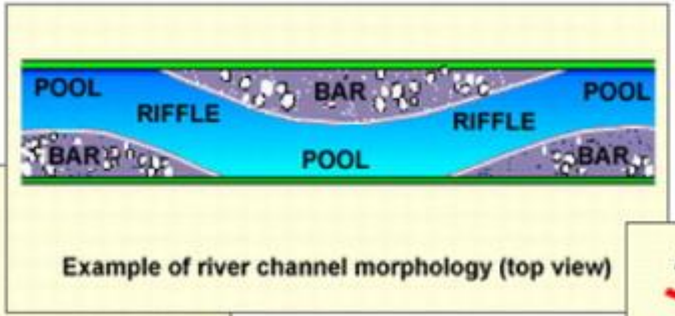
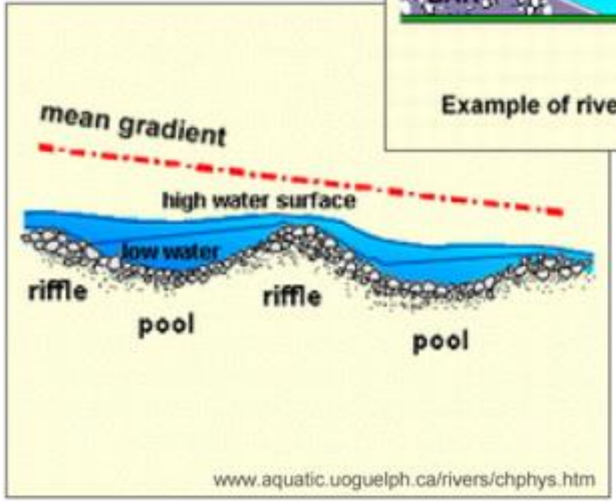
Sample questions

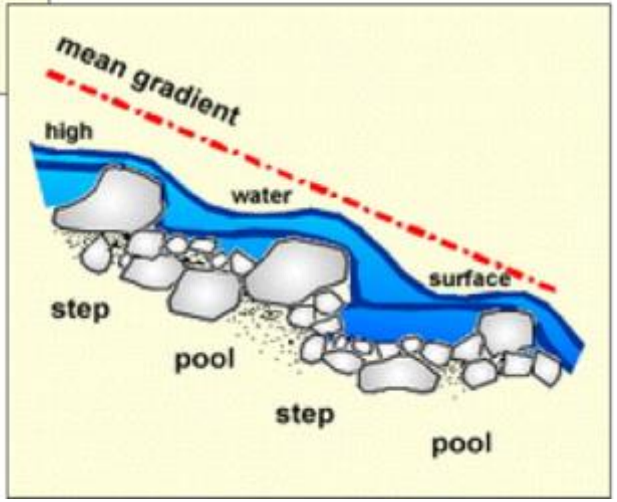
1. What are three major differences between the benthic and hyporheic zones in streams and rivers?
2. What is the compensation point in a lake and what is its ecosystem relevance?
3. What is the fate of the anthropogenic CO_2? Quantify the respective fluxes.
4. Explain the water density anomaly, uinc and discuss two ecosystem consequences of it.
5. What is an hypertrophic lake and what looks the vertical distribution of phytoplankton like in an hypertrophic lake compared to an oligotrophc lake?

Basic stream and river geomorphological units

Riffle-pool sequence
Step-pool sequence



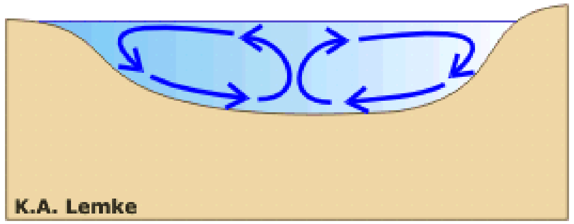


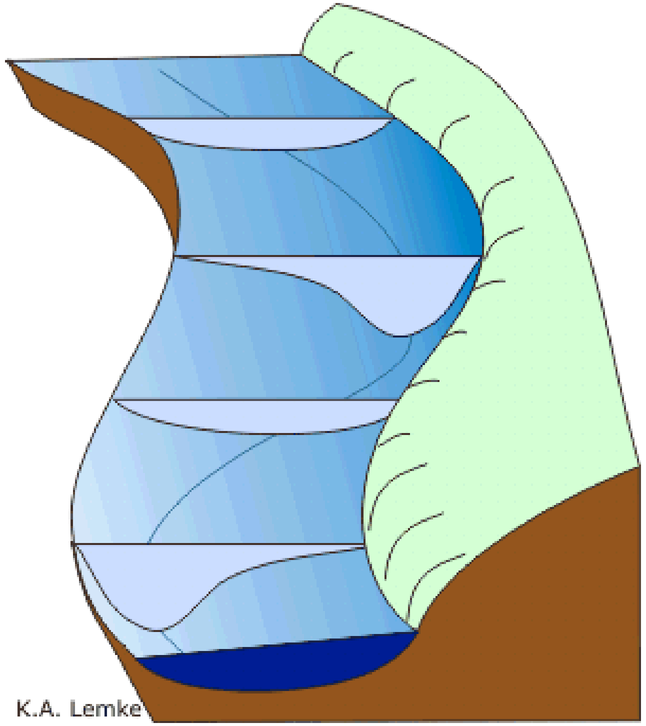


Basic stream and river geomorphological units

Riffle

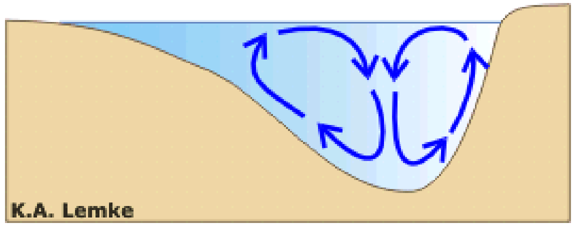
divergent flow
(deposition)





Pool

convergent flow
(scouring)



- shallow (& wide)
- high velocity
- steep water surface gradient
- coarse-grained bed material

- deep (& narrow)
- low velocity
- gentle water surface gradient
- fine-grained bed material

Geomorphology, habitats and functions

Debris dams

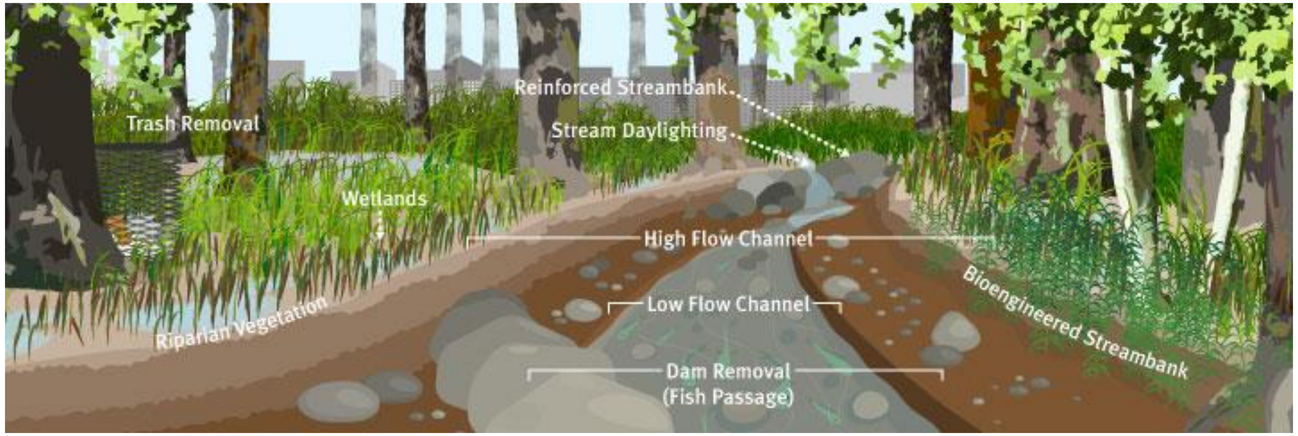
Can facilitate hyporheic exchange

Important for local biodiversity

Geomorphology, habitats and functions

- Macrophyte stands
- Residence time
- Biodiversity
- Primary production

Geomorphology, habitats and functions



- Channel regulation
- Removal of riparian vegetation
- Stream bottom sealing

Loss of the lateral and vertical dimensions
Consequences for hydraulic geometry

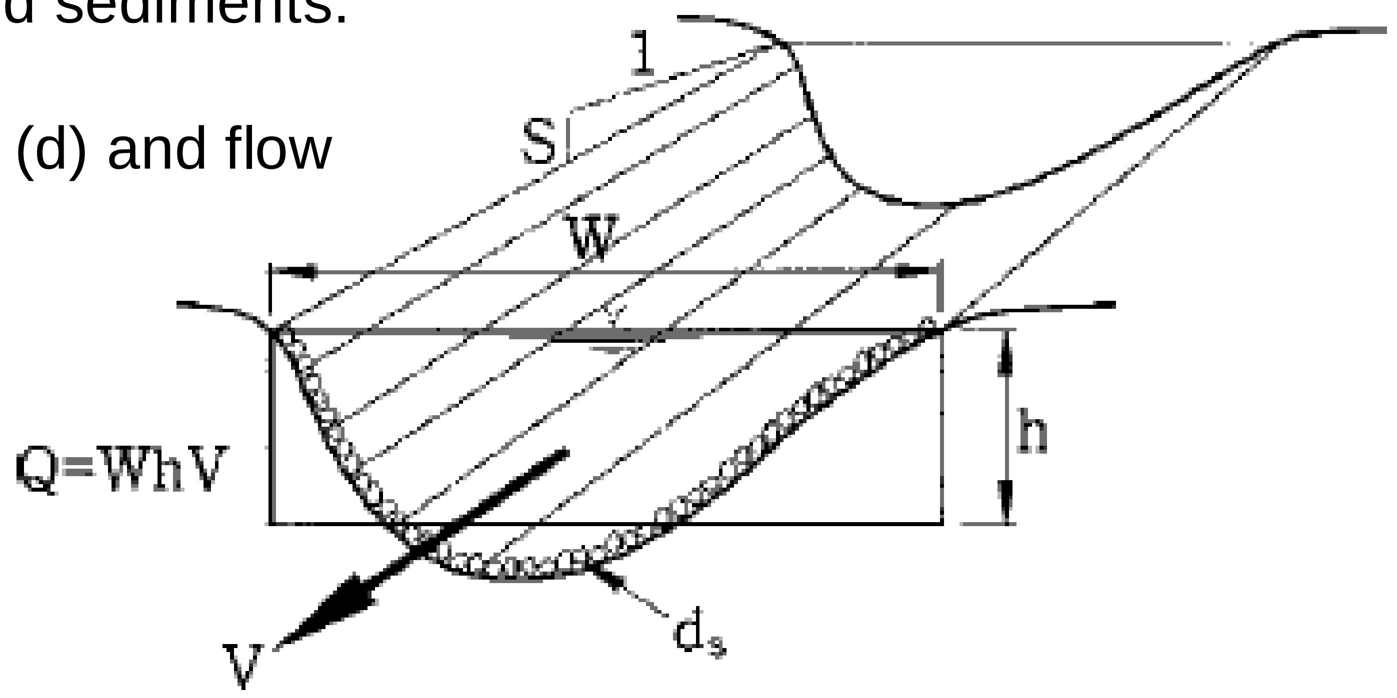
<u>Channel geomorphology and hydraulics</u>

Hydraulic geometry

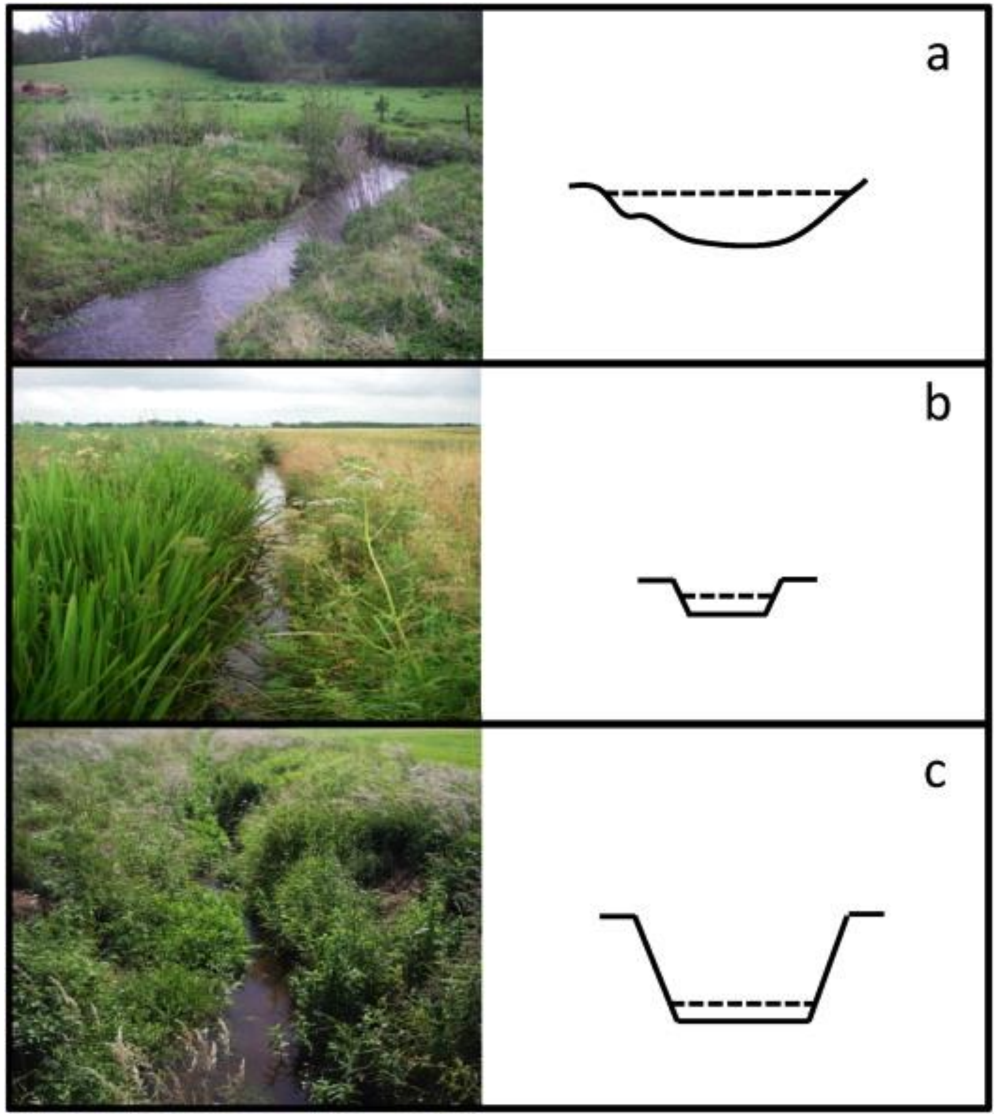
The downstream change of channel geometry to accomodate discharge and sediments

- The geometry of the channel is configured such that is can receive and transport upstream deliveries of water and sediments.

- Channel width (w), water depth (d) and flow velocity (v).



Hydraulic geometry



Depending on catchment geology, position within the network, terrain slope, but also riparian vegetation (land use), stream channels can differ in average width and depth, and velocity.

Hydraulic geometry

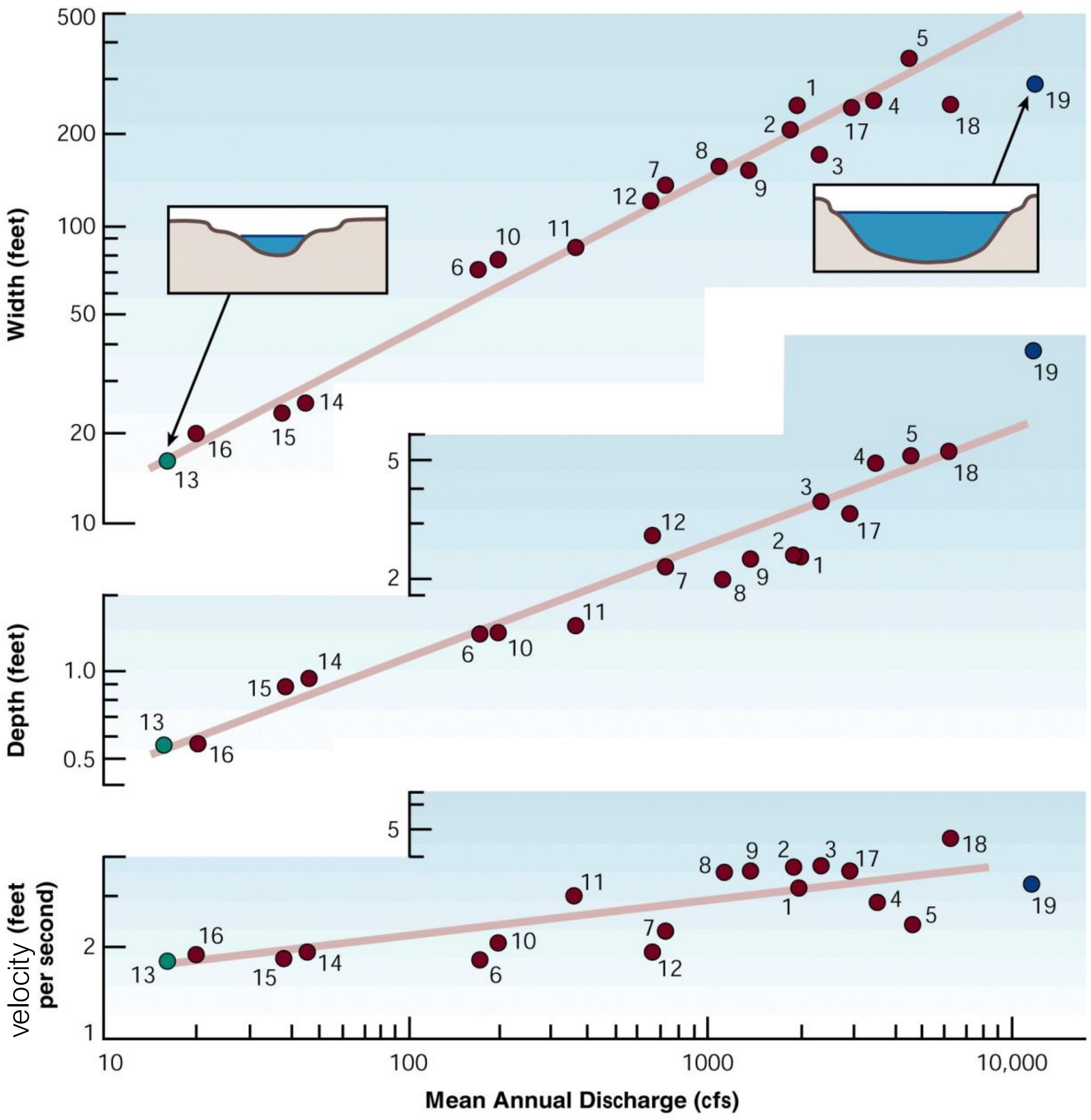
The Hydraulic Geometry of Stream Channels and Some Physiographic Implications

By LUNA B. LEOPOLD and THOMAS MADDOCK, Jr.

