LAND AND ECOLOGY

CE 766 LECTURE 6

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Image: https://upload.wikimedia.org/wikipedia/commons/thumb/4/44/AlgonquinBeaverDam.JPG/1200px-AlgonquinBeaverDam.JPG

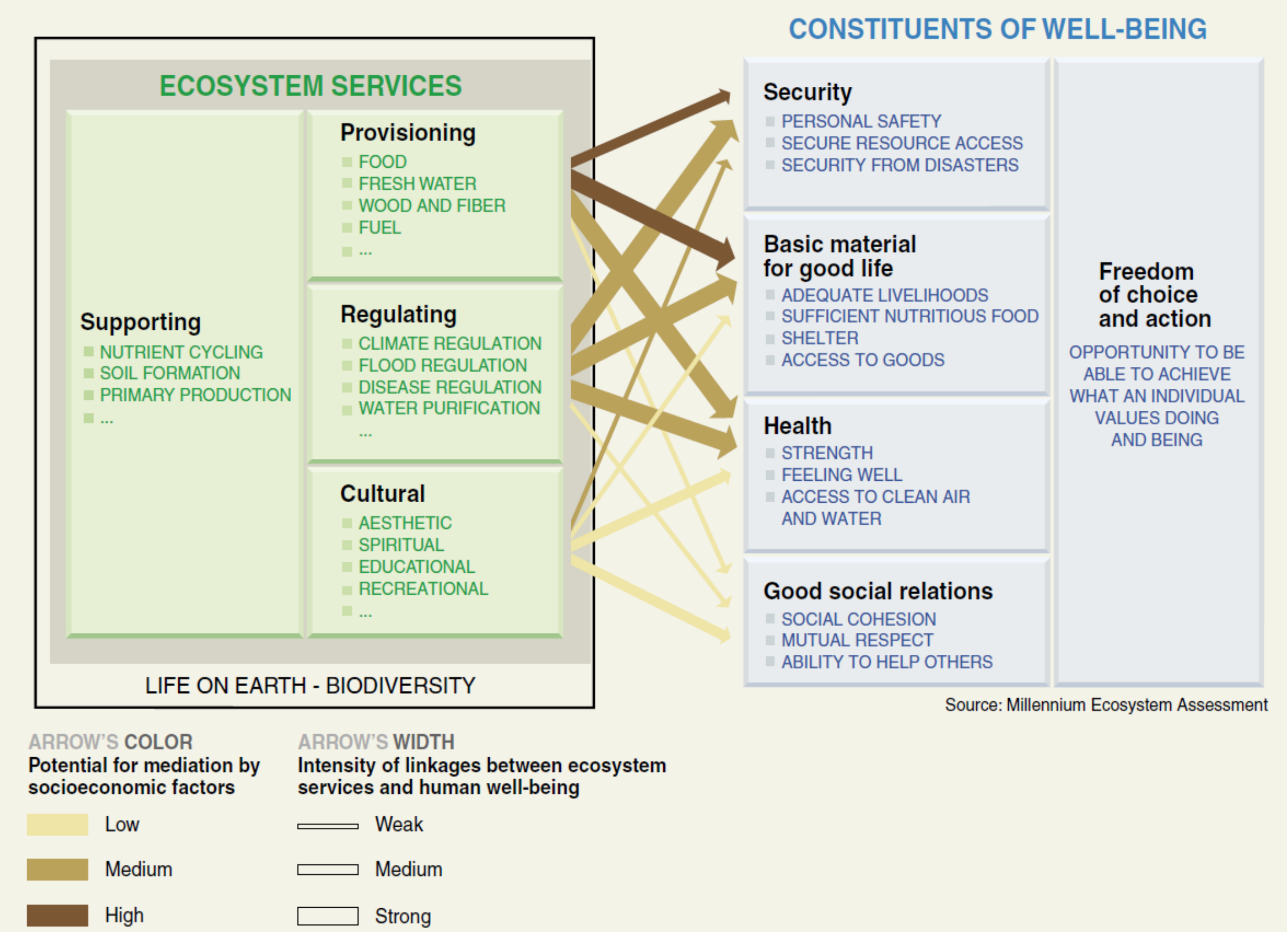
Today we will cover* …

- Introduction to catchment ecology and ecosystem services
- Coupling of catchment characteristics and ecosystem function
- Characterising an ecologically healthy catchment

*All material sourced from: Chapters 5 and 6 in Naiman, unless other specified.

INTRODUCTION TO CATCHMENT ECOLOGY

Ecosystem services: how do ecosystems support the human system?



Millennium Ecosystem Assessment 2005. General Synthesis Report. *World Resources Institute, Washington, DC.*

Why we should understand land and ecology of catchments?

- To gain a basic understanding of the linkages (two-way coupling) between catchment characteristics (its climatic, geomorphological, and hydrological) and catchment ecosystems
  - We need to know this so that we can better understand the impact of any management action on 'ecosystem services'
- We will find that catchment ecology is not only affected BY the catchment characteristics but also affects them (beavers!)

Ecology

noun

the branch of biology that deals with the relations of organisms to one another and to their physical surroundings.

- the political movement concerned with protection of the environment.

  noun: **Ecology**

Google Dictionary

Ecology … is the scientific study of interactions among organisms and their environment. It is an interdisciplinary field that straddles biology, geography, and Earth science. Objects of study include interactions of organisms with each other and with abiotic components of their environment. Topics of interest include the biodiversity, distribution, biomass, and populations of organisms, as well as cooperation and competition within and between species.

Ecosystems are dynamically interacting systems of organisms, the communities they make up, and the non-living components of their environment. Ecosystem processes, such as primary production, pedogenesis, nutrient cycling, and niche construction, regulate the flux of energy and matter through an environment. These processes are sustained by organisms with specific life history traits. Biodiversity means the varieties of species, genes, and ecosystems, enhances certain ecosystem services.

https://en.wikipedia.org/wiki/Ecology

The Beaver Dams

Image: https://upload.wikimedia.org/wikipedia/commons/thumb/4/44/AlgonquinBeaverDam.JPG/1200px-AlgonquinBeaverDam.JPG

Beavers make their home just as we do. They like to live in and around water!

