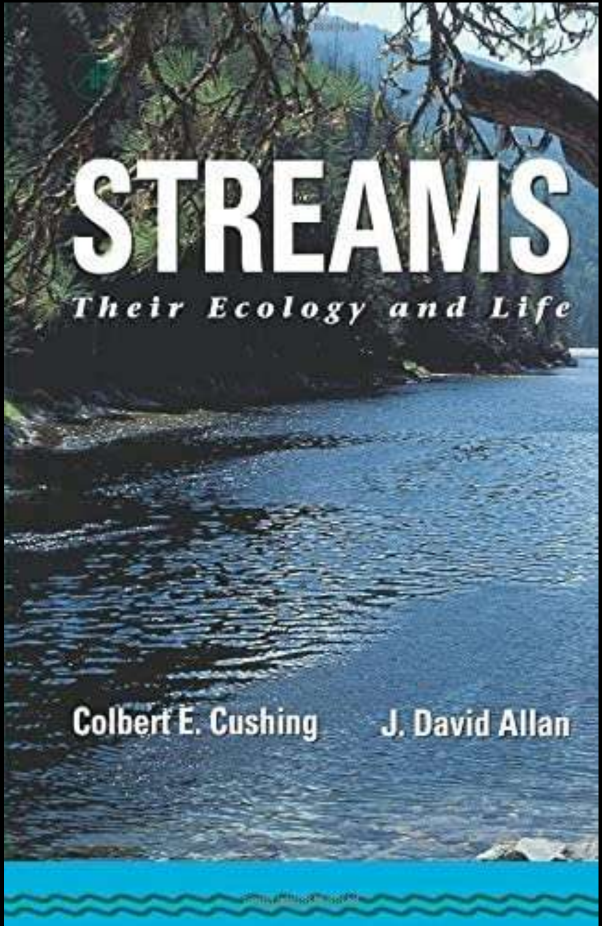
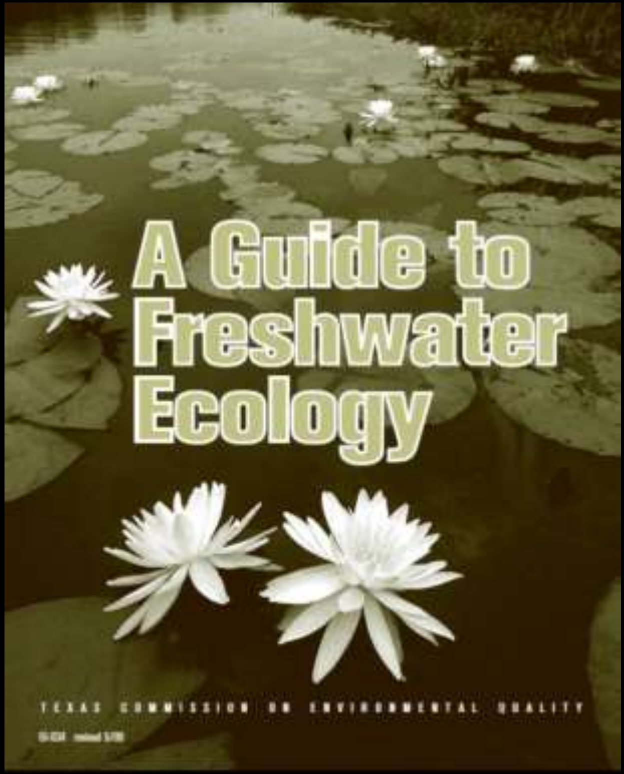
Center for Environmental Research at Hornsby Bend

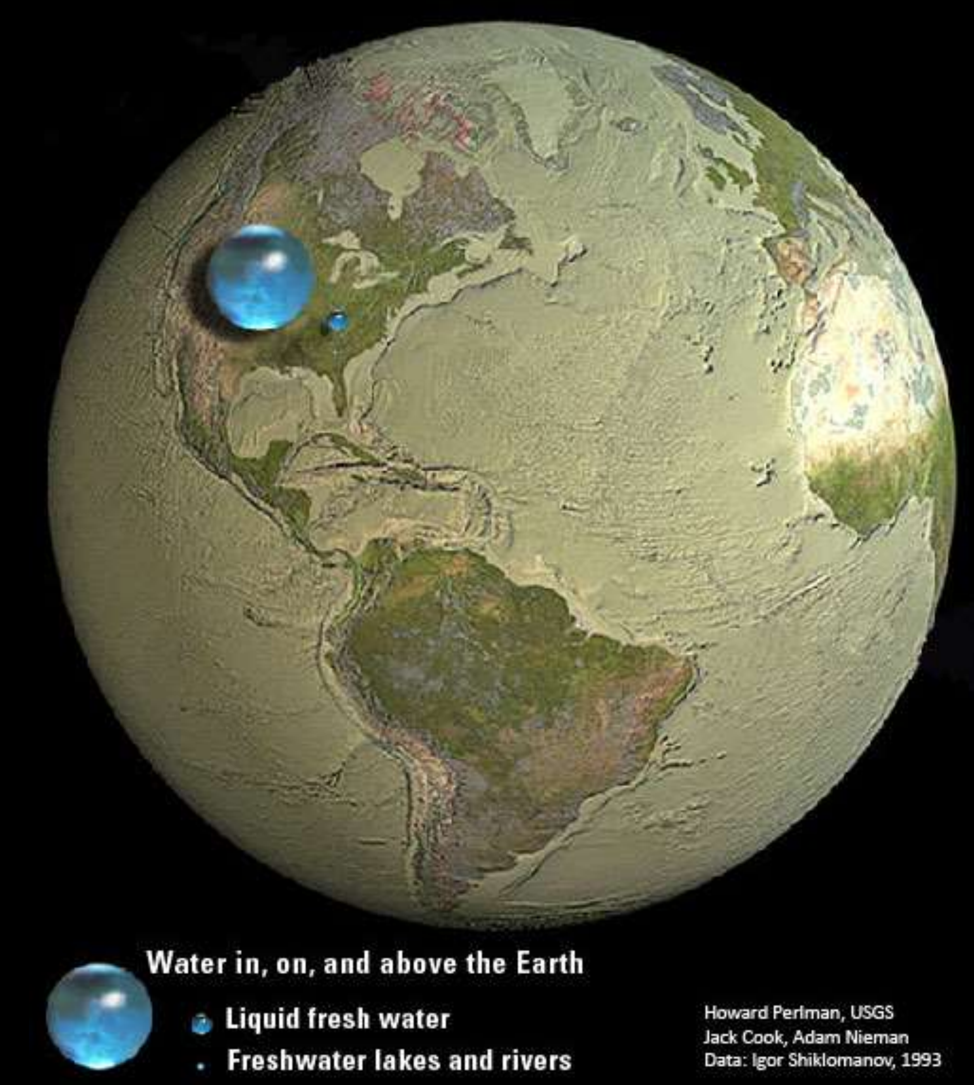
Austin WATER

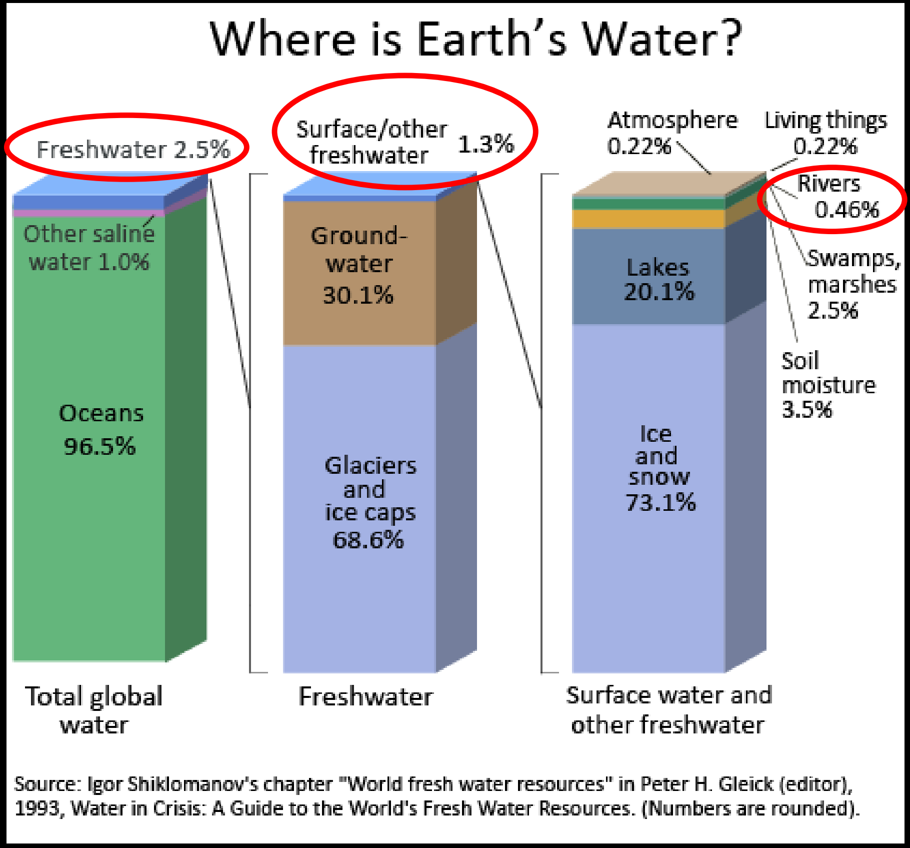
Fluvial Life: Ecology of Flowing Water

Kevin M. Anderson, Ph.D.
Austin Water – Center for Environmental Research









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).

General Differences Between Streams and Lakes

Streams (Lotic)	Lakes (Lentic)
One direction of flow, upstream to downstream	Various flows, no particular direction
Normally oxygen rich	Oxygen depletion exists at times in deeper water
Shallower	Deeper
Narrower and longer	Wider and shorter
Various effects from different terrestrial environments along the stream's course. The shoreline has more potential to affect water quality because a larger portion of the water body is near shore.	Terrestrial environment similar all around the lake shore. A smaller portion of the water is in close proximity to the shore.
Stream continually cuts into the channel, making it longer, wider, and deeper	Lakes become shallower over time from depositing sediments
Age progression of a stream goes from young stream, narrow and shallow, to mature stream, wider and deeper	Age progression of a lake or pond goes from lake to marsh or swamp to land
Shorter retention time for water	Longer retention time for water
Top and bottom waters generally have the same temperature	May have different temperatures from the top to bottom

Flowing Water vs. Nonflowing Water
Lotic vs. Lentic

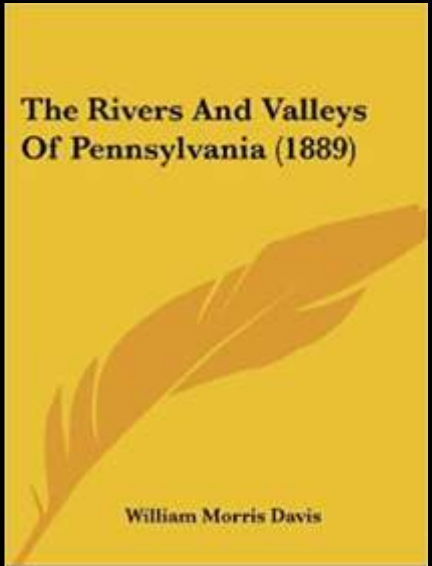
Flowing Water and Erosion – Earth Writing

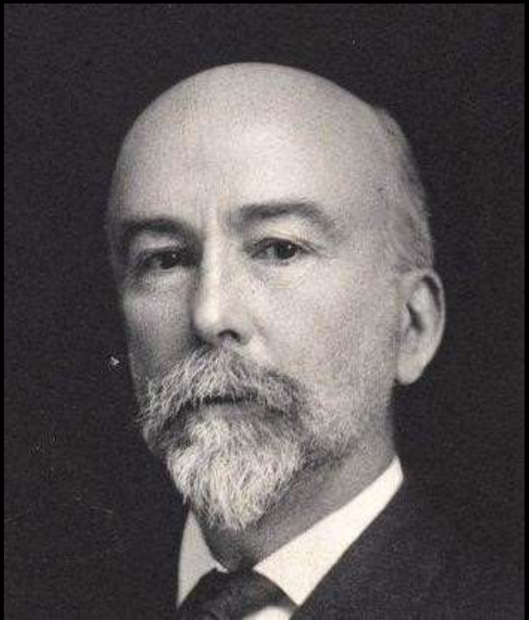
William Morris Davis (1850 - 1934) - American geographer, geologist, geomorphologist, and meteorologist, often called the "father of American geography".

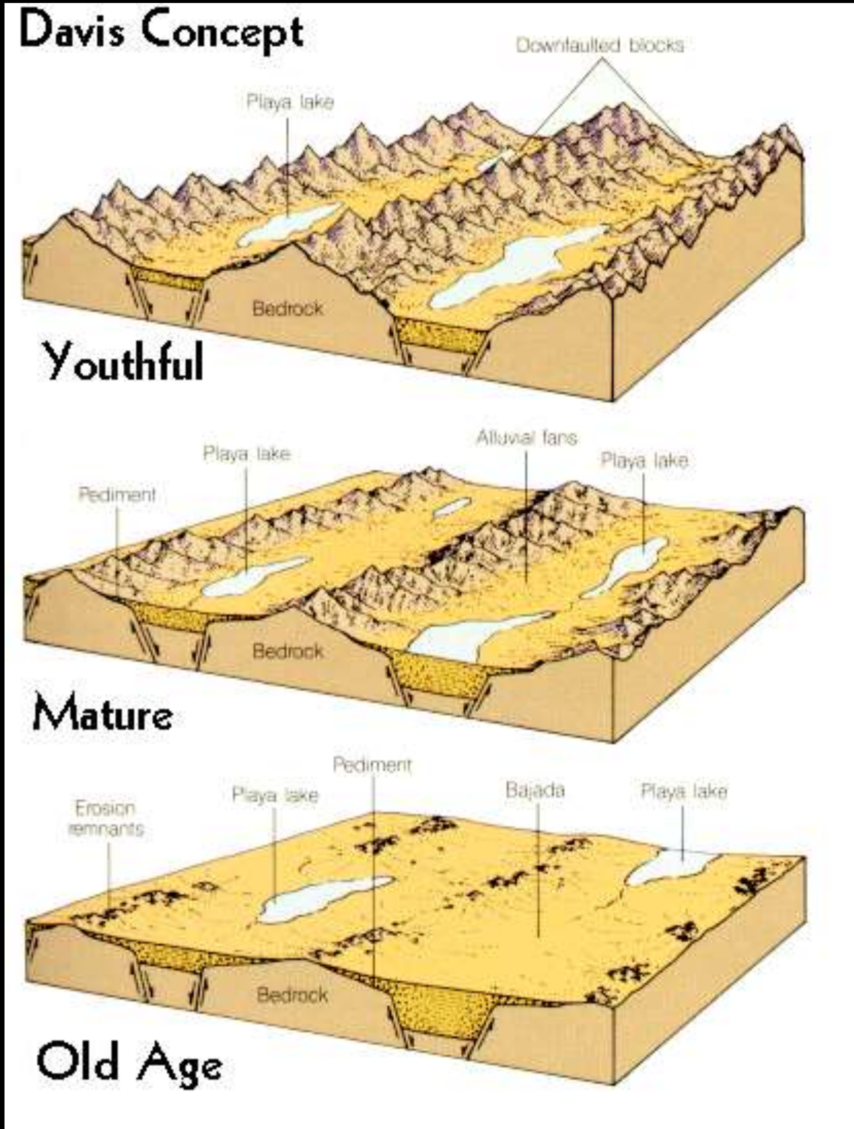
The Geographical Cycle – Erosion Cycle

His most influential scientific contribution was the “geographical cycle” or the cycle of erosion, first defined around 1884, which was a model of how rivers create landforms.

Flowing water always wants to carry a sediment load





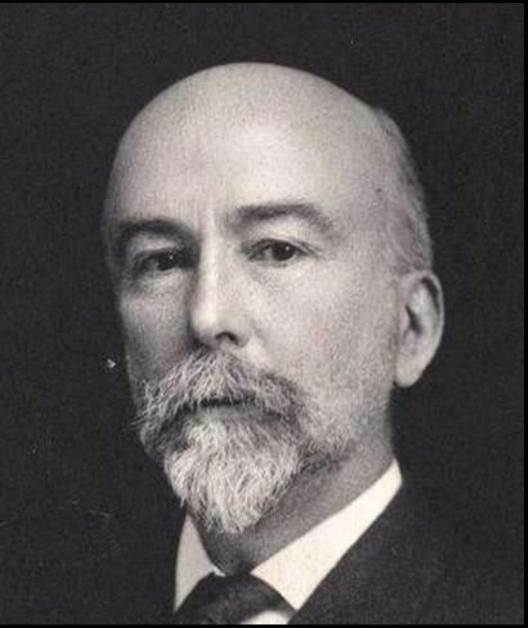


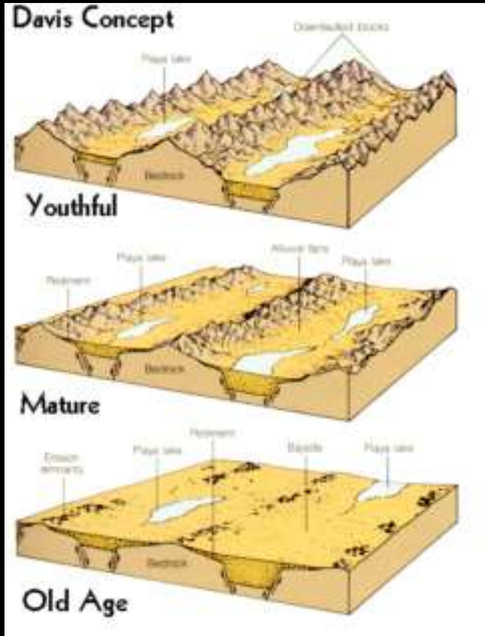
Waterways: The Life of a River – Physical Geography - Abiotic

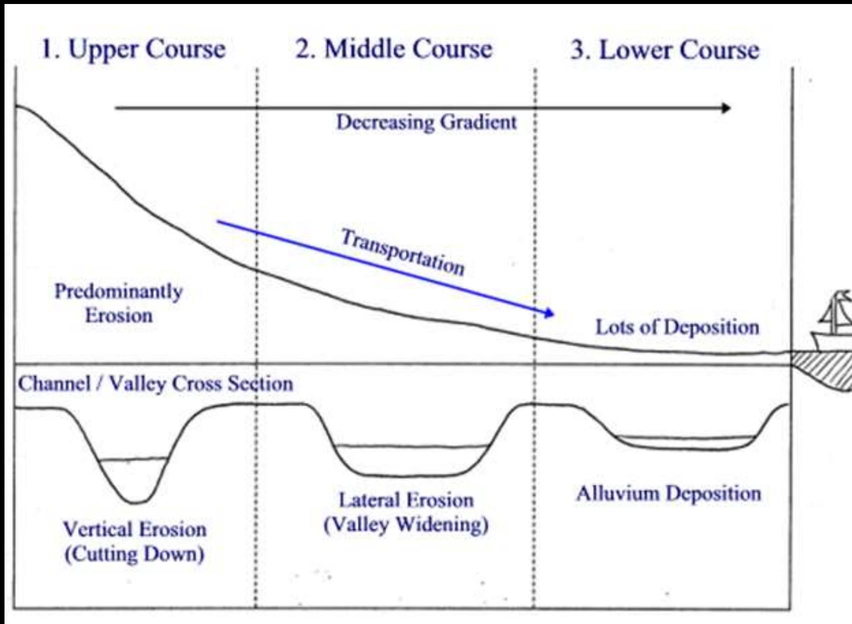
Luna Leopold wrote that Davis "viewed the river system as having a life of its own -

- Its youthful headwaters are steep and rugged.
- 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."

Flowing water always wants to carry a sediment load



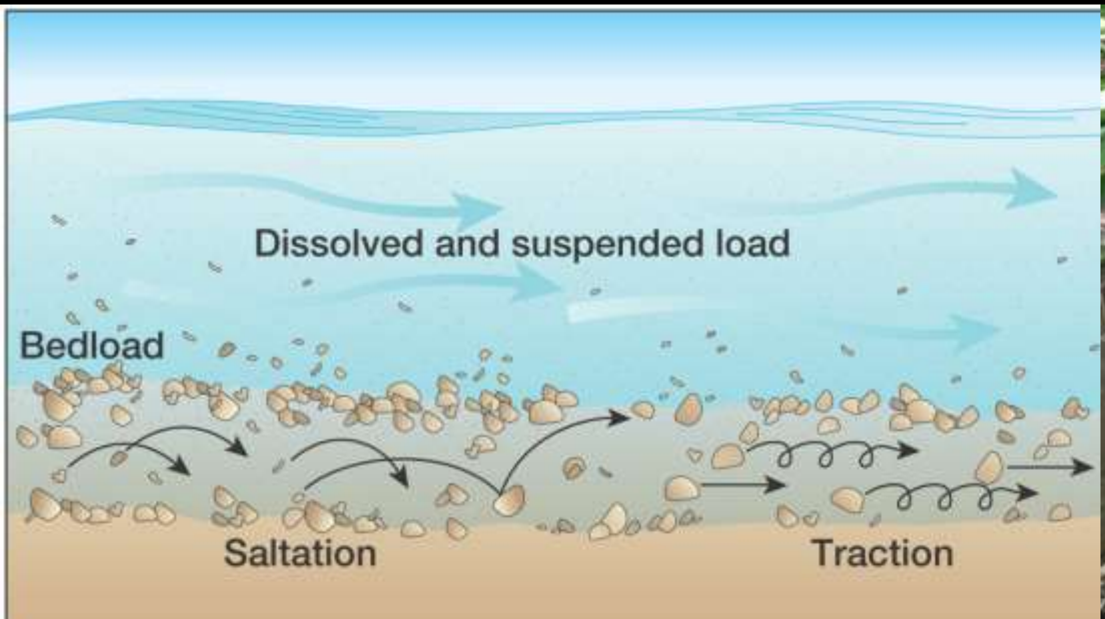




Fluvial Transportation and Ecology

Biotic and Abiotic Loads

- Rivers transport <u>three main materials downstream</u> – water, sediment, and organic material.
- Fluvial Geomorphology - the <u>abiotic components</u> – water and sediment – most directly impact the shape of the river channel.
- Aquatic Ecology - the <u>biotic components</u> of a river's transported load range from <u>dissolved organic matter</u> to <u>large woody debris</u>.



Dissolved Organic Matter (DOM)

- Very small particles (<0.5 microns in diameter) but the fundamental component of the organic material in rivers.
- Sources: some of it enters via subsurface drainage and originates from terrestrial decomposition processes - other sources are detrital leaching and exudates and excreta from aquatic organisms. [Everything Poops!]
- DOM tends to increase in concentration downstream. The highest levels occur in blackwater rivers, especially those draining peat swamps, which are rich in humic substances that color the water.
- DOM is consumed directly by microorganisms or filter feeders

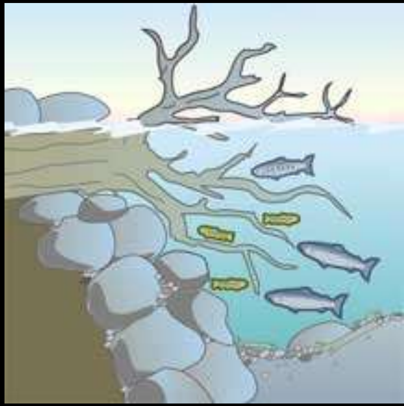
Large Organic Matter - Woody Debris

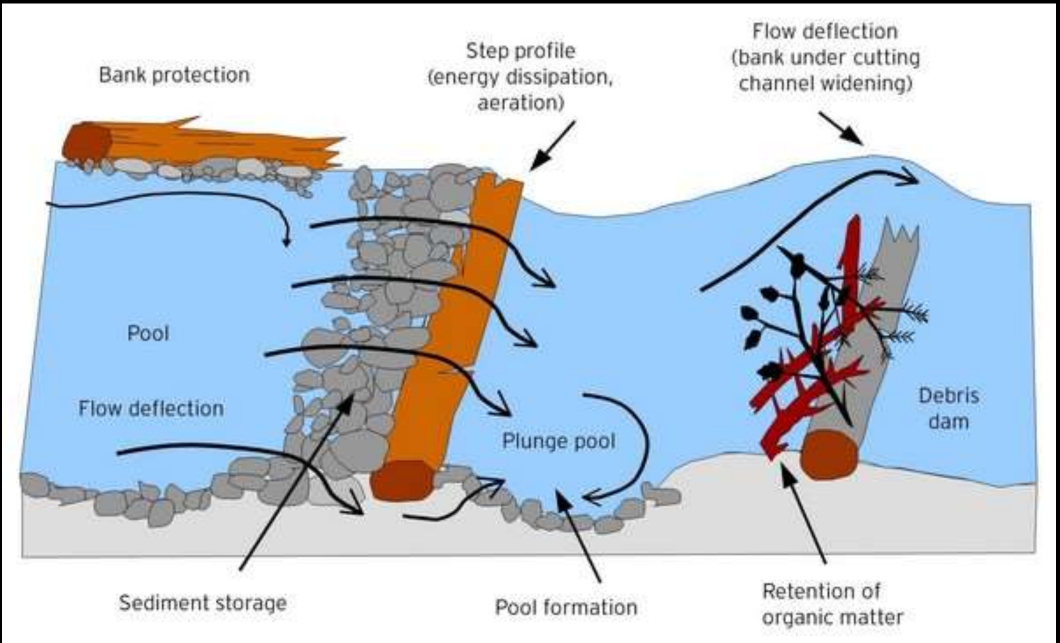
Trees and tree limbs that fall into streams and rivers increase habitat heterogeneity.

Submerged woody debris persists for long periods in streams and rivers.