GEOLOGICAL SURVEY PROFESSIONAL PAPER 252

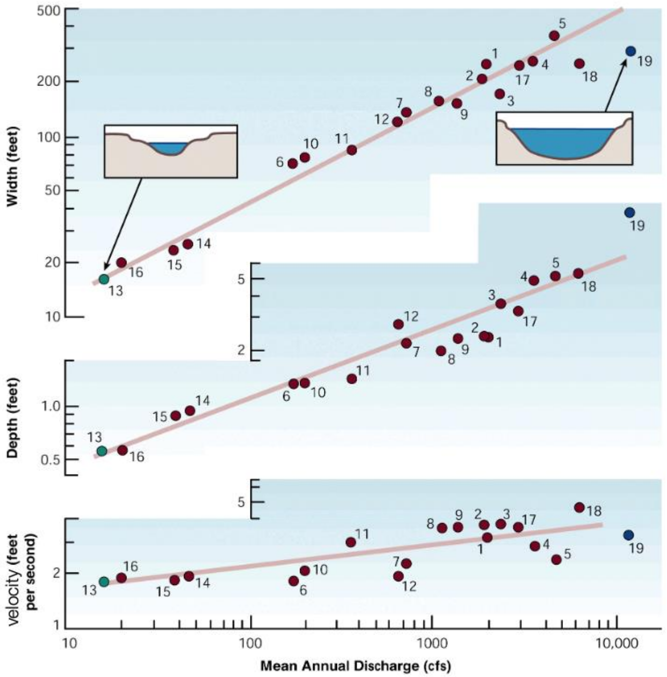
Quantitative measurement of some of the hydraulic factors that help to determine the shape of natural stream channels: depth, width, velocity, and suspended load, and how they vary with discharge as simple power functions. Their interrelations are described by the term "hydraulic geometry."

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1953



From Leopold and Maddock, 1953.

Hydraulic geometry



Relationships between the mean stream channel form and discharge downstream along a stream network (or at a station).

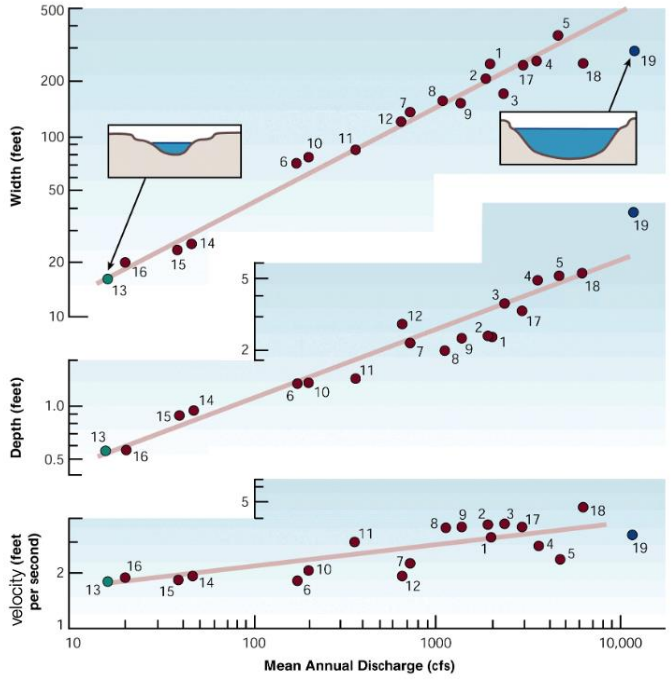
Hydraulic geometry: relationship for a channel in the form of power functions of discharge as:

$$w = aQ^b \quad d = cQ^f \quad v = kQ^m$$

where w = width, d = depth, v = velocity

Exponents (b, f, m) indicate rate of increase in a hydraulic variable (w, d, v) with increasing Q

Hydraulic geometry



Q is the product of w, d and v, therefore

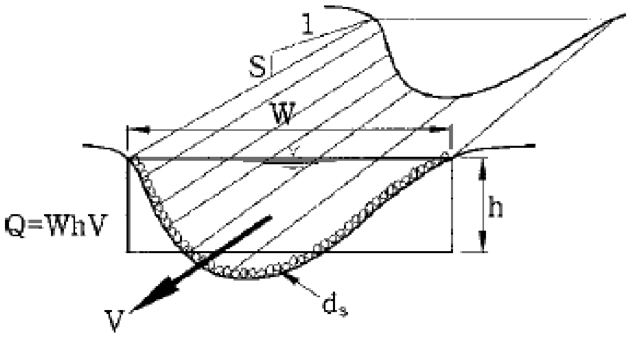
$$Q = (aQ^{b})\ (cQ^{f})\ (kQ^{m}) \text{ or}$$

$$Q = ack\ Q^{\ b+f+m}$$

and $b+f+m = 1$

Exponents (b, f, m) change with position in the network, climate, and discharge conditions

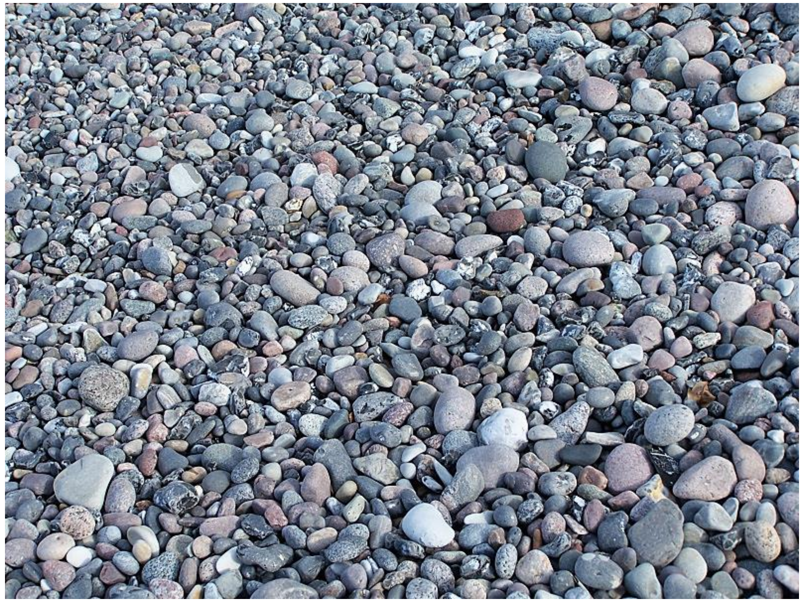
Hydraulic geometry



Hydraulic geometry relates to

- hydrogeomorphology to position in the stream network
- sediment characteristis
- hydraulics
- benthic life
- ecosystem processes

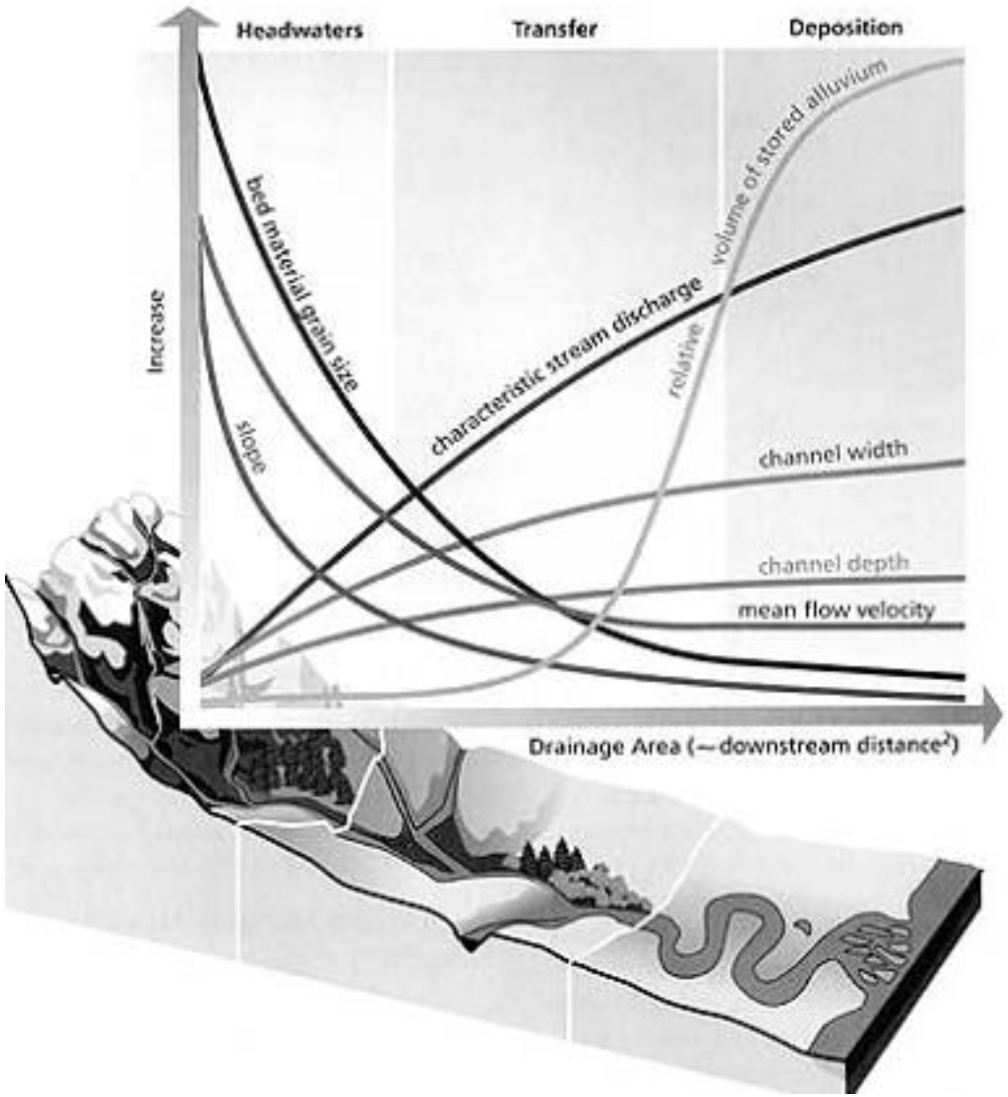
Sedimentary dynamics



- Stream energy (e.g., channel slope, velocity)
- Sediment composition

Sedimentary dynamics

Downstream gradients



- Mean flow velocity and channel properties change downstream (see hydraulic geometry)
- How are sedimentary dynamics affected?

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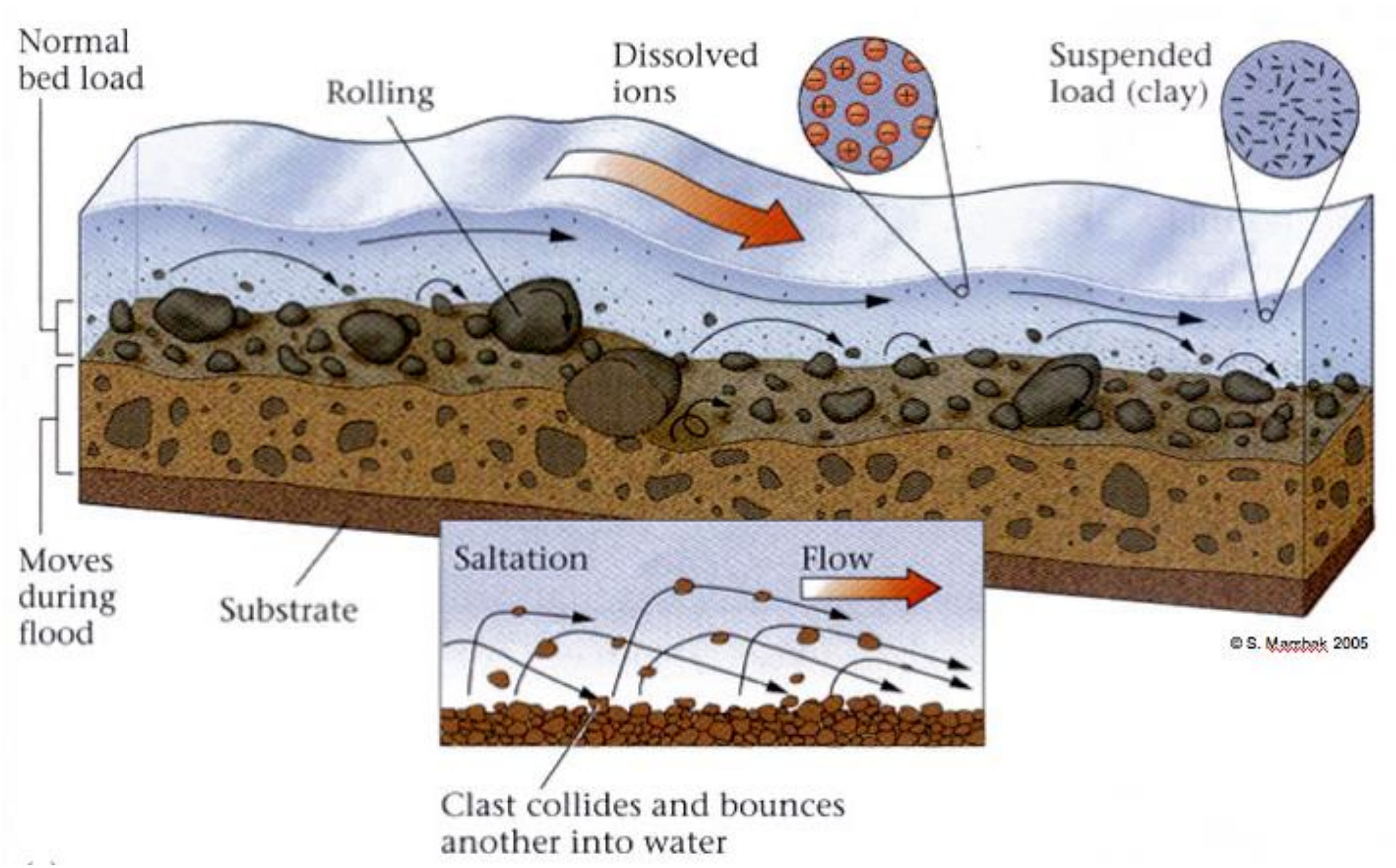
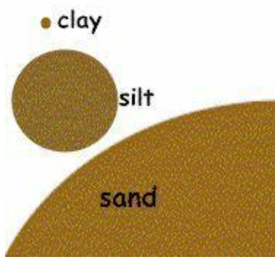
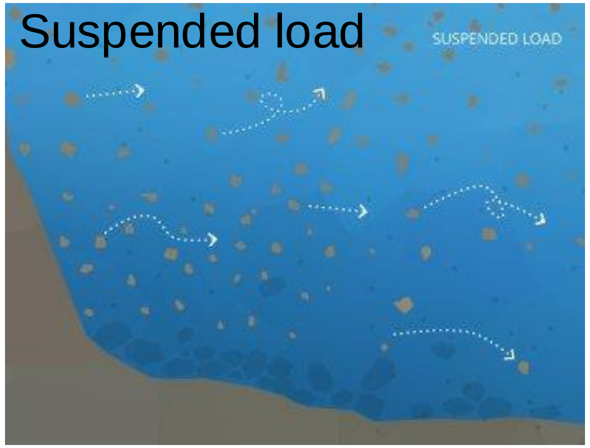
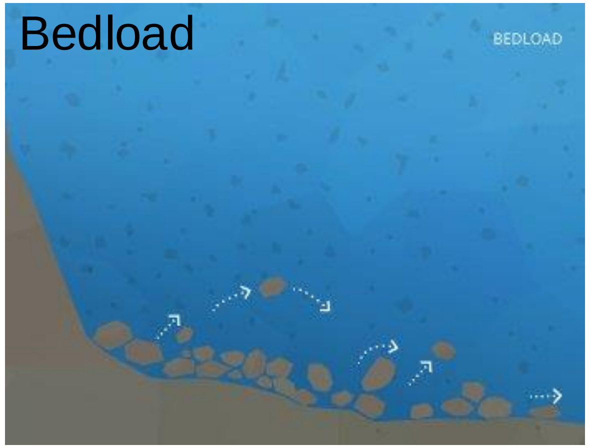
Sedimentary dynamics and the Hjulstrom curve