Beavers live in the ***Ripairan zone***, including the stream bed
They fell large trees to form the basis of a dam
They are a keystone species in an ecosystem
They keep the watery systems where they reside 'healthy'

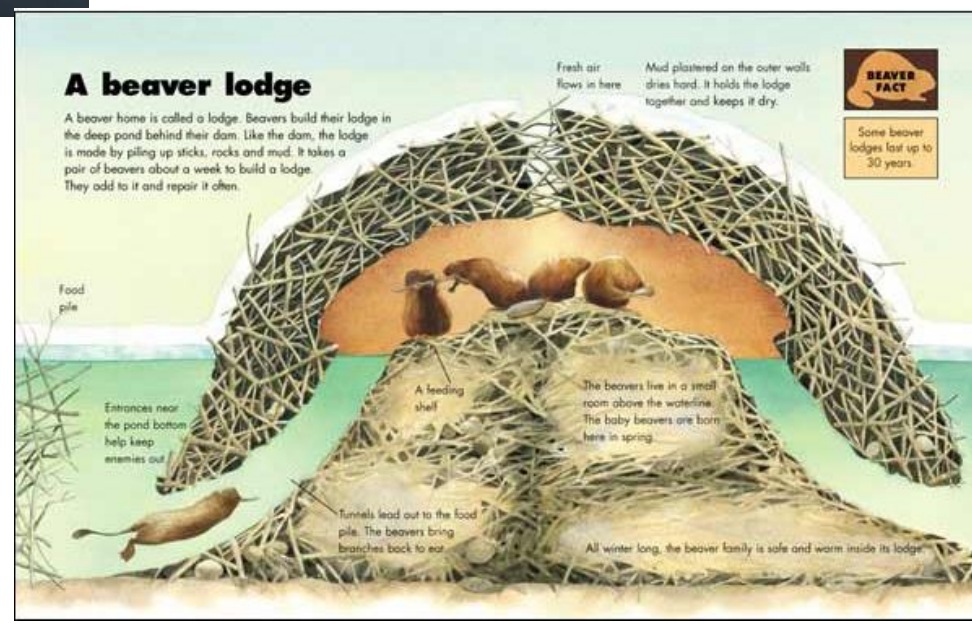
https://en.wikipedia.org/wiki/Beaver

Image: https://d1o50x50snmhul.cloudfront.net/wp-content/uploads/2017/05/24180000/gettyimages-566188109-800x533.jpg (left)

Beavers live in ‘lodges’.
The make these structures in the pool of deep water behind the dam they construct.
They are quite sophisticated with their lodge design, they leave a gap at the top for fresh air, and ‘plaster’ it with mud to hold it together and keep it dry.

Beavers alter the structure and dynamics of aquatic ecosystems with a minimum of direct energy or nutrient transfer

They alter hydrology, channel geomorphology, biogeochemical pathways, and community productivity.



Naiman, R.J., Melillo, J.M. and Hobbie, J.E., 1986. Ecosystem alteration of boreal forest streams by beaver (Castor canadensis). *Ecology*, *67*(5), pp.1254-1269.

Image: http://www.thirteen.org/13pressroom/files/2014/03/211R3878.jpg (left)
http://environmentalcore.org/wp-content/uploads/2016/02/beaver-lodge.jpg (right)

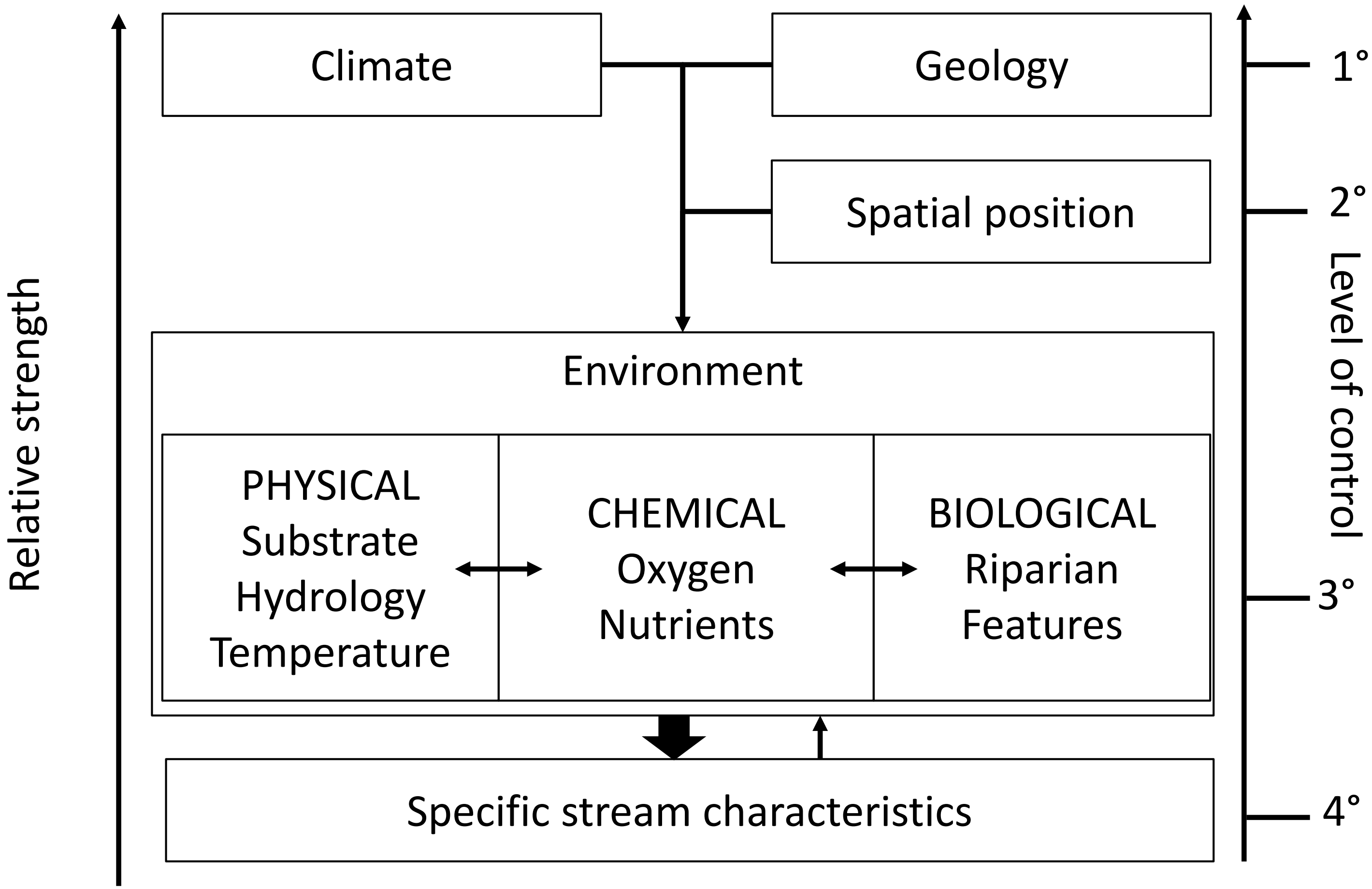
CATCHMENT CHARACTERISTICS AND ECOSYSTEM FUNCTION

Delivery and routing of water, sediment, and woody debris to the stream channel are the key processes determining the ecological health.