Woody debris can –

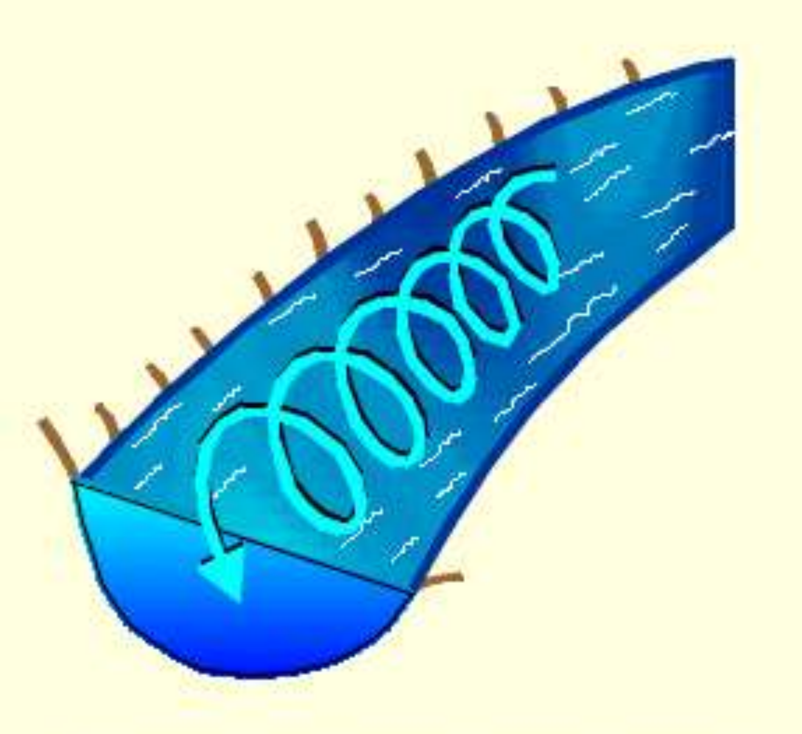
- stabilize river beds
- modify erosion and deposition
- create essential fish habitat
- form pools that retain organic matter



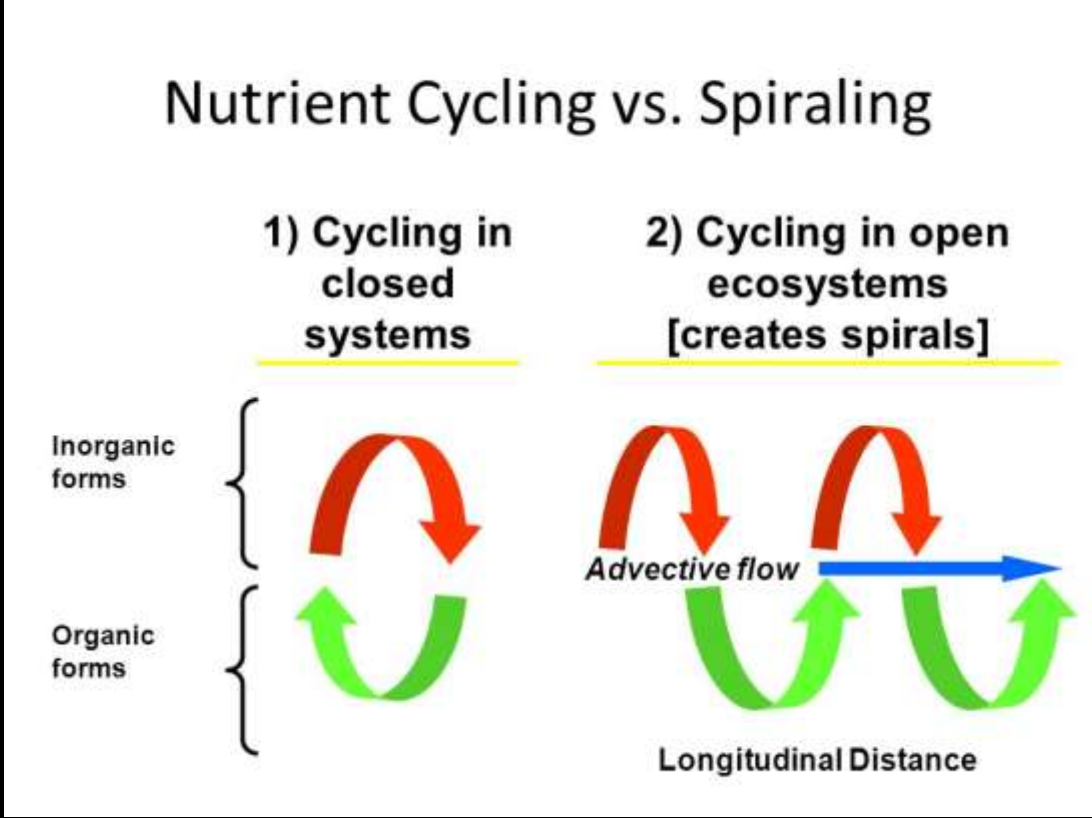


Terrestrial Ecology vs. Fluvial Ecology
Nutrient Cycles and Nutrient Spiraling

- Nutrient cycles describe changes in nutrient states through time and usually do not consider a large spatial component
- But water in streams have a large spatial component.
- Because these nutrient cycles occur simultaneously with downstream transport, nutrient transformations in streams are conceptualized as "spiraling"

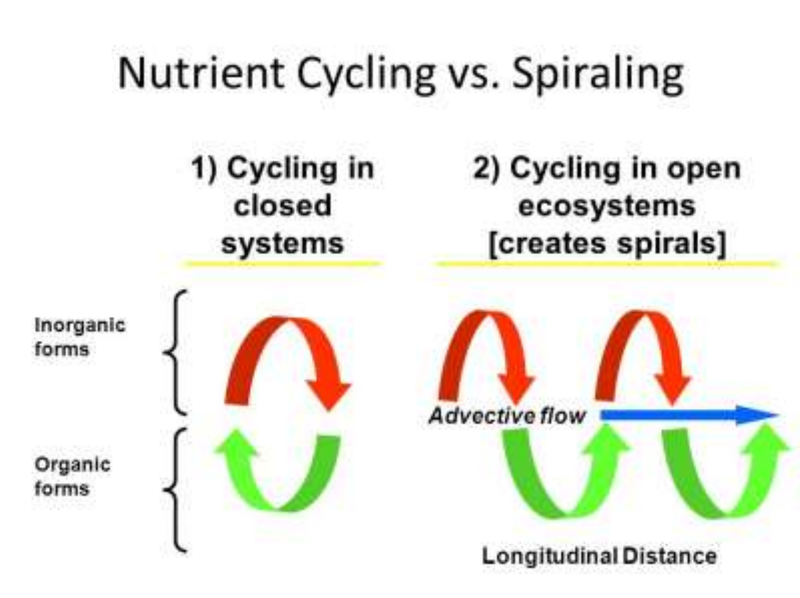


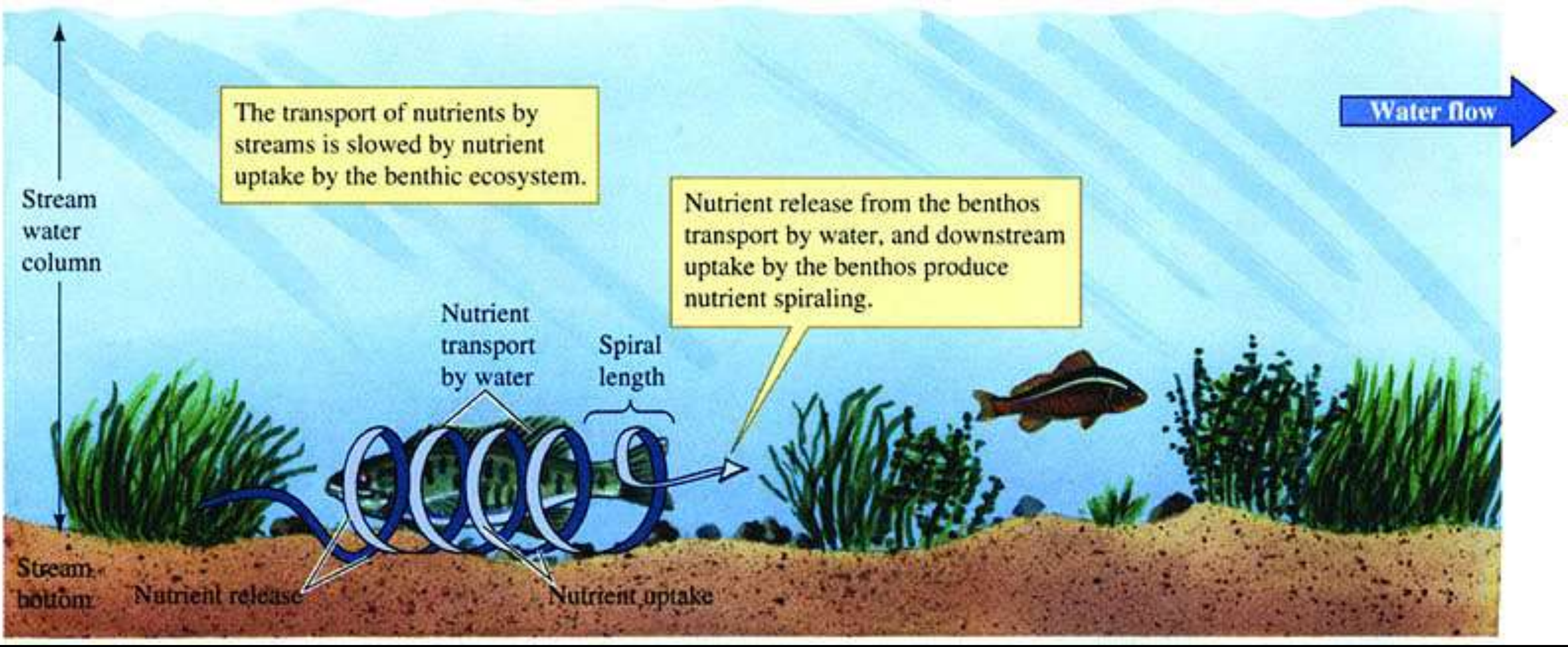
The nutrient cycle, in conjunction with downstream transport, describes a spiral.



Terrestrial Ecology vs. Fluvial Ecology
Nutrient Cycles and Nutrient Spiraling

- The spiraling length represents the distance over which the average nutrient atom travels as it completes one cycle of utilization from a dissolved available form, passes through one or more metabolic transformations and is returned to a dissolved available form.



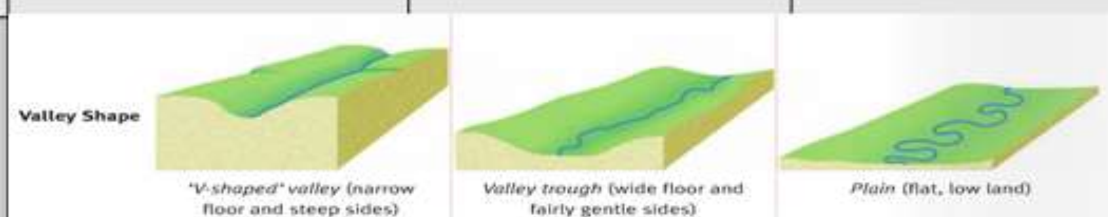


The Biogeography of the Waterway Ecosystem

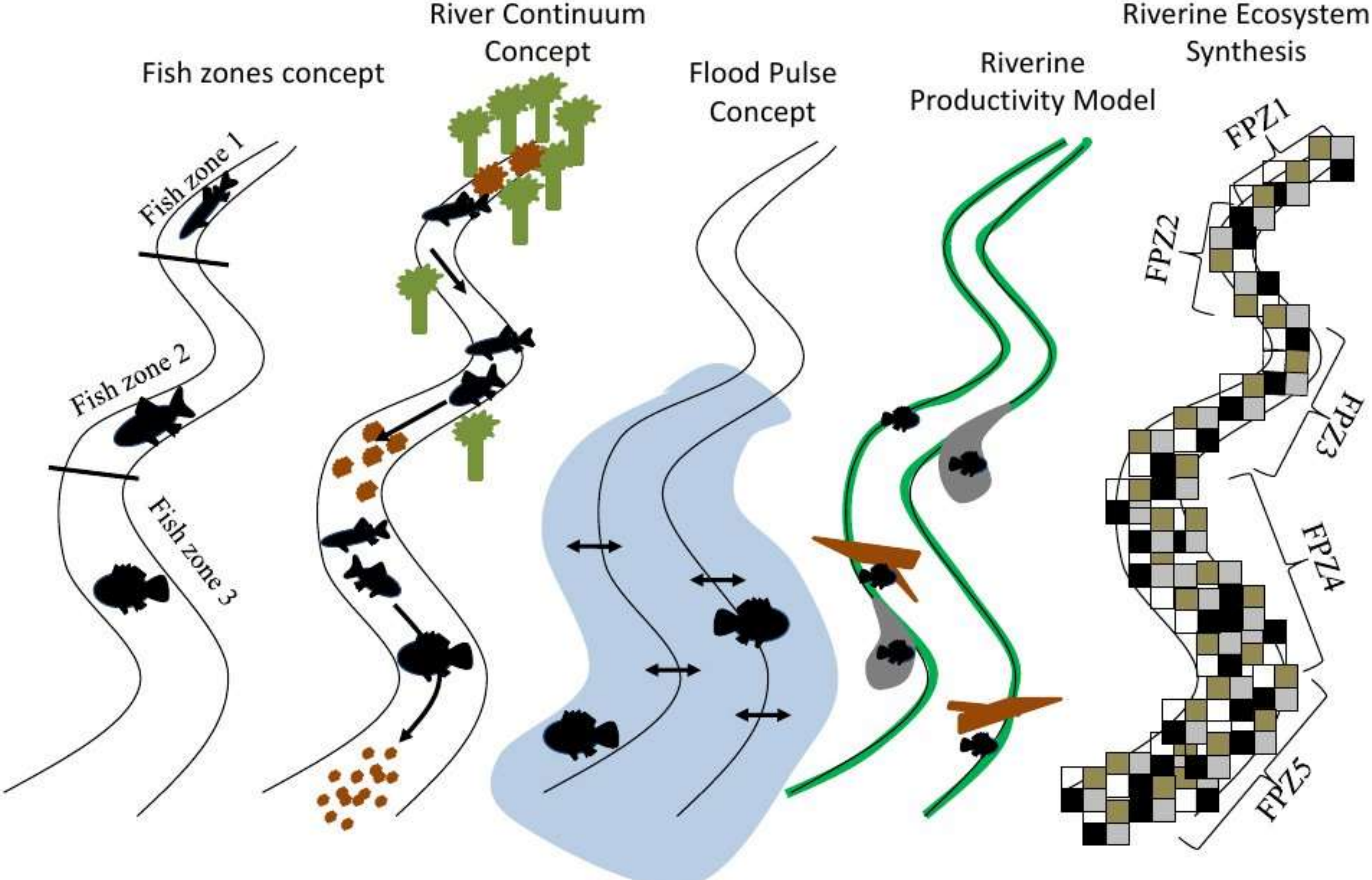
The Upper Course: steep and rugged

The Middle Course: winding sedately through wide valleys

The Lower Course: a somewhat aimless course toward final extinction

Course Stage	Upper Course Youth Stage	Middle Course Mature Stage	Lower Course Old Age Stage
Slope			
Main processes	Hydraulic Action Abrasion **Erosion**	**Erosion** and **Deposition**	**Deposition**
Valley shape			
Main features	V-shaped Valleys Interlocking Spurs Waterfalls	Meanders and Ox-Bow lakes	Deltas Levees Flood Plains (and m+ob lakes)

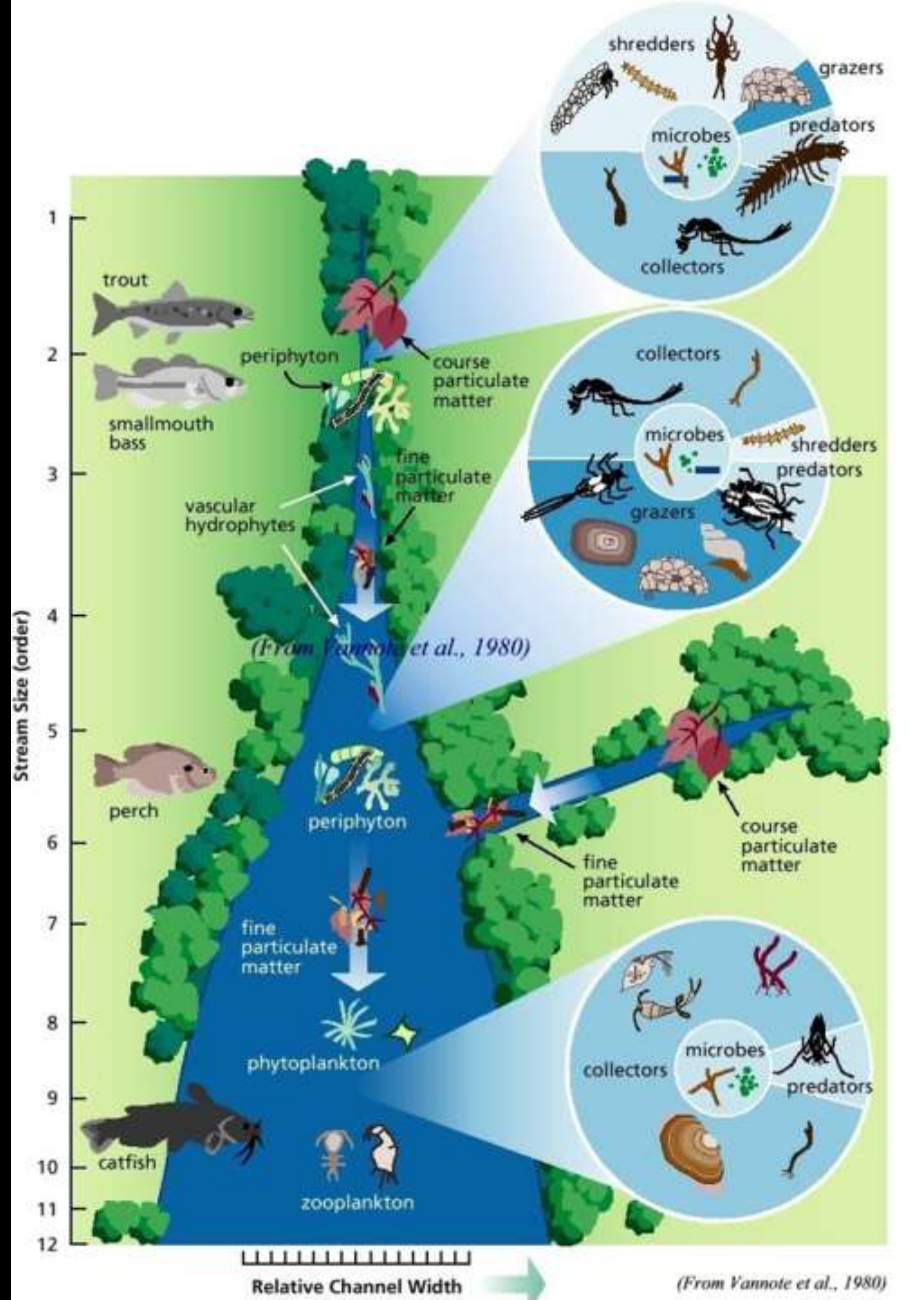
River ecosystem concepts

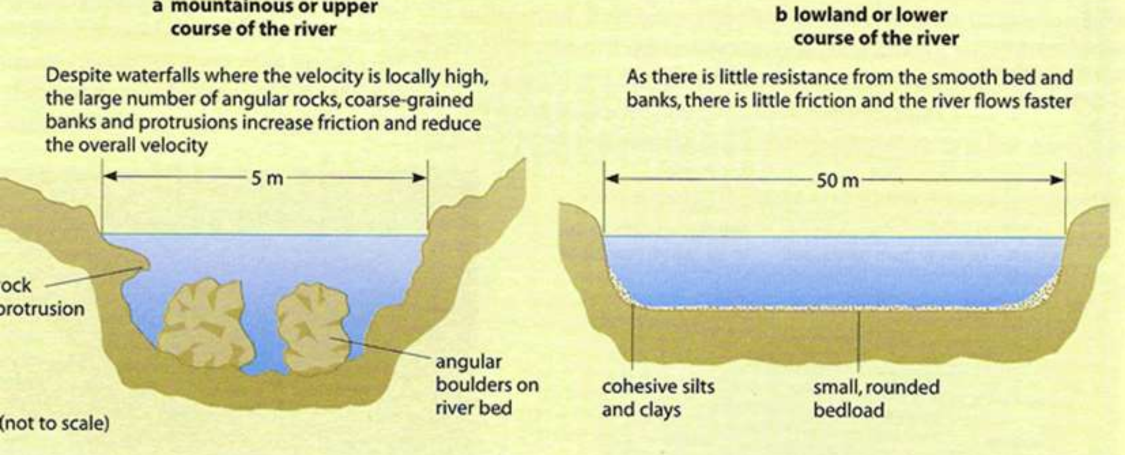


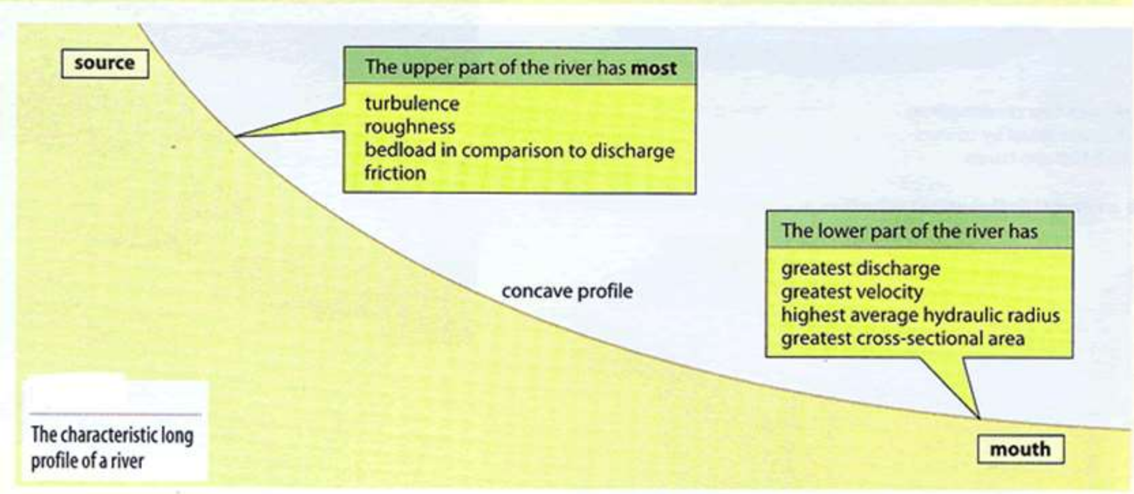
River Continuum Concept [RCC] An Ecological Model

How the physical and biological characteristics of a river change in a downstream direction.

- The foundation concept - rivers have physical gradients which are influenced by the surrounding environment, natural disturbance regime, local hydrology, and upstream conditions.
- They in turn impact and define the biological components of the stream within the river as the river increases in size and moves downstream.
- RCC focuses on the interaction of stream invertebrates with their habitat and food resources.
- The concept was developed in 1980 by Dr. Robin L. Vannote and others







How the abiotic river system changes downstream

Luna Leopold

"Downstream Change of Velocity in Rivers"

Luna Leopold *American Journal of Science*, VOL. 251, August 1953

Apparent vs. Mean Velocity

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

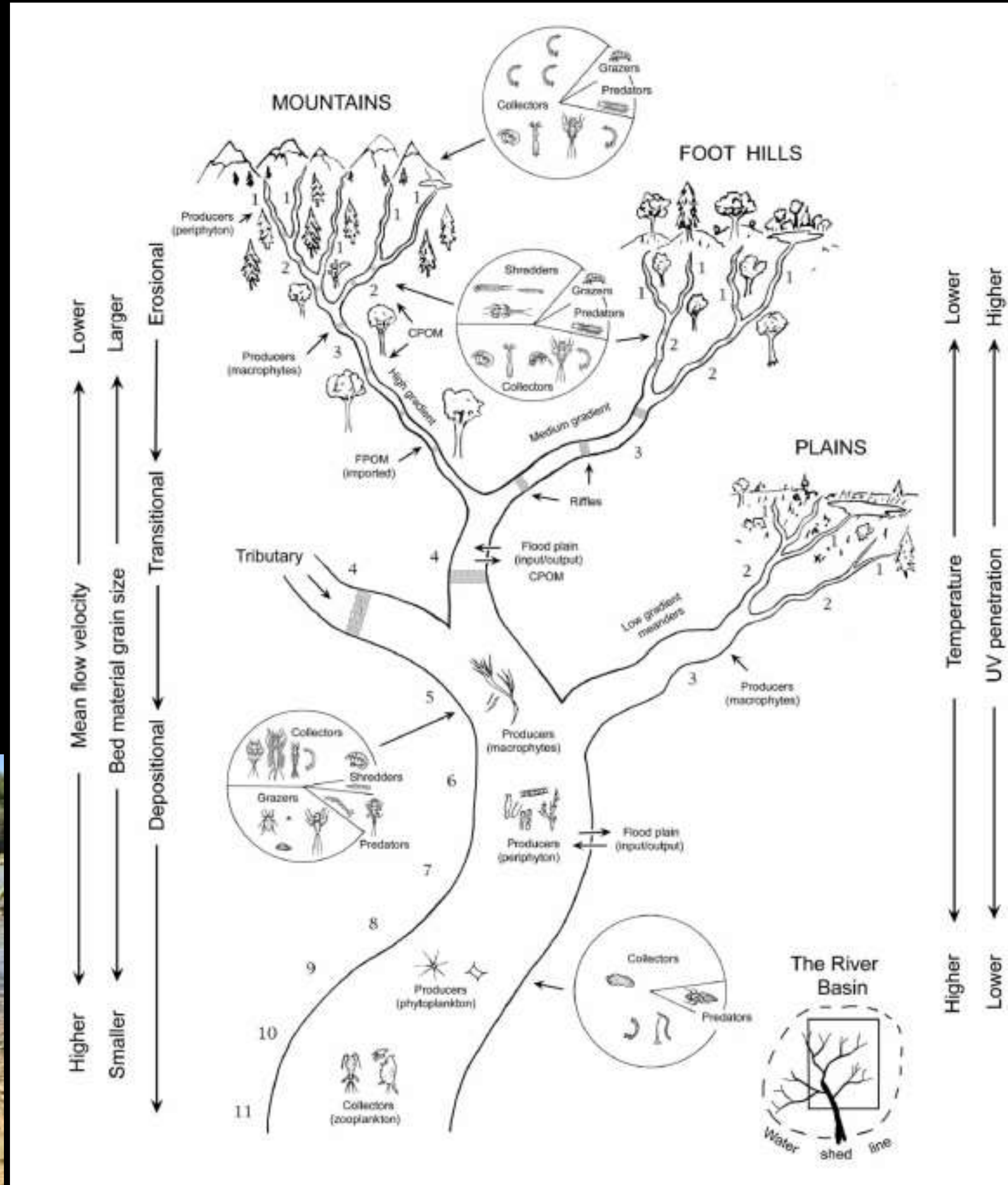
Analysis of some of the large number of velocity measurements made at stream-gaging stations demonstrates that mean velocity generally tends to increase downstream.