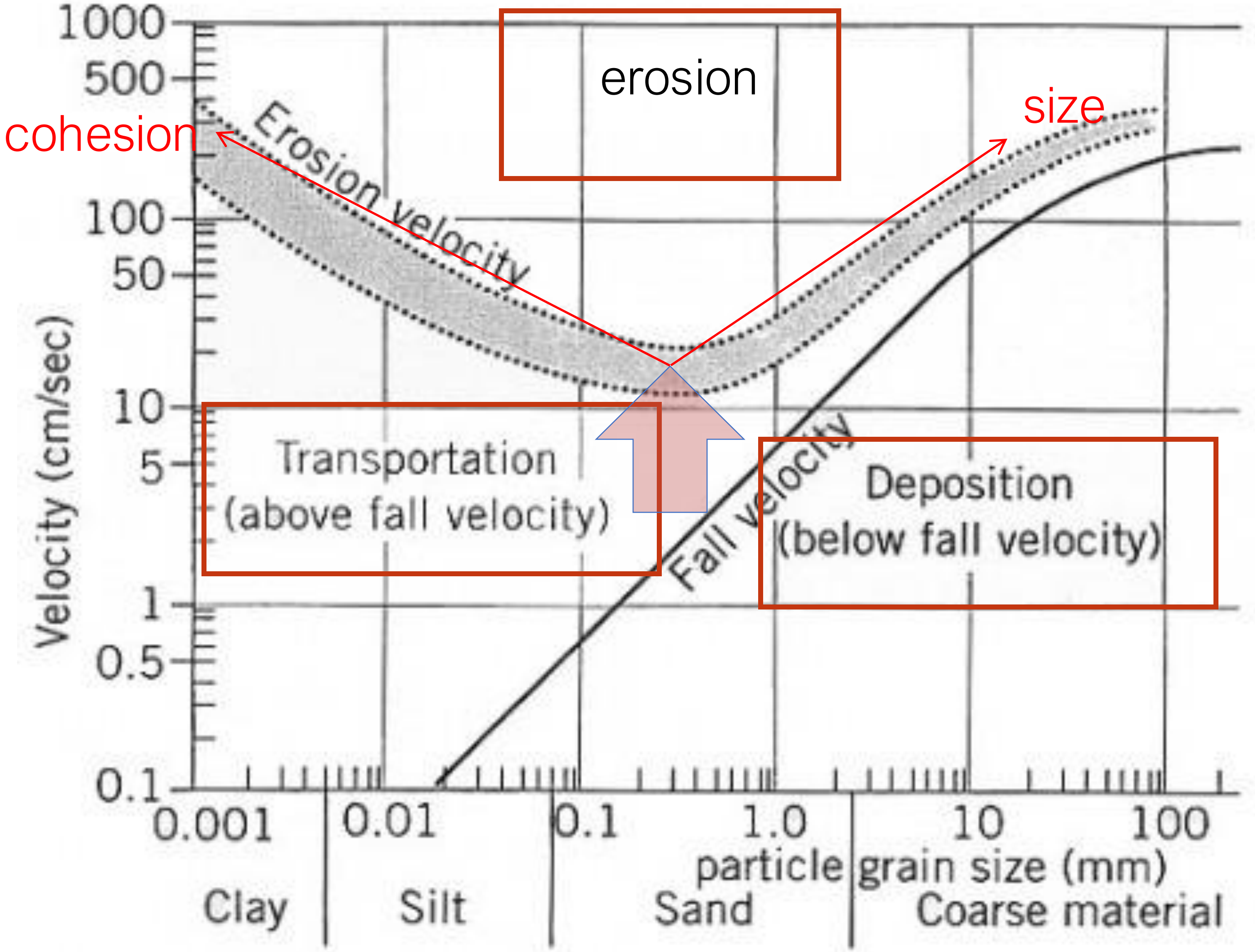


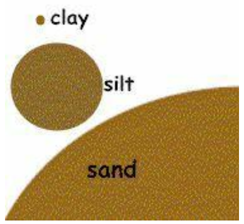


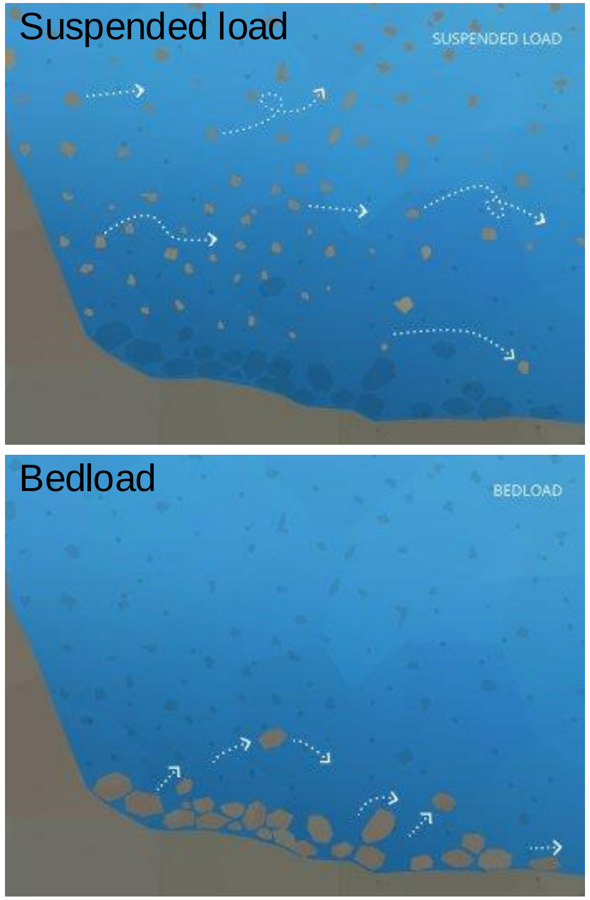




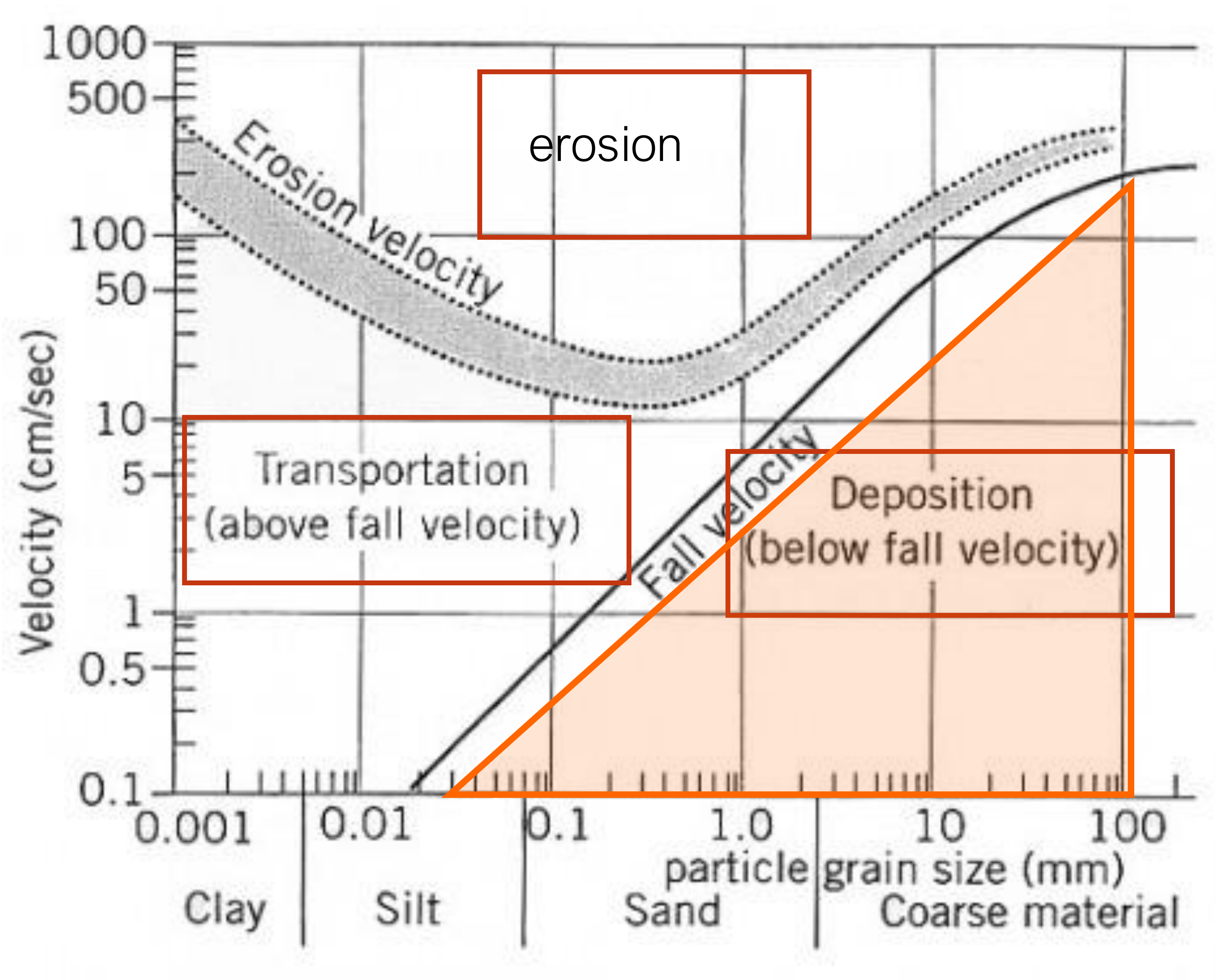
Sedimentary dynamics and the Hjulstrom curve





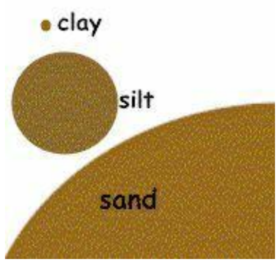


Sedimentary dynamics and the Hjulstrom curve



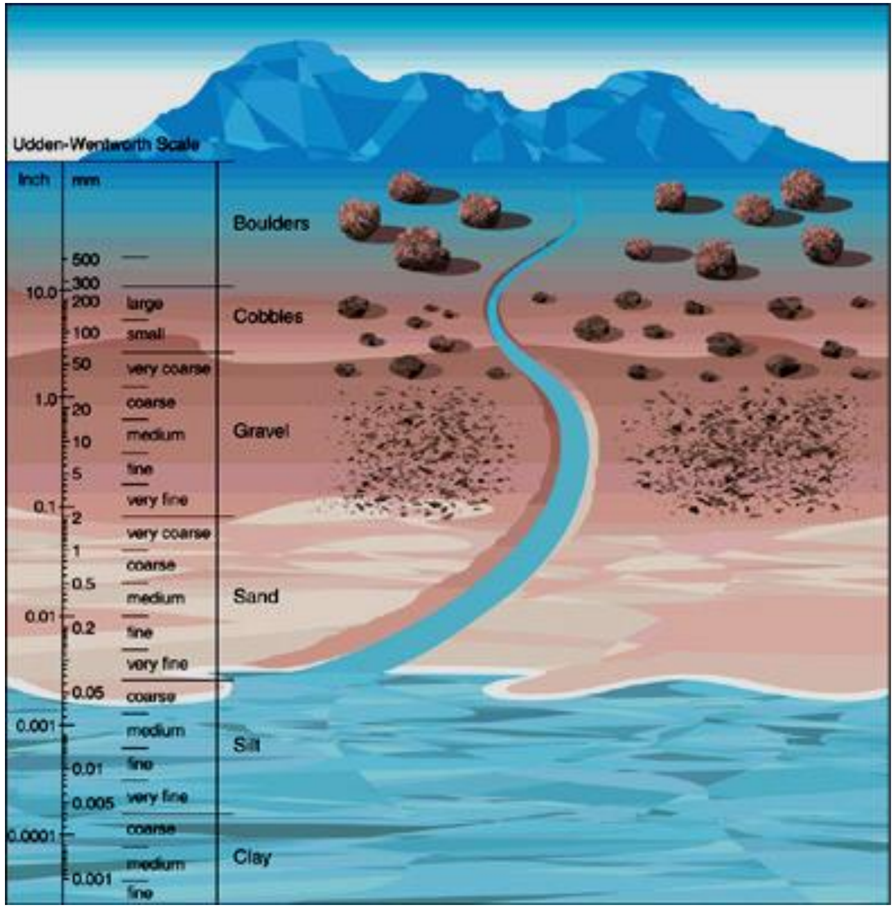
Downstream sorting

- Coarser sediments accumulate upstream
- Fine sediments accumulate downstream
- Turbidity increases downstream (implications for light availability)



Consequences

Downstream fining/sorting



Progress in Physical Geography 22,1 (1998) pp. 1–32

Patterns and processes of sediment sorting in gravel-bed rivers

D. Mark Powell

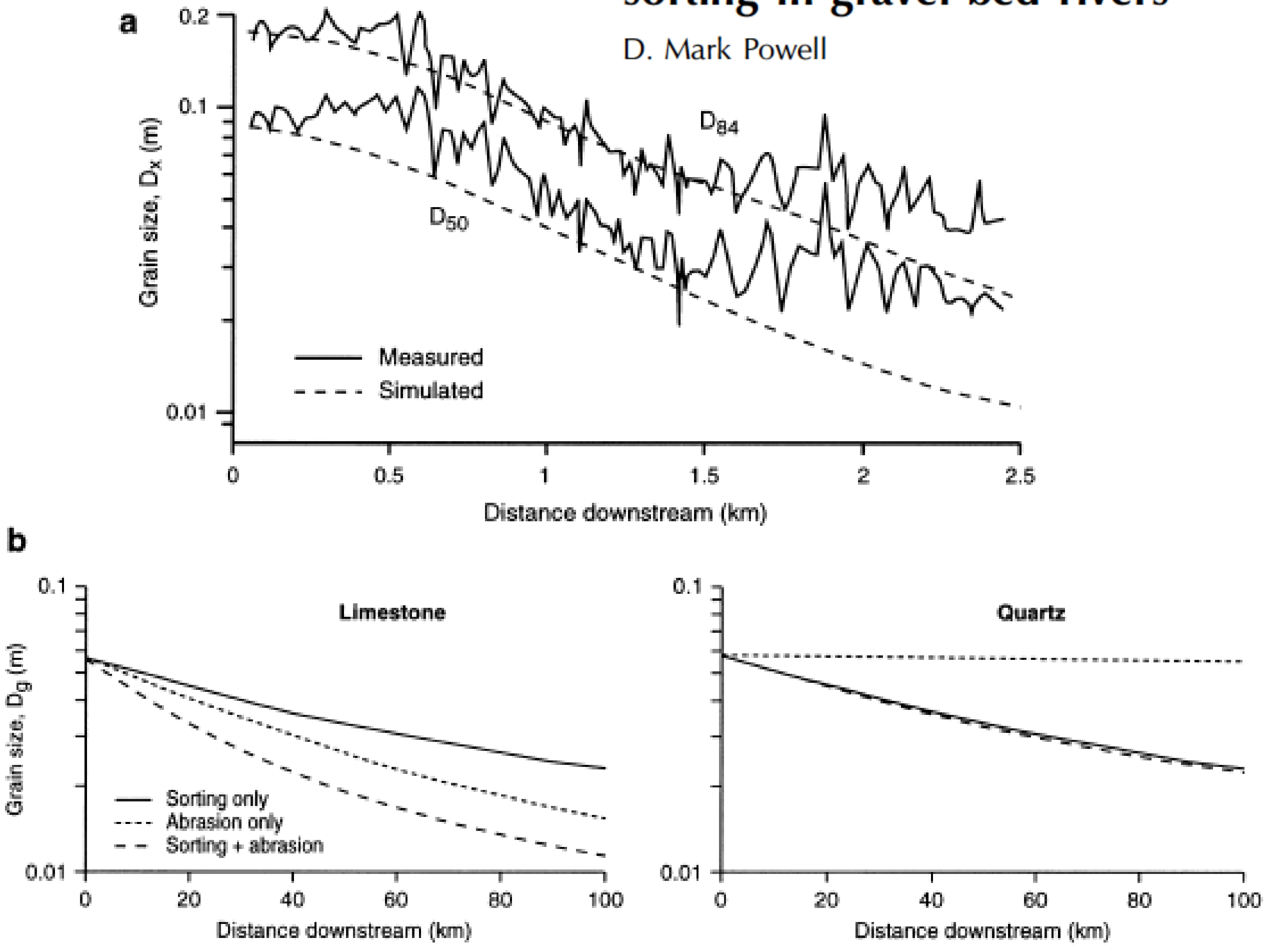
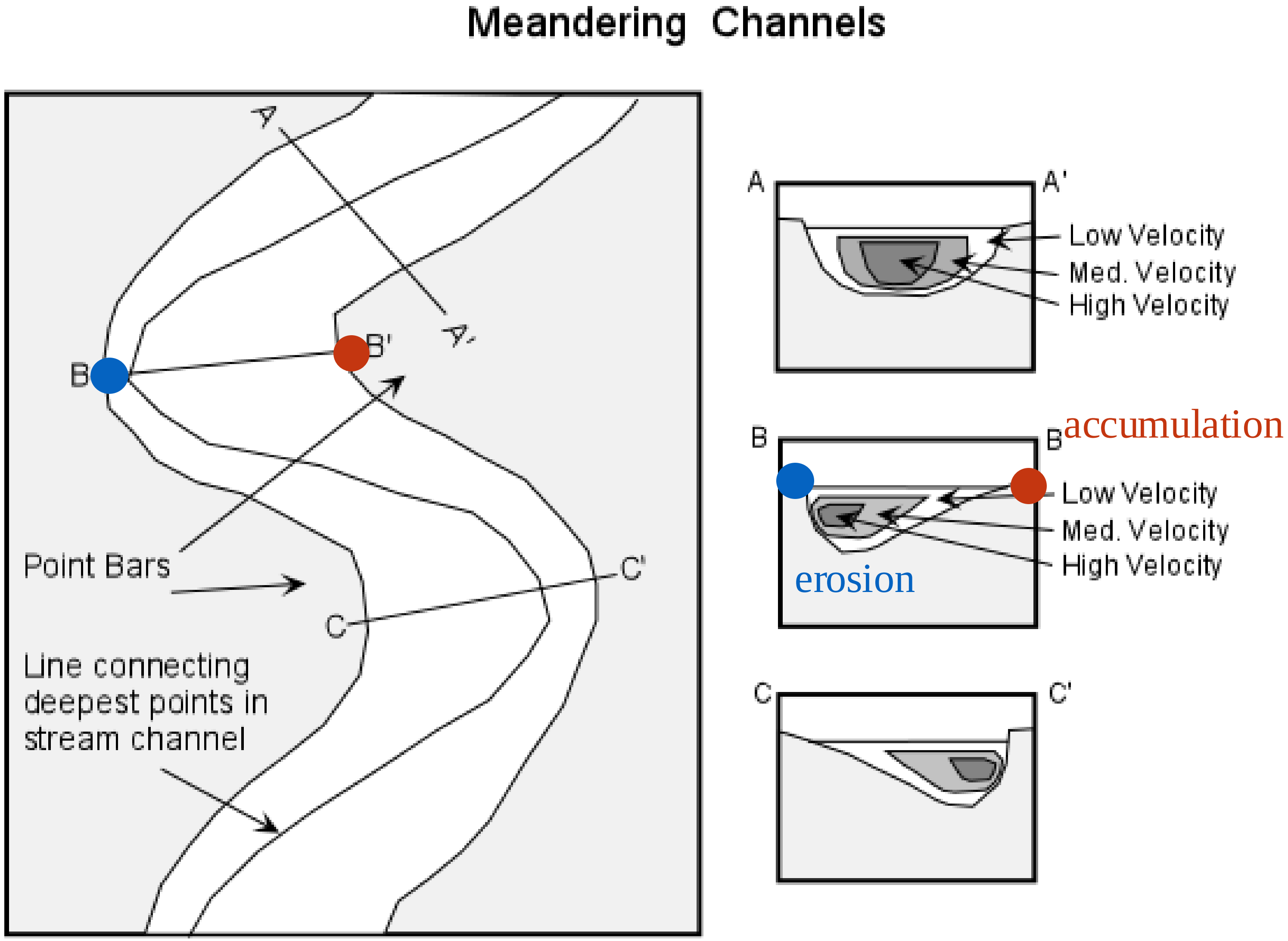


