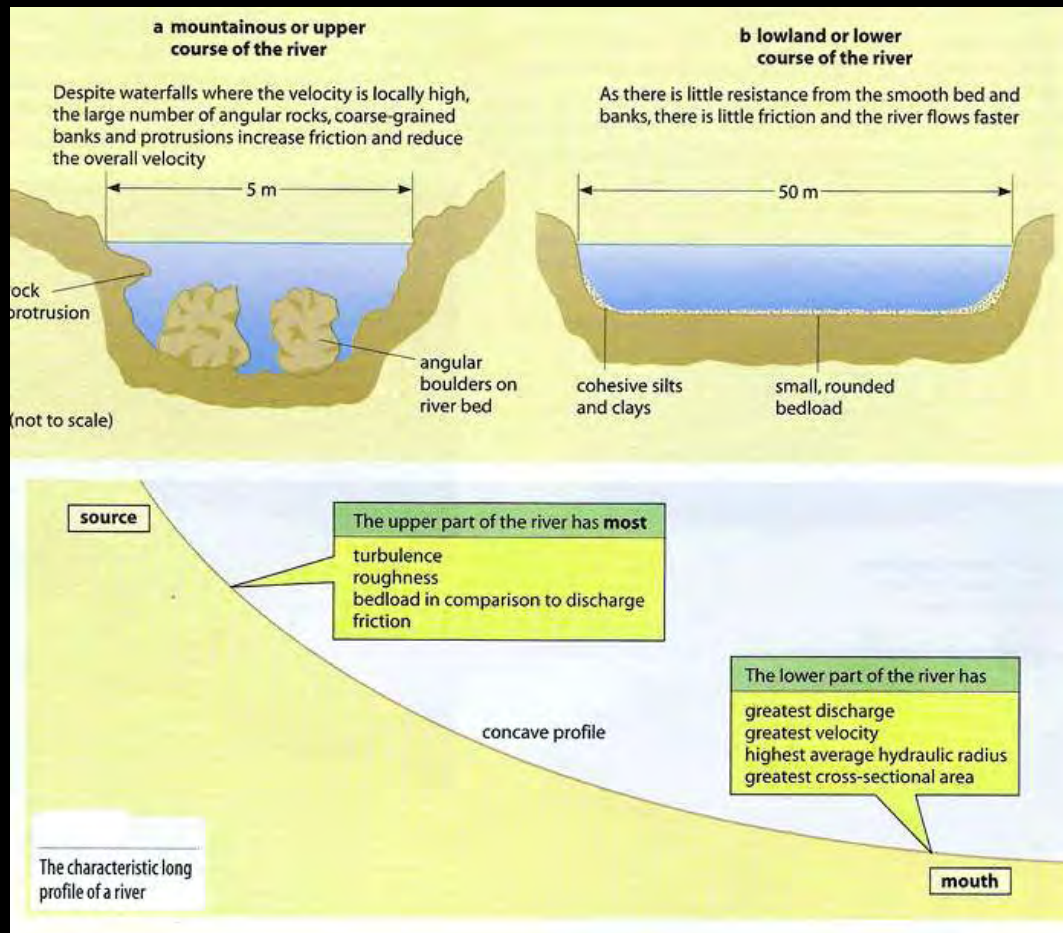
When the floods subside, alluvium is deposited on the floodplain.

The larger materials, being heavier, are deposited at the river banks while the finer materials are carried and deposited further away from the river.

The larger materials at the river banks build up into embankment called levees.



"DOWNSTREAM CHANGE OF VELOCITY IN RIVERS" LUNA B. LEOPOLD



	DISCHARGE
	OCCUPIED CHANNEL WIDTH
	CHANNEL DEPTH
	MEAN VELOCITY
	VOLUME OF LOAD
LOAD PARTICLE SIZE	
CHANNEL BED ROUGHNESS	
GRADIENT	

Delta - final extinction as it joins the ocean

River deltas form at the mouth of the river or inland on the approach to lakes.

There is great variation in the shapes of deltas due to the complex interaction between fluvial and marine systems.

Their shape is influenced by the amount and type of sediment being transported by the river, the velocity, discharge and capacity of the river and the strength of marine tides and waves.

Arcuate deltas like that found on the Nile are the most common type of delta. They are characterised by a gently curving shoreline, smoothed by longshore currents. They have a distinct pattern of branching distributaries and tend to be dominated by coarser material.