These are in turn affected by the physical setting of the stream. Thus understanding the physical controls that determine stream characteristics is essential.

Image: http://l450v.alamy.com/450v/f5ehgw/footbridge-over-a-stream-in-humid-cloudforest-at-2200m-elevation-on-f5ehgw.jpg (left)
http://c8.alamy.com/comp/F0414G/stream-arid-ladscape-firuzabad-fars-province-iran-F0414G.jpg (right)

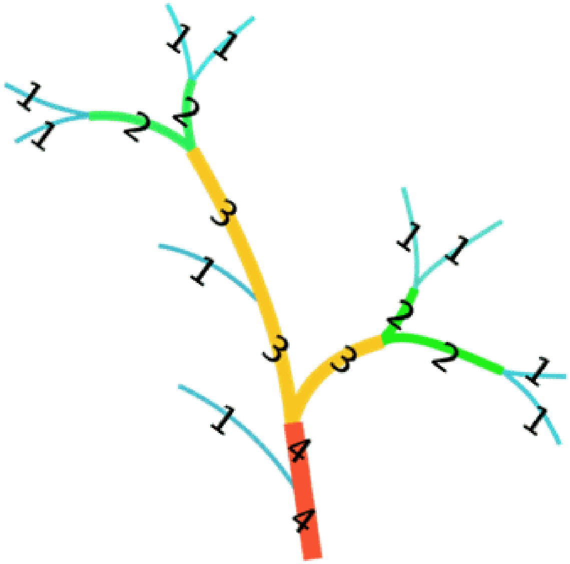
Factors influencing stream characteristics…

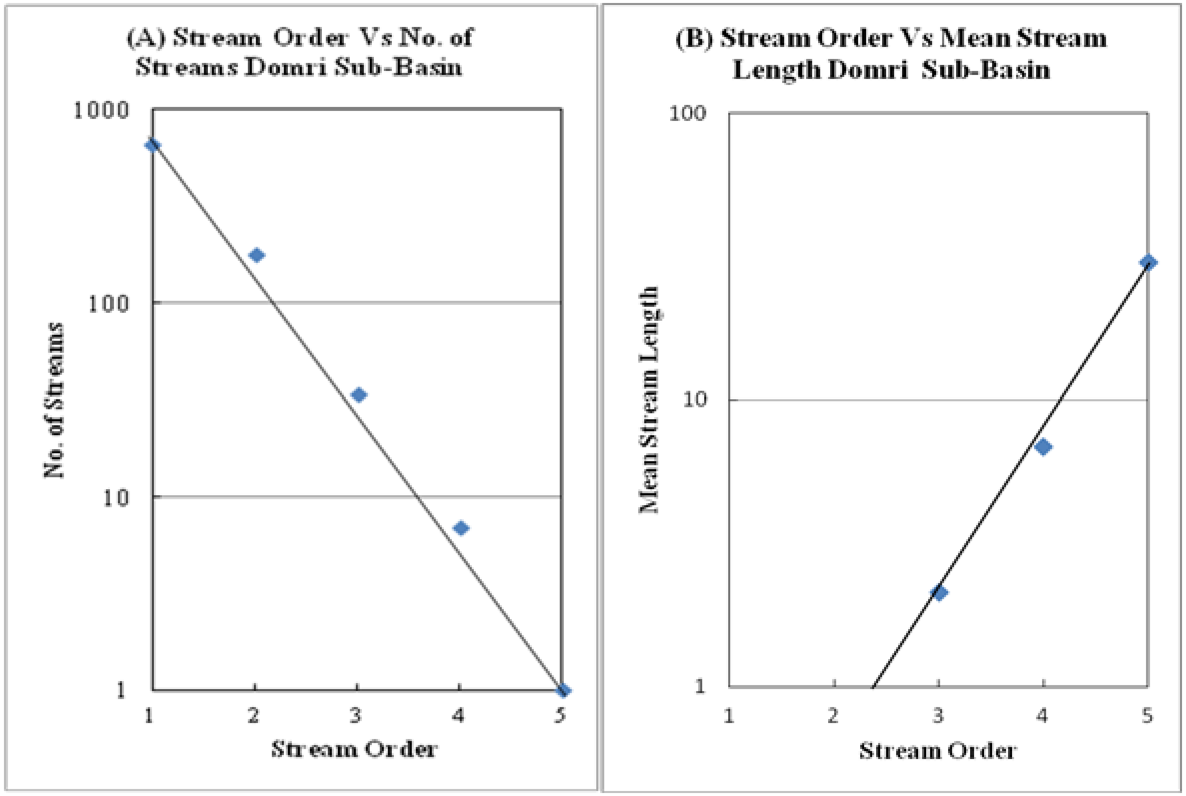


1. Basin geomorphology
2. Hydrologic patterns
3. Water quality
4. Riparian forest characteristics
5. Habitat characteristics

Figure 6.2 in Naiman. Different controls determining stream characteristics along with degree of influence.

Geomorphology is about the form and evolution of landscape structure





Channel networks control transport of water and nutrients through the landscape, not very different from veins and arteries of the human body!

Image: https://usgs-mrs.cr.usgs.gov/NHDHelp/WebHelp/image630.gif (left)
http://pubs.sciepub.com/jgg/1/1/5/image/fig3.png (right)

Geomorphic processes

- In low order channels
  - Represent the largest portion of channel length
  - Primary conduits for water, sediments and vegetative material routed from hill slopes to higher order rivers
  - **Catastrophic erosion from landslides, post wildfire, and debris flows**
  - Steep gradients (>8 degree) overall but may have lower gradients over shorter lengths (stepped profile)
  - Debris jams contribute to discontinuous sediment transport
  - Limited fluvial sediment transport, (~20% of total sediment yield)
  - Filled with colluvium (coarse unsorted sediments including silts and clays derived from landslides and debris flows
  - Boulders and woody debris