River Continuum Concept

Throughout the continuum of the river, the proportion of the four major organism types change.

- shredders
- collectors
- grazers (scrapers)
- predators

With the exception of the predators, all these organisms feed directly from plant material



Freshwater Ecology - Food Webs

Freshwater ecosystems begin with the consumption of living or dead plant material

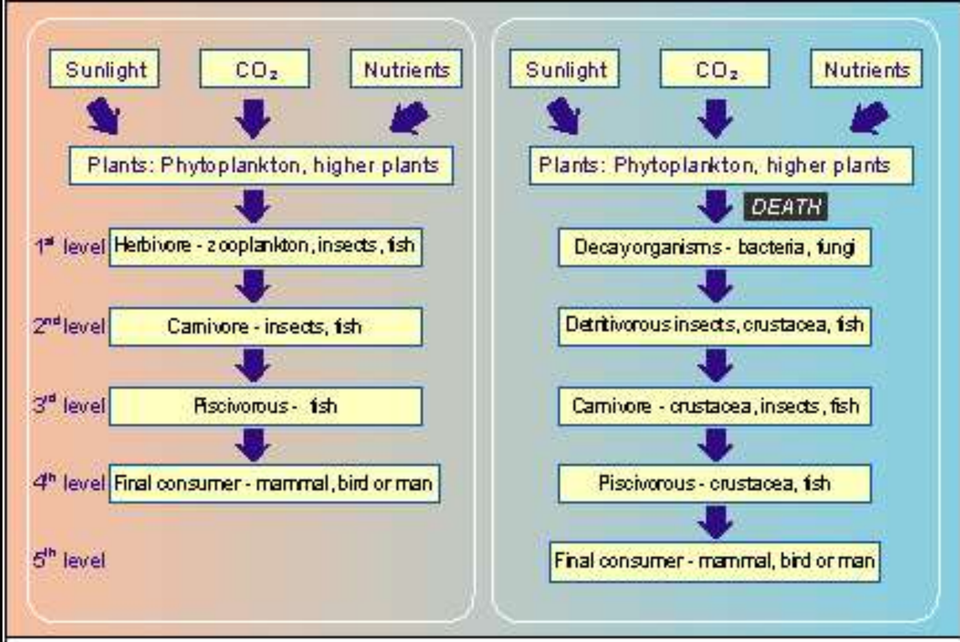


Figure: Alternative pathways for energy and nutrient flow among river organism.

Freshwater Invertebrate Biological Types and Food Types

Shredders are organisms that feed off of coarse particulate organic material (CPOM) such leaves.

- They ingest the organic matter along with volunteer organisms (fungi, microorganisms) attached to the source.
- The preferred size of the CPOM is about one millimeter, therefore shredders must break up leaves into a finer particulate.
- In the process of shredding, much of the now fine particulate organic matter (FPOM) is left in the system, making its way further downstream.
- Some common shredders of North American waters – Larva of mayflies, crane flies, stoneflies, caddisflies, and aquatic sow bugs

Freshwater Invertebrate Biological Types and Food Types

Collectors are designated by their use of traps or other adaptive features to filter and catch organic matter.

- The preferred particle size for collectors lies between 0.5 and 50 micrometers (UPOM = Ultrafine particulate organic matter and FPOM).
- Collectors – net spinning caddisfly, fly larvae, nematodes.

Grazers (scrapers) feed off of ***periphyton*** that accumulates on larger structures such as stones, wood or large aquatic plants.

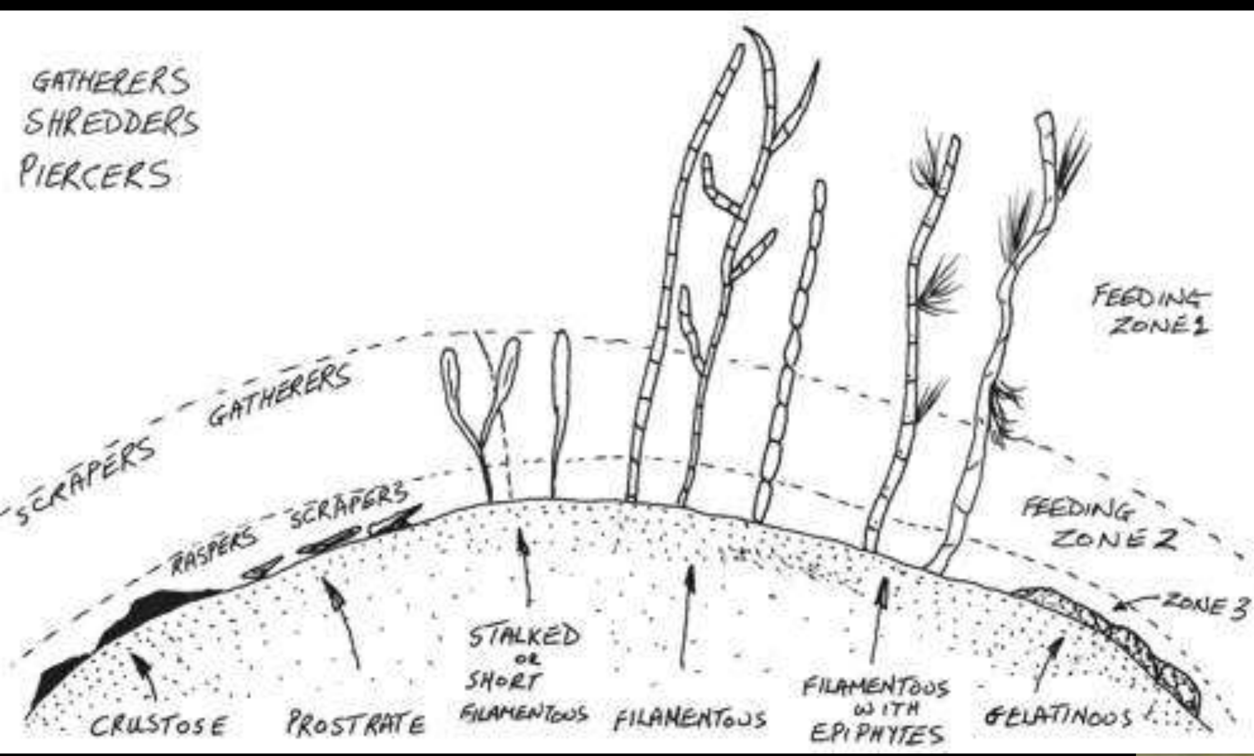
- Grazers - snails, caddisflies, and other organisms.

The Benthos

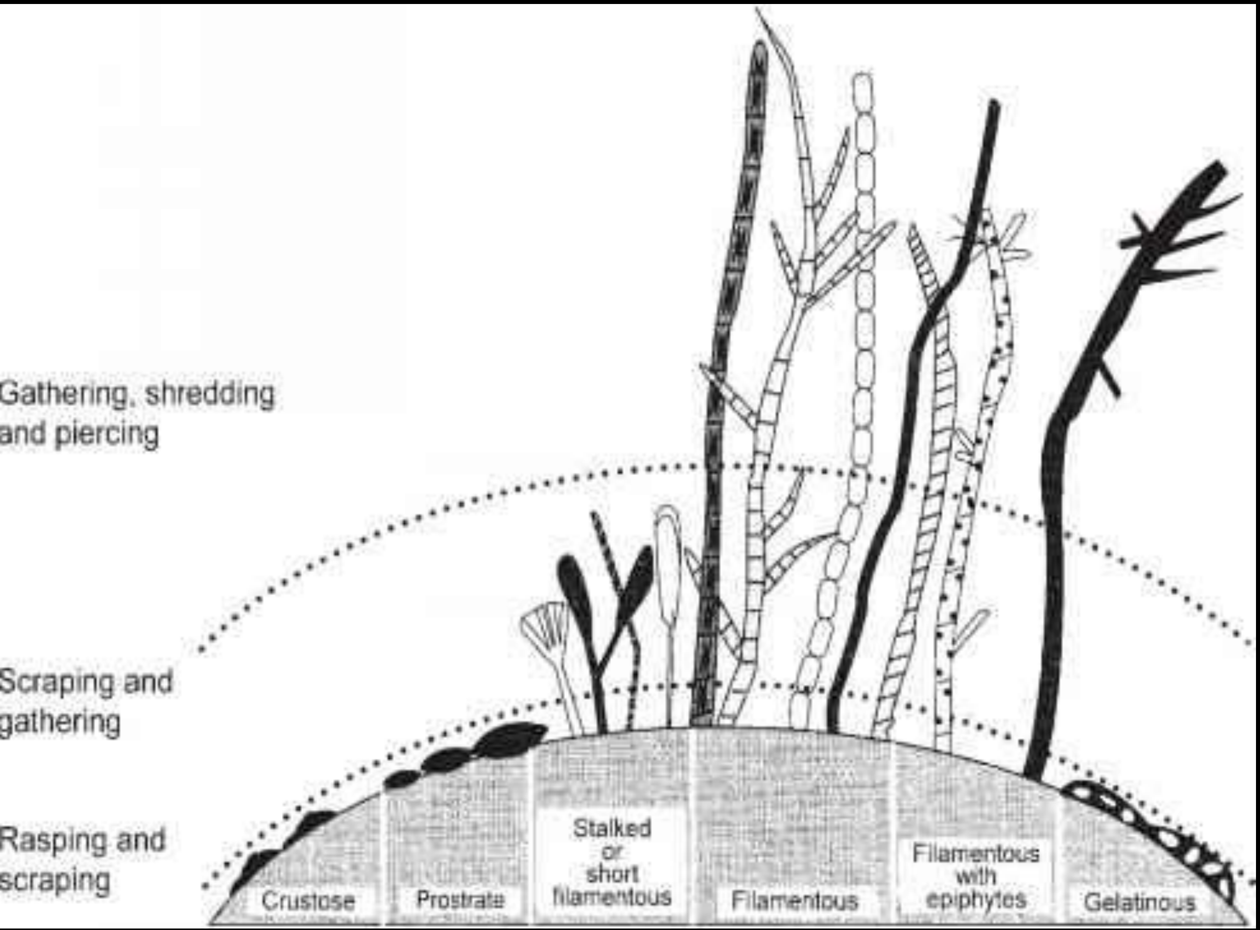
Periphyton

A complex mixture of algae, cyanobacteria, and detritus that are attached to submerged surfaces in most aquatic ecosystems.

The three zones of Periphyton on stones



Benthos Surface Habitat
Scrapers (and Piercers)

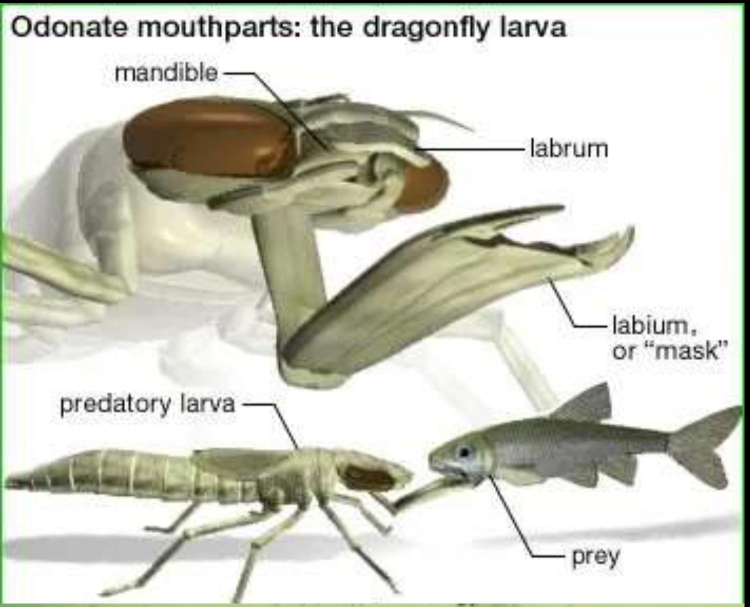


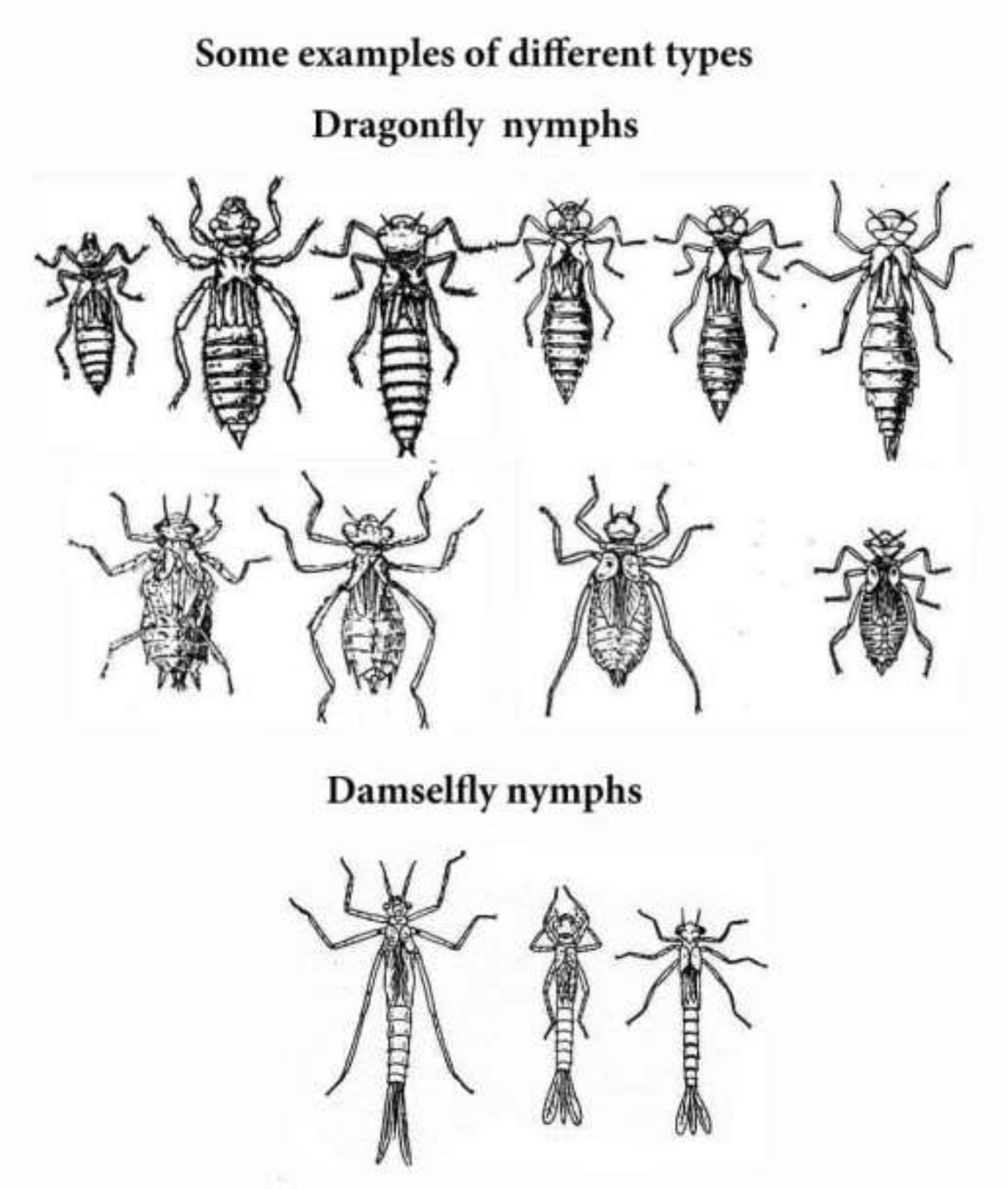
By a variety of mechanisms, the periphyton-bacteria-organic microlayer on substrate surfaces is scraped or browsed.

<u>Diatoms</u> are a prominent constituent of this matrix.

Freshwater Invertebrate Biological Types and Food Types

Predators are organisms that eat each other





Freshwater Invertebrate Biological Types and Food Types

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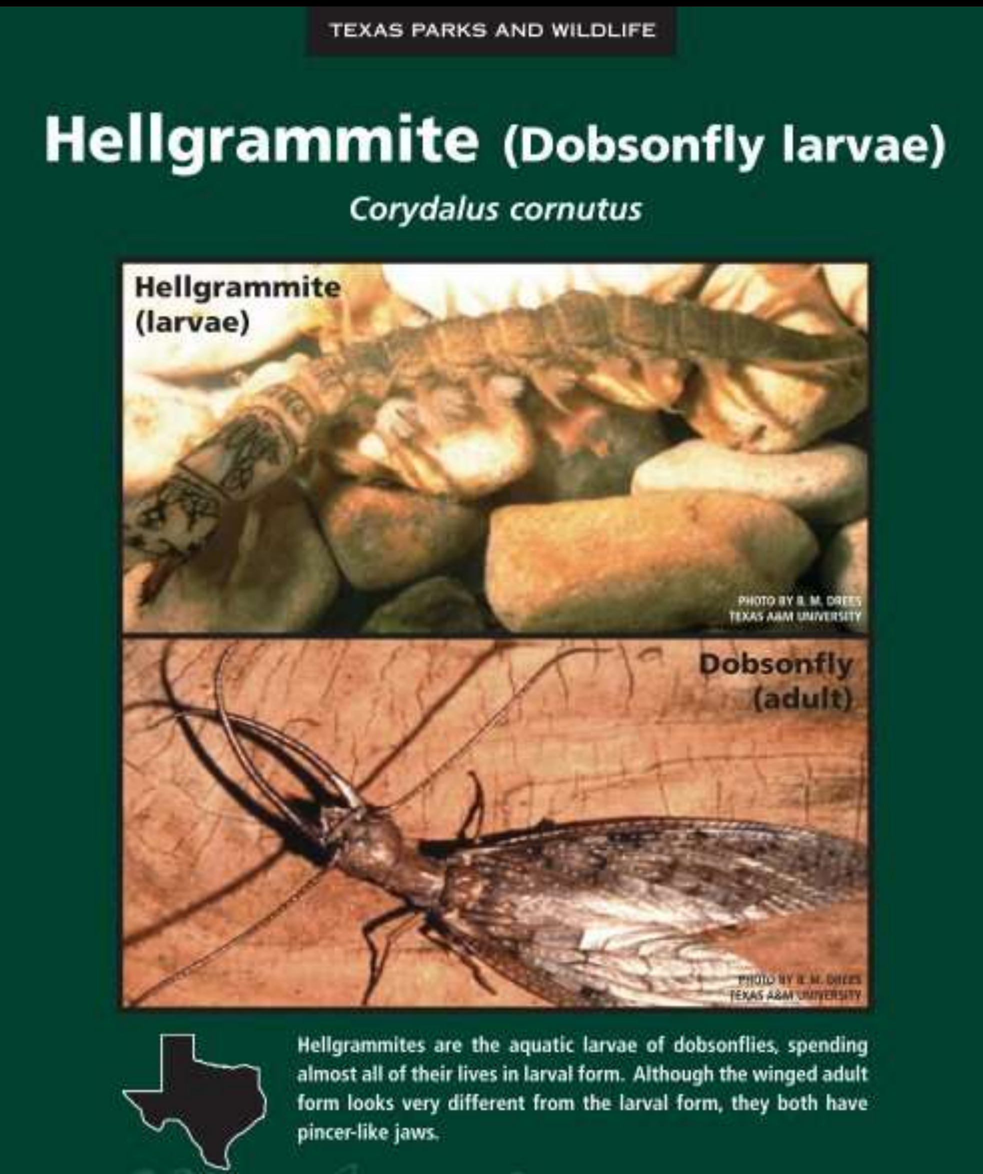

Freshwater Invertebrate Biological Types and Food Types

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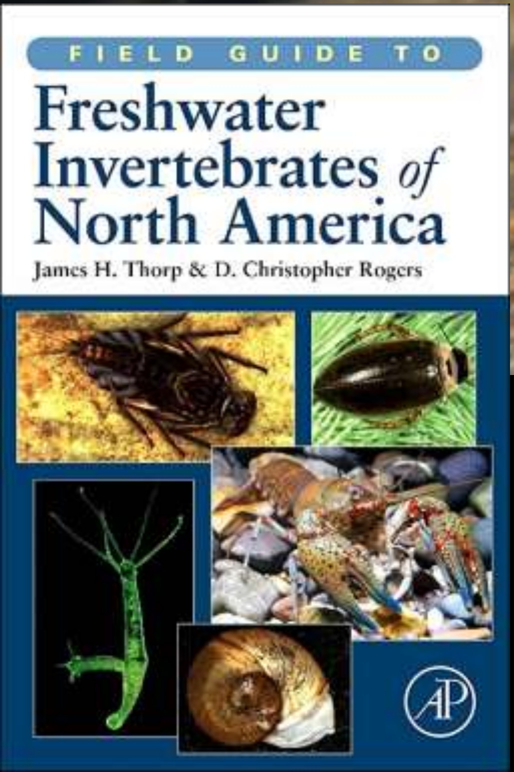
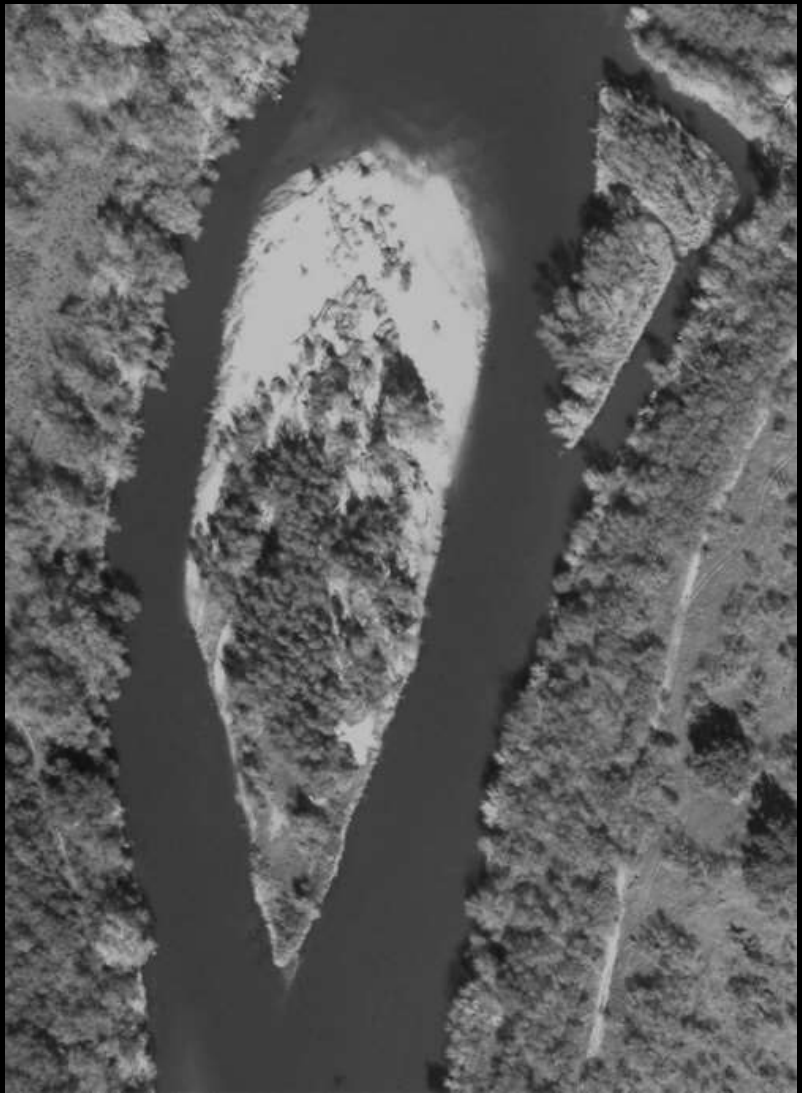
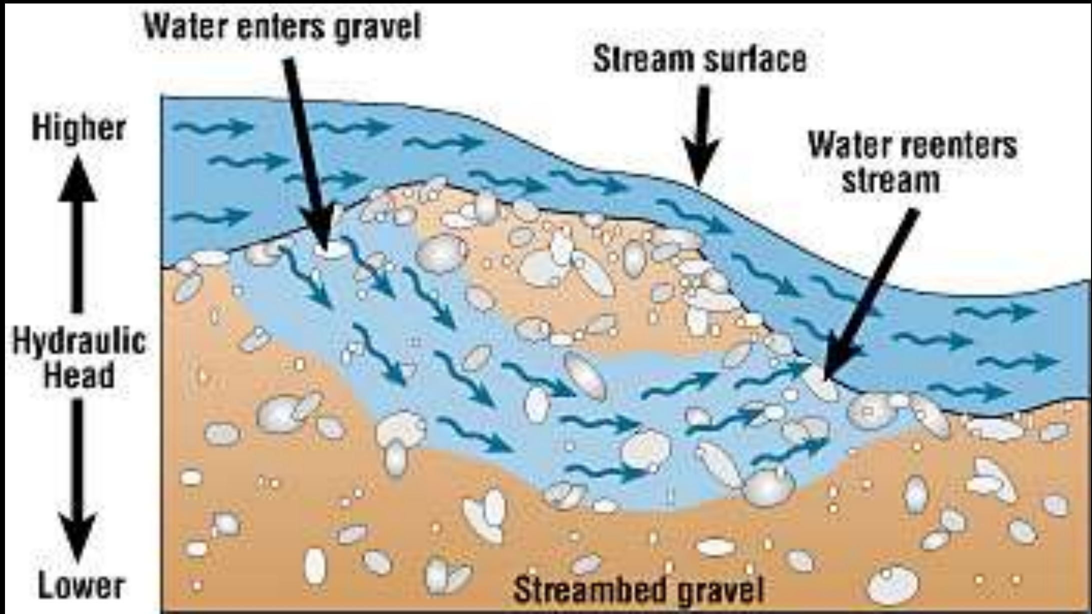


Beneath the Benthos

The Hyporheic Zone

Hydrogeology and Ecology





Subsurface Habitat – The Microbial Zone

Streams exchange water, nutrients, and organisms with surrounding aquifers.