Bird-foot deltas have long finger-like projections that reach out to the sea, like the Mississippi River's delta. These deltas might have broad, shallow shelves. The bird-foot delta is named for its long thin shape, much like a bird's toe.





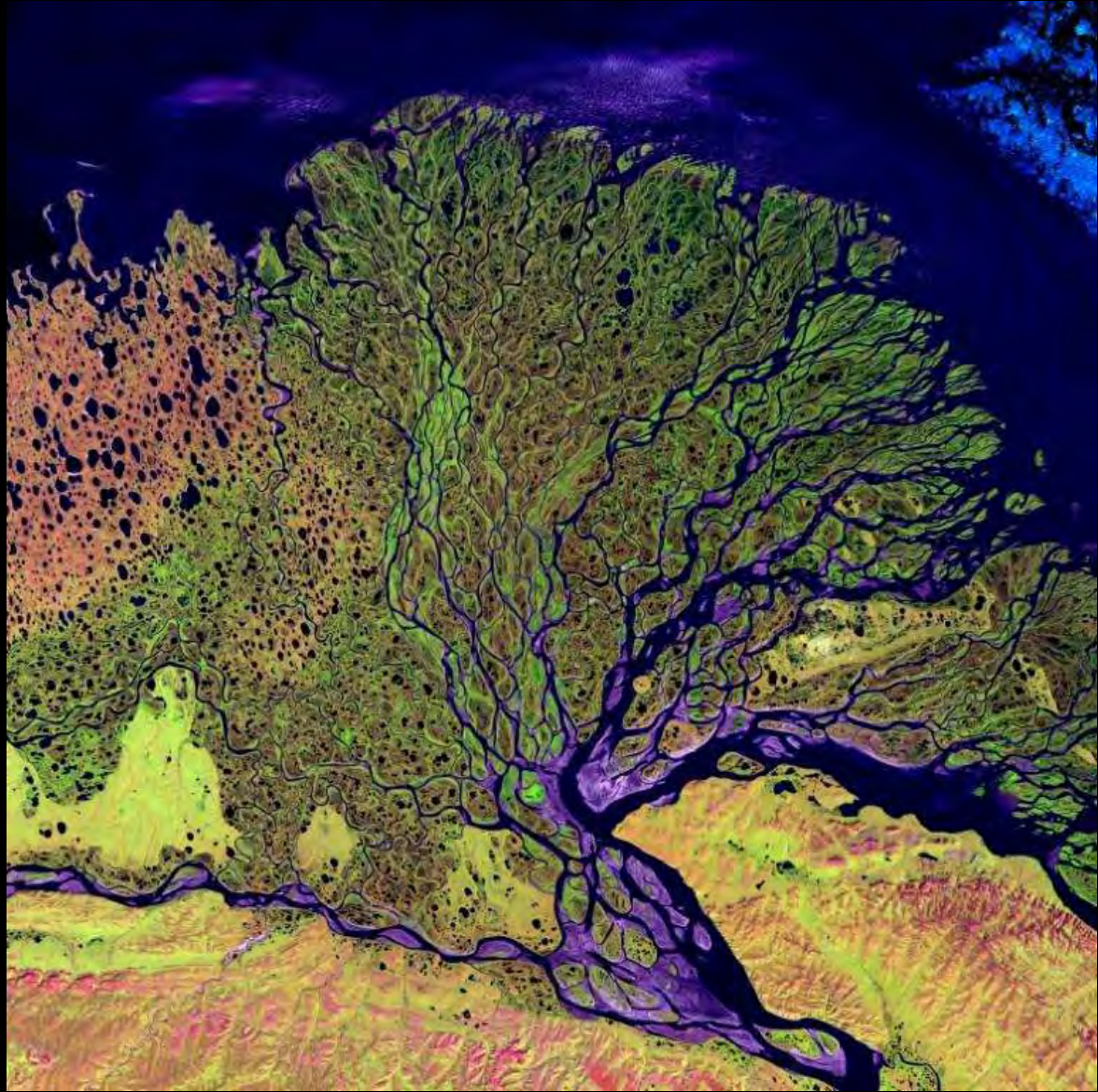
The Danube Delta is the second largest river delta in Europe, after the Volga Delta.

The greater part of the Danube Delta lies in Romania, while its northern part, on the left bank of the Chilia arm, is situated in Ukraine .