Geomorphic processes

- In mid order channels
  - Moderate to steep gradients (1 to 6 degrees), well armored channel banks, narrow valley floors
  - Single channels (except diversions around debris)
  - **Dam-break floods**
  - Transport majority of sediments delivered to them instead of storing them
  - Stochastic nature of sediment supply by debris flows and landslides
  - Spatial variation in channel form can be significant
  - Boulder, gravel, and sands, large organic debris in jams

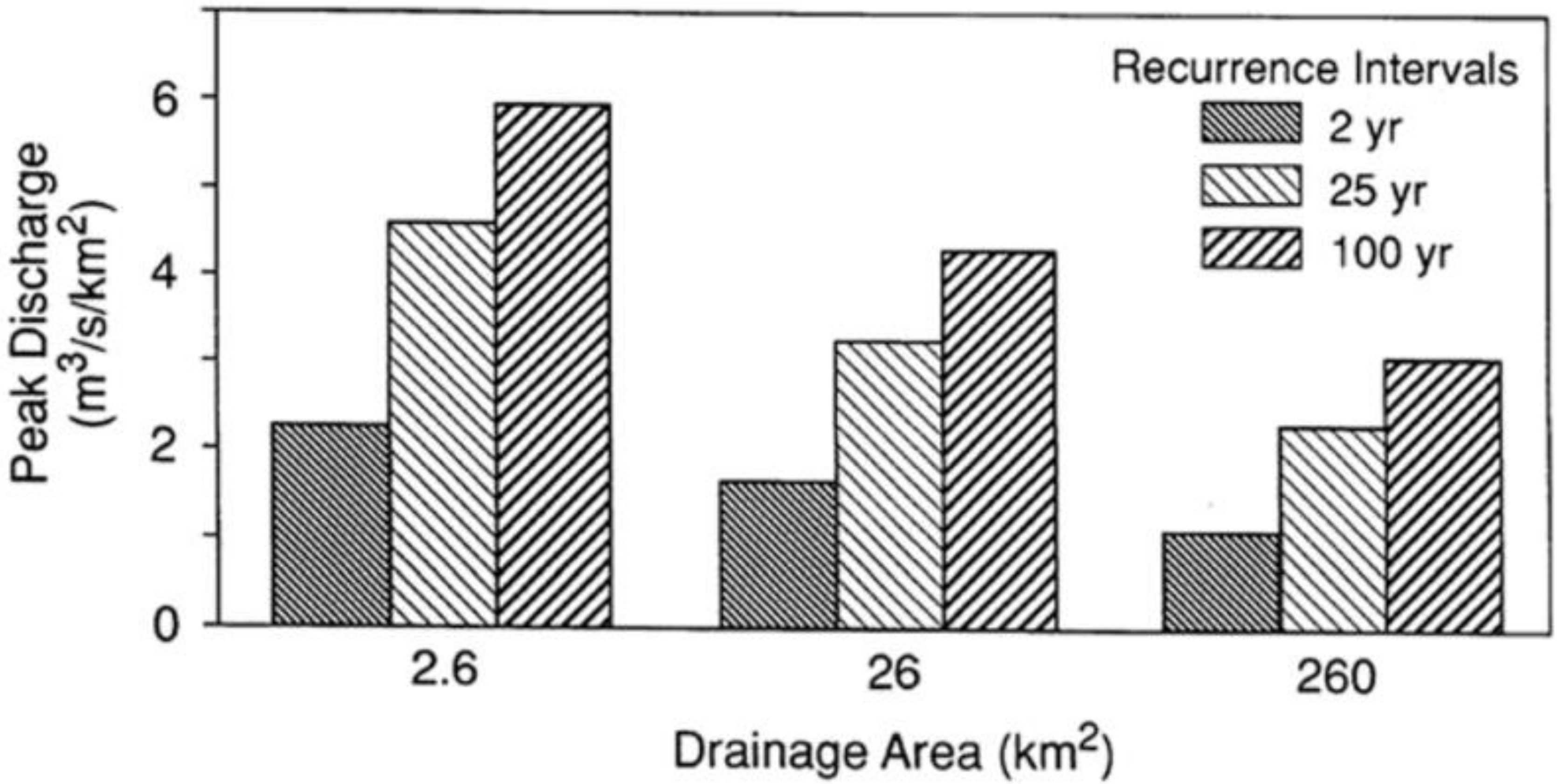
Geomorphic processes

- In high order channels
  - Integrate the diversity of erosion processes -> sediment supply is more steady in time and space
  - More uniform channel form (because of above)
  - Alluvial terraces and flood plains isolate the river from direct contact with hillslopes and low-order tributary basins
  - Selectively transport sediments (by size)
  - Coarsest sediment is found upper reaches and vice-versa
  - Braided channels, lateral migrations
  - Wetlands, ox bow lakes

Hydrologic patterns

- Timing and quantity of flow
  - Seasonality
  - Surface sub-surface exchanges
- Quantification
  - Discharge vs. time (in months for seasonality)
  - Flood frequency analysis for peak floods, floods of given return period
  - How does peak discharge (per unit area) scale with catchment area?
  - How does peak discharge (per unit area) scale with return period?

Relationship of peak discharge with drainage area and return period



Role of floods: disturbance events creating heterogeneous habitat and a recharge source for alluvial aquifers

Role of runoff processes

- Affects riparian vegetation, nutrient inputs, and stream productivity
- Lateral subsurface flow dominates in forests
  - Matrix flow through soil
  - Macropore flow through root channels, animal burrows, and soil pipes
- Variable source areas: expansion and contraction