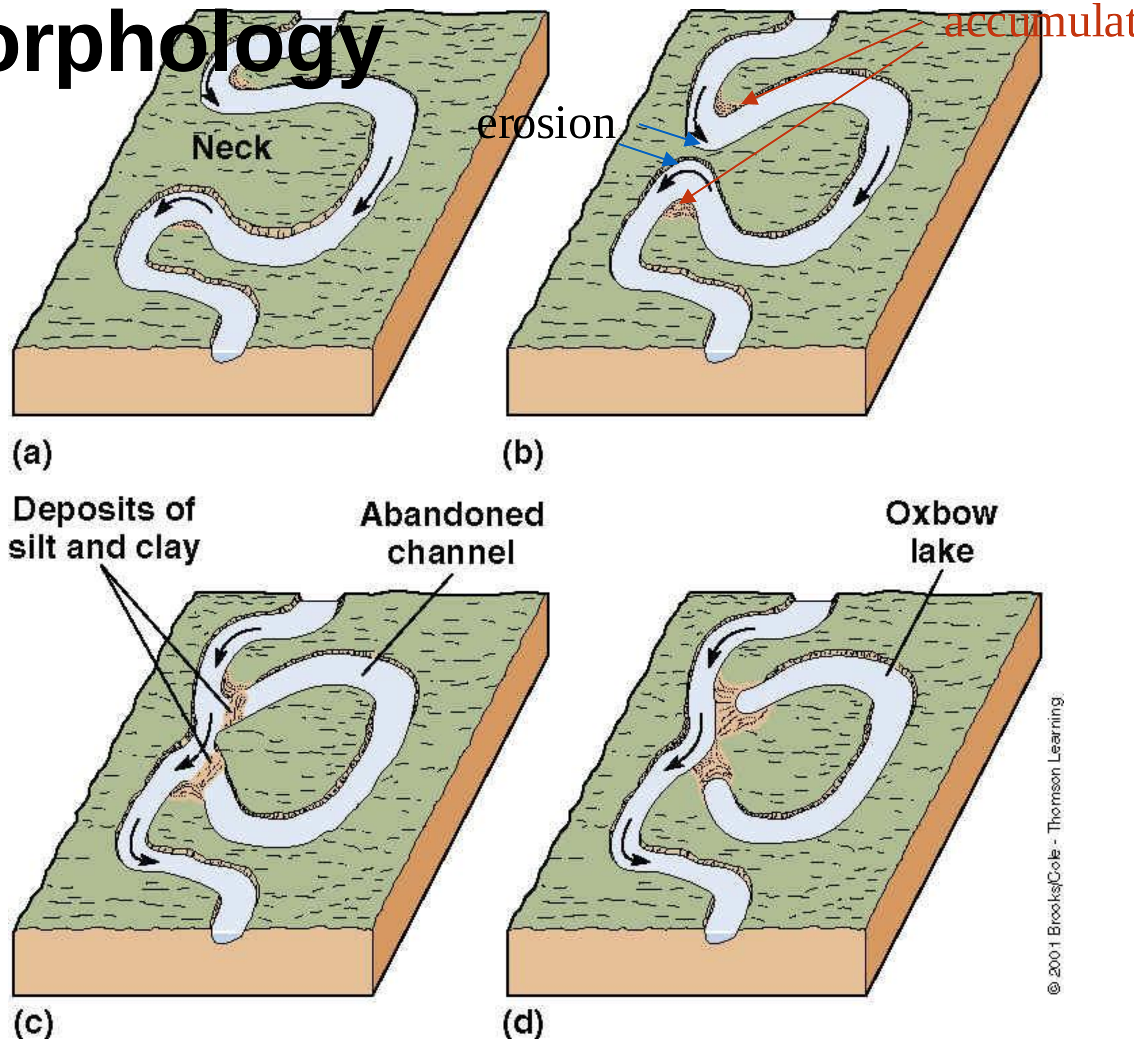
Figure 6 Numerical simulations of downstream fining. (a) The role of size-selective entrainment, the Alt Dubhaig, after Hoey and Ferguson (1994); (b) the relative roles of selective entrainment and abrasion, two hypothetical rivers with contrasting lithologies, after Parker (1991b), reproduced with the kind permission of the ASCE. D_x and D_g are the *x*th percentile and geometric mean of the grain size distribution respectively

Consequences for channel geomorphology



- Low gradients
- Easily eroded banks
- Straight channels eventually eroding into meandering channels
- Erosion: outer parts of the meander bends with highest velocity
- Sediment deposition along the inner meander bends with lowest velocity

Consequences for channel geomorphology



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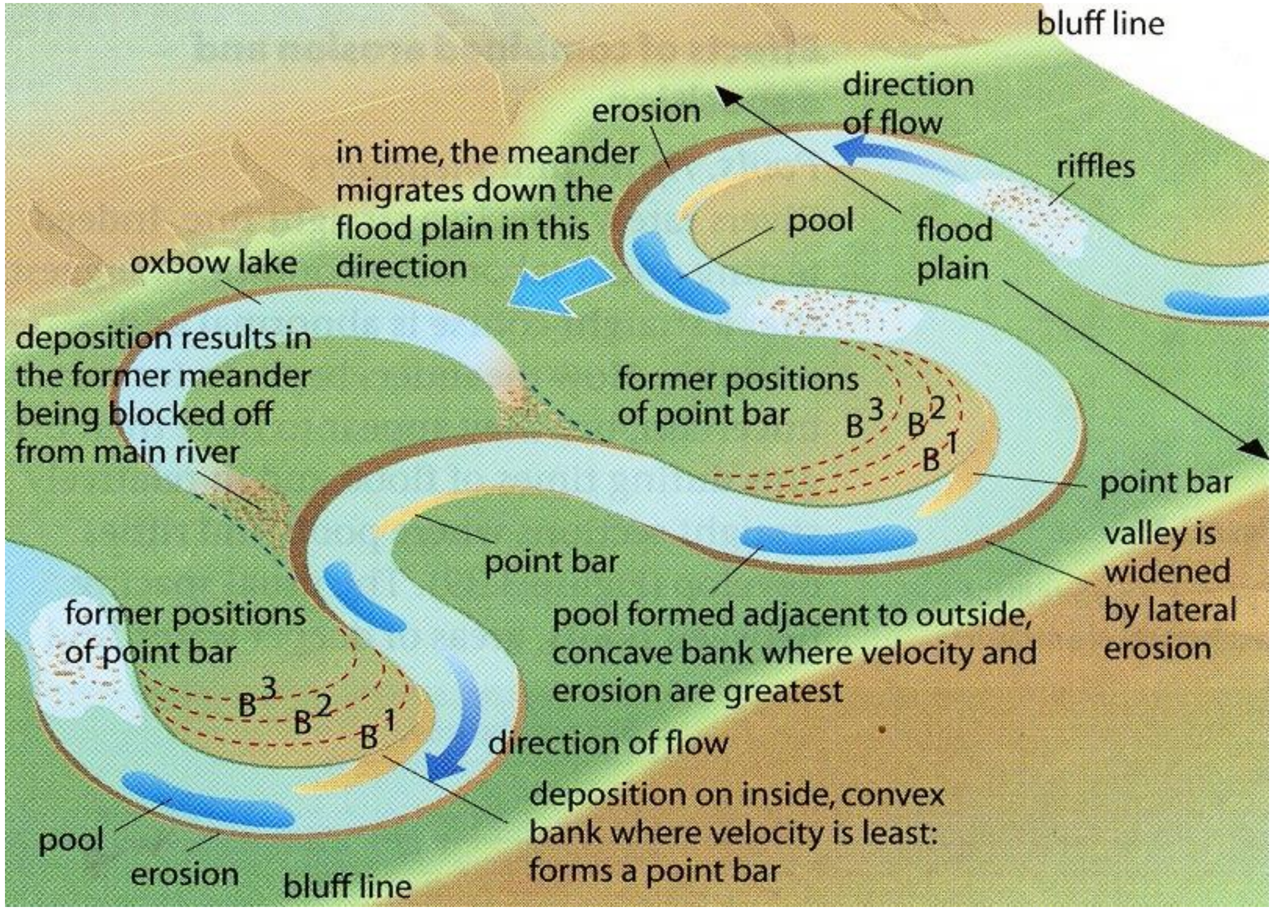
Consequences for channel geomorphology



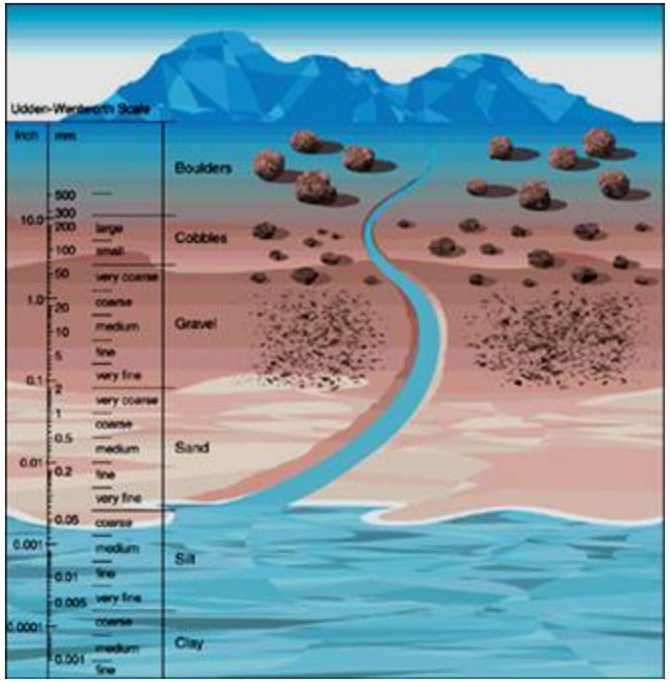
Meanders

- Interplay between erosion and accumulation
- Horizontal sorting of sediments
- Shaping the landscape, its environmental heterogeneity and biodiversity
- Shaping hydrodynamic exchange

EPFL

Consequences

Hydrodynamic exchange



Vertical sorting of sediments

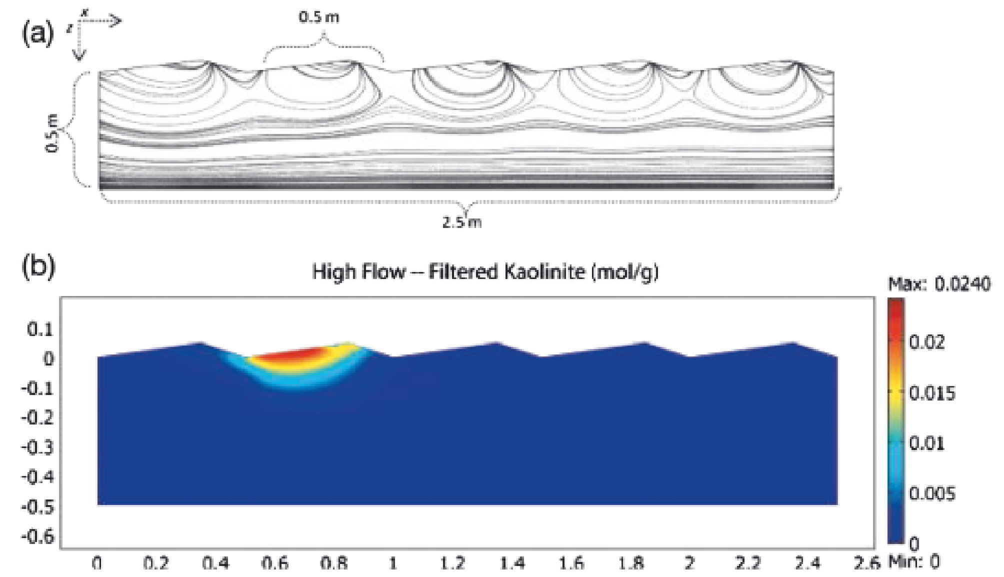
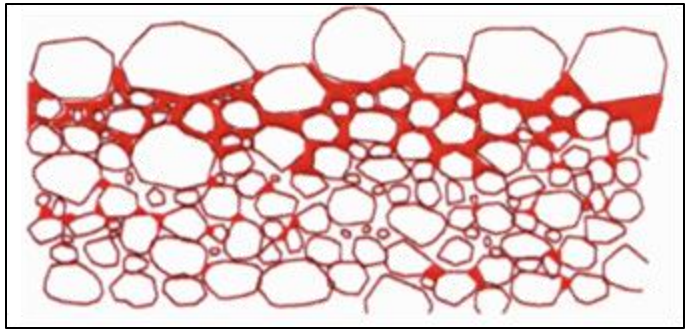
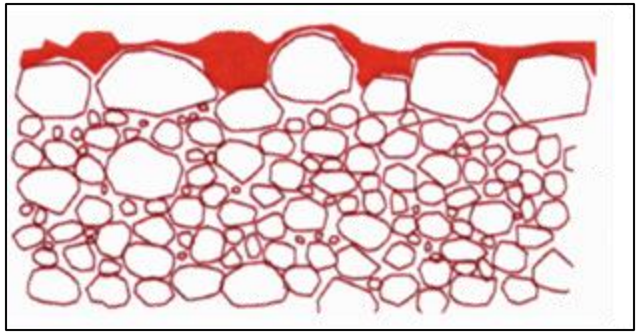


Figure 24. Spatial patterns of pore water flow and clay deposition in a streambed simulated by *Karwan and Saiers* [2012]. Compare simulated particle accumulation with typical experimental observations in Figure 25.