The interstitial, water-filled space beneath river beds, where most active aquifer-river water exchange occurs and is an important habitat for a number of aquatic organisms and for fish spawning.

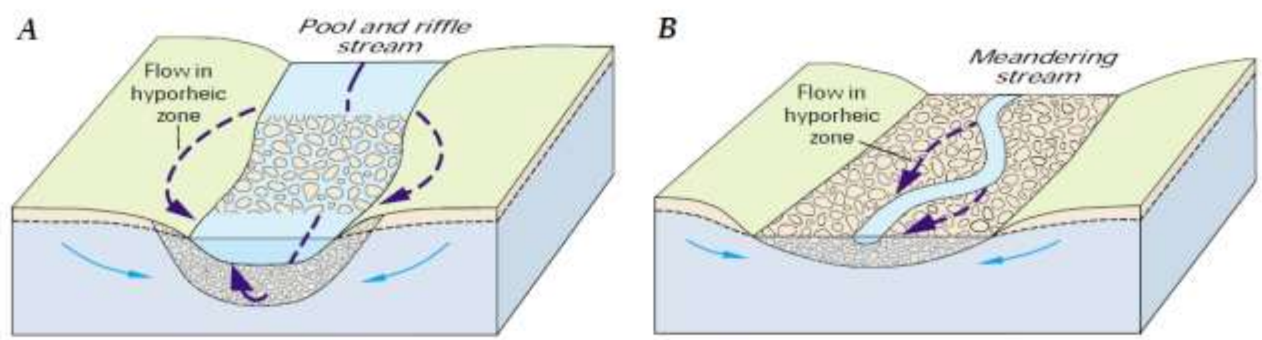
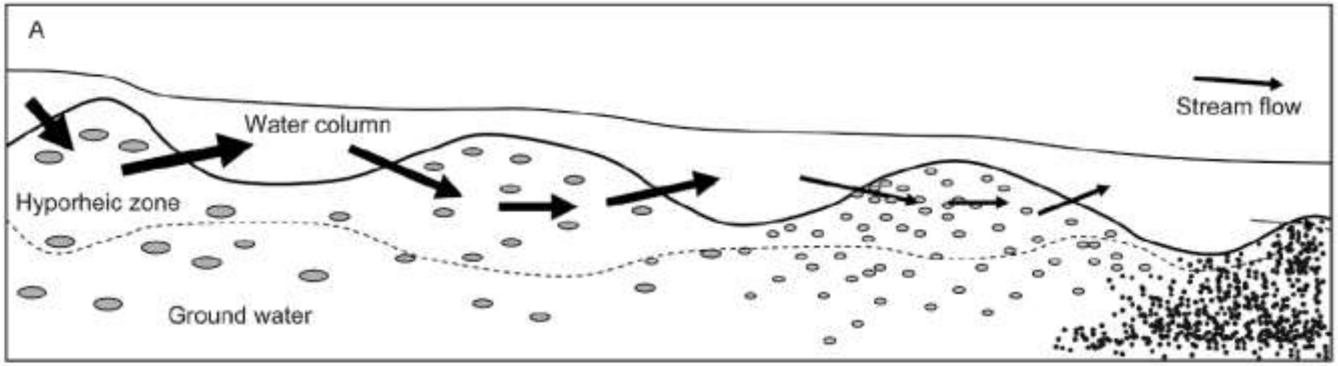
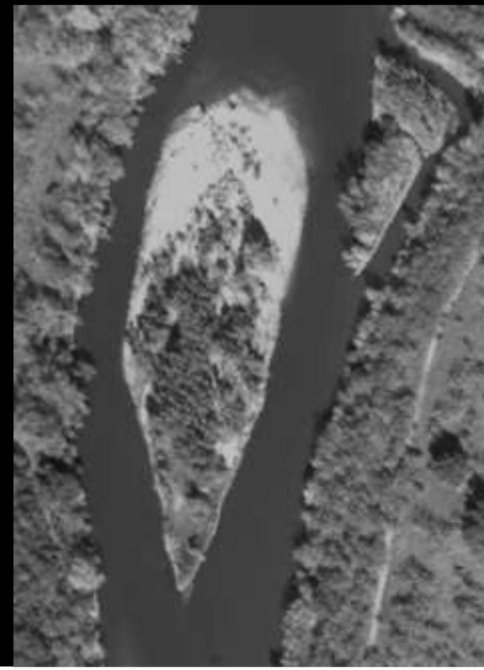


Figure 14. Surface-water exchange with ground water in the hyporheic zone is associated with abrupt changes in streambed slope (A) and with stream meanders (B).



The Hyporheic Zone Research at Hornsby Bend

THE UNIVERSITY OF TEXAS AT AUSTIN
JACKSON
SCHOOL OF GEOSCIENCES



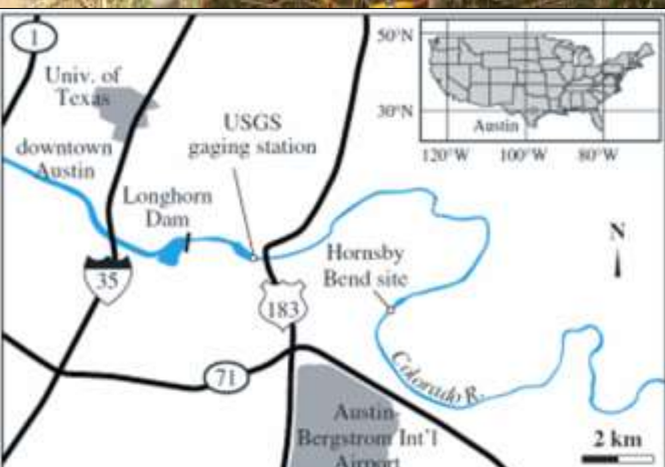


Figure 1. Location of study site on the Colorado River in relation to Austin, Texas, USA. USGS gaging station 08158000 is 2 km downstream from Longhorn dam, and the study site is another 13 km downstream

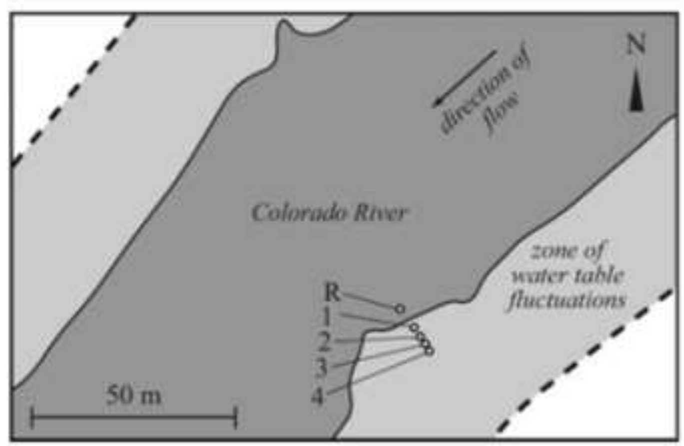
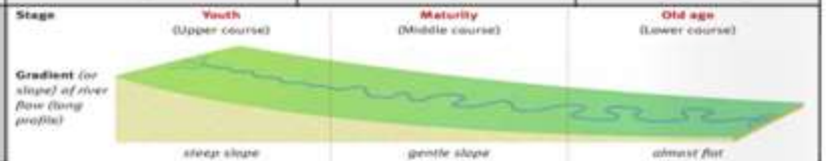
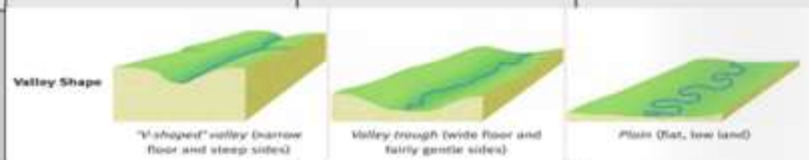


Figure 2. Map of Hornsby Bend piezometer transect. Bank piezometers are numbered in order of distance from the river, and the river stage recorder is denoted as (R). Dashed lines indicate the estimated extent of dam influence on the water table

The Life of a River - The Biogeography of Fluvial Life

Course Stage	Upper Course Youth Stage	Middle Course Mature Stage	Lower Course Old Age Stage
Slope			
Main processes	Hydraulic Action Abrasion **Erosion**	**Erosion and Deposition**	**Deposition**
Valley shape			
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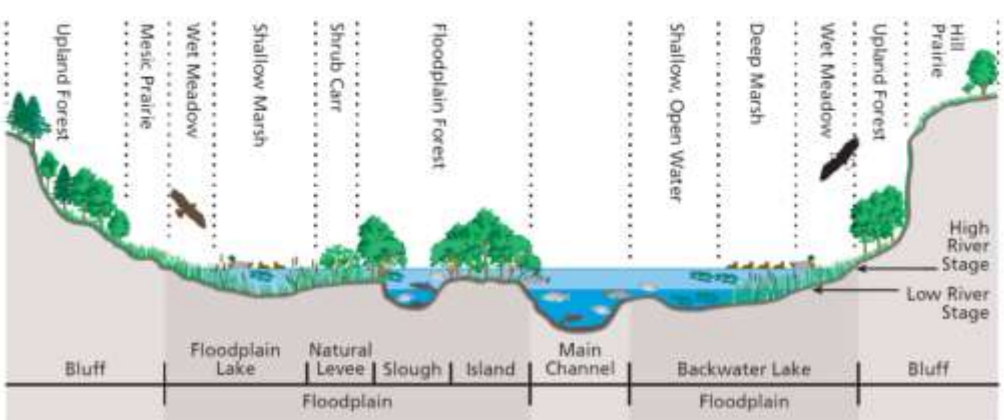
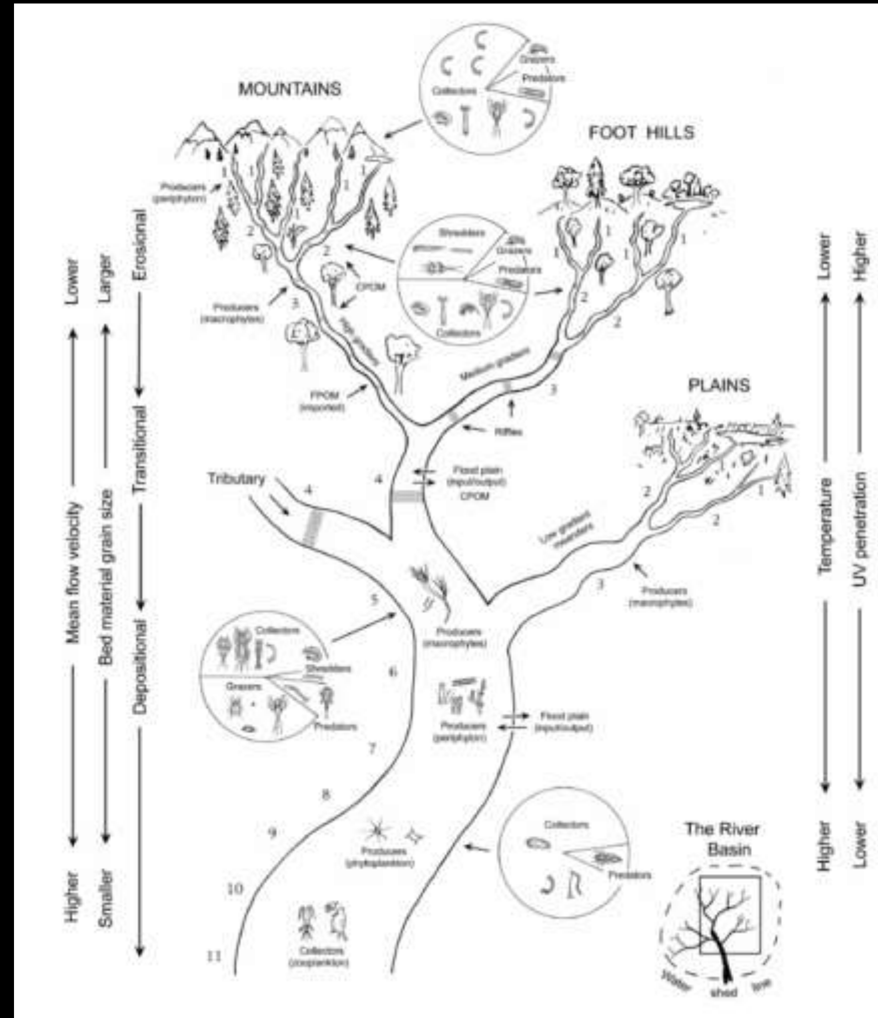
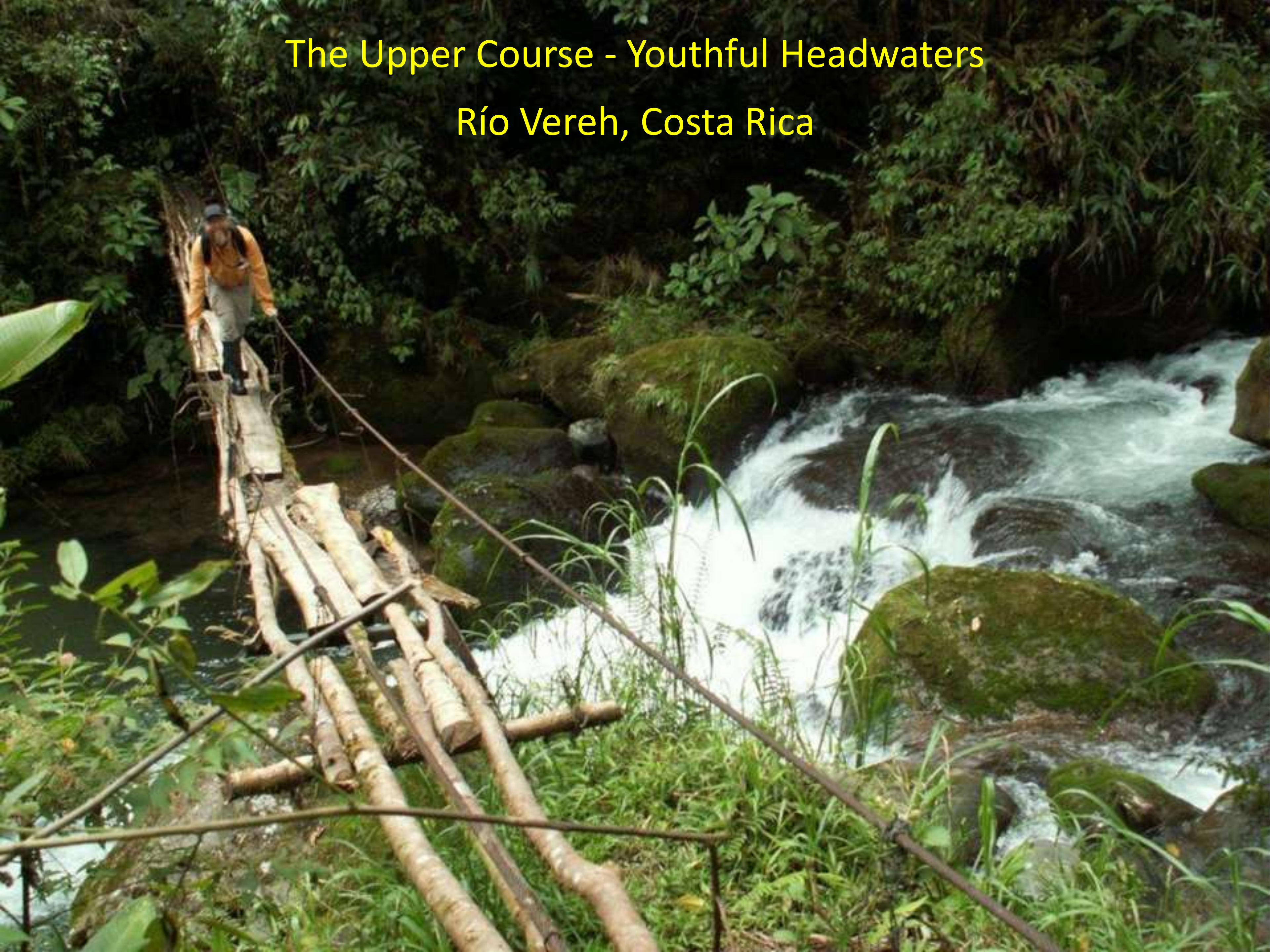





The Upper Course - Youthful Headwaters
Río Vereh, Costa Rica

The Upper Course

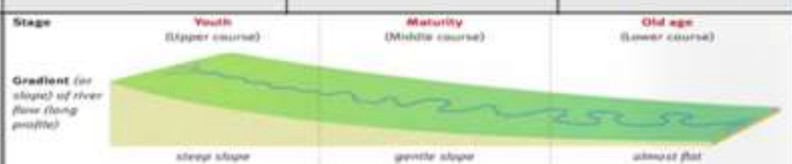
Roughness = Rapids = Oxygen

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

The Upper Course

Shade and Plant Material

- <u>Shade</u> - In temperate environments, small streams tend to be <u>shaded by an interlocking, overhead tree canopy</u>.
- Such conditions result in <u>cool, well-oxygenated streams</u> that are abundantly supplied with <u>a food base of plant material</u>.
- <u>Fine particles of organic matter</u> are released as the plant material is broken down by biological communities in the streams



Course Stage	Upper Course Youth Stage	Middle Course Mature Stage	Lower Course Old Age Stage
Slope			

Plant Material

Freshwater ecosystems begin with the consumption of living or dead plant material

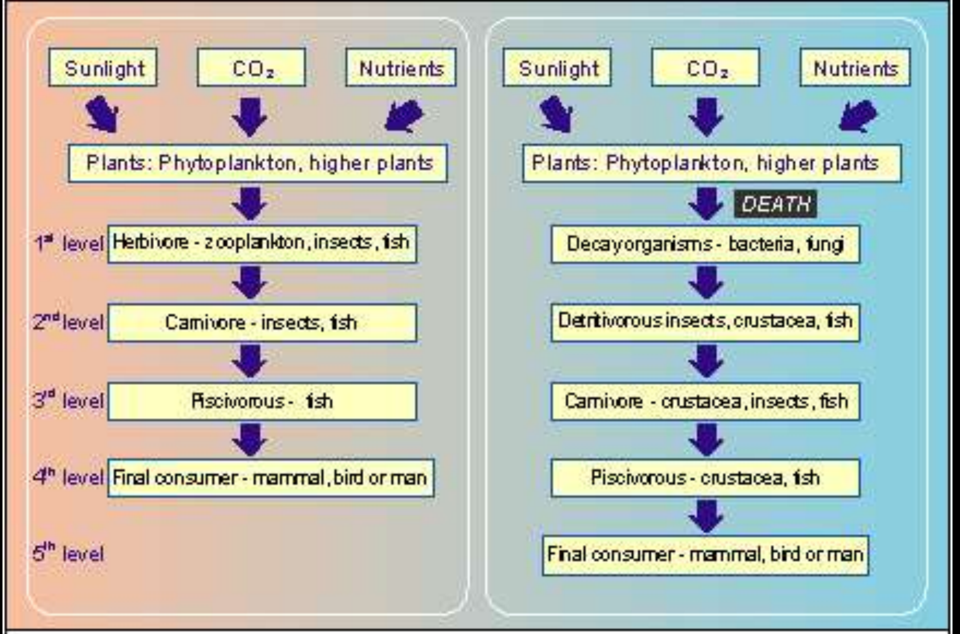


Figure: Alternative pathways for energy and nutrient flow among river organism.

Leaves and Leaf Packs

- Invertebrates – Shredders and Collectors
- Leaf fall from the forest canopy in small streams are used by shredders who get nutrition primarily from the fungi and bacteria that colonize the leaf surface.
- Small fragments of leaves and feces from shredders are captured by collectors

The Leaf Pack Network

Citizens, teachers, and students investigating their local stream ecosystems.

- Create an artificial leaf pack and place it in a stream for 3-4 weeks.
- Collect and examine the packs in the classroom.
- Discover aquatic insects that indicate stream health, showing the connection between trees and streams.
- Share data through the network.

Leaf Pack Network

STROUD
WATER RESEARCH CENTER
www.stroudcenter.org

The Upper Course – Pools

Macroinvertebrate communities in rapids are typically more diverse than communities in pools. The pattern in fish communities is reversed, with pool fish communities tending to be more diverse than those in rapids.

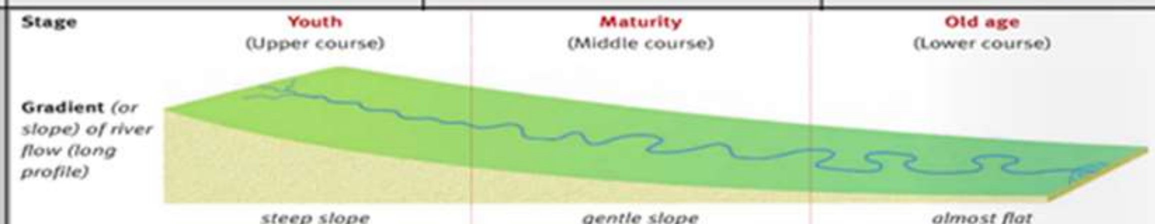
Río Vereh, Costa Rica

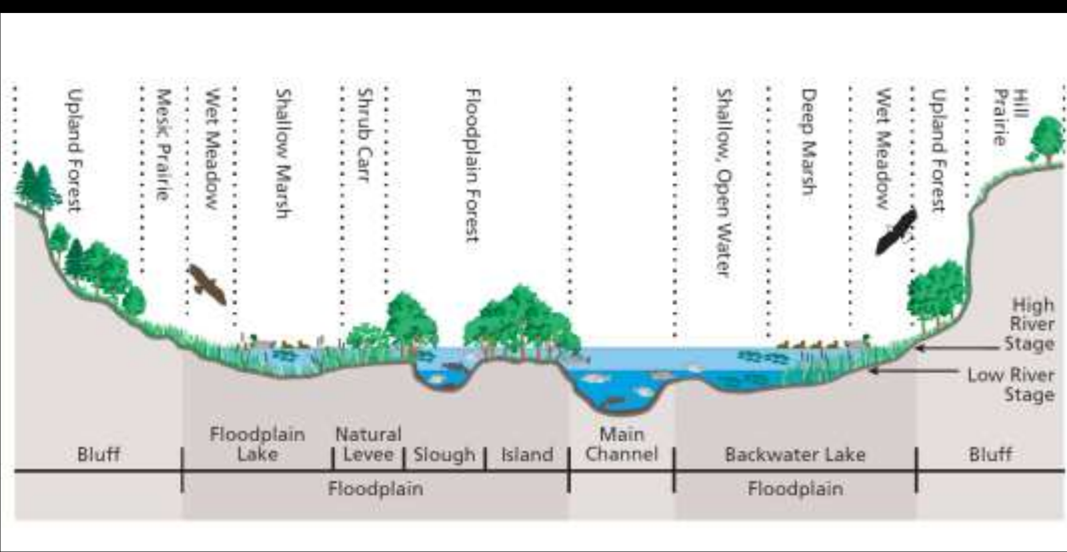
Brook trout – state fish of PA and Laurel Run, PA

The Middle Course
Winding Sedately – Erosion and Deposition

Sinuosity is inversely proportional to slope

Life in the Meander Belt - Habitat Diversity

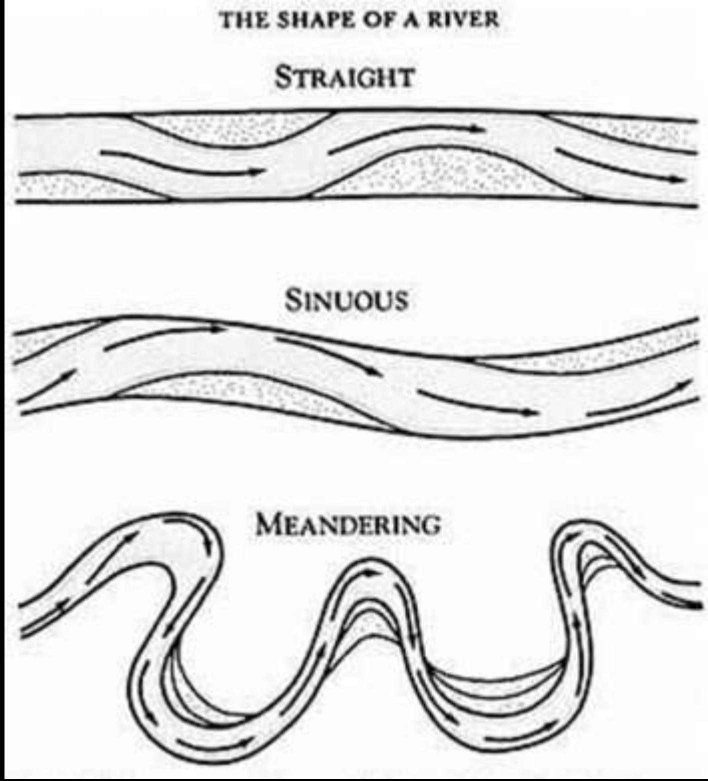
Course Stage	Upper Course Youth Stage	Middle Course Mature Stage	Lower Course Old Age Stage
Slope			



Meanders - Winding sedately
Erosion and Deposition

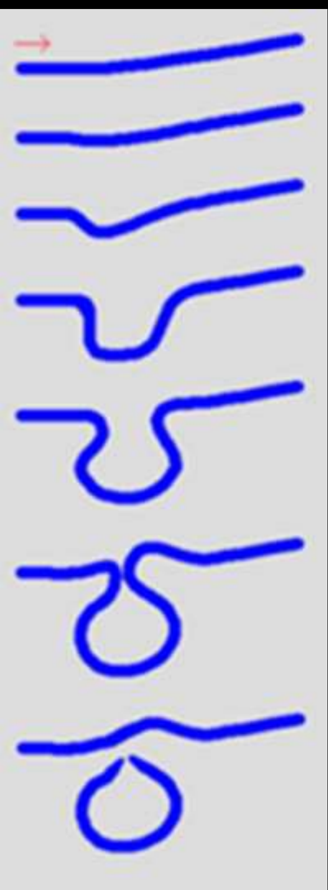
Meanders are loop-like bends in a river.