The approximate surface is 4,152 km², of which 3,446 km² are in Romania.



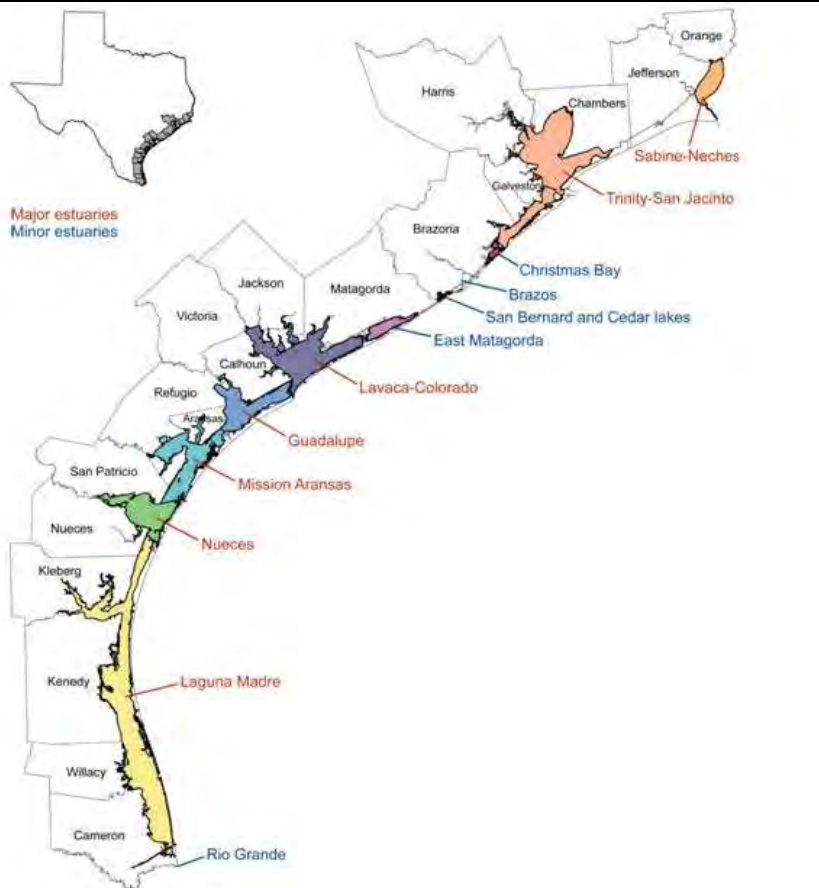
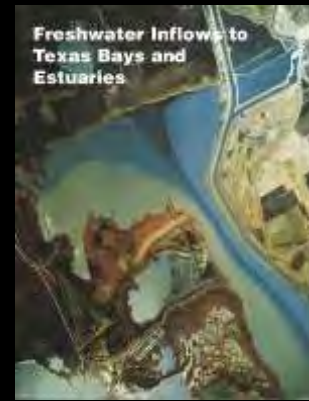
The Lena River, some 2,800 miles (4,400 km) long, is one of the largest rivers in the world. At the end of the Lena River there is a large delta that extends 100 km into the Laptev Sea and is about 400 km (250 mi) wide. The delta is frozen tundra for about 7 months of the year, but in May transforms the region into a lush wetland for the next few months. The Lena Delta Reserve is the most extensive protected wilderness area in Russia. It is an important refuge and breeding ground for many species of Siberian wildlife.



Estuary

An estuary is a partly enclosed coastal body of brackish water with one or more rivers or streams flowing into it, and with a free connection to the open sea.

Estuaries form a transition zone between river environments and maritime environments and are subject to both marine influences, such as tides, waves, and the influx of saline water; and riverine influences, such as flows of fresh water and sediment. The inflows of both sea water and fresh water provide high levels of nutrients in both the water column and sediment, making estuaries among the most productive natural habitats in the world



Sinuosity is inversely proportional to slope

What is needed is a gentler basis for perceiving the effects of our engineering capabilities.
This more humble view of our relation to the hydrologic system requires a modicum of
reverence for rivers.

- Luna Leopold "A Reverence for Rivers"



We need knowledge – public awareness – of the small cogs and wheels, but sometimes I think there is something we need even more. It is the thing that *Forest and Stream*, on its editorial masthead, once called ‘a refined taste in natural objects.’

Have we made any headway in developing ‘a refined taste in natural objects’?

- Aldo Leopold, “Round River”