Internal clogging



External clogging



Reduced permeability and hydrodynamic exchange

Consequences

Hydrodynamic exchange

- Reduction of permeability
- From macro-porous to micro-porous flow
- Impacts on hydrodynamic exchange
- Shifting chemical gradients
- Habitat deterioration (siltation and anoxia)

Département de la mobilité, du territoire et de l'environnement
Service de l'environnement

Departement für Mobilität, Raumentwicklung und Umwelt
Dienststelle für Umwelt

CANTON DU VALAIS
KANTON WALLIS

Le Rhône

Campagne 2017

Observation de la qualité des eaux de surface

Rapport et annexes

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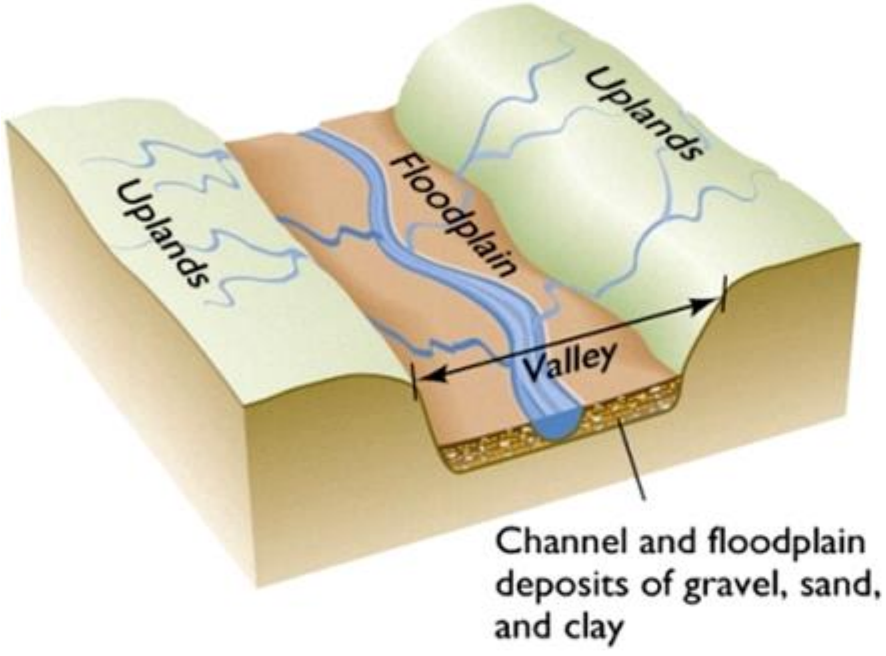
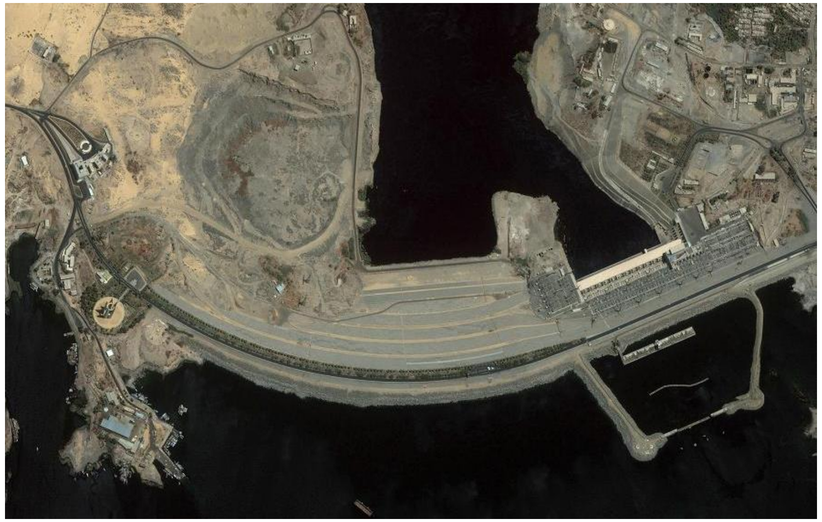
Août 2018

Consequences

- High productivity of floodplains, estuaries
- (hydraulic geometry, Hjulstroem)
- Downstream accumulation of fine sediments
- Lateral accumulation of fine sediments within the floodplain during the receding limb of the storm hydrograph



Aswan Dam

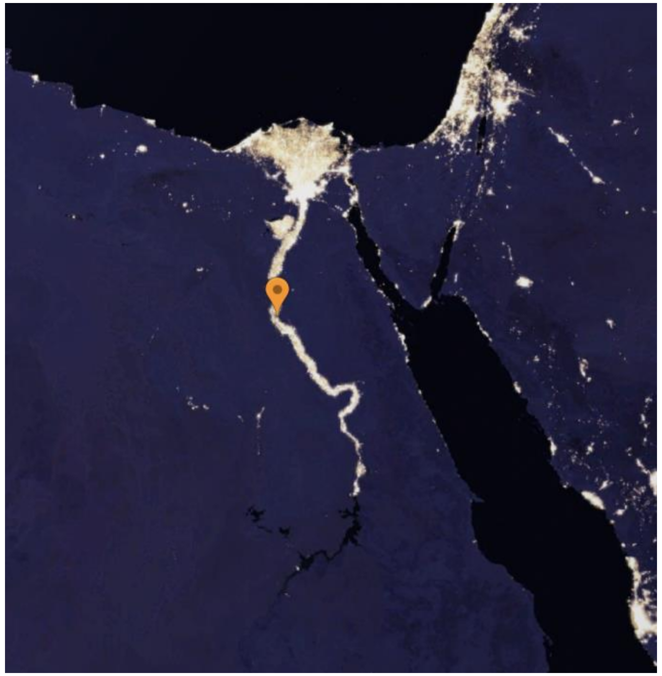


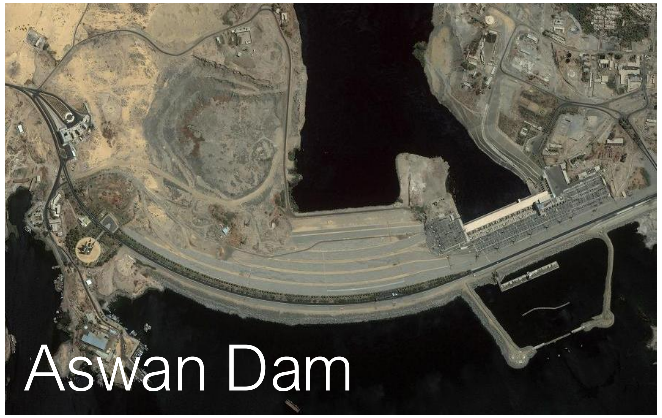
Downstream and lateral gradients, a ‘legacy’ of the Hjulstrom curve

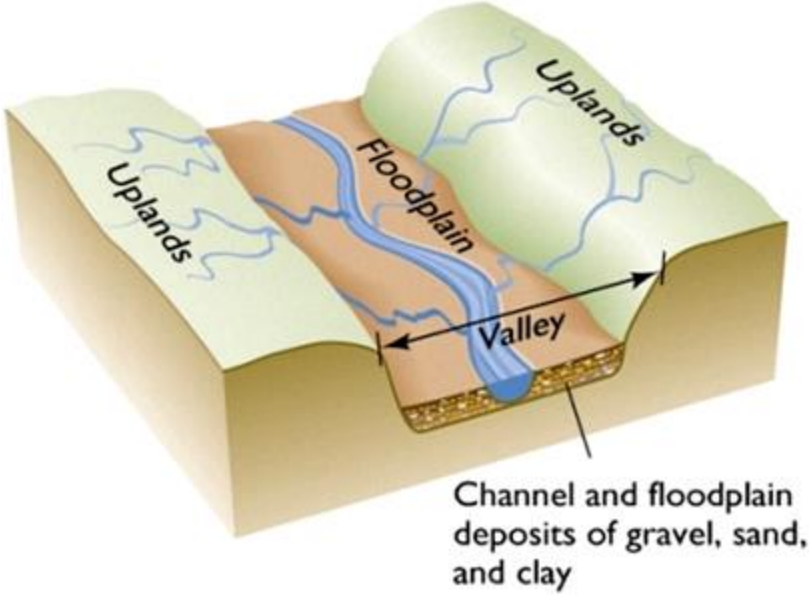
Example: Egyptian high culture and the Nile

EPFL

Example: Aswan Dam and the Nile valley







- Prior to the construction of the Aswan dam, the Nile innundated the fringing floodplains annually (rainy season in tropical Africa)
- Fertilizing the floodplains, promoting agriculture
- Stimulating the ‘Nile bloom’, sustaining fisheries
- At the basis of the Egyptian high culture (see pyramides etc)

- After the construction of the Aswan dam, synthetic fertilizers replace the natural fertilization

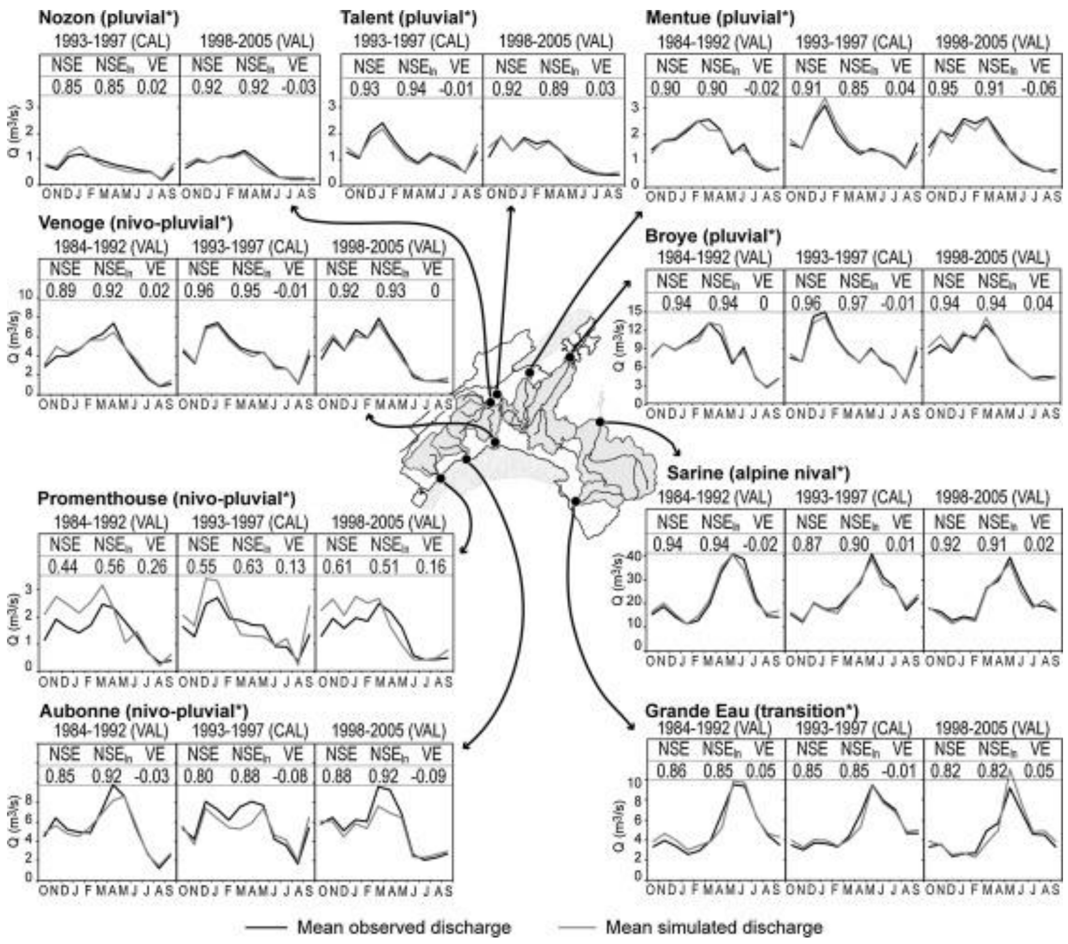
The flood pulse and nutrient dynamics

Why are floodplains so fertile and hence relevant for agriculture?

- Regular inundations provide natural ‘fertilizers’
- Sustain high biodiversity



Annually recurrent pattern of floods (snowmelt, monsoon…)




Journal of Hydrology: Regional Studies
Volume 4, Part B, September 2015, Pages 748-761

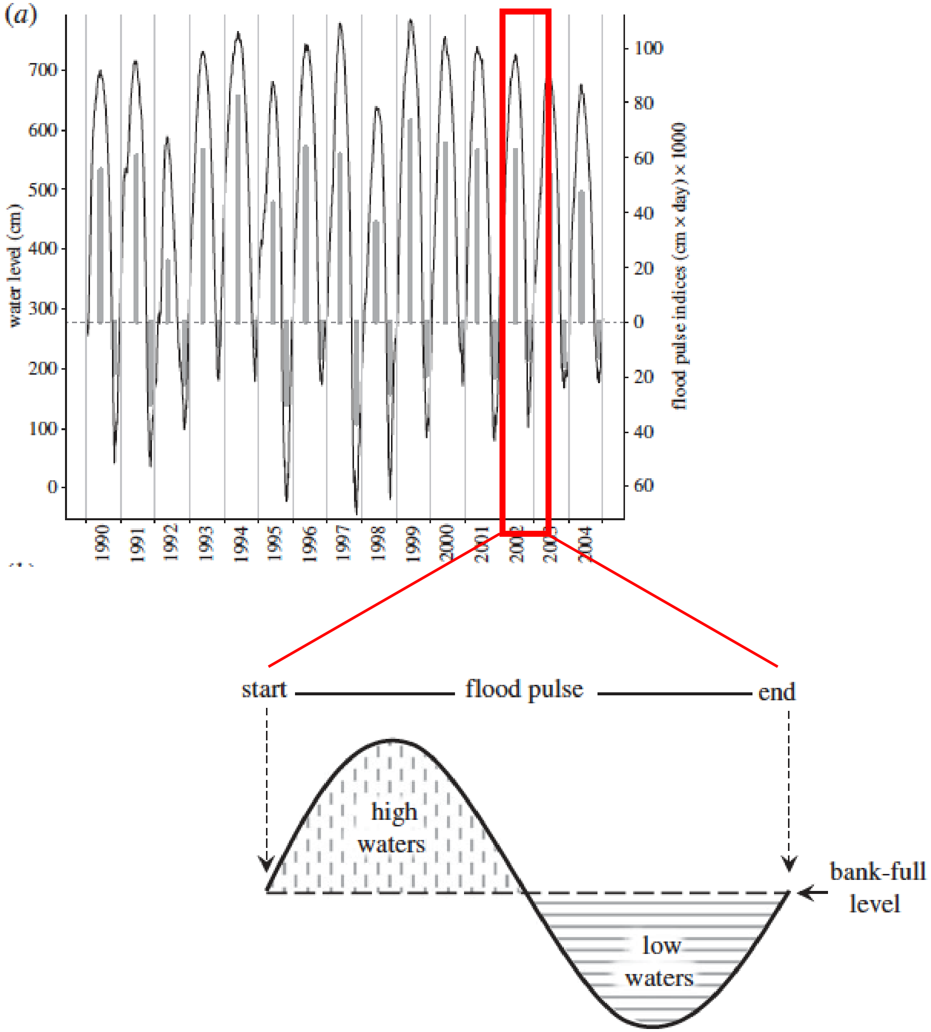
Simulating future trends in hydrological regimes in Western Switzerland

Marianne Milano, Emmanuel Reynard, Nina Bosshard, Rolf Weingartner

- Various hydrological regimes (pluvial, nival, nivo-pluvial, tansition)

- Snow and glacier melt (Danube, Rhine, Rhone, Po)
- Monsoon driven
- High interannual predictability
- Relevant for ecosystem functioning

The flood pulse and nutrient dynamics



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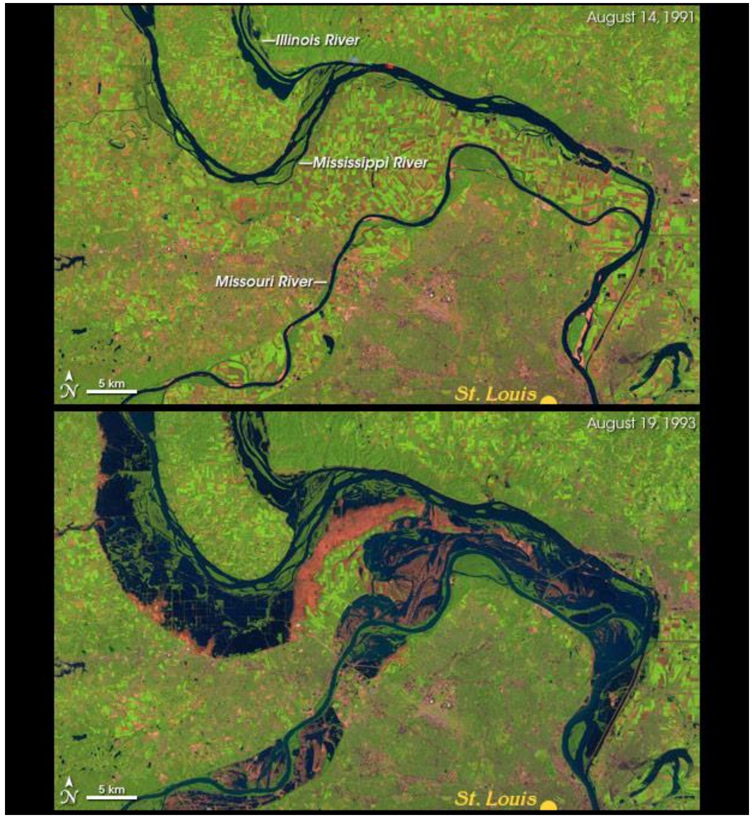
Research

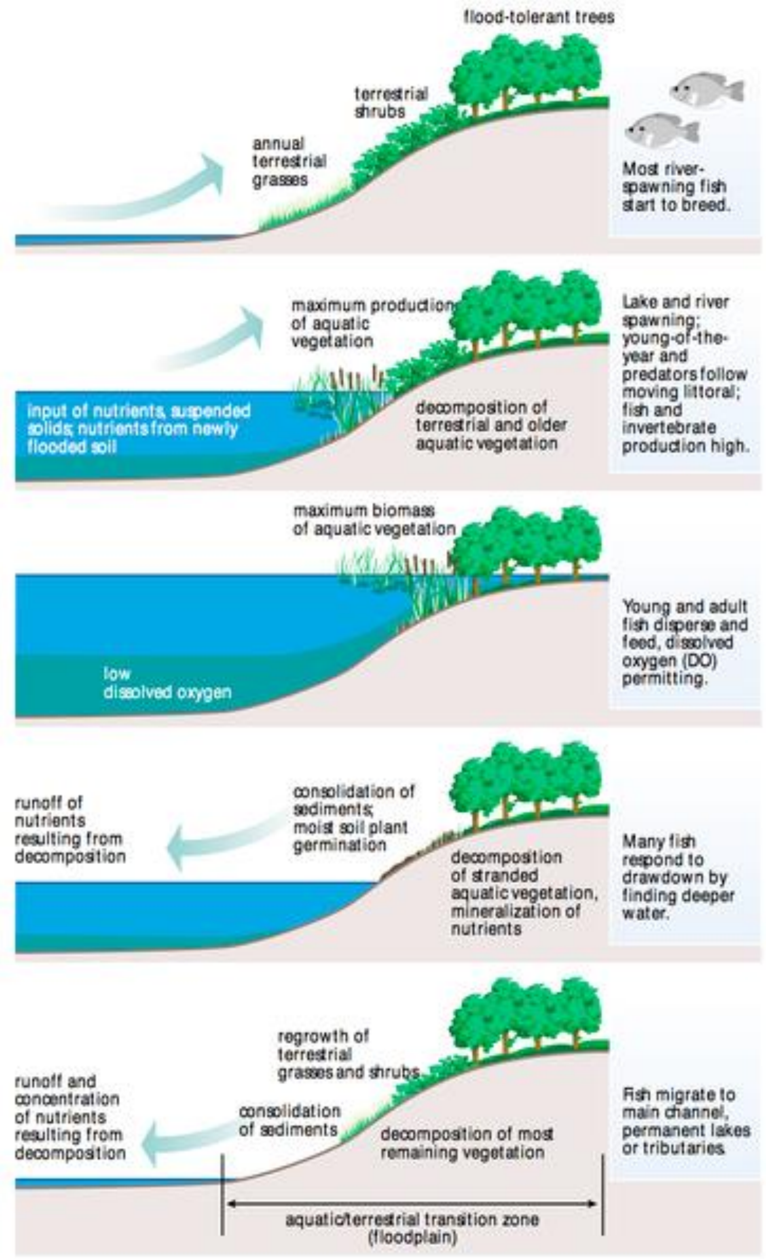
Flood pulse effects on multispecies fishery yields in the Lower Amazon