Hydrologic patterns

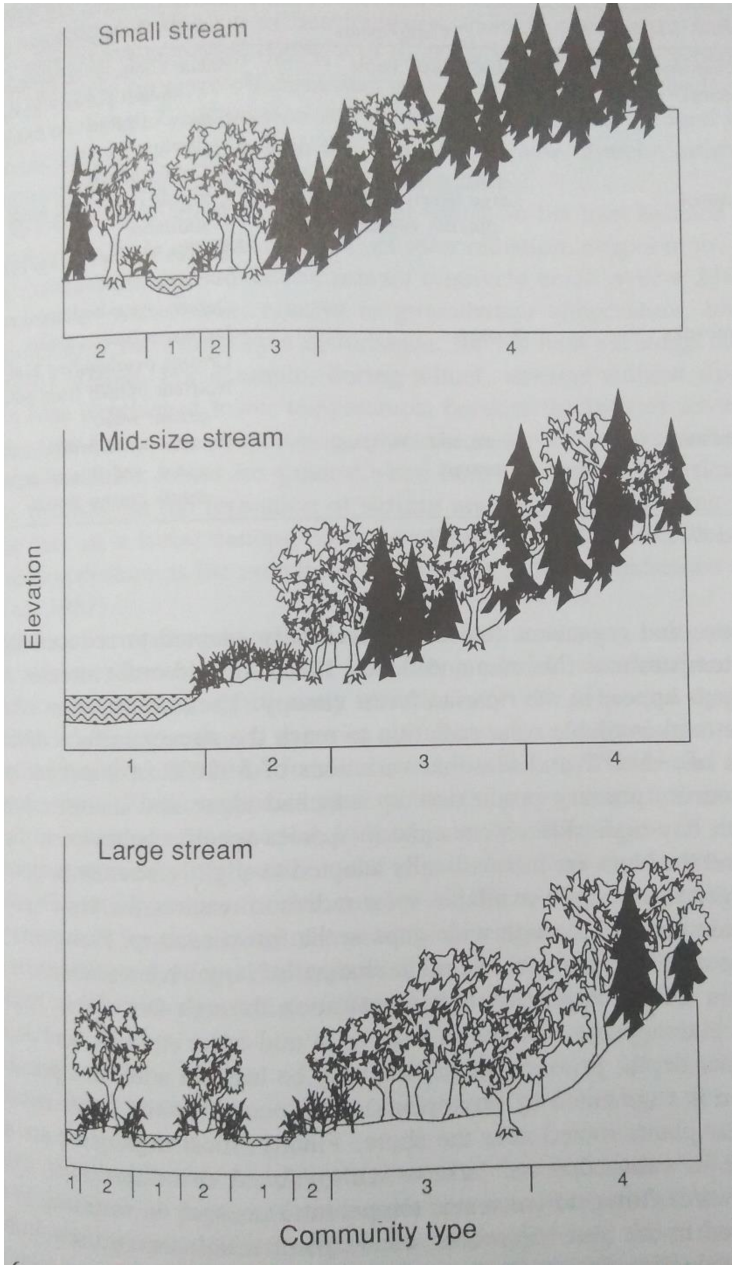
- Low order streams
  - Dominate at higher elevations
  - Major source areas for downstream surface water and alluvial aquifers
  - Limited water storage
  - Significant expansion contraction of variable source area
  - Low spatial connectivity of hyporheic zones
- Mid order streams
  - Wetlands as important storage areas
  - Duration of flood is shorter than higher order channels
- High order streams
  - High depression storage increases duration of flooding while dampening the peaks
  - More stable variable source areas

Water quality

- Integrates the full range of geomorphic, hydrologic and biological processes
- Affects the riparian, aquatic and hyporheic ecosystems
- Extremely complex cause-effect relationships
- Considerable variation in space and time
- Measured by:
  – Nitrogen (nitrates)
  – Phosphorus (phosphates)
  – Turbidity
  – Temperature
  – Dissolved oxygen
  – Buffering capacity (pH and alkalinity)
  – Organic nutrients (dissolved carbon)
  – Potential toxicants (insecticides, herbicides, wastes)

Riparian forest characteristics

- The riparian zone extends from the edge of the high water mark of the wetted channel towards the uplands
- Includes terrestrial areas where vegetation and microclimate are influenced by perennial or intermittent water associated with high water tables
- Continuous ribbon of vegetation along stream channel
- Control stream temperature, provide nourishment, bank stability
- Variation with stream size



Examples of riparian zones

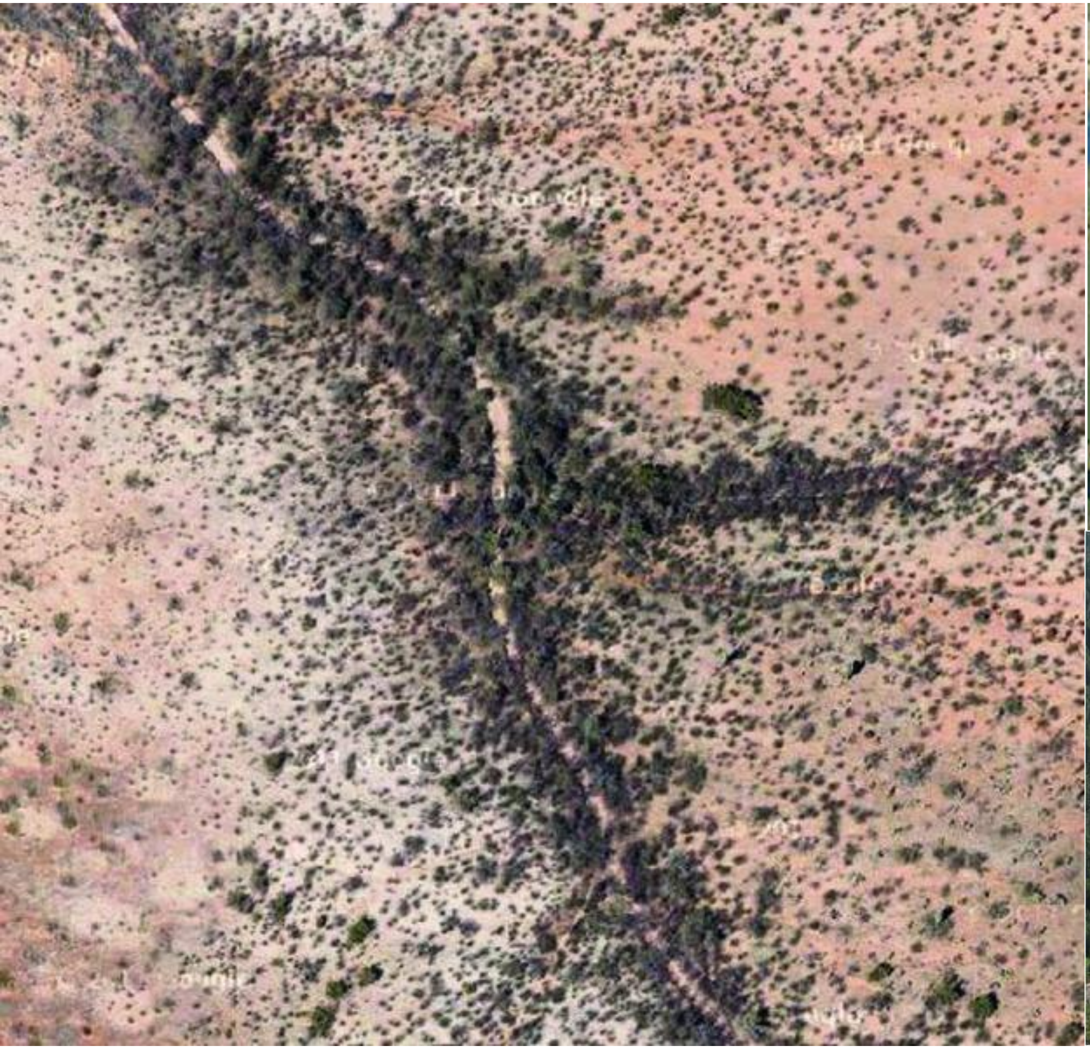
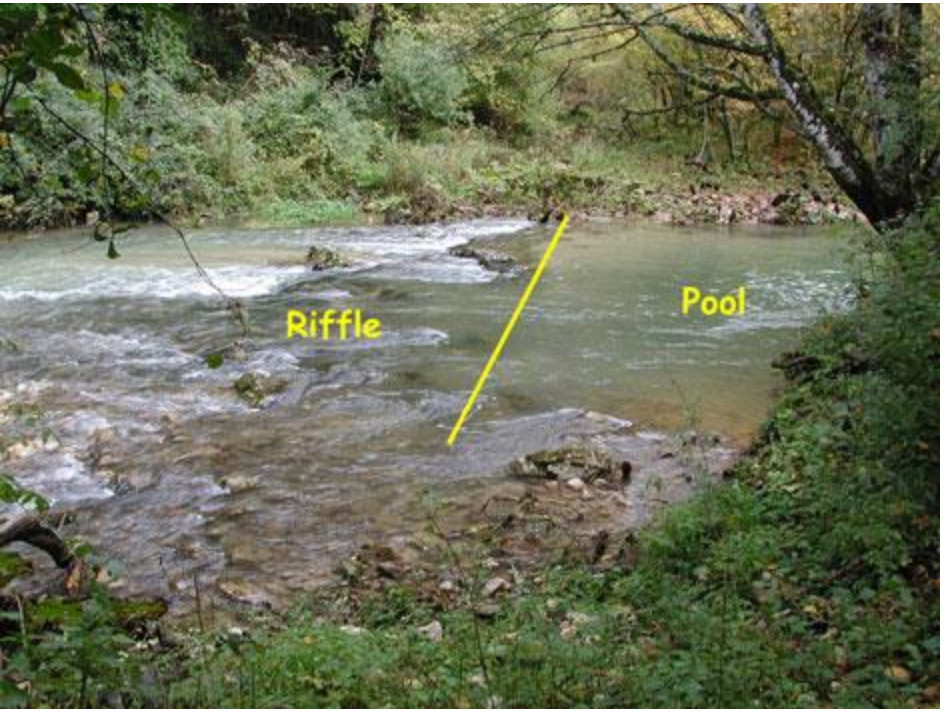