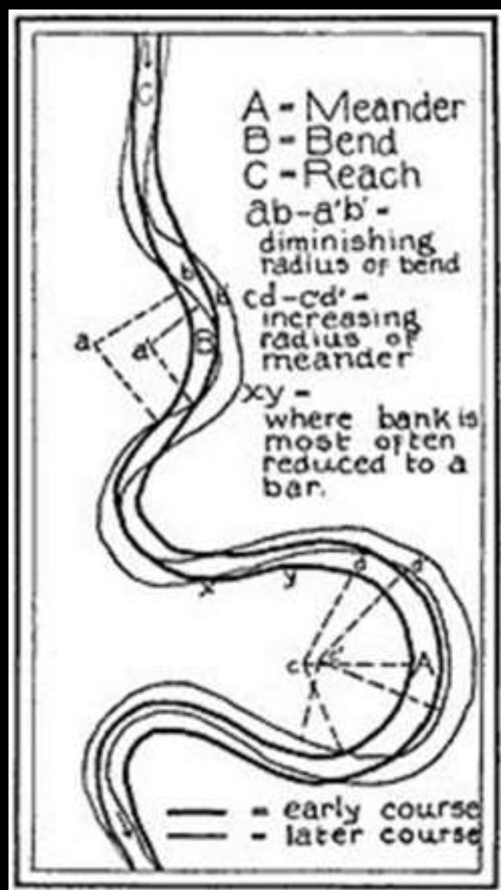
- The water flows round the meander in a <u>spiral manner</u>.
- This causes <u>erosion</u> to take place on the <u>outer bank</u> and <u>deposition</u> on the <u>inner bank</u>.

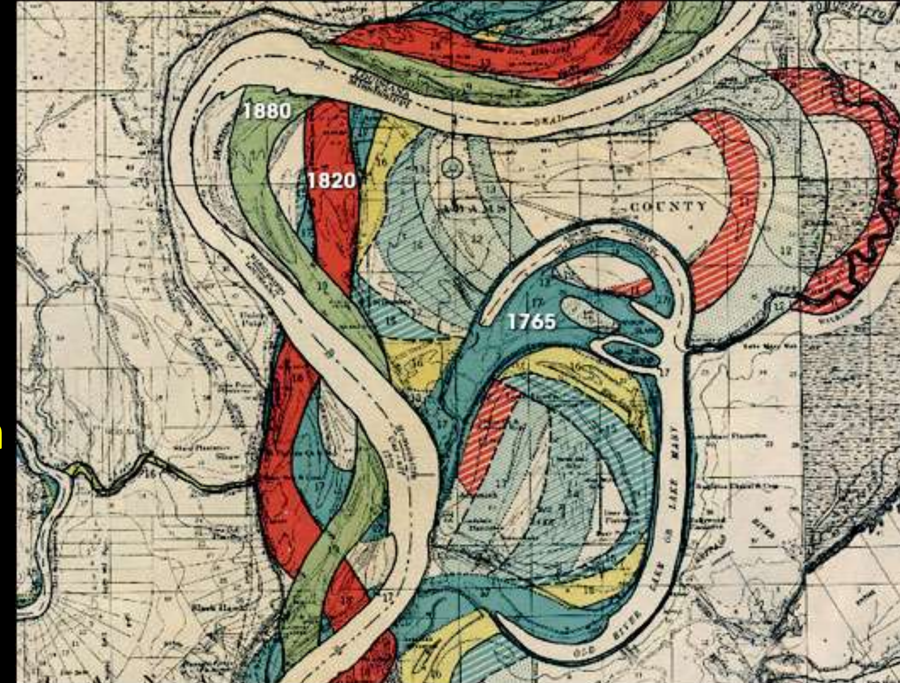


The Life of a Meander - Habitat

- When deposition seals off the cut-off meander from the river channel, an oxbow lake is formed. It may silt up and eventually dry up.
- This leaves meander scars on the floodplain that simply mark the old channel.







Map, 1944

Mississippi River

Satellite Image September 22 1999

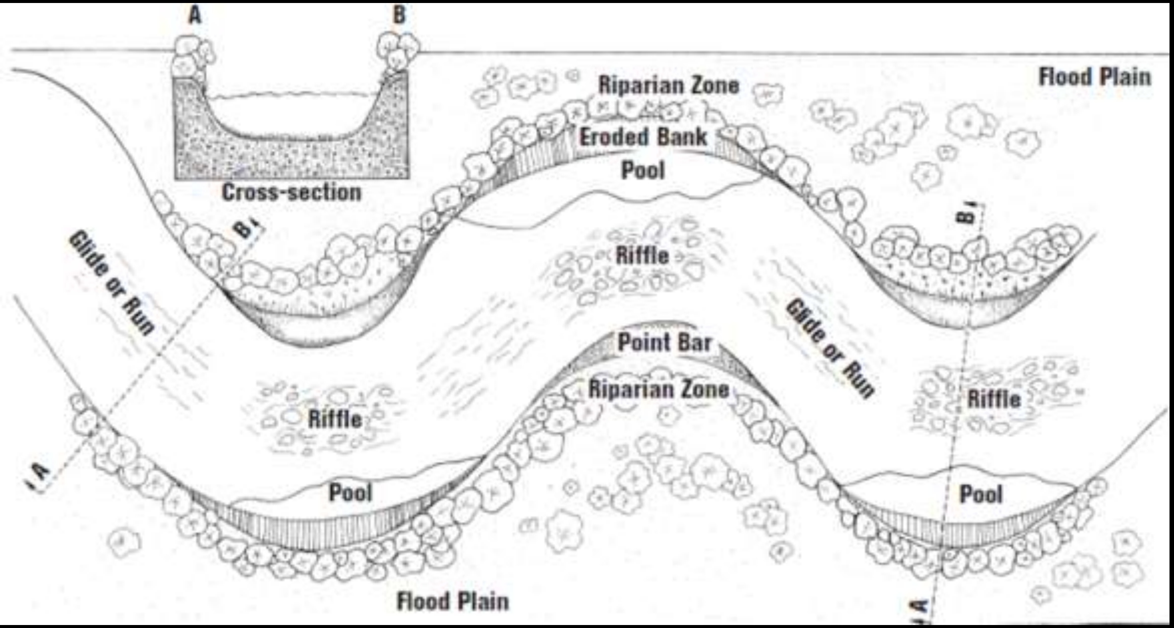
The Middle Course

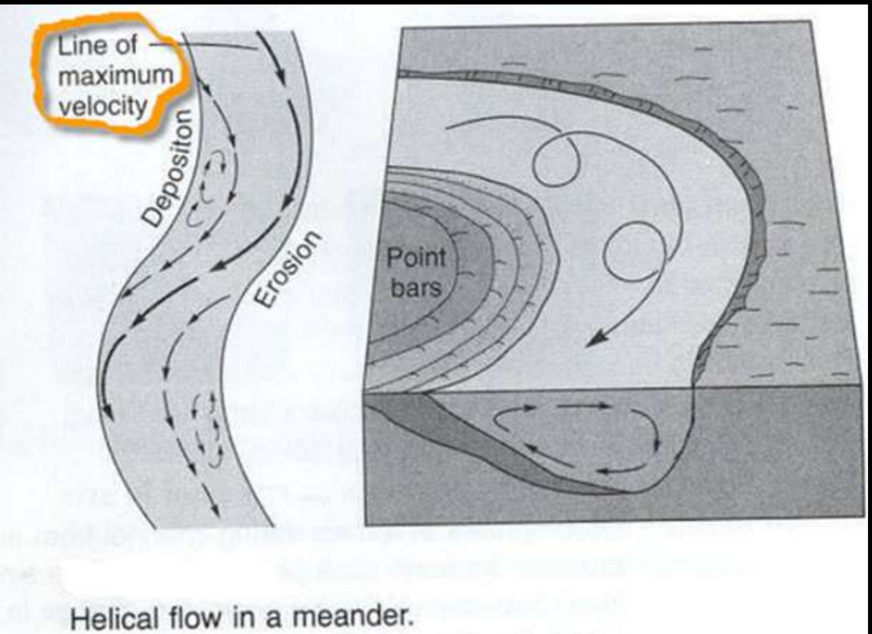
Wider Channel = More Solar Energy

- At some point along their path to the sea, rivers have typically gained enough water and width to preclude interlocking tree canopies.
- Streams at this point are warmer and less abundantly supplied with leaves than was the case upstream.
- Open canopy, and fairly shallow water, means that light can reach the river benthos, increasing in-stream primary productivity.

Colorado River, Texas

Aquatic Life Worlds: Erosional Zone and Depositional Zone



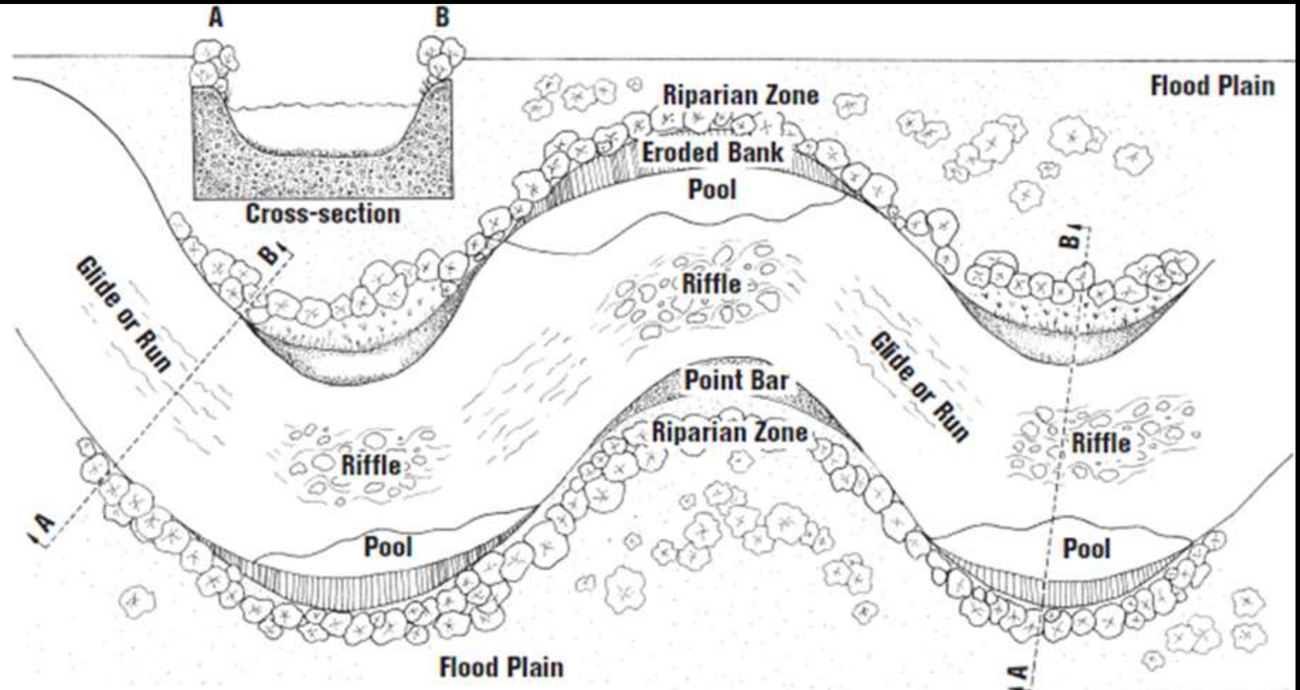


Helical flow in a meander.

Erosional Zone – Riffles

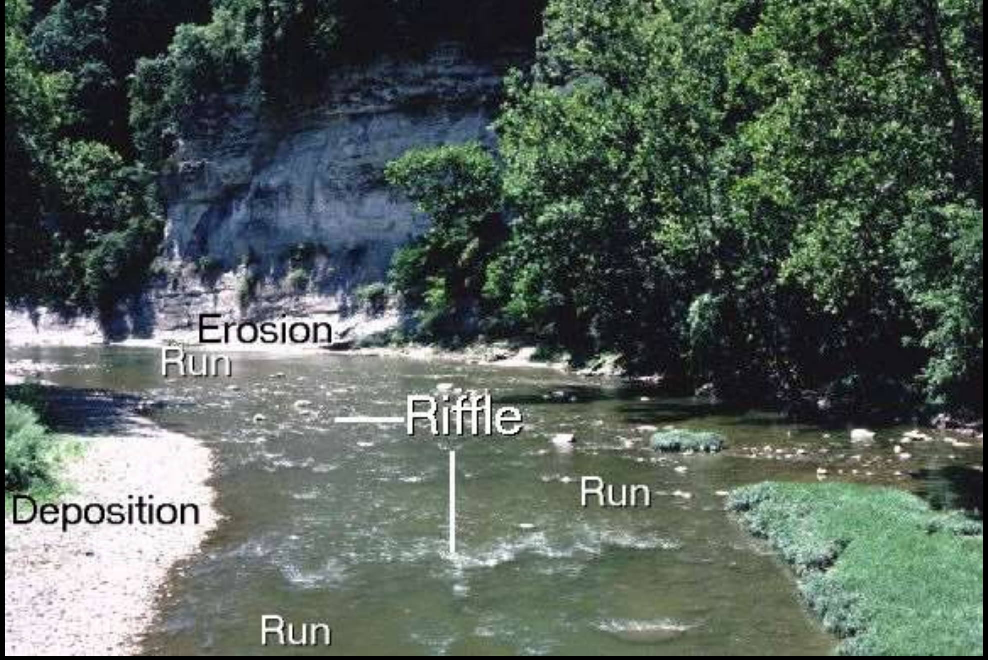
Riffles are the shallow portions of a stream characterized by relatively fast-moving, turbulent water with bottom materials composed of cobble, gravel, or bedrock.

- Riffle areas of streams are important habitats for many aquatic insects and small fish that require flowing water for feeding and high oxygen levels
- Riffle areas commonly support those organisms adapted to life in fast-moving waters, such as algae, plants, and invertebrates that can anchor themselves to rocks, logs, and other stream debris. (mayflies, caddisflies, riffle beetles, water pennies)



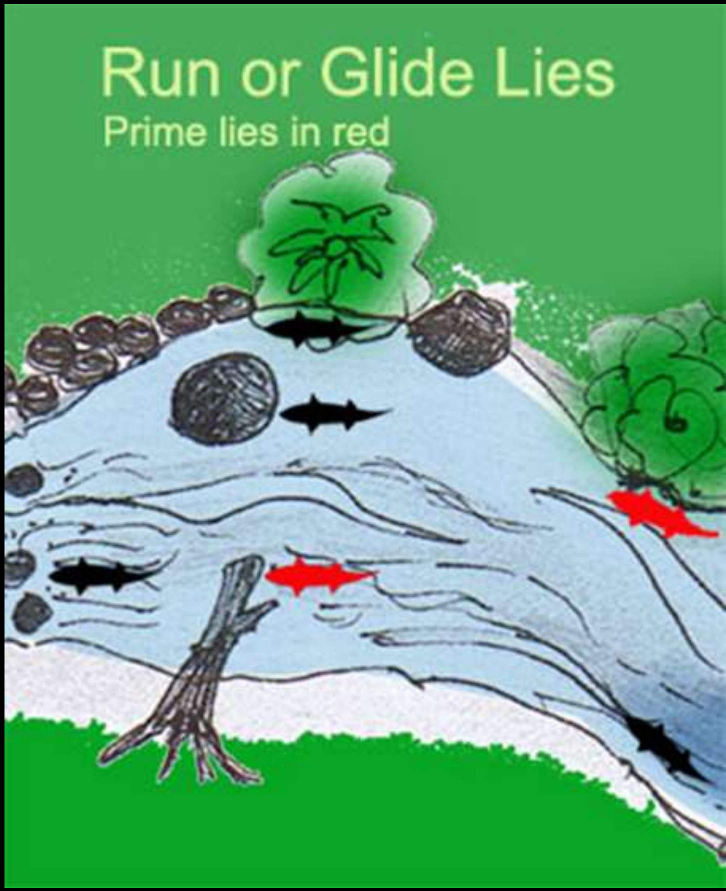
Erosional Zone – Runs and Glides

- Glides and runs are intermediate habitat types that fall between riffles and pools.
- A glide is an area where the flow is characterized by slow-moving, nonturbulent flow referred to as laminar, similar to that in a shallow canal. A glide is too shallow to be a pool, but the water velocity is too slow to be a run.
- A run is a relatively shallow portion of a stream characterized by relatively fast-moving, nonturbulent flow.



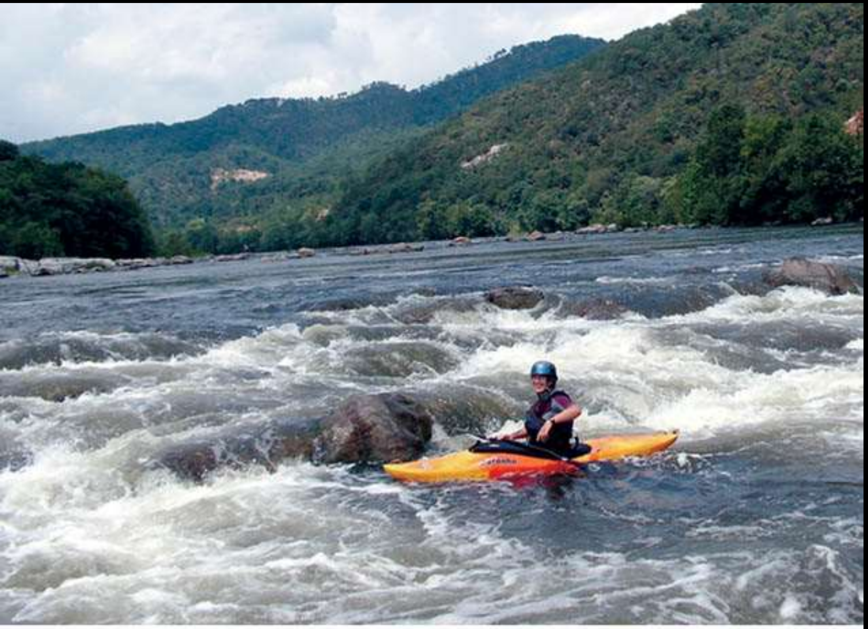
Erosional Zone – Run and Glide Habitat

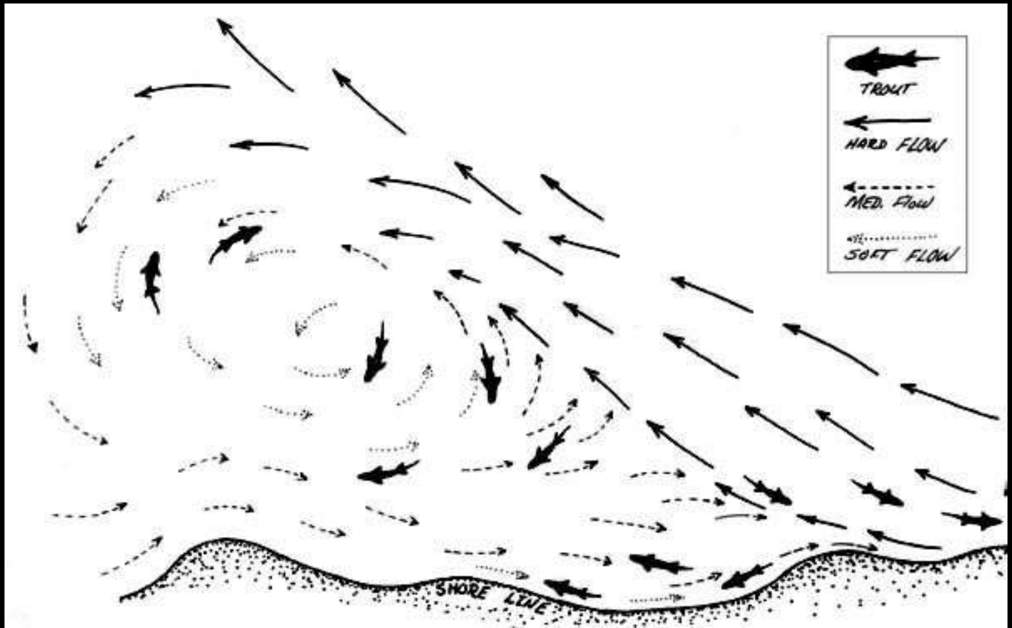
Spotted Gar in the Colorado River



Some fish prefer the fastest part of a stream.
Many fish spawn in the riffles of streams.

<u>Eddies</u> are currents that move in a direction other than downstream, usually in a circular motion.





Depositional Zone - Pools

A pool is relatively deep and wide with slow-moving water compared to riffle, run, or glide areas. Pools often contain large eddies with widely varying directions of flow compared to riffles, glides, and runs, where flow is nearly all downstream.

Deposition - Reduced velocity allows suspended materials to settle to the bottom.

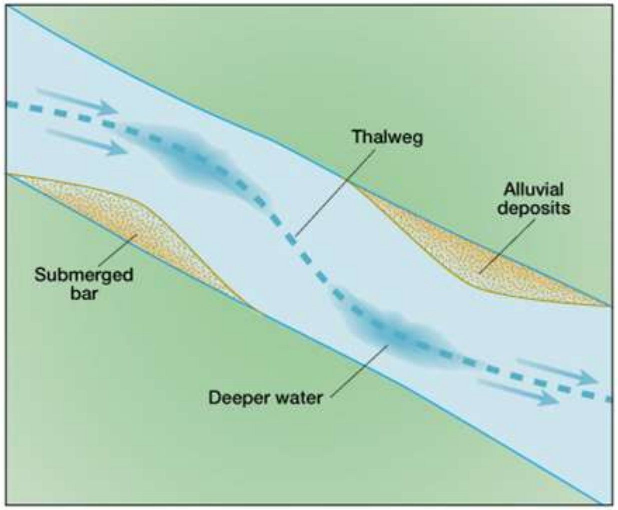
Sediment in most pooled areas of streams and rivers is composed of sand, silt, clay, and organic matter, compared to the coarser sediment of riffles, runs, and glides.

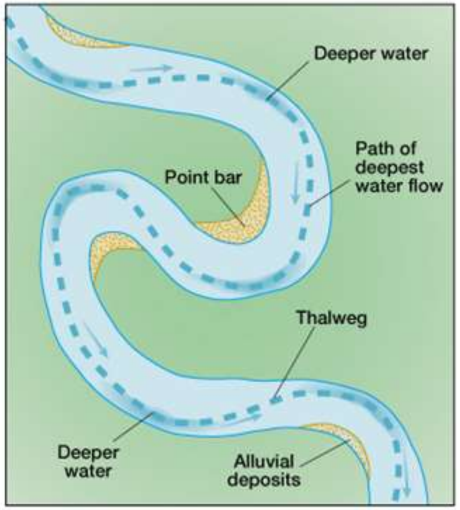
The slower-moving water supports organisms similar to those found in lakes and pond systems (dragonflies, damselflies, water striders) and shelter fish out of the strong downstream flow.

Depositional Zone – Gravel Bars

- The depositional zone refers to the inner bank of a stream where velocity is at a minimum.
- The slower velocities allow for the deposition of suspended sediment and bed materials (gravel, pebbles), which form bars.
- These bars support emergent aquatic vegetation and as the bars grow larger they are colonized by terrestrial plants to form islands.







Aquatic Stream Habitats

General Aquatic Habitat Types	Characteristics	Description
Lotic–erosional	Flow	Relatively shallow area of a stream. Three areas defined by flow: Riffle–fast-moving, turbulent water Run–fast-moving, nonturbulent water Glide–slow-moving water
	Sediment	Coarse sediment comprised of cobble, pebble, and gravel
	Aquatic plants (macrophytes)	Plants typically grow on or in coarse sediment (pondweed)
	Aquatic animals	Aquatic insects and small fish that require high oxygen levels, flowing water for feeding, and are adapted to living in swift water through the ability to swim or cling to rocks in riffle areas
	Organic materials (detritus)	Comprised of leaf litter, twigs, and other coarse particulate matter, usually trapped in stream riffles behind large rocks or logs; also known as *leaf packs*
Lotic–depositional	Flow	Relatively deep and wide with slow moving water compared to riffles, runs, or glides
	Sediment	• Primarily found in pools and backwater areas of streams • Fine sediment comprised of sand and silt
	Aquatic plants (macrophytes)	Submergent vegetation growing in fine sediment *(Hydrilla, Potamogeton)*
	Aquatic animals	• Organisms similar to those found in lakes and pond systems (dragonflies, damselflies, water striders) • Many fish use the deeper water of the pools and areas along the banks for cover and find food easier to catch in slower moving water
	Organic materials (detritus)	Comprised of leaf litter and other particulate matter found at the bottom of pools and backwater areas of streams

Adapted from Merritt and Cummins, 1995.