Leandro Castello[1], Victoria J. Isaac[3] and Ram Thapa[2]



- Flood pulses are predictable in time as they are often climate driven (e.g., monsoon, snowmelt)
- Life at the edge between the river and land has adapted to these recurring events

The flood pulse and nutrient dynamics



Floodplains

- Aquatic-terrestrial transition zone, wetlands with high biodiversity
- Elevated spatial and temporal dynamics of the environment
- Flood pulse introduces nutrients (bound to sediments) into floodplains
- Promotes aquatic primary production at the interface to the terrestrial milieu
- Annual cycle of production of aquatic vegetation and decomposition
- Remineralisation of nutrients – reside within floodplains versus export via runoff
- High productivity sustains biodiversity
- Built on annual recurrence of hydrological events

The vertical and lateral dimensions of streams and rivers

River corridors and floodplains

From taming to restoration

From taming to restoration

UN environment programme

Who we are ⌄ Where we work ⌄ What we do ⌄ Publications & Data

- Freshwater Challenge led by Colombia, DR Congo, Ecuador, Gabon, Mexico, Zambia
- Aims to restore 300,000km of rivers and 350 million hectares of wetlands by 2030

6 CLEAN WATER AND SANITATION | 14 LIFE BELOW WATER

https://www.youtube.com/watch?v=zZEG_ln3IYo

Stream and river ecosystems

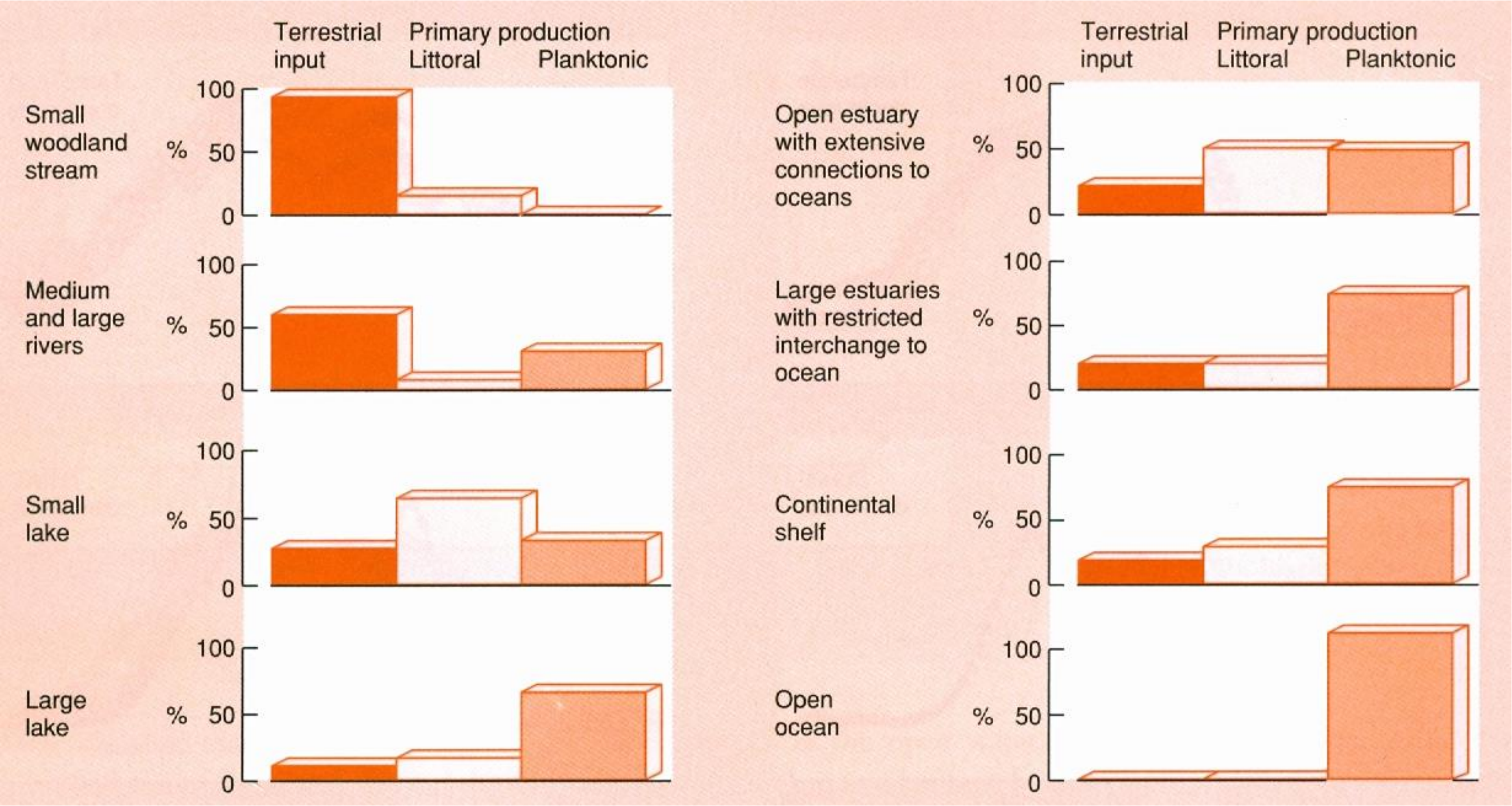
- Hydrodynamic exchange
- Three dimensions (longitudinal, vertical, lateral) of streams and rivers
- Basic bedforms
- Hydraulic geometry
- Sediment dynamics and consequences
- Flood pulse and fertility of floodplains

Ecosystem energetics

Where does the organic energy come from in lakes and river

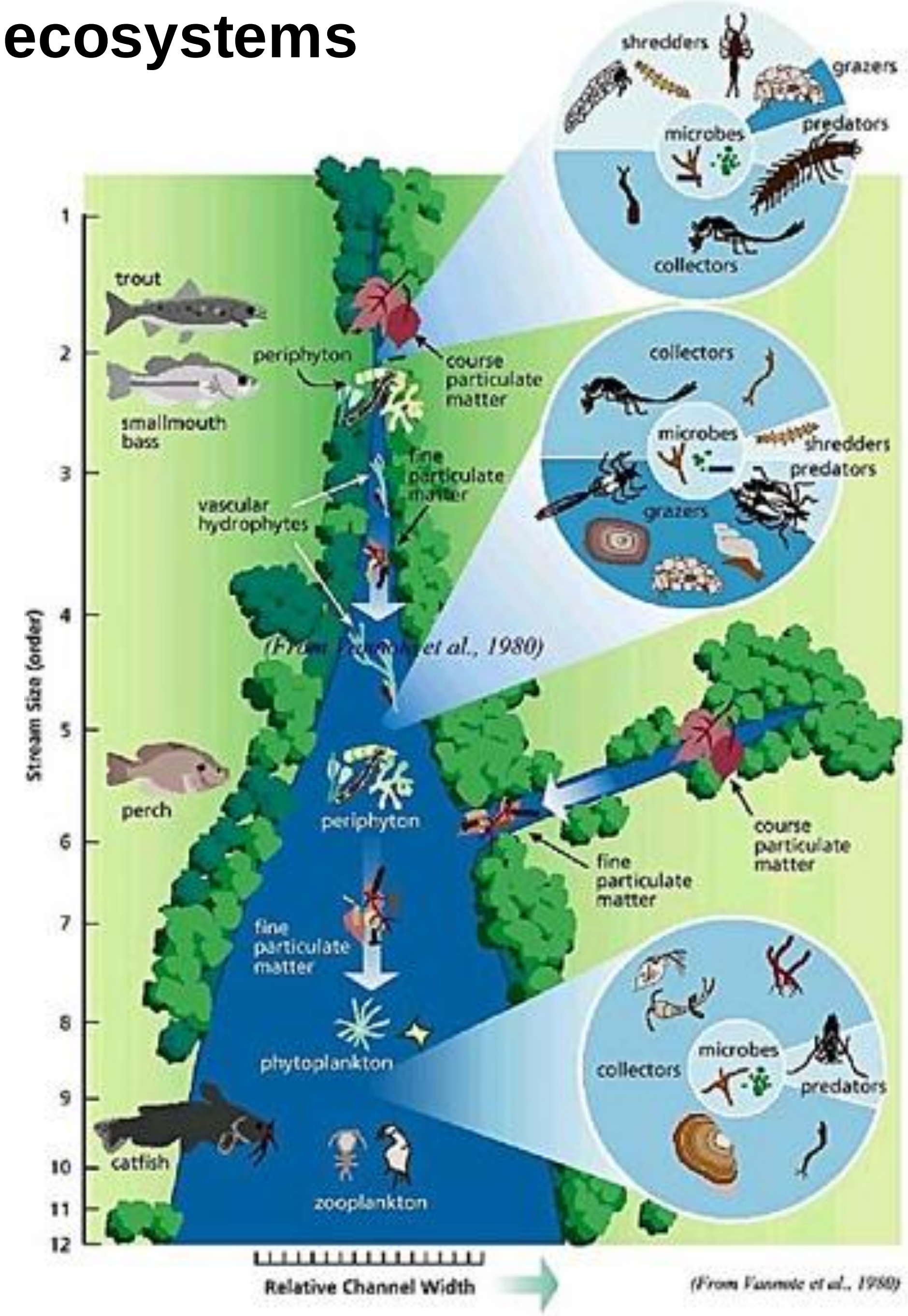
Different surface-to-perimeter ratios

Different sources and forms of energy



EPFL

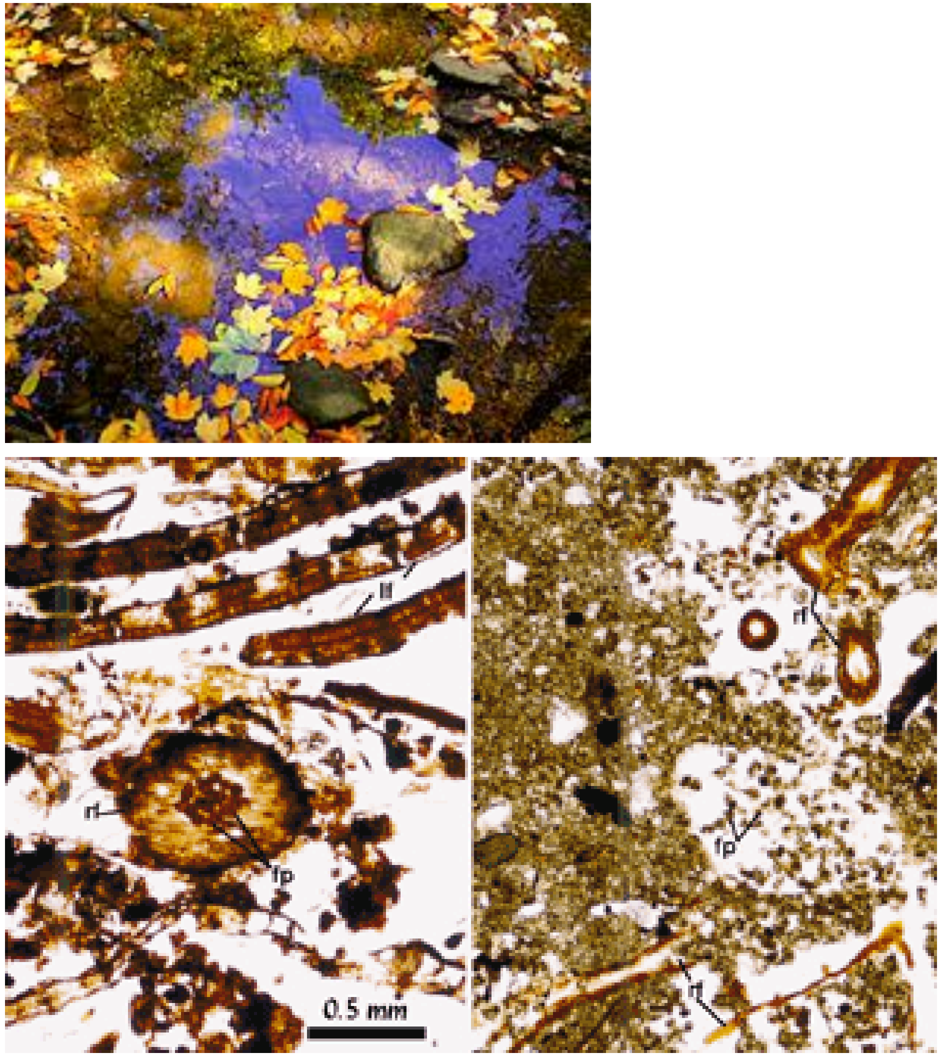
Various forms of organic carbon in aquatic ecosystems



Allochthonous (produced outside the ecosystem boundaries) versus autochthonous (produced inside the ecosystem boundaries) sources of organic carbon

Particulate organic matter (POC)
Dissolved organic carbon (DOC)

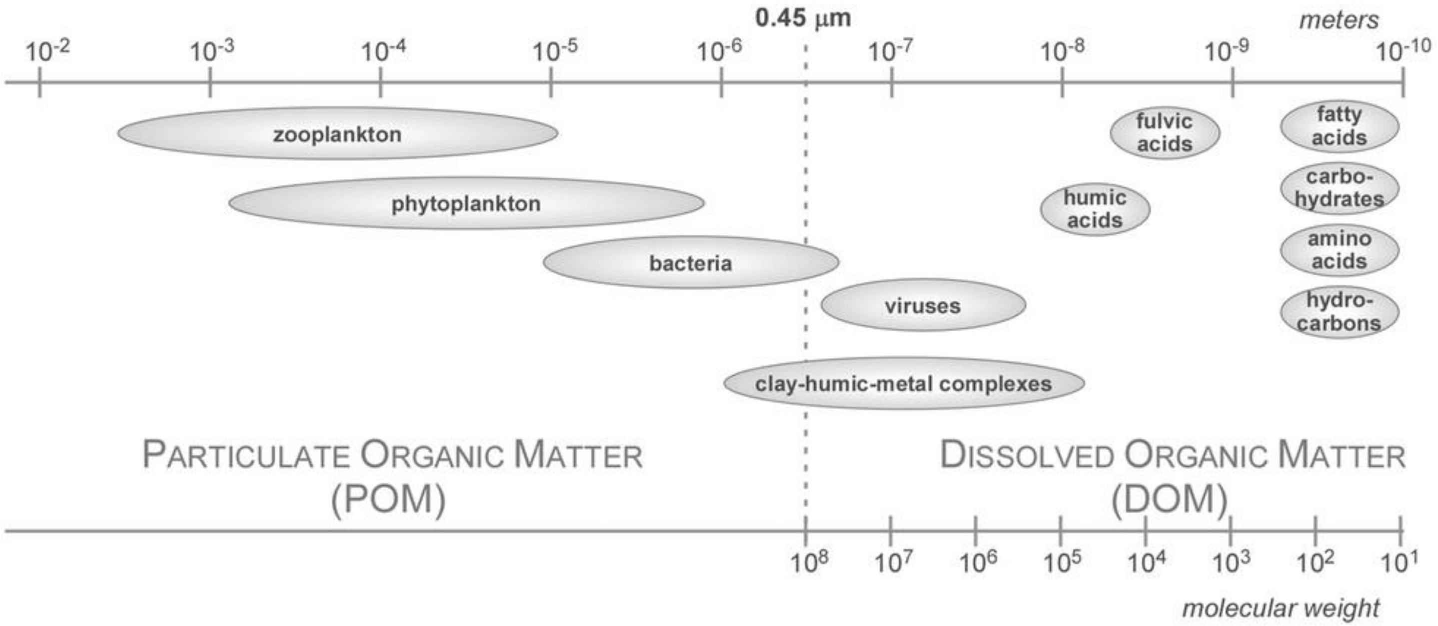
Coarse Particulate Organic Matter (CPOM)



Fine Particulate Organic Matter (CPOM)

Browning of surface waters

- Light regime
- Metabolism
- Contaminant transport



Dissolved Organic Matter (DOM)

How much DOM, FPOM and CPOM is transported by streams?