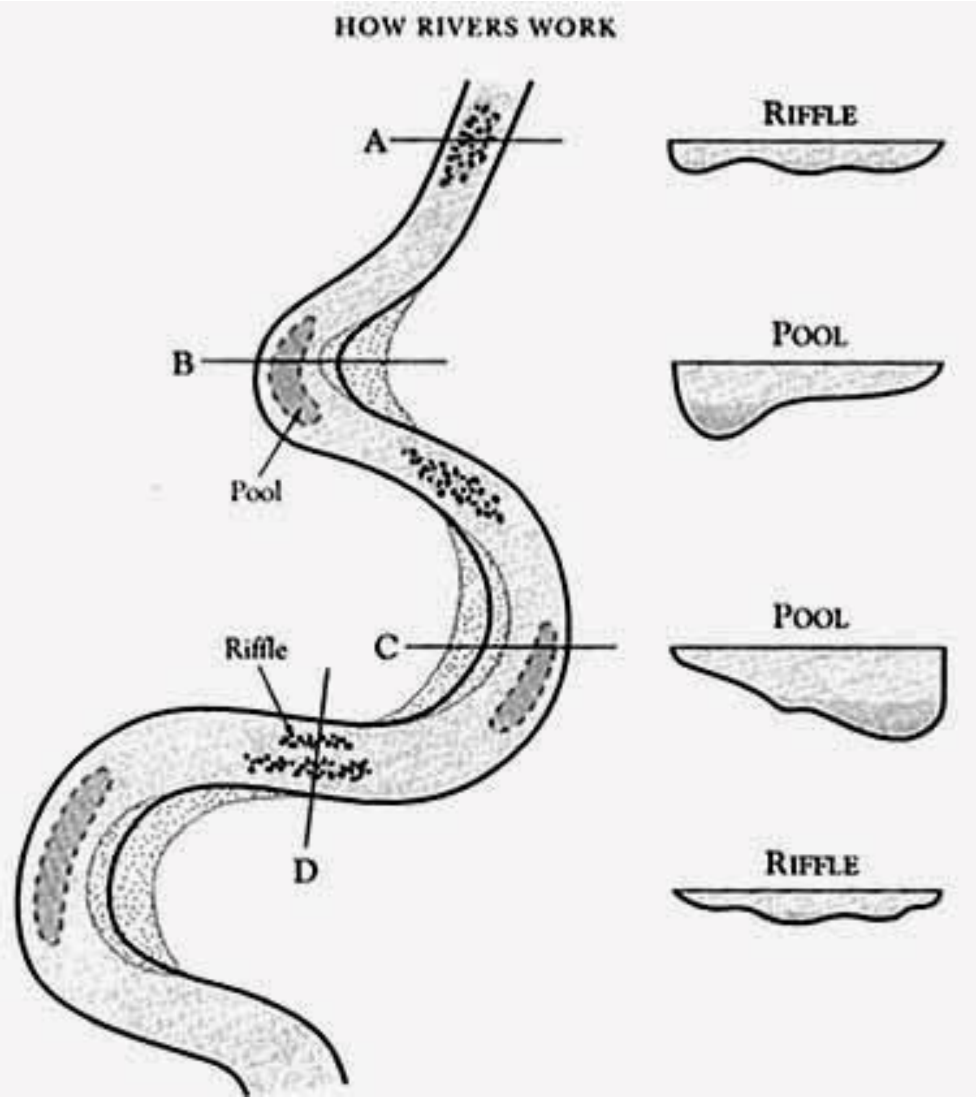
Image: https://www.researchgate.net/profile/Khalid_Alfarouk/publication/235442065/figure/fig2/AS:203002339172355@1425410937227/Riparian-habitat-in-the-Sonoran-Desert-of-Arizona-The-riparian-zone-is-seen-around-the.png (left)
http://www.agr.gc.ca/resources/prod/img/terr/images/RiparianAreaManagement1.JPG (top right)
https://www.fs.fed.us/pnw/lwm/aem/images/mfjd_cropped.jpg (bottom right)