Diversity of Life in The Middle Course

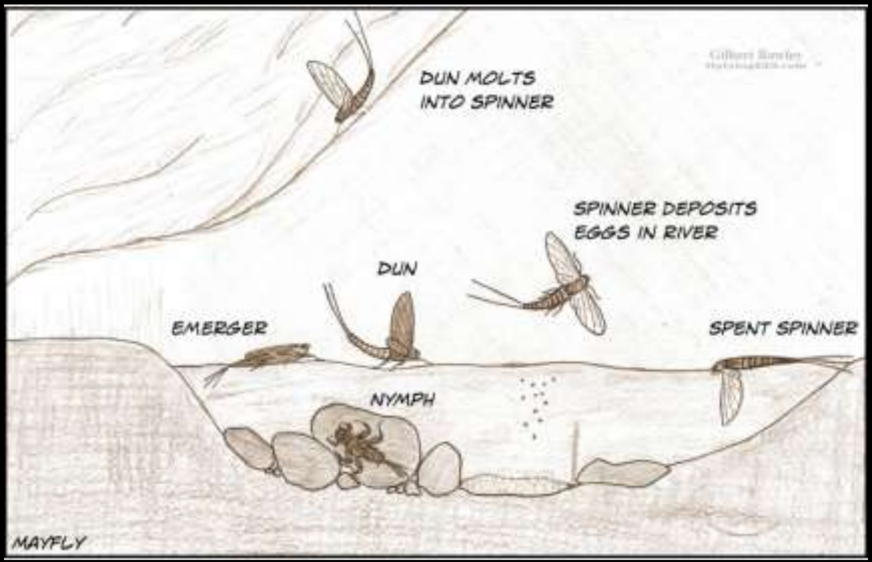


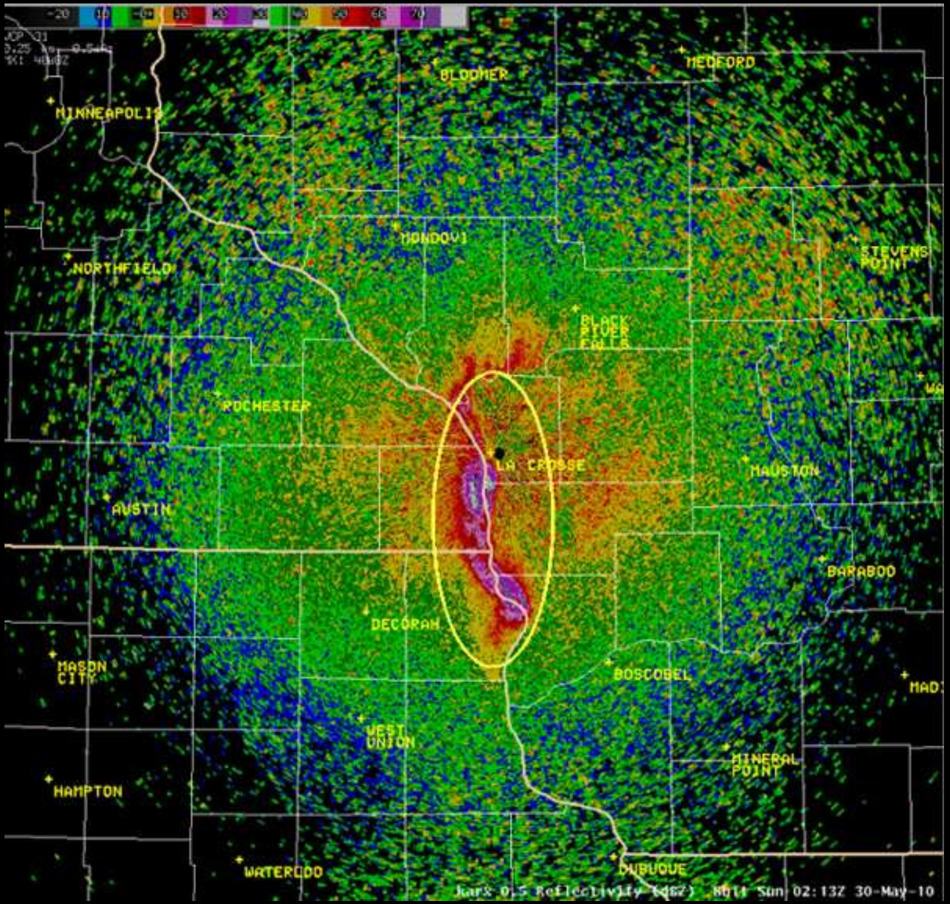






Otters of the Colorado River in Austin

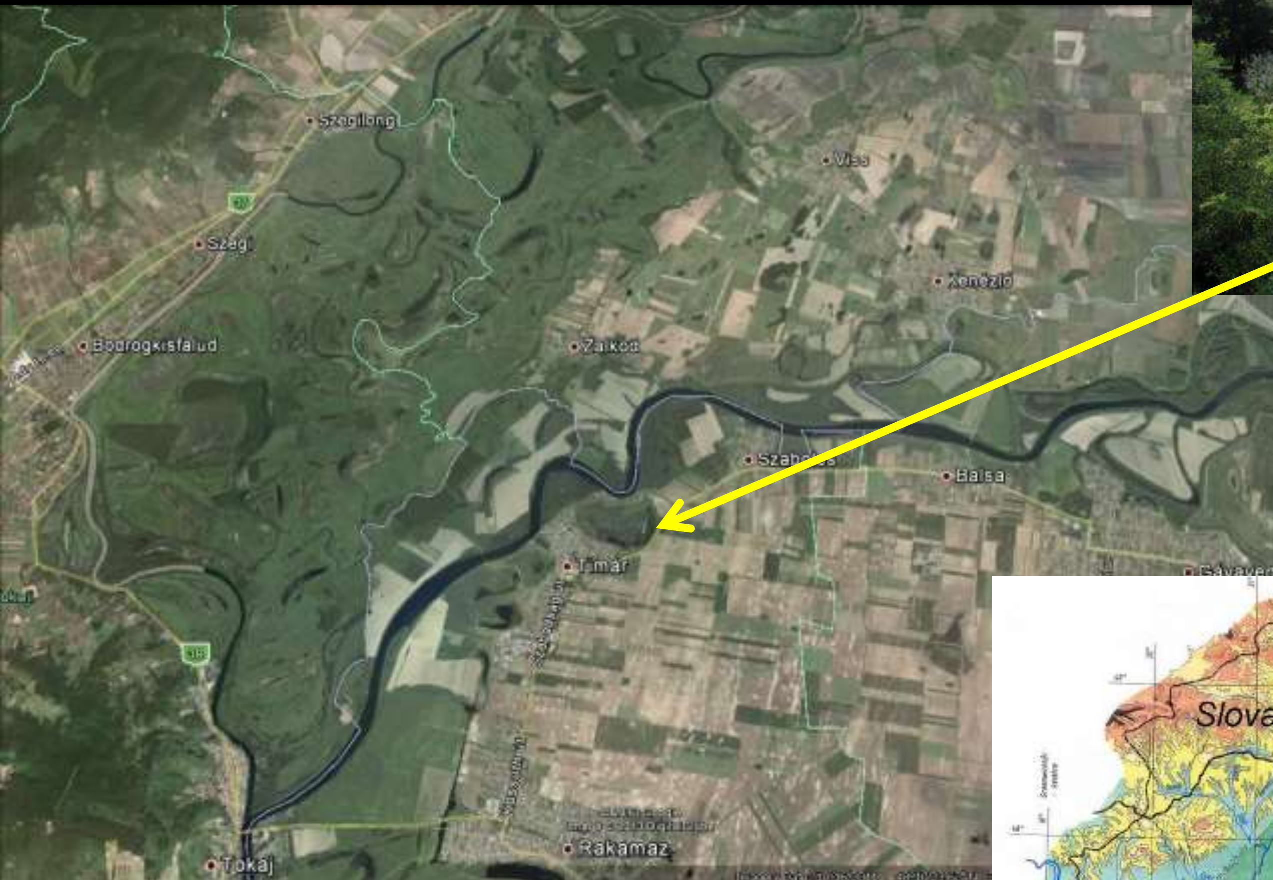


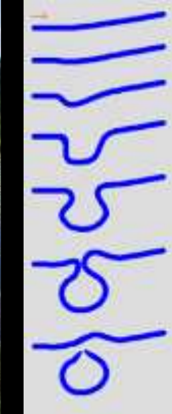


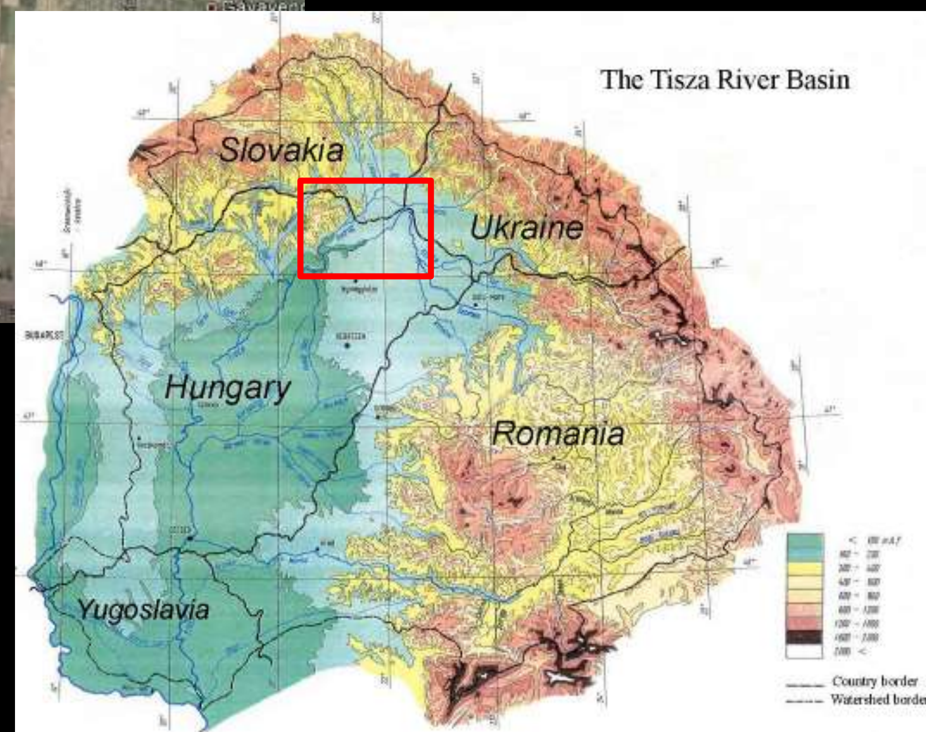
A mayfly mass emergence or hatch from the Mississippi river captured by the National Weather Service Doppler radar in La Crosse Wisconsin (USA) in May 2010

The adult mayflies in flight are represented by the bright pink, purple, and white.

The Bodrogköz Region – Northeastern Hungary







The Bodrogköz region between the Bodrog and Tisza rivers. The southern part belongs to Hungary and the upper is on the other side of the border in Slovakia.

A cross-border UN Ramsar Wetland of International Importance

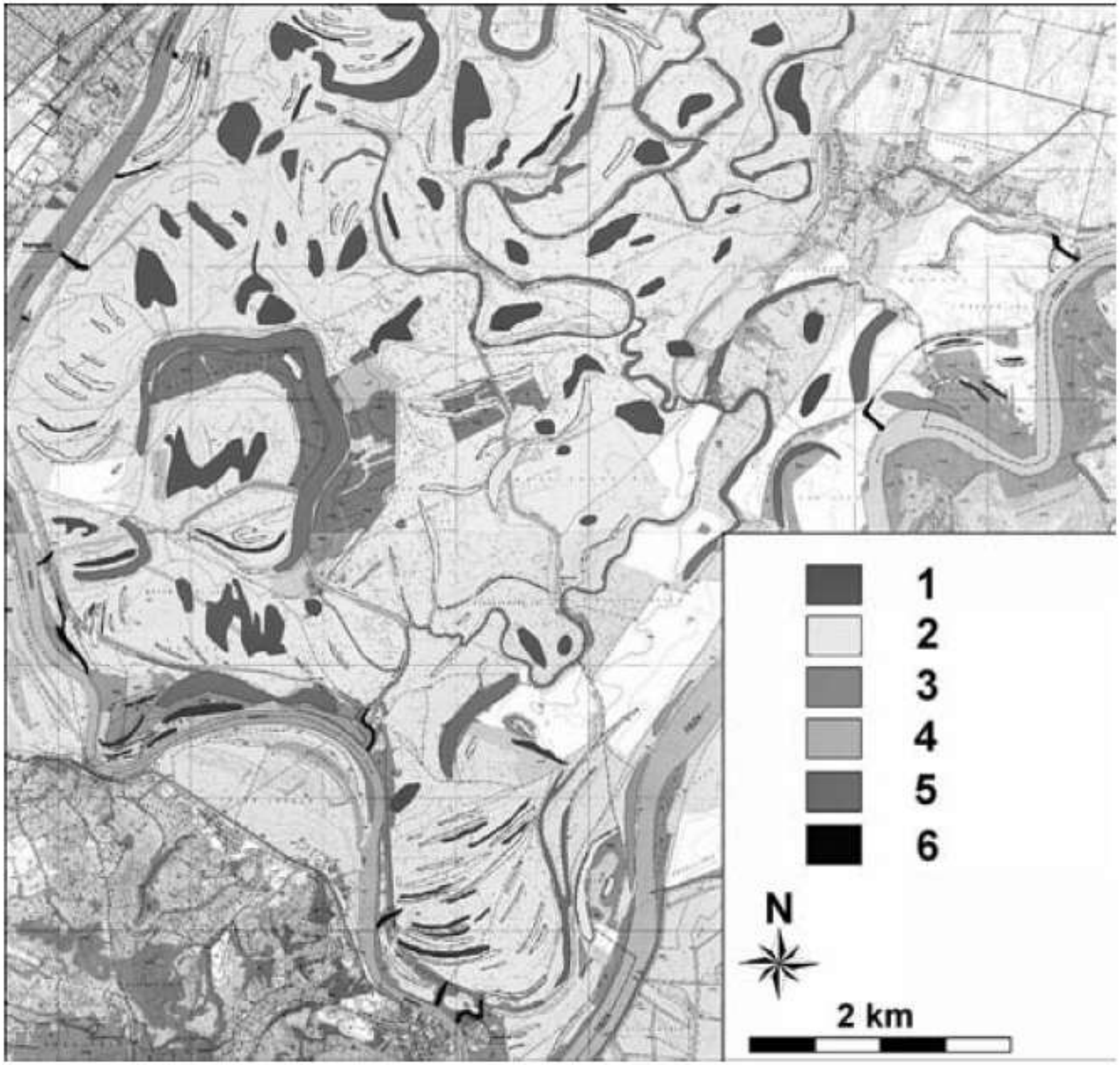
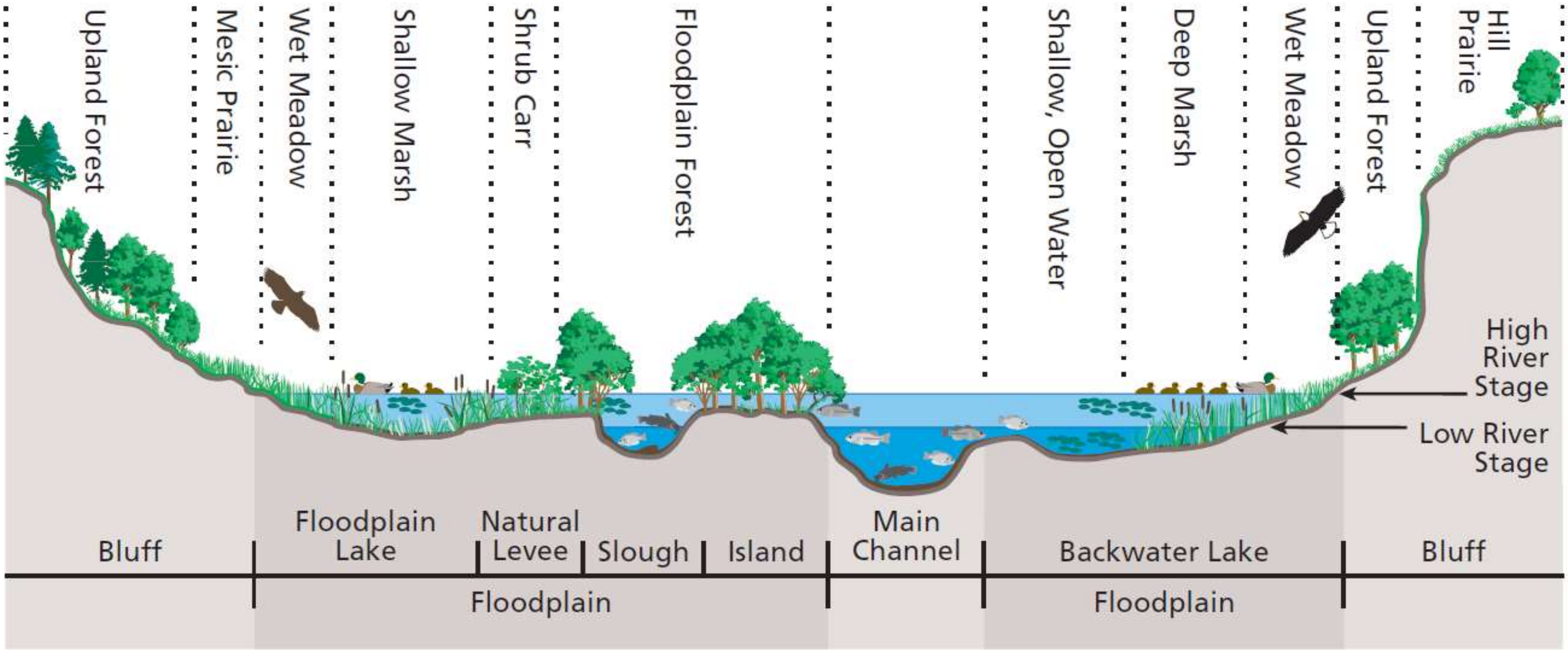


FIG. 2 - Landforms of the SW Bodrogköz (In: Szabó & *alii*, 2004). 1: fluvial ridge, 2: swale, 3: abandoned cut-offs, 4: present natural levee, 5: backswamps, 6: (remnants of) one-time flood-plain ditches.

The Middle and Lower Course: Life in the Meander Belt

Habitat Diversity = Biodiversity



The Lower Course – Old Age

A somewhat aimless course toward final extinction

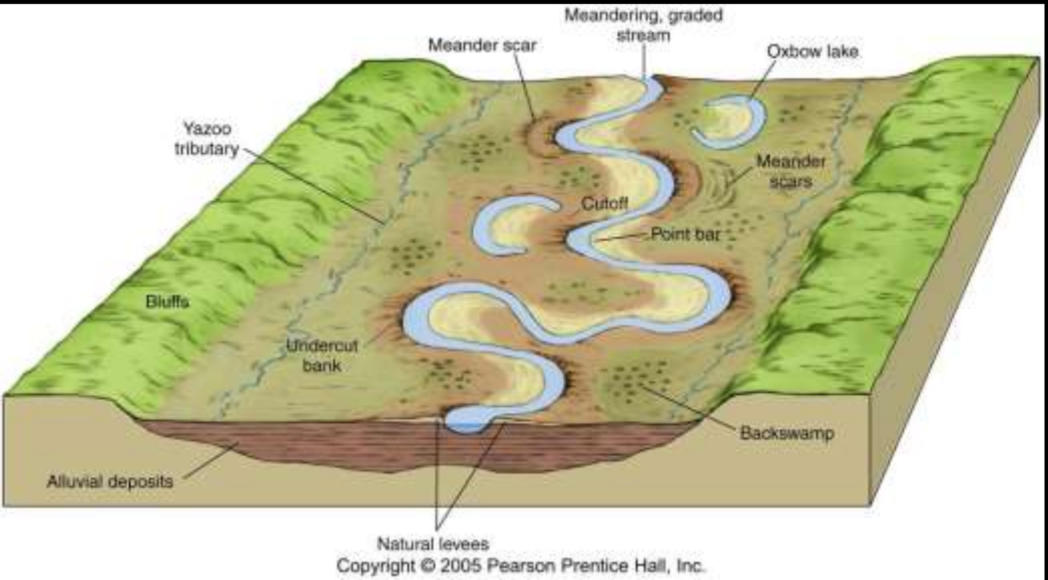
Wandering, Carrying, and Deposition

Floodplains, Bottomland Forests, and Riparian Levees

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

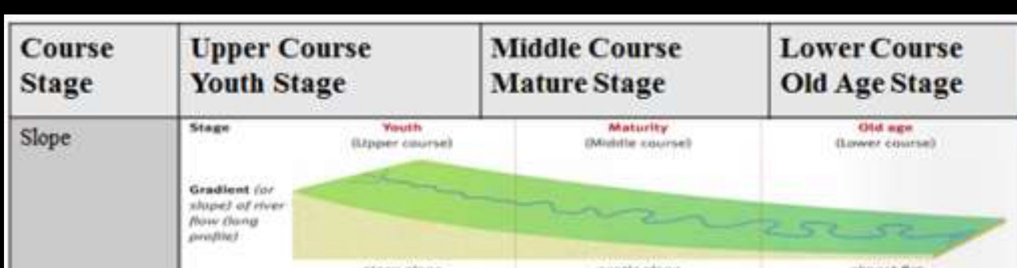
Bottomland Forest - When the floods subside, alluvium is deposited on the floodplain which can support a forest adapted to periodic flooding (hydric soils).

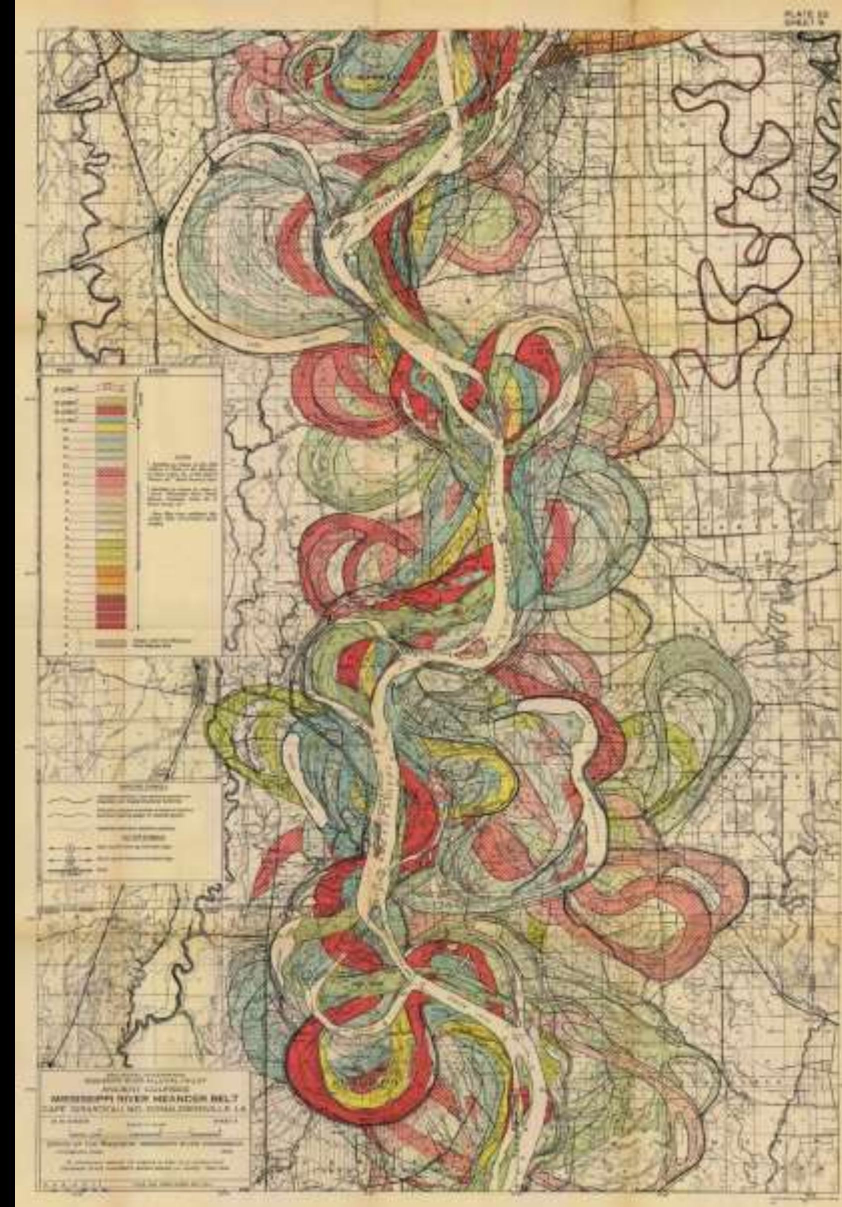
Natural levees - The larger materials, being heavier, are deposited at the river banks while the finer materials are carried and deposited further away from the river. The larger materials at the river banks build up into embankment called levees.



The Lower Course: From River to Sea

- Very large rivers are usually <u>low gradient and very wide</u>, resulting in <u>negligible influence of riparian canopy</u> in terms of shading and leaf-litter input.
- Water currents keep <u>fine solids in suspension, reducing light penetration</u> to the benthos.
- <u>Organic matter in suspension is by far the largest food base</u> in these very large rivers.
- Larger alluvial rivers in their natural state are <u>diverse habitats</u> with side channels, sand and gravel bars, and islands that are formed and reformed on a regular basis.