Decadal carbon discharge by a mountain stream is dominated by coarse organic matter

Jens M. Turowski[1*], Robert G. Hilton[2], Robert Sparkes[3,4]

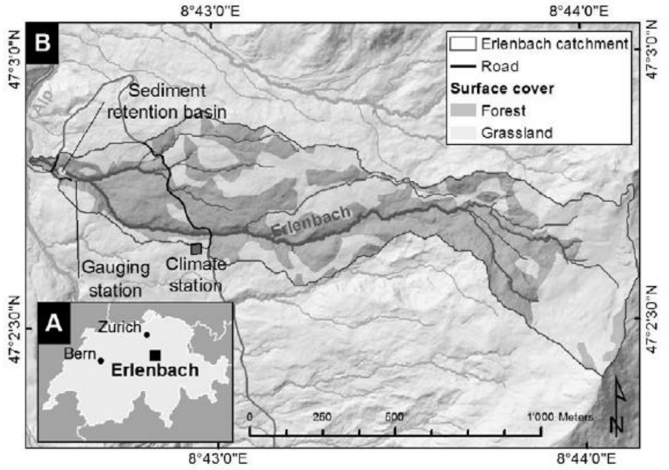


Figure 1. A: Location of the Erlenbach catchment in Switzerland. B: Map of the catchment.

How much DOM, FPOM and CPOM is transported by streams?

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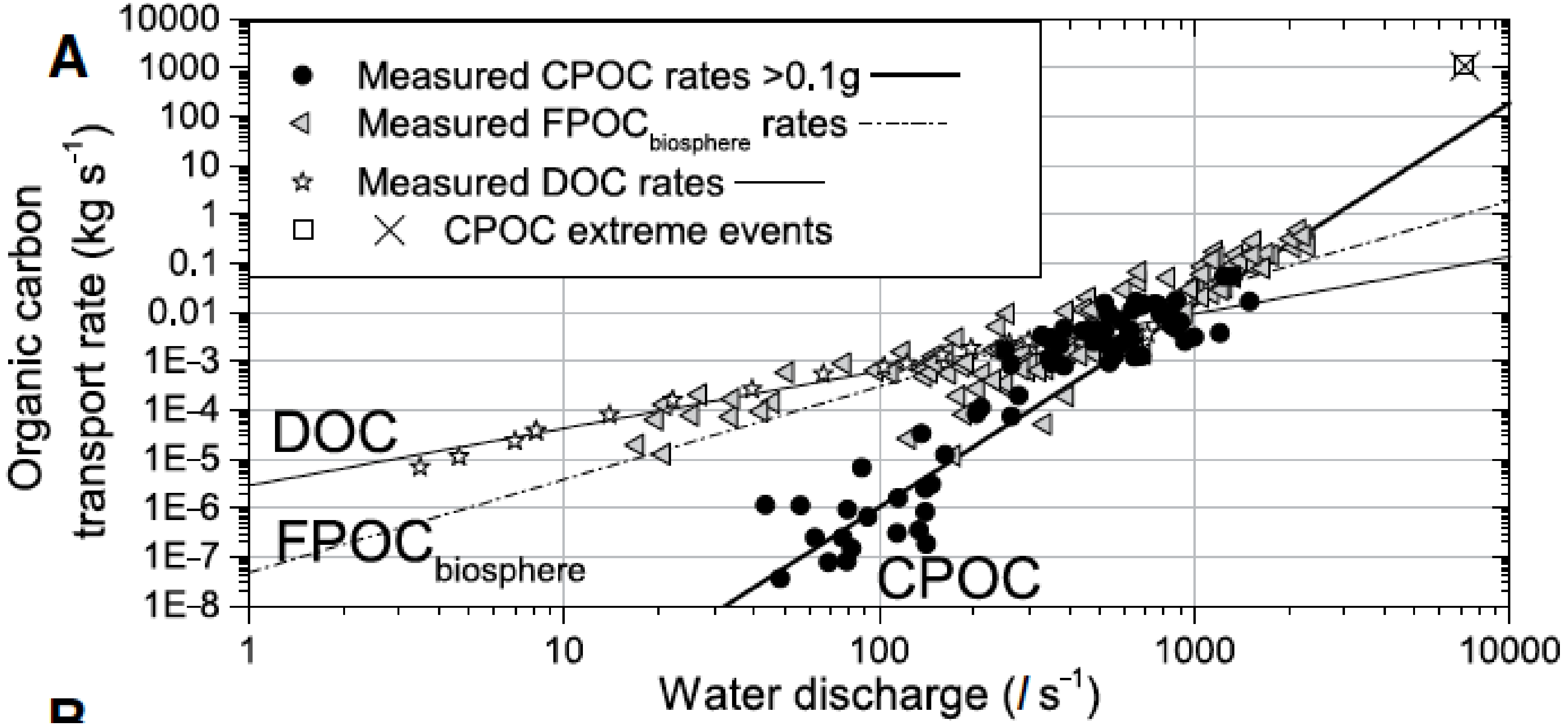
Jens M. Turowski[1]*, Robert G. Hilton[2], Robert Sparkes[3,4]

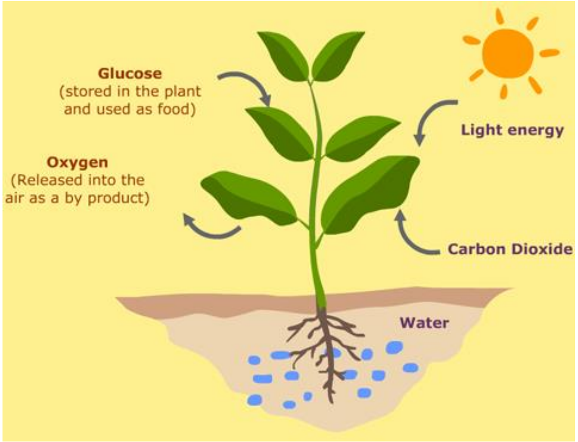


- DOC flux overall dominates
- Change point when larger debris (i.e., CPOC) are mobilized at a critical discharge (cf Hulmstroem curve)

- **DOC as the largest pool of reduced carbon in the world's aquatic ecosystems**
- **A major intermediary to the global carbon cycle**

DOC (or DOM): Energy basis for microbial heterotrophs

Photosynthesis (CHO)

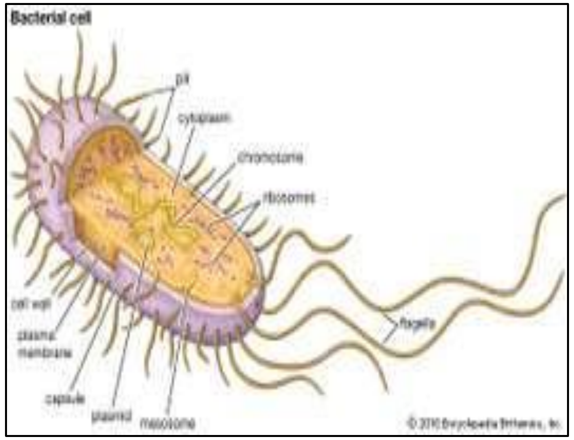


CO_2 assimilation

DOC →

← CO_2

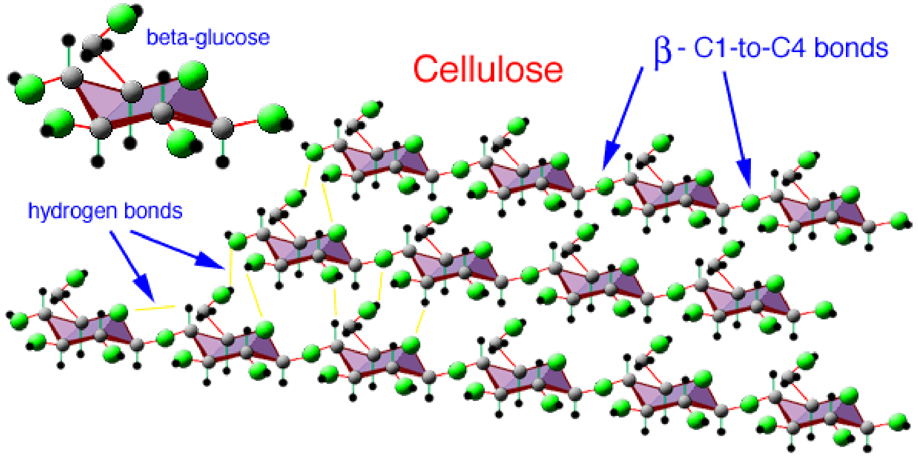
Respiration
DOC metabolism



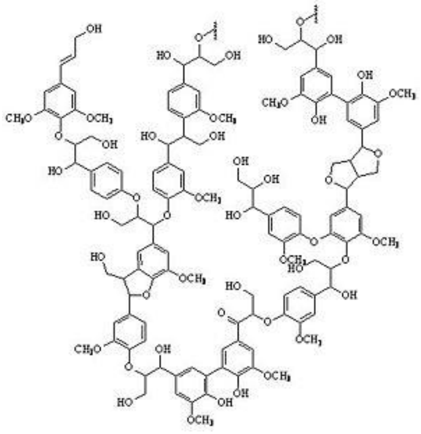
CO_2 and CH_4 production

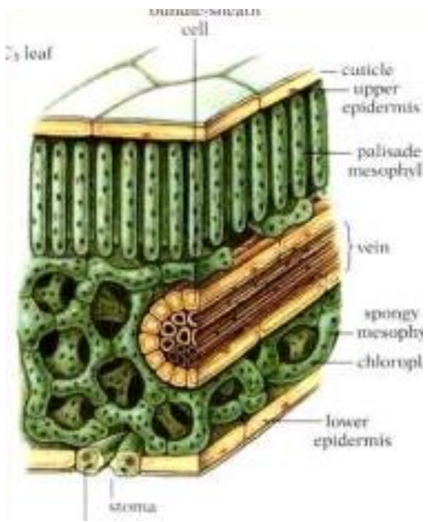
DOM pool

Humic substances (majority of the DOC)



The formation of humic substances occurs during the degradation of aquatic and terrestrial plant material (celluloses, hemicelluloses, and lignin) by fungi and bacteria.





Humic substances in soils and sediments can be divided into three main fractions:
humic acids, fulvic acids, humin

Generally highly abundant in freshwaters, colored (brown, yellow) and conferring color to the water

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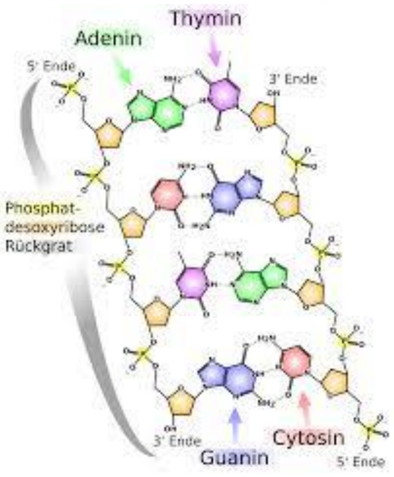
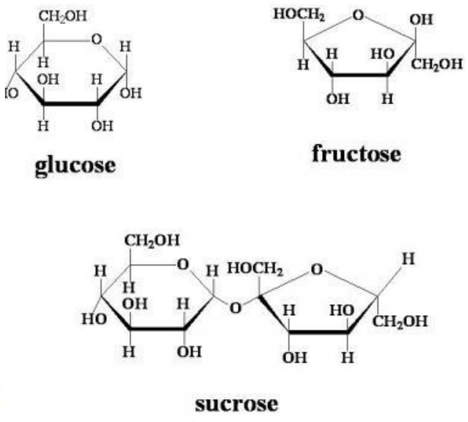
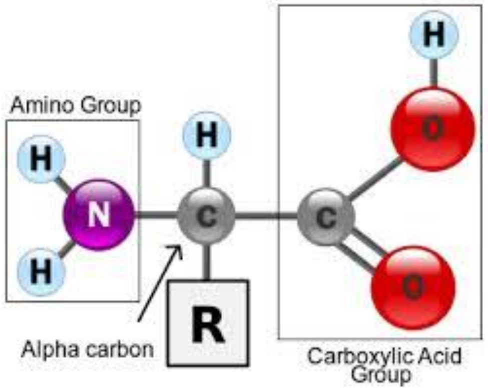
DOM Pool

Non-humic substances

Carbohydrates
Proteins
Peptides
Amino acids
Lipids
Waxes
Pigments...







- Biomolecules that also contain N and P
- Low concentrations in freshwaters
- High bioavailability to the microbial metabolism
- High turnover
- Important to biogeochemical cycling

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Chemodiversity of dissolved organic matter in lakes driven by climate and hydrology

Anne M. Kellerman[1], Thorsten Dittmar[2], Dolly N. Kothawala[1] & Lars J. Tranvik[1]

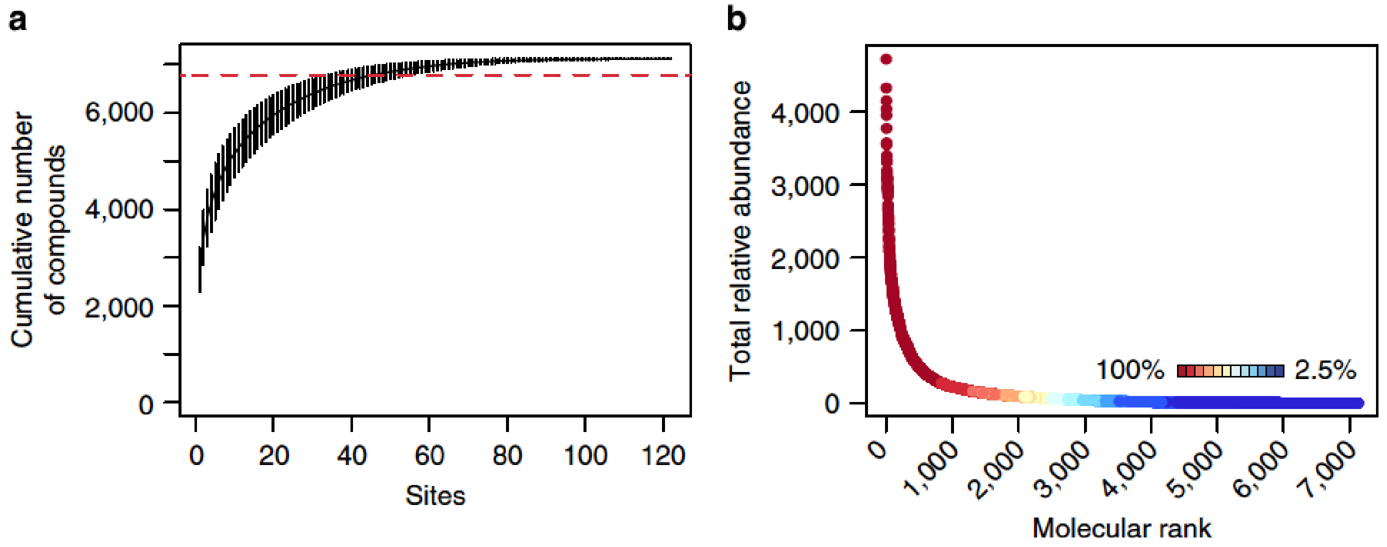
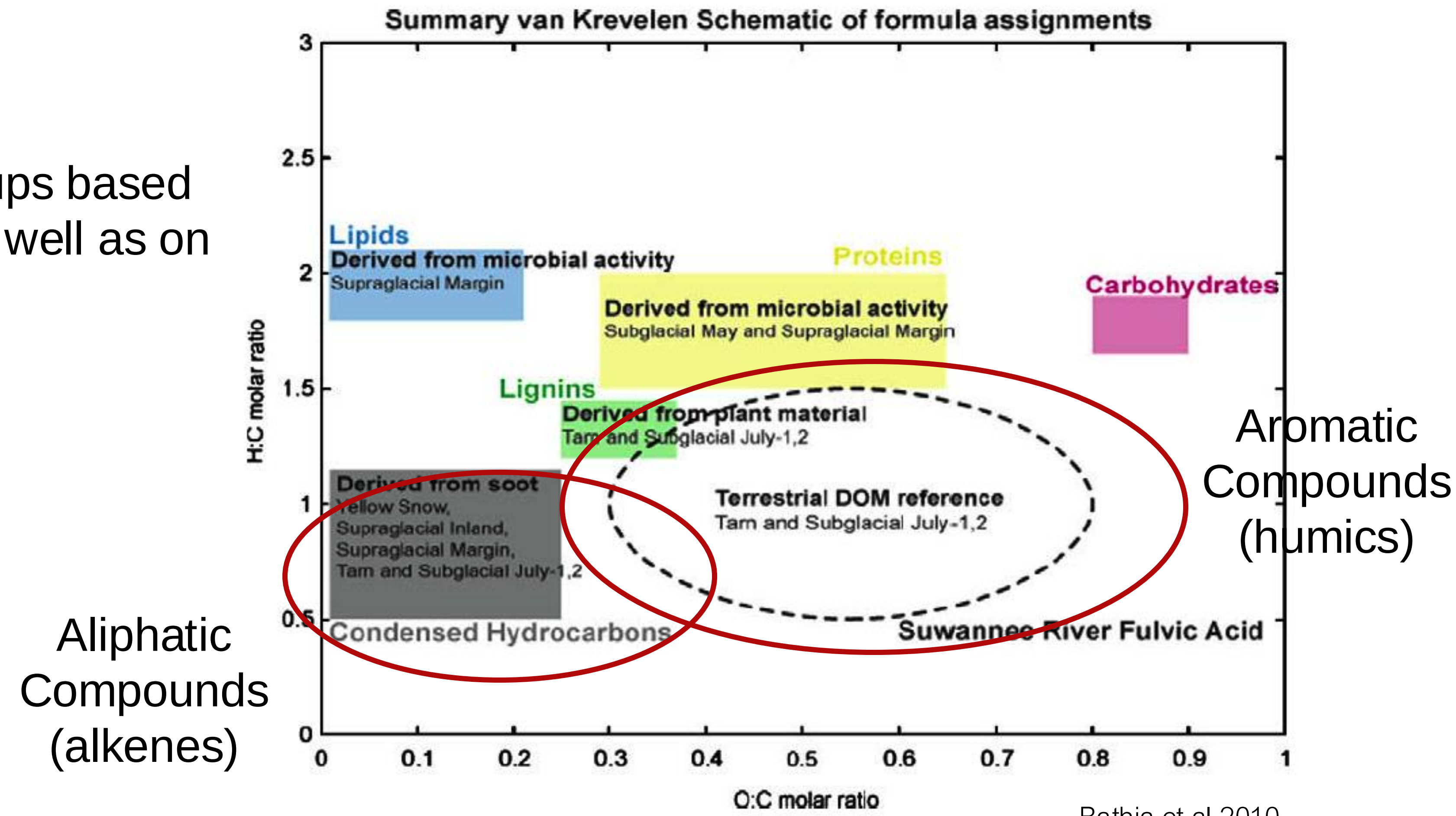


Figure 1 | Molecular distributions of FT-ICR-MS detected compounds across Swedish lakes. (**a**) Number of unique molecules with each added lake. Confidence intervals are calculated over 1,000 permutations. The red dotted line indicates 95% of compounds. (**b**) Rank abundance of the compounds across all lakes shows that the compounds with the highest total relative intensity are most ubiquitous. Molecular compounds are colour coded by the percentage of samples in which they occurred.