Habitat characteristics

- Influence animal population dynamics, productivity, biodiversity, and evolutionary processes
- Are related to:
  - Riparian forest dynamics
  - Spatial and temporal variability of habitat availability
  - Maintenance of migratory connectivity
- Salman utilize habitats throughout the drainage network during different stages of their life cycles – connectivity is of fundamental importance
- Large woody debris has a unique role in controlling habitats along streams of low to mid order
- Fish communities are correlated with stream order and stream gradient
- Organisms themselves may alter habitats (beavers, deer, elks)

Pool and riffles





>many organisms prefer to stay in pools
>few organisms adapt to riffles

Image: http://www.life-inhabit.it/cnr-irsa-activities/images/stories/aniene.jpg (left)
http://2.bp.blogspot.com/-n529yUDOZv0/UoZ16y6BEXI/AAAAAAAAAEs/Zk7LFoTLeC0/s1600/pool-riffle.jpeg (right)

Ice/Debris jams cause flooding both upstream and downstream

http://www.floodsafety.noaa.gov/hazards.shtml

Affects navigation, hydropower operations, riverbank erosion, impede migration of aquatic creatures.
Snowmelt tends to occur simultaneously with ice jam break up, causing flash flooding

Main controls on water, sediment and woody debris delivery to channels and their routing

Component	Approximate hierarchical level	Factors considered	Sphere of influence
Basin geomorphology	1°-2°	A. Physiographic and geologic setting B. Significant geomorphic processes C. Natural disturbance regimes	Effects all factors except climate
Hydrologic patterns	1°-2°	A. Discharge patterns, flood characteristics, water storage B. Bedload and sediment routing C. Subsurface dynamics	Channel geomorphology and other physical characteristics, some aspects of chemical regime, riparian forest, in channel community dynamics
Water quality	3°-4°	A. Biogeochemical processes B. Fundamental parameters	Feedbacks to terrestrial vegetation and direct effects on chemical and biotic characteristics
Riparian forest characteristics	2°-3°	A. Light and temperature B. Allochthonous inputs C. Woody debris source	Most aspects of the physical, chemical, and biotic characteristics
Habitat characteristics	3°	A. Fish habitat preferences B. Fish community dynamics C. Spatial and temporal dynamics D. Woody debris accumulations E. Wildlife communities F. Trophic pathways	Influence in other biotic communities in stream and strong feedbacks to physical, chemical, and terrestrial dynamics

Table 6.1 in Naiman. Six fundamental components of ecologically healthy catchments in the Pacific Northwest coastal ecoregion

WHAT IS AN ECOLOGICALLY HEALTHY CATCHMENT?

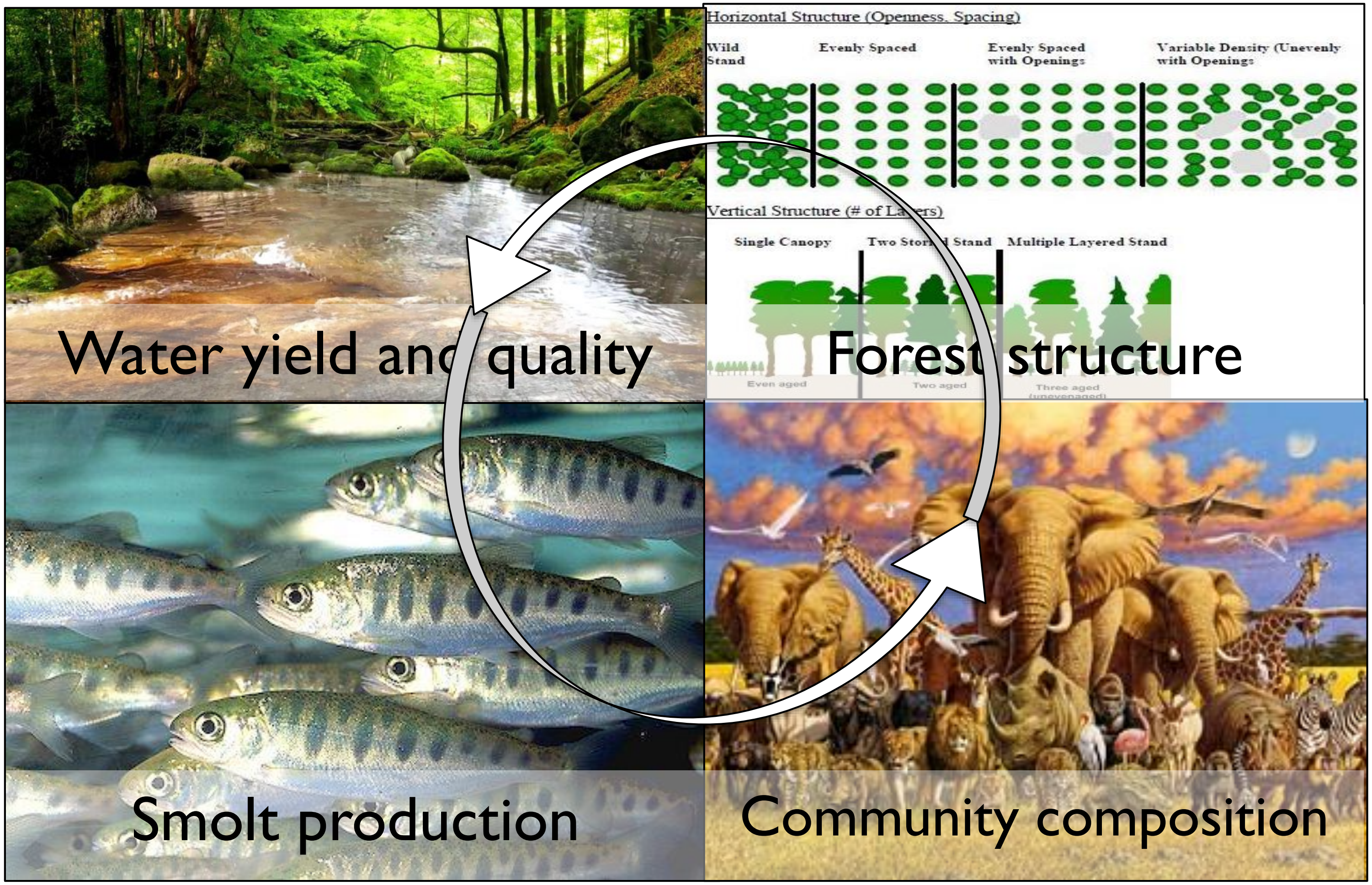
Ecological health refers to… functions affecting biodiversity, productivity, biogeochemical cycles, and evolutionary processes that are adapted to the climatic and geologic conditions in a region. Collectively, these functions can be a measure of system vitality.