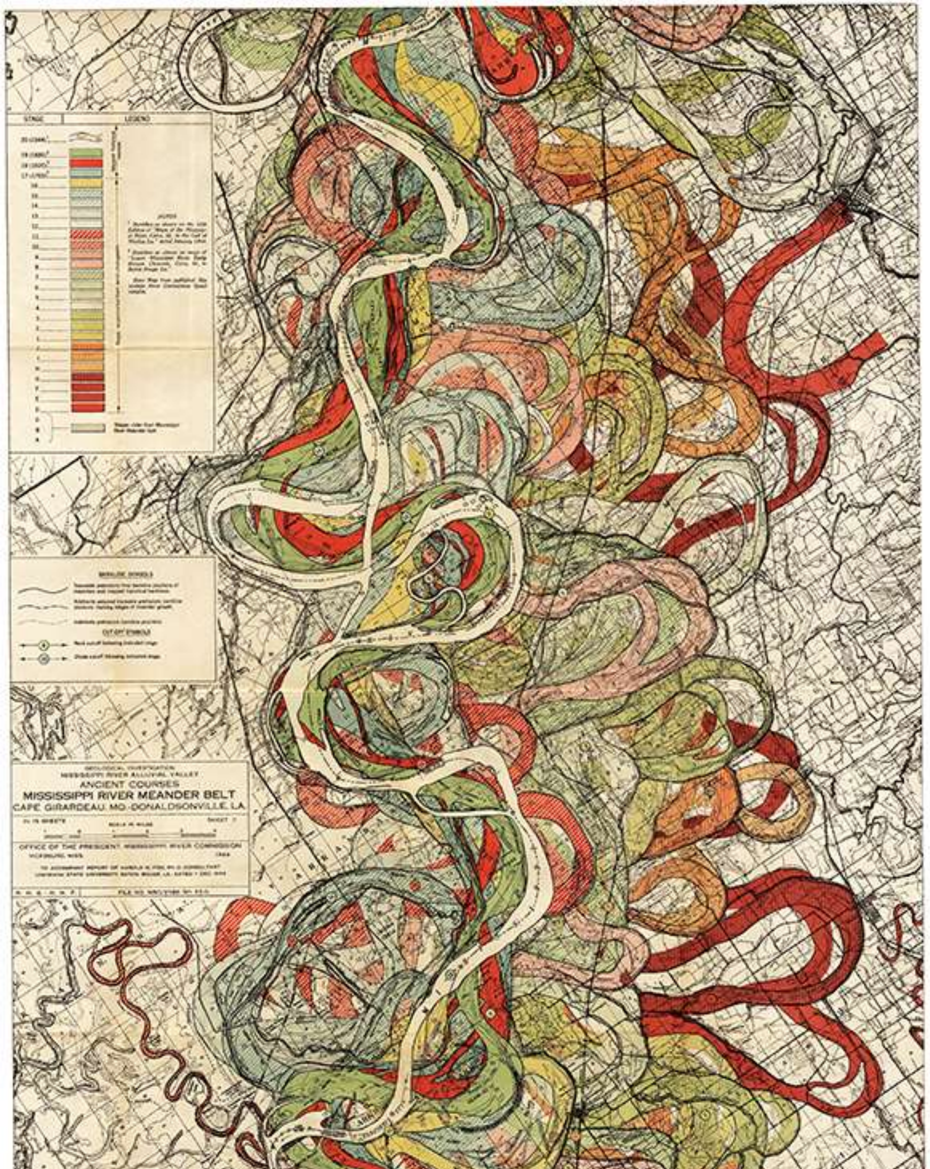


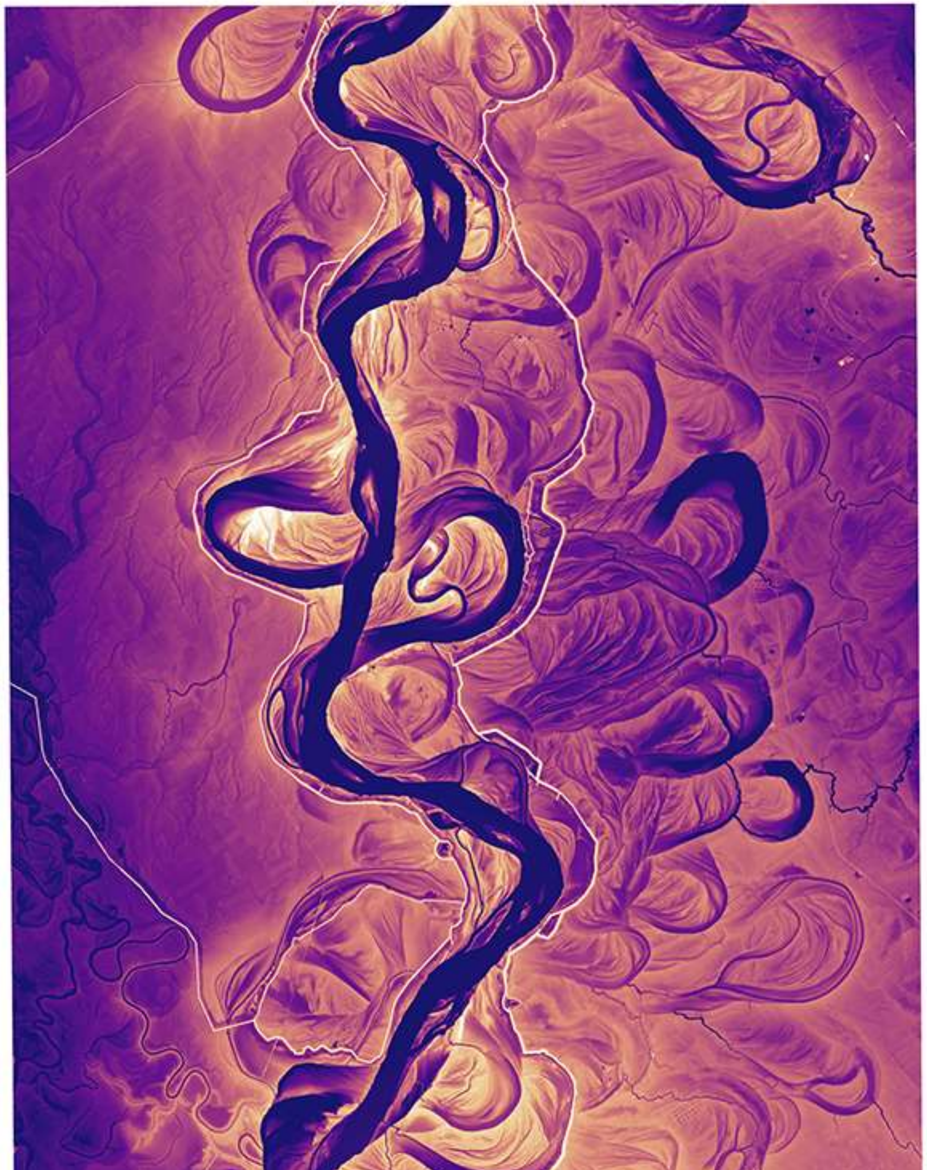


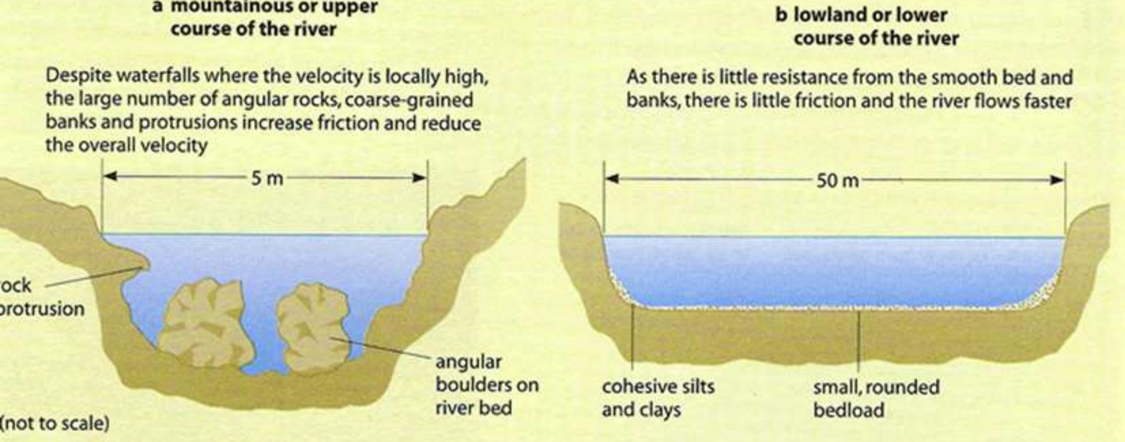
Mississippi River

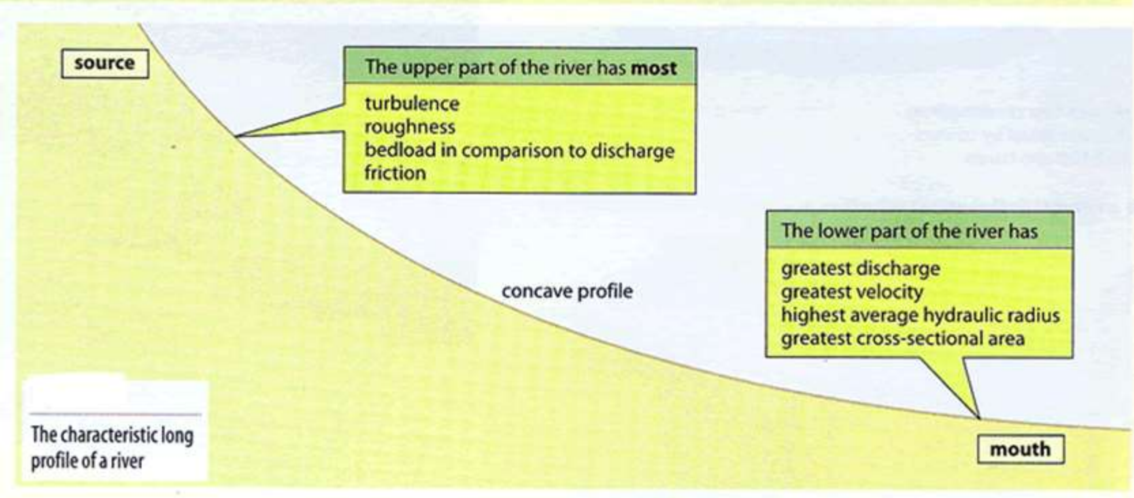
Habitat Diversity

Comparison of Plate 7 from Harold Fisk's 1944 report "The Alluvial Valley of the Lower Mississippi River" with a modern-day lidar derived image of the same area.









Greatest Capacity for Organic Load

"Downstream Change of Velocity in Rivers"

Luna Leopold

Mean velocity generally 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 (can carry small particles not big particles).

Greatest Capacity - volume of sediment load – murky (Big Muddy) water full of Dissolved and Suspended Organic Matter = Food!

Delta - final extinction as it joins the ocean

River deltas form at the mouth of the river

<u>Arcuate deltas</u> - the most common type of delta - a gently curving shoreline, smoothed by longshore currents - a distinct pattern of branching distributaries and tend to be dominated by courser material.

<u>Bird-foot deltas</u> - have long finger-like projections that reach out to the sea - broad, shallow shelves - long thin shape

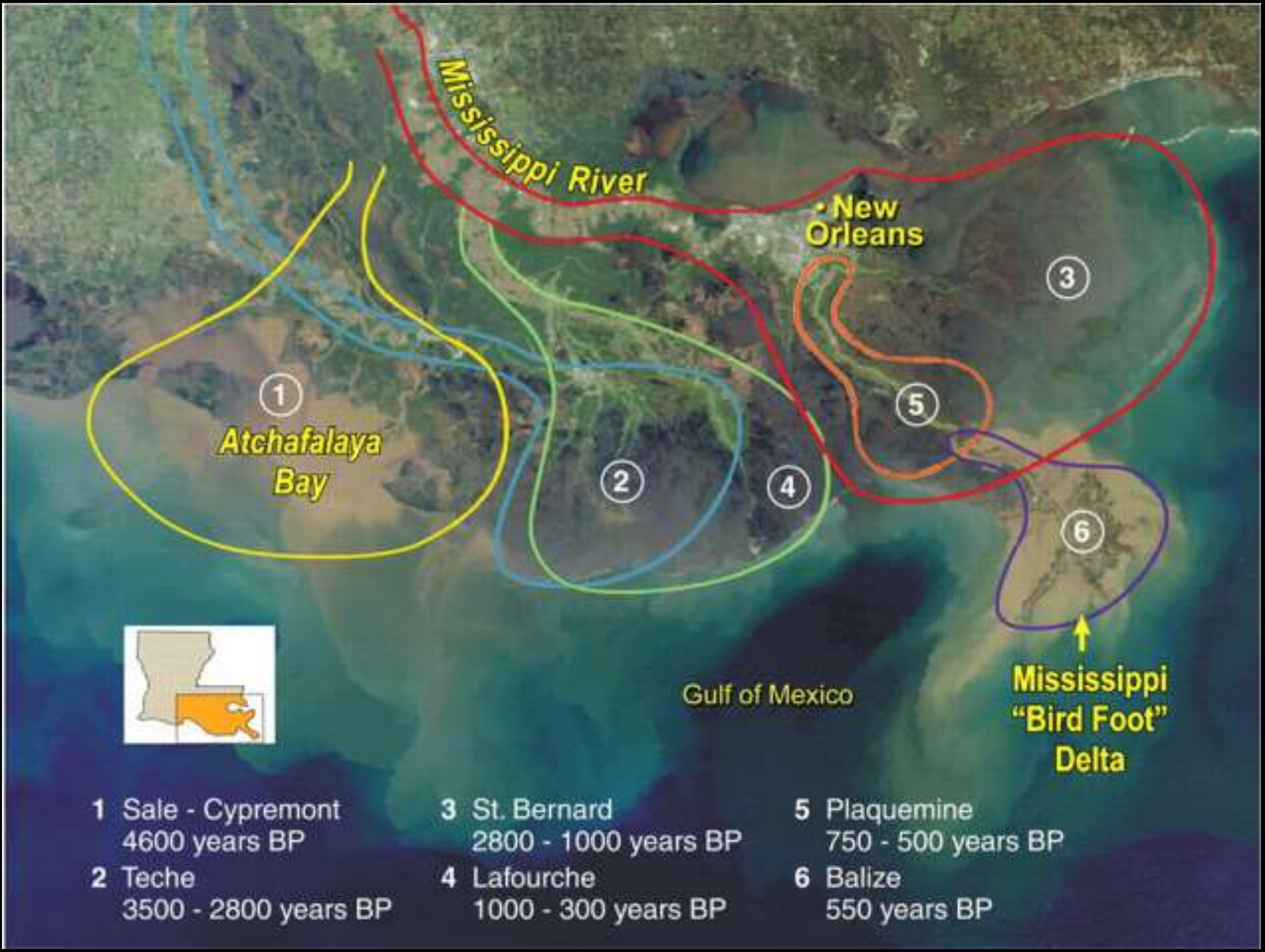
Arcuate delta

Bird-foot delta

Avulsion

Rapid abandonment of a river channel and the formation of a new channel

This process of avulsion in deltaic settings is also known as delta switching. When this avulsion occurs, the new channel carries sediment out to the ocean, building a new deltaic lobe. The abandoned delta eventually subsides



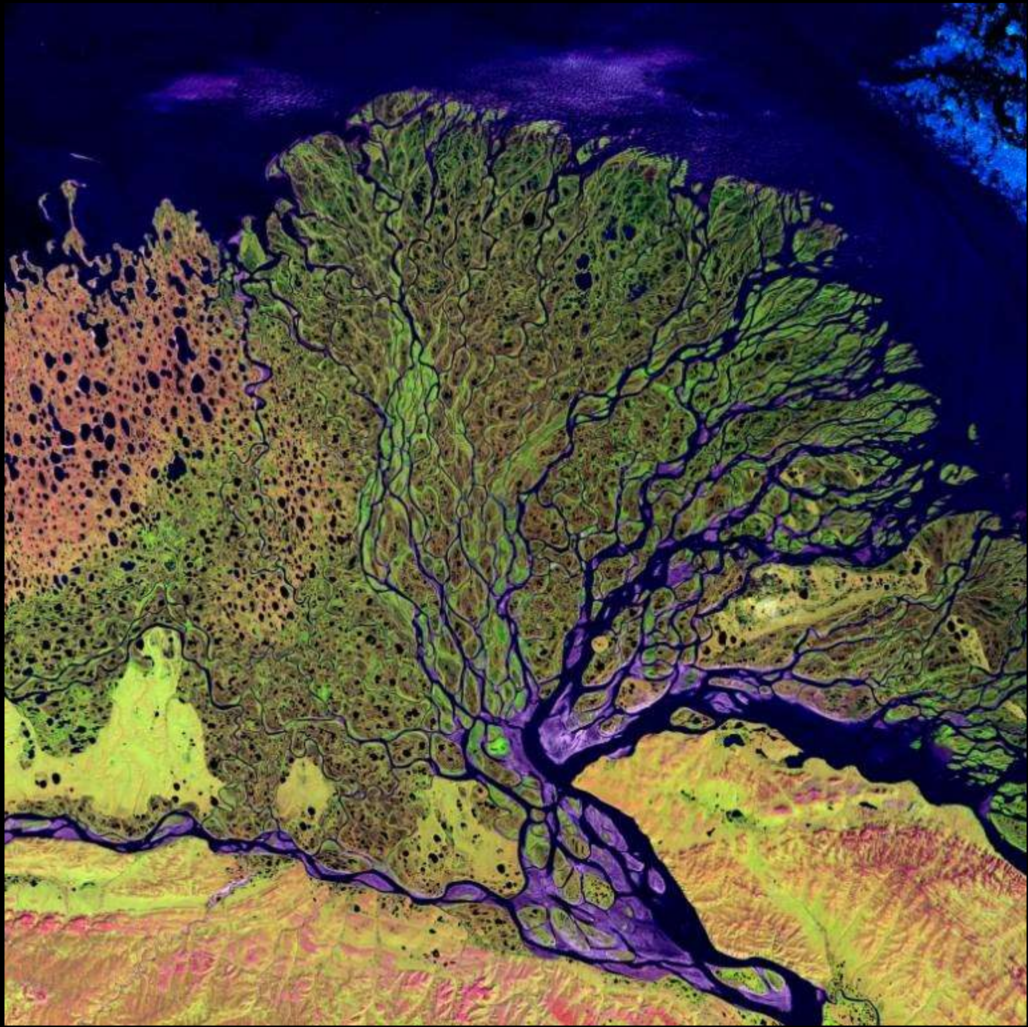
Location of Mississippi River channels discharging water into the Gulf of Mexico over the past 5000 years. Notice the location changes from time to time, keeping all areas of the delta supplied with sediments that balance the natural sinking of the delta. Today, two-thirds of the flow are through the Bird Foot Delta (6) and one third through the Atchafalaya

The Danube Delta

- 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
- World Heritage Site, UNESCO Biosphere Reserve

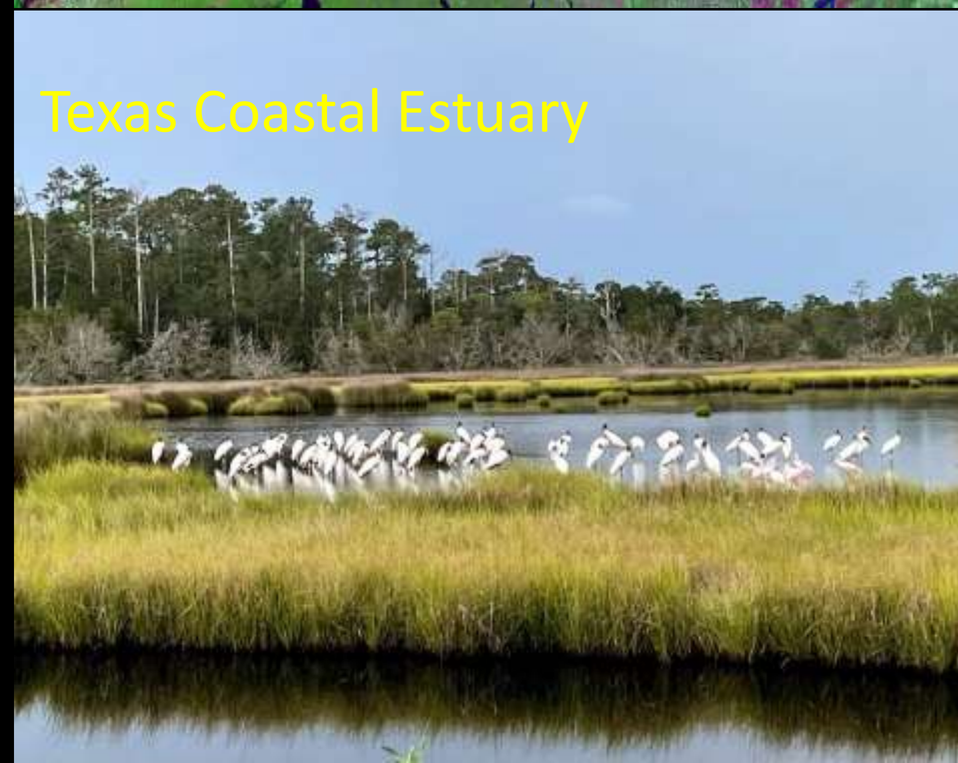
The Lena River

- 2,800 miles (4,400 km) long and flows north into the Arctic
- 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 an important refuge and breeding ground for many species of Siberian wildlife.



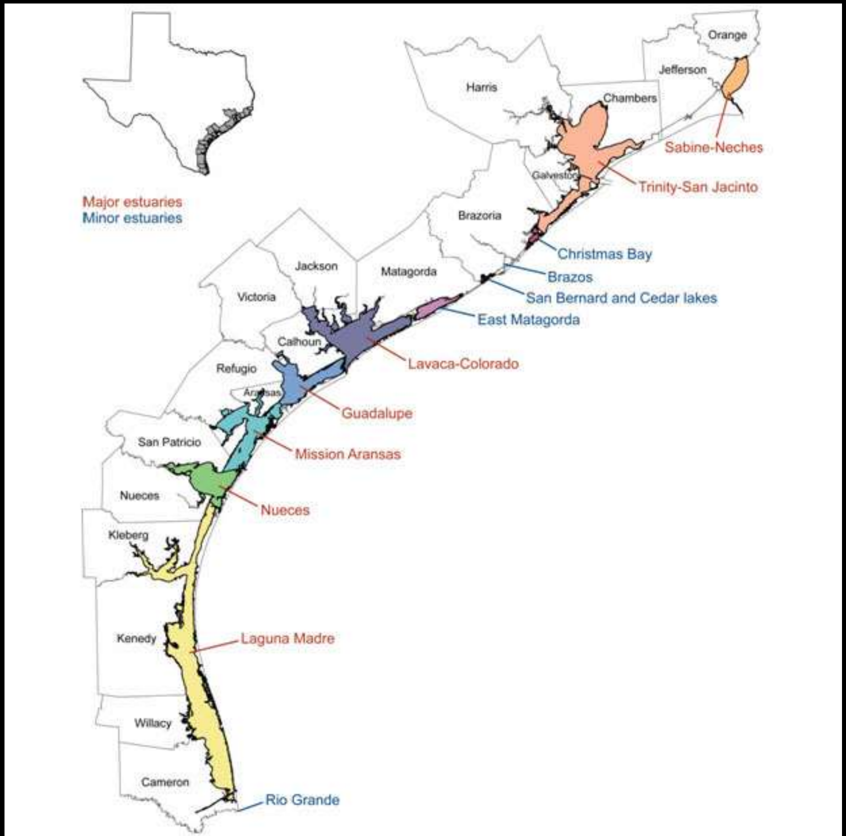
Estuary

- An estuary is a semi-enclosed coastal body of water, which has a free connection with the open sea, and within which seawater is measurably diluted with freshwater (hypersaline) derived from land drainage.
- Estuaries form a transition zone between river environments and maritime environments
- 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



Barrier island estuaries – Texas

- Found in a place where the deposition of sediment has kept pace with rising sea levels so that the estuaries are shallow and separated from the sea by <u>sand spits or barrier islands</u>.
- Building up of offshore bars by wave action, in which sand from the seafloor is deposited in elongated bars parallel to the shoreline growing into barrier islands.