- Thousands of DOM molecules contained within the water of streams, rivers and lakes
- Distribution skewed towards relatively few abundant molecules and numerous non-abundant molecules

Van Krevelen diagram

Separating molecular groups based on O:C and H:C ratios, as well as on N and P



Bathia et al 2010

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Precipitation, hydrological residence time, annual temperature and chemodiversity as drivers of molecular-level patters DOM composition across Swedish lakes

Shown are chemical groups assigned to combustion derived polycyclic aromates, vascular plant-derived polyphenols, unsaturated phenolic compounds and aliphats

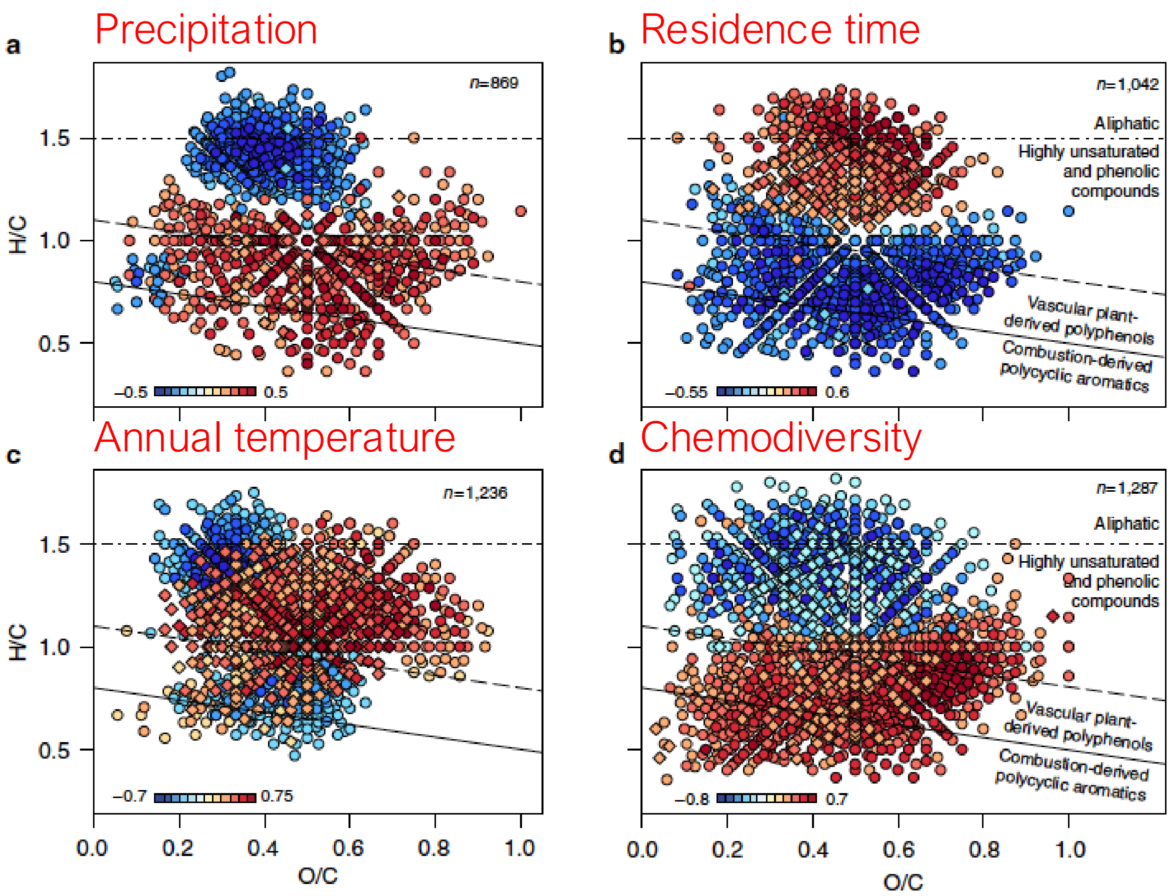

Figure 3 | Molecular-level DOM patterns across 120 Swedish boreal lakes. Significant Spearman rank correlation coefficients (*P*-value <0.02674) of individual molecules with (**a**) mean annual precipitation, (**b**) water residence time, (**c**) mean annual temperature and (**d**) the chemodiversity index. The colour scale indicates Spearman correlations between the intensity of individual molecules and mean annual precipitation, water residence time, mean annual temperature and chemodiversity index (red, positive; blue, negative). Circles indicate compounds without N and diamonds indicate N-containing compounds. Compound groups include combustion-derived polycyclic aromatics (aromaticity index[37] (AI) >0.66), vascular plant-derived polyphenols ($0.66 \geq AI > 0.50$), highly unsaturated and phenolic compounds ($AI \leq 0.50$ and $H/C < 1.5$), and aliphatic compounds ($2.0 \geq H/C \geq 1.5$). Compound category labels for delineation in panels (**b**) and (**d**) also apply to delineated regions in (**a**) and (**c**). Lines separating compound categories on van Krevelen diagrams are for visualization only and exact categorization may slightly differ. The number of positive and negative significant correlations can be found in Supplementary Table 2.

Wildfires and black carbon in streams and rivers

Global Charcoal Mobilization from Soils via Dissolution and Riverine Transport to the Oceans

Rudolf Jaffé,[1]*† Yan Ding,[1] Jutta Niggemann,[2] Anssi V. Vähätalo,[3,4] Aron Stubbins,[5] Robert G. M. Spencer,[6] John Campbell,[7] Thorsten Dittmar[2]*†

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- The incomplete combustion of organic molecules produces a chemically diverse suite of pyrogenic residues termed black carbon.
- The significance of black carbon cycling on land has long been recognized, and the recognition of dissolved BC as a major component of the aquatic carbon cycle is developing rapidly.

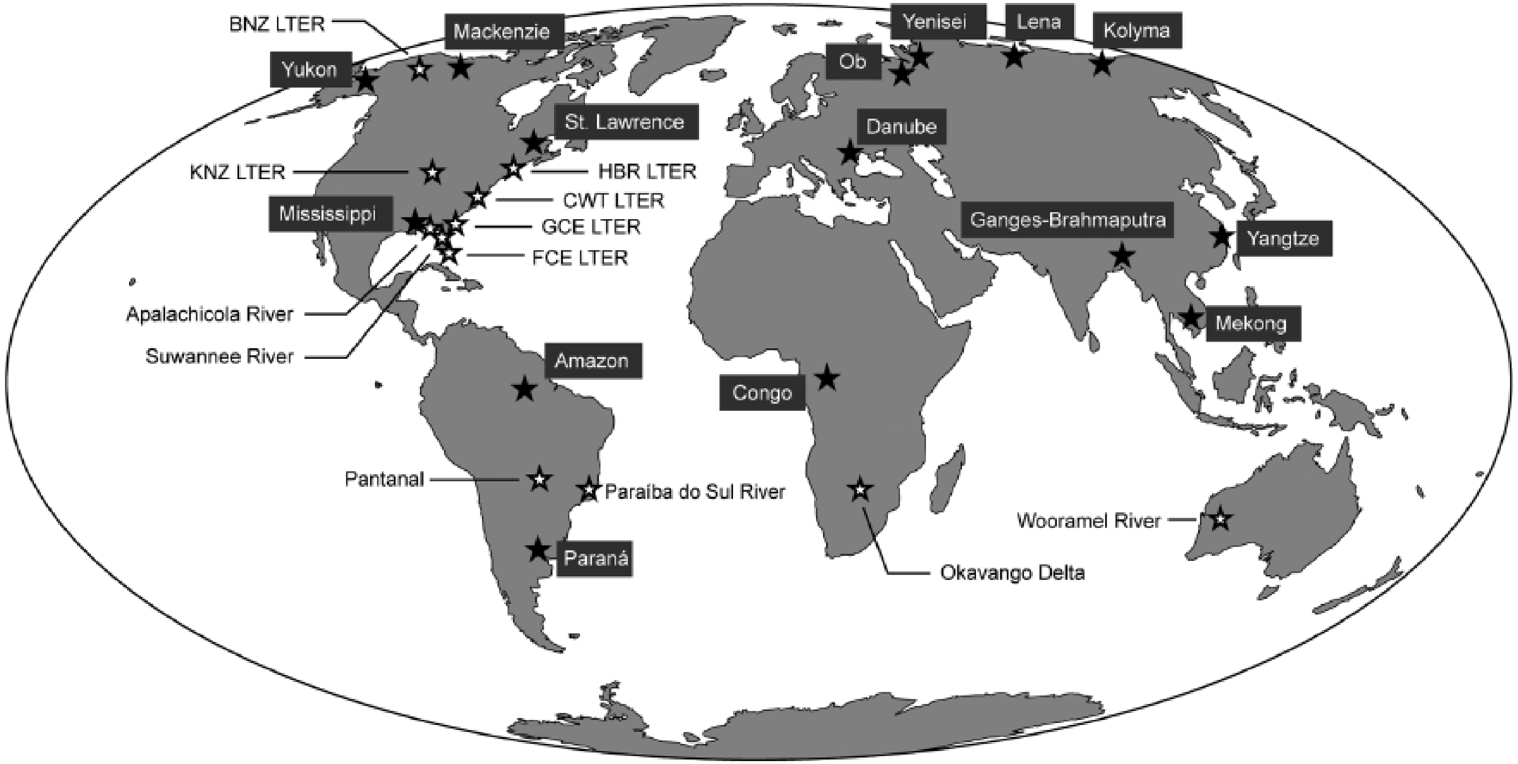

Fig. 1. Map of global freshwater DBC sampling sites. Black stars indicate major world rivers, and white stars indicate all other sites, including minor to intermediate rivers and wetland-associated streams, including Long-Term Ecological Research (LTER) sites. BNZ, Bonanza Creek; KNZ, Konza Prairie; HBR, Hubbard Brook; CWT, Coweeta; GCE, Georgia Coastal Ecosystems; FCE, Florida Coast Everglades.

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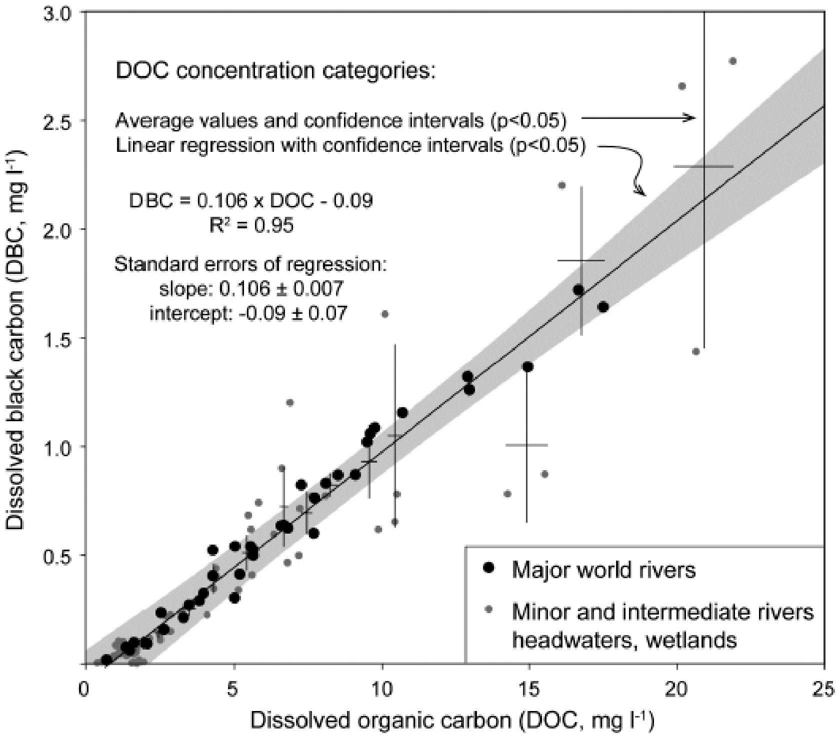

Fig. 2. DBC versus DOC concentrations of global rivers. The regression parameters are for the average values of 15 DOC concentration groups (crosses). Raw data regression yields the same slope and intercept, but the confidence intervals are smaller because of the larger number of samples.

- Black carbon: ca. 26.5±1.8 x 10^6 tons per year
- ca. 10% of DOC concentration
- Interesting because black carbon was long thought to be insoluble
- Highly oxidized, hence potentially of little relevance to the carbon metabolism

Wildfires and black carbon in streams and rivers

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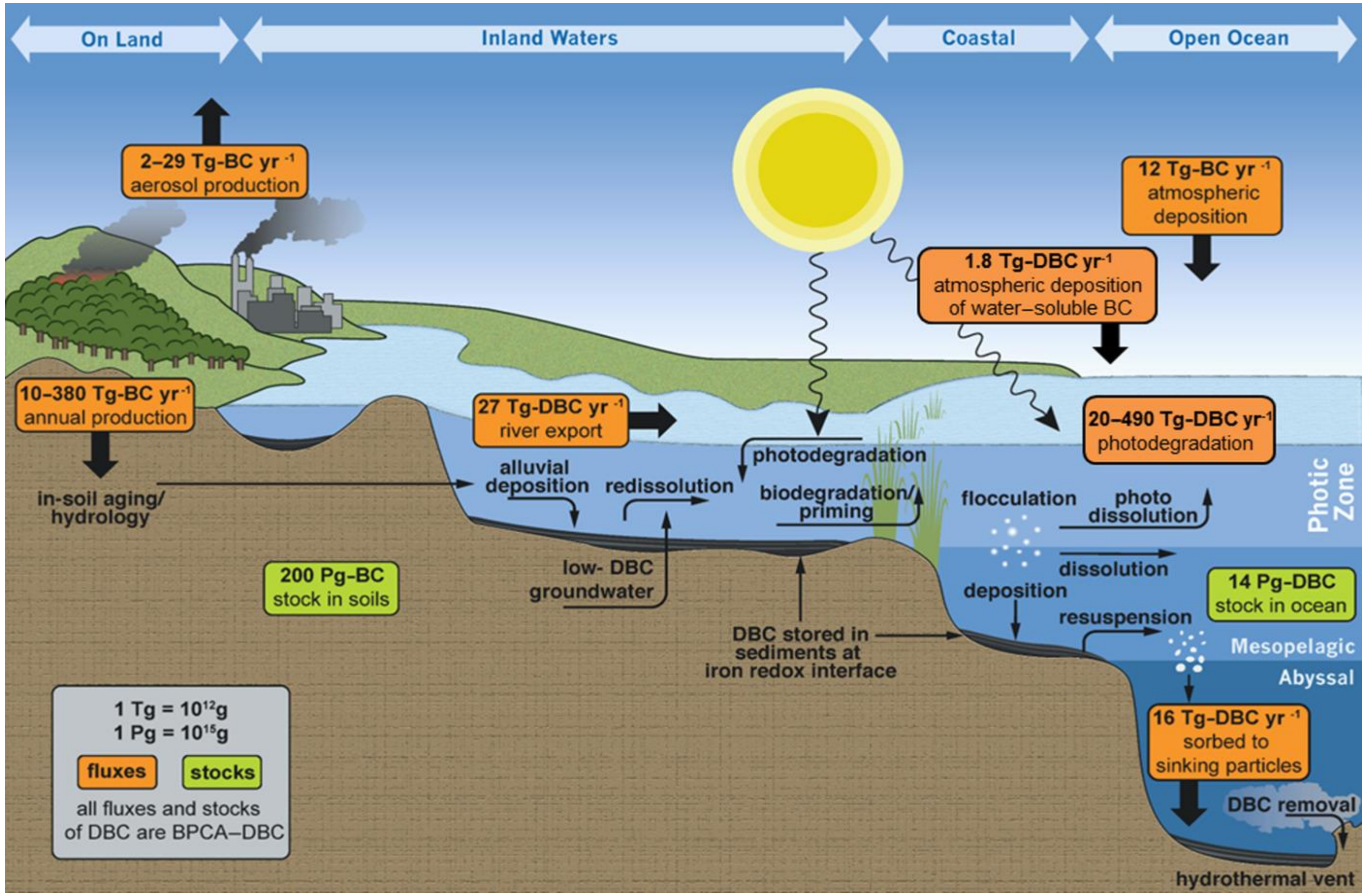
Dissolved black carbon in aquatic ecosystems

Sasha Wagner, Rudolf Jaffé, Aron Stubbins



Fate of dissolved black carbon

- Photodegradation by solar radiation
- Biodegradation (low) by microorganisms
- Flocculation and deposition (estuaries)
- Storage in oceans