Biological integrity … the ability to support and maintain 'a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region.

…ecological health … 'a biological system … can be considered healthy when its inherent potential is realized, its condition is stable, its capacity for self-repair when perturbed is preserved, and minimal external support for management is needed'

Karr and Dudley, 1981; Karr et al. 1986; Karr 1991

Characteristics of a healthy catchment



- Wildlife use
- Genetic diversity

Images: https://lewseportfolio.files.wordpress.com/2010/10/smolt-silvers_1782.jpg (bottom left)
http://www.careerlinecourses.com.au/wp-content/uploads/2015/04/Wildlife-Conservation.jpg (bottom right)
https://i.ytimg.com/vi/zVXnoloWu88/maxresdefault.jpg (top left)
http://outreach.oregonstate.edu/programs/forestry/sites/default/files/canopy_structure_diagram.jpg (top right)

Rivers are manifestation of the biogeochemical nature of the valleys they drain…understanding the inherent connectivity between terrestrial and lotic biotopes would lead to important predictions about the future structure and function of river ecosystems

Hynes, 1975

- How do we define connectivity in a catchment ecosystem?
- Key controls on specific population:
  - Matter (organic and inorganic) and energyr
    - Matter: water, nitrogen, phosphorus, carbon, …
  - Fluxes: Inputs, transport, storage, use (uptakes) of these

Four dimensions of structural connectivity

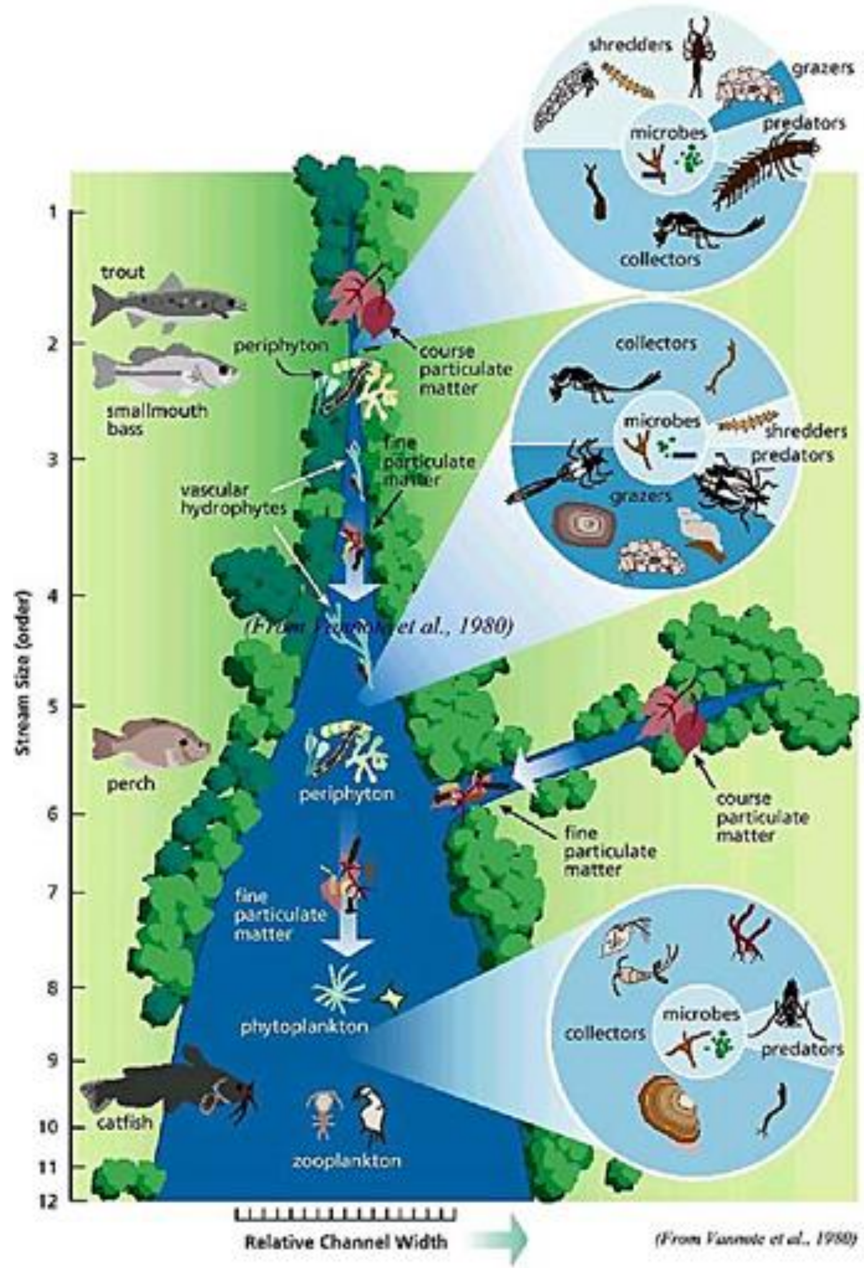
- Upstream-downstream connectivity
- Channel-hyporheic connectivity (groundwater)
- Channel-floodplain connectivity (riparian)
- Time

Some common terms before we look at the upstream downstream continuity concept

- Autochthonous (at the site) vs. allochthonous (coming from far away)
- Primary producers or autotrophs are plants (on land) or algae (in water) that make food from carbon dioxide to food, using light (photosynthesis) or oxidation/reduction (chemosynthesis, not of our interest today) as a source of energy
- Consumers:
  - Shredders: coarse particulate organic matter (>1 mm in size), eg. Woody debris, leaves, etc., caddisfly, stonefly
  - Collectors: fine particulate organic matter (0.01-1.0 mm), beetle
  - Grazers: microbes on rocks or woody debris, snails
  - Predators: prey on animal tissue, dragonflies

Upstream-downstream connectivity: The river continuum concept

- Species composition = f(stream order)
- Generally divided as:
  - Headwater (1st to 3rd order)
  - Middle reaches (4th to 6th order)
  - Lower reaches (7th or higher)
- Proportion of shredders, grazers, collectors, and predators* varies along the longitudinal gradient
- Biological dynamics = f(physical factors)
- P/R ratio (gross primary production/ community respiration)



Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R. and Cushing, C.