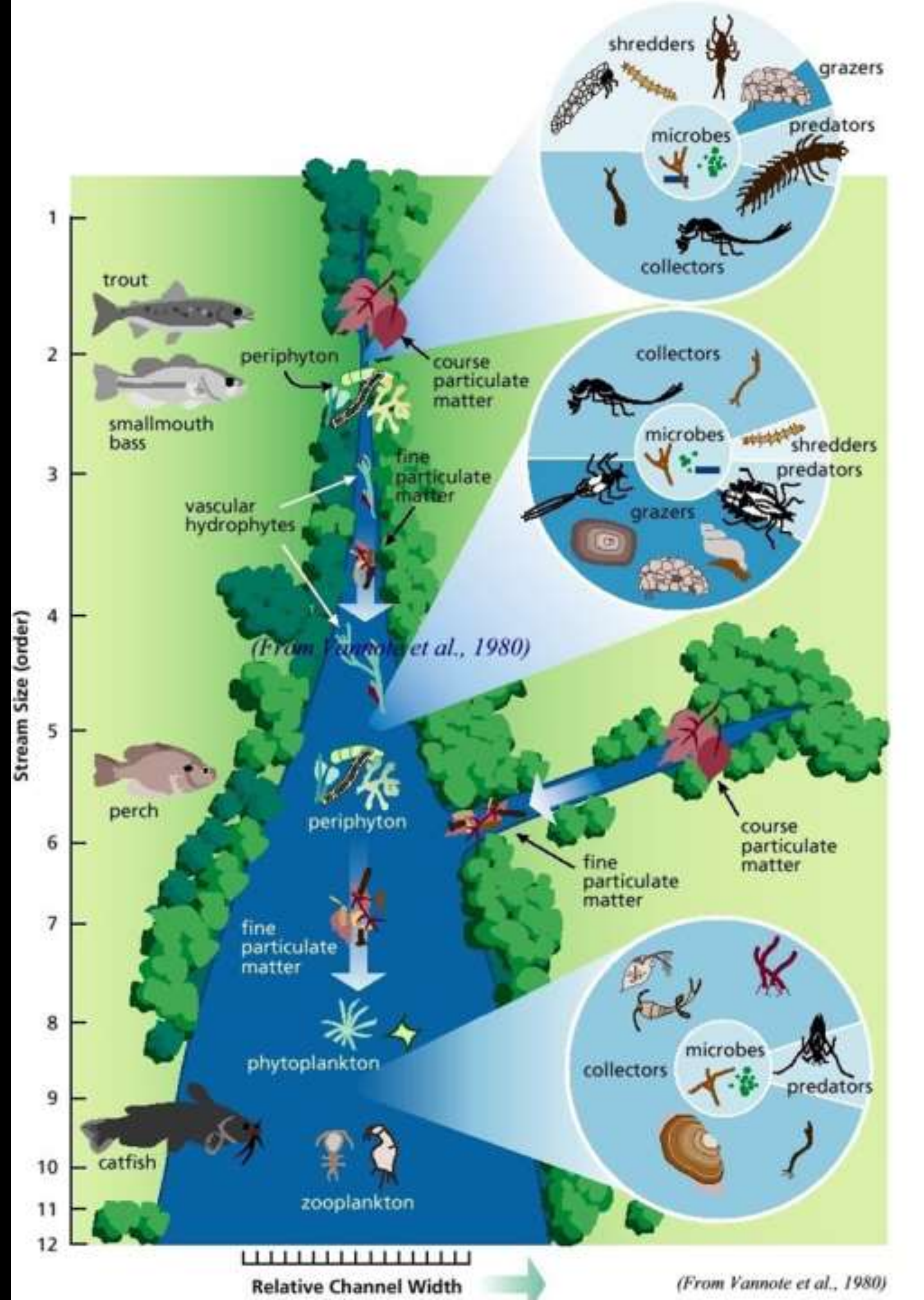


TEXAS COASTAL WETLANDS

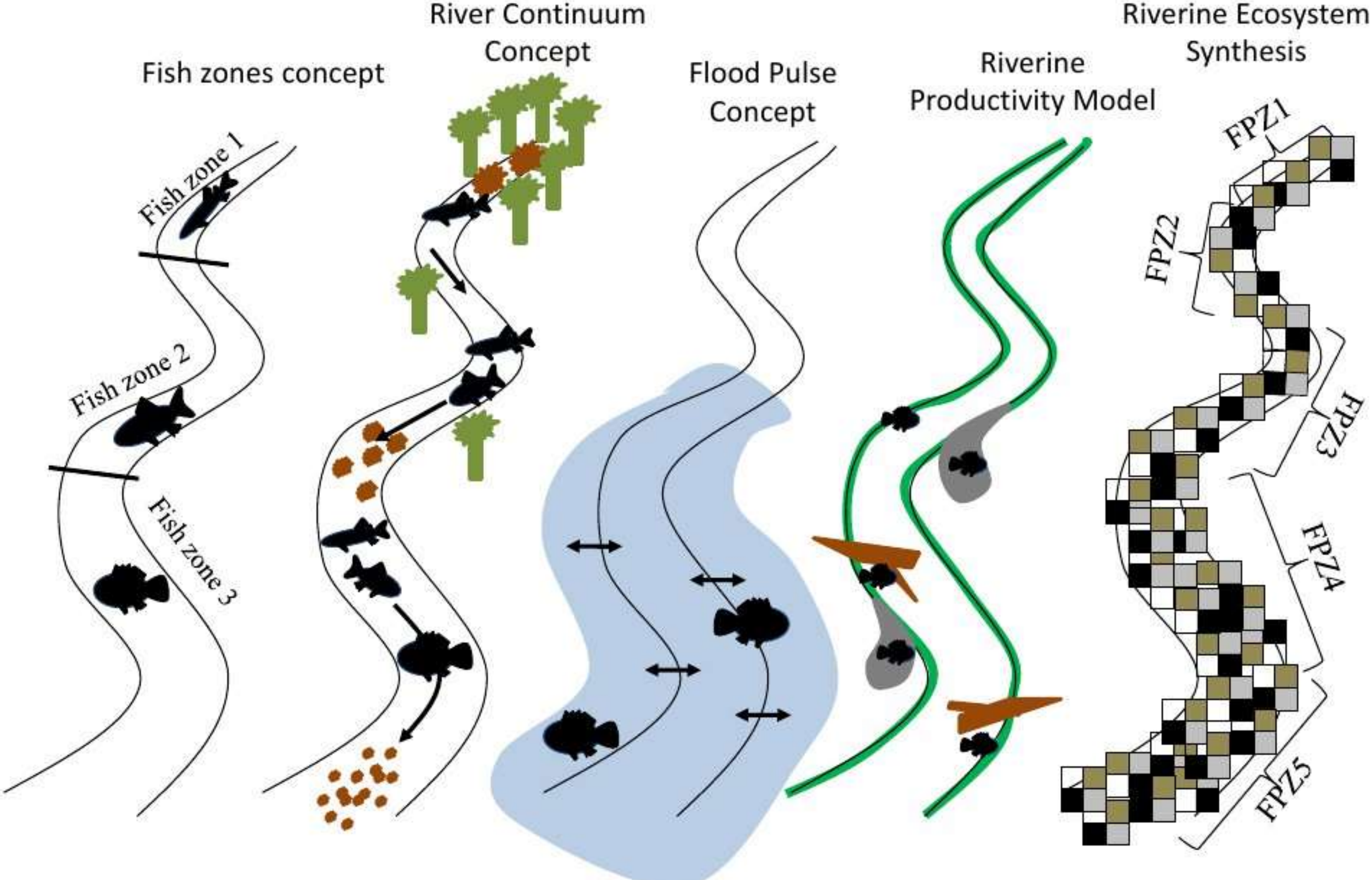
The River Continuum Concept [RCC]

Although the RCC is a broadly accepted theory,

- It is limited in its applicability.
- It describes a perfect model without taking into account changing riverine disturbances and irregularities.
- Disturbances such as congestion by beaver dams or natural blockages of large woody debri and flooding are not included in the model.
- Human impacts - The RCC is a model that might apply to pristine rivers, but few rivers remain unchanged or unaffected by human activities.



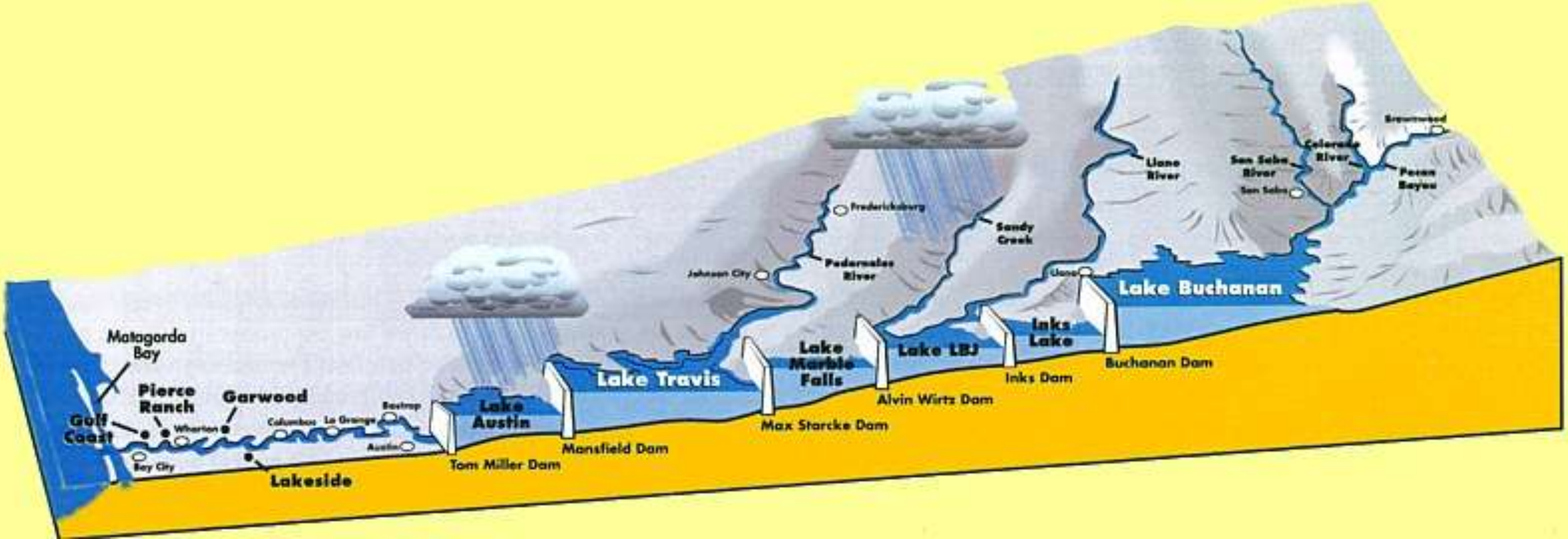
River ecosystem concepts



The Serial Discontinuity Concept

Dams are certain to have an impact on the organization of aquatic communities, since the flow is blocked and the longitudinal transition of conditions along the river is altered.

The dam creates a "serial discontinuity" in the river because the gradual downstream transition in conditions is disrupted, and the longitudinal transfer of material is prevented.

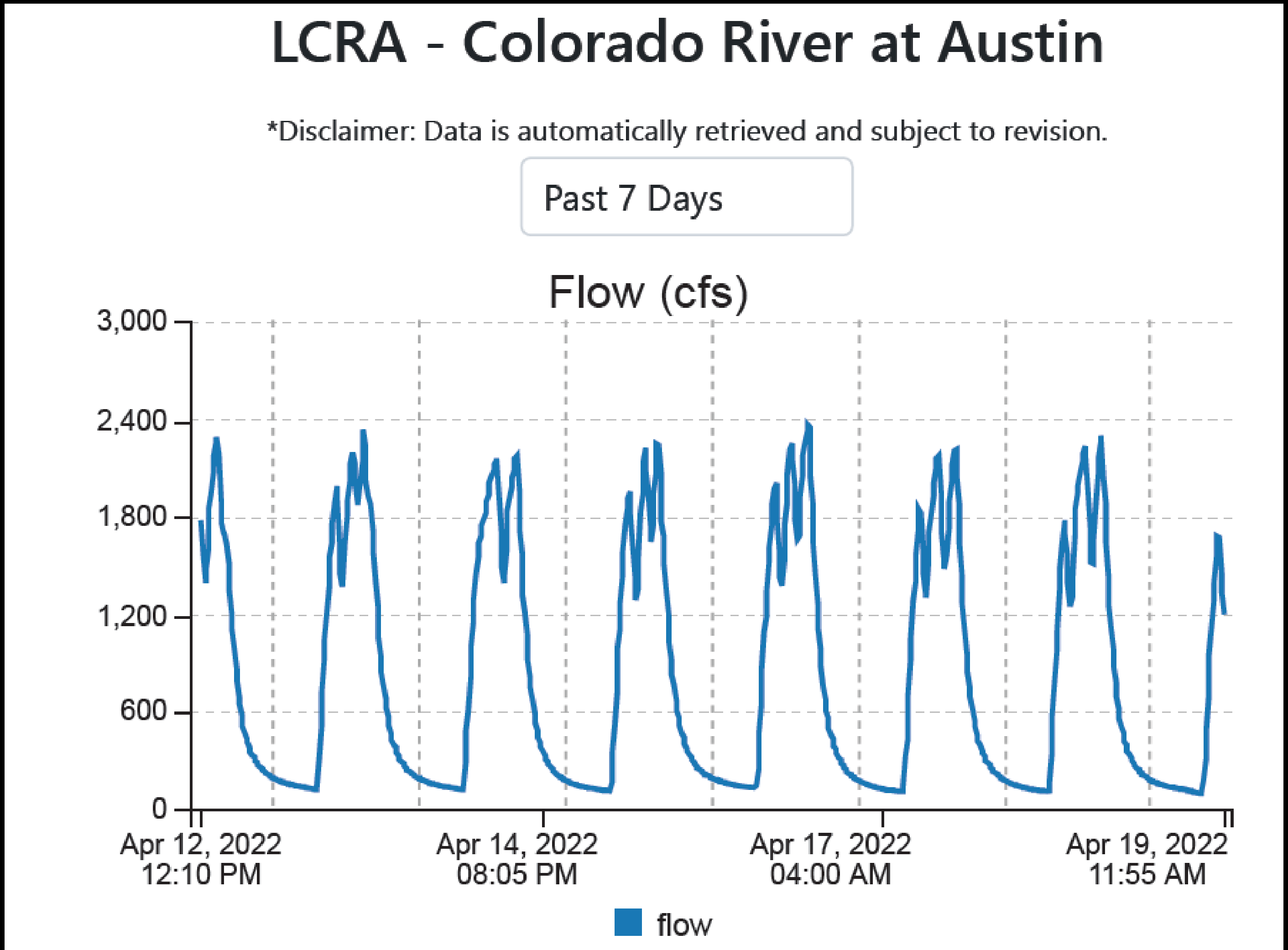


The Serial Discontinuity Concept

- Suspended sediments are deposited behind the dam.
- Water released from the dam will pick up a 'normal' sediment load downstream where it may erode the riverbed and banks.
- The downstream transition of water temperature is altered, and water released from the dam may be either warmer (if it is taken from the surface) or cooler (if it is taken from the depths) than natural conditions.

The Serial Discontinuity Concept

- The <u>seasonal patterns of flow will be altered</u>, especially if the function of the dam is to provide water for irrigation (in which case dry-season flows downstream will be reduced) or to control flooding (in which case wet-season flows and floodplain inundation will change).



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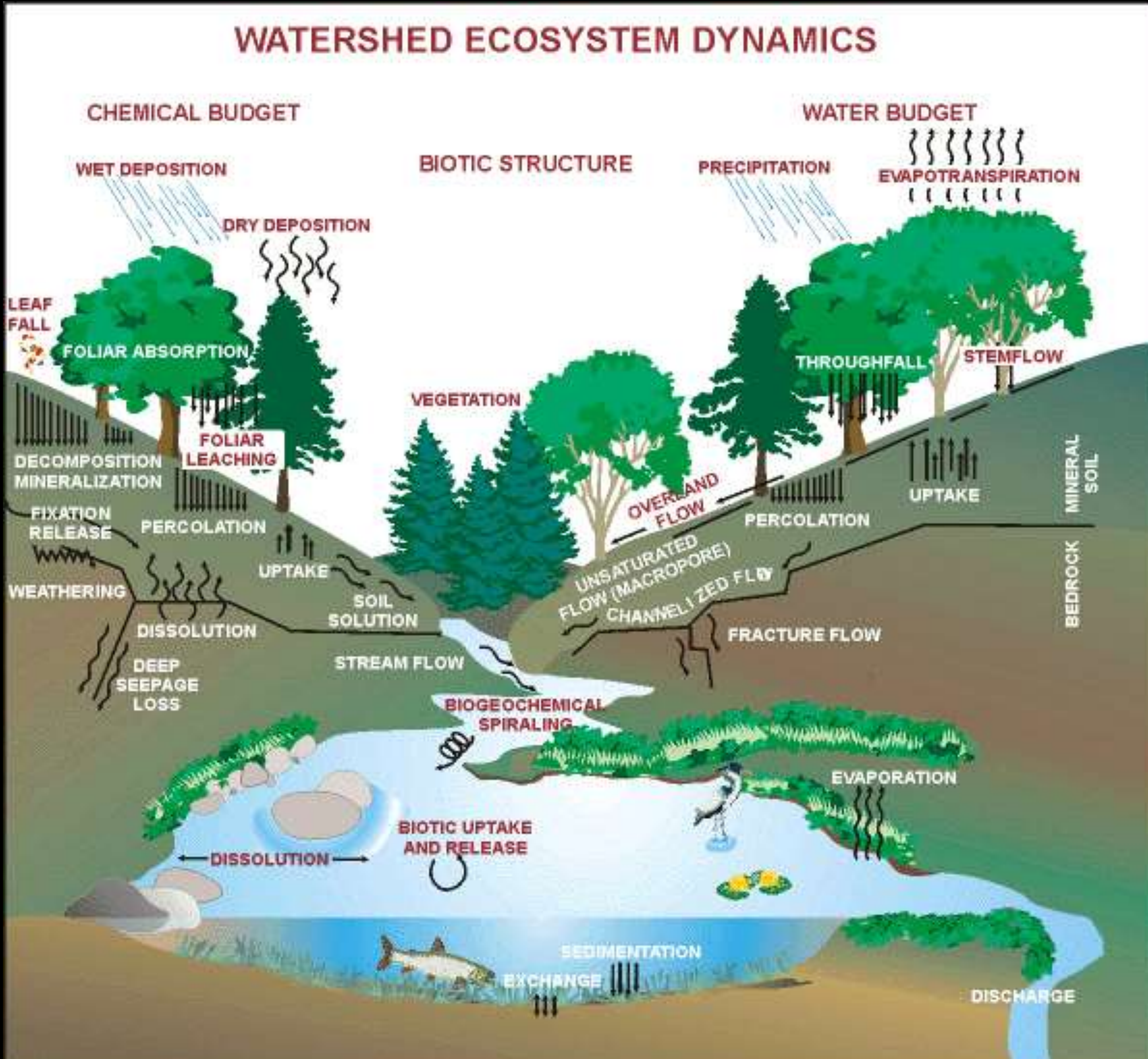
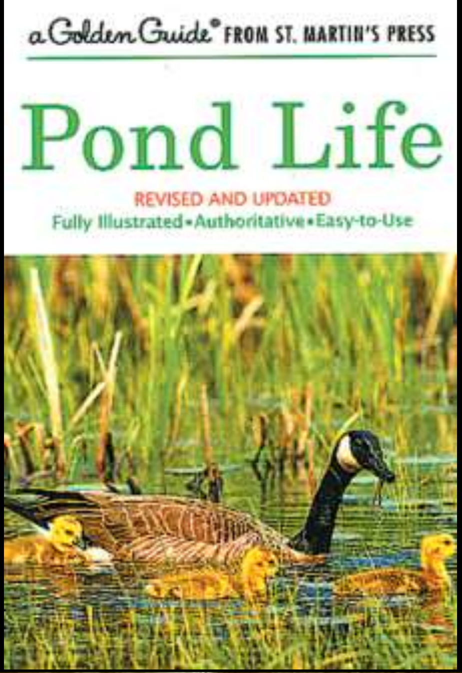
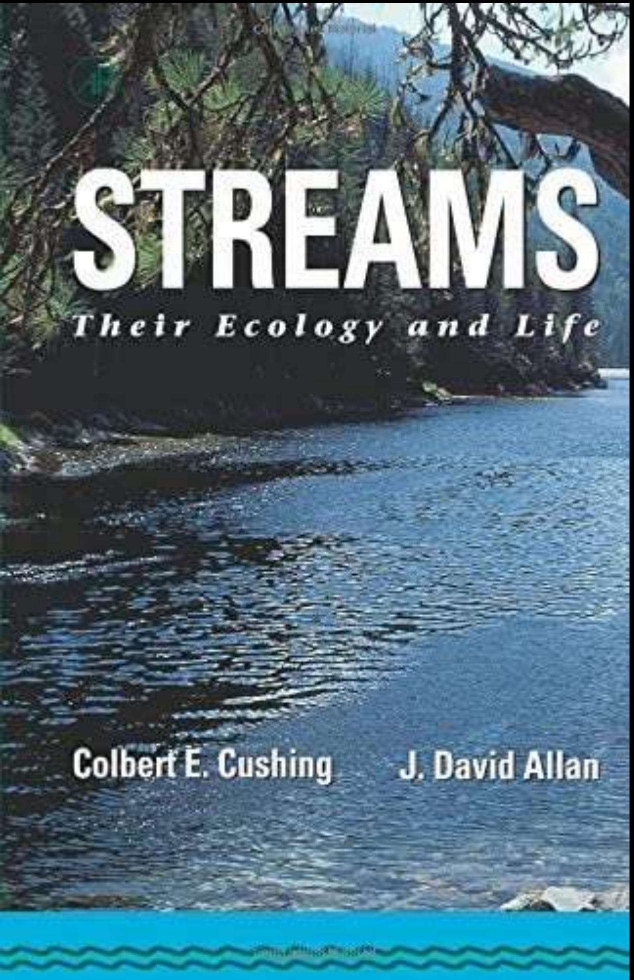
The Serial Discontinuity Concept

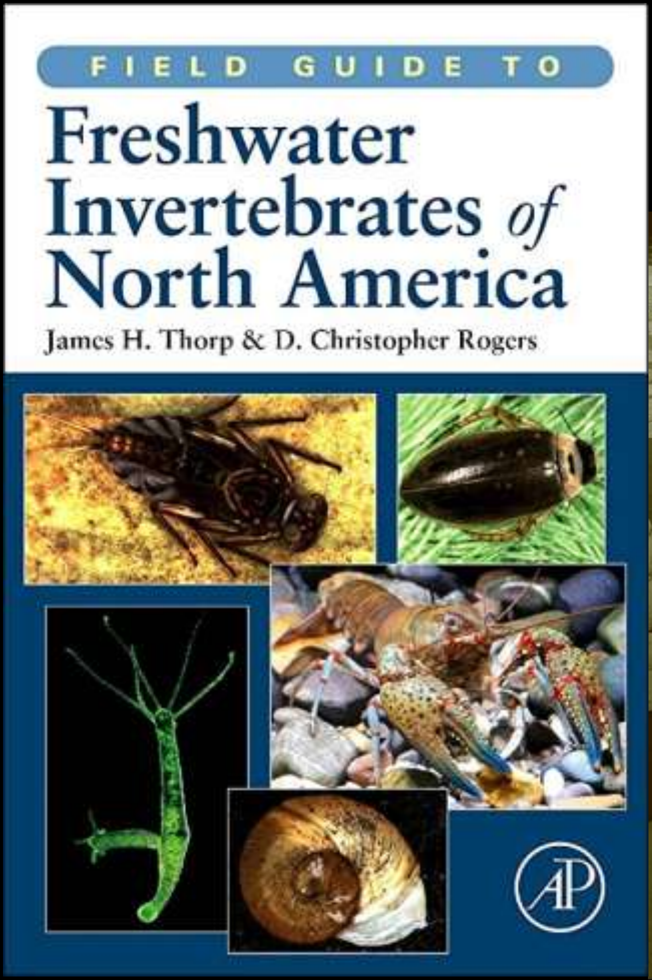
- Concentrations of dissolved oxygen may be changed.
- Phytoplankton that develops behind the dam may be released downstream providing a food resource for filter-feeders that would be unavailable under natural conditions.
- Physical barrier to migration and movement upstream

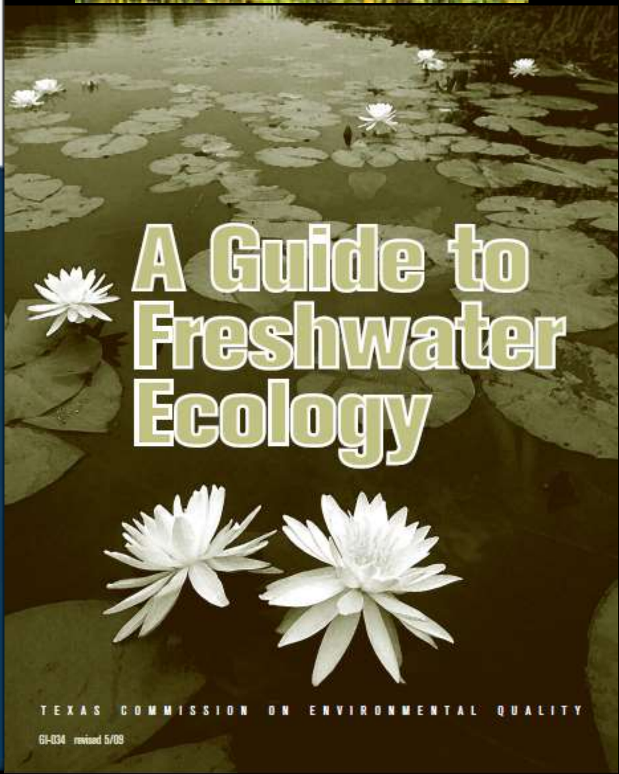

WATERSHED ECOSYSTEM DYNAMICS
CHEMICAL BUDGET
BIOTIC STRUCTURE
WATER BUDGET
WET DEPOSITION
DRY DEPOSITION
PRECIPITATION
EVAPOTRANSPIRATION
LEAF FALL
FOLIAR ABSORPTION
THROUGHFALL
STEMFLOW
VEGETATION
FOLIAR LEACHING
DECOMPOSITION MINERALIZATION
FIXATION RELEASE
PERCOLATION
UPTAKE
OVERLAND FLOW
PERCOLATION
UPTAKE
MINERAL SOIL
WEATHERING
SOIL SOLUTION
UNSATURATED FLOW (MACROPORE)
CHANNELIZED FLOW
BEDROCK
DISSOLUTION
FRACTURE FLOW
STREAM FLOW
DEEP SEEPAGE LOSS
BIOGEOCHEMICAL SPIRALING
EVAPORATION
BIOTIC UPTAKE AND RELEASE
DISSOLUTION
SEDIMENTATION
EXCHANGE
DISCHARGE

Field Guides









Happy Valentine's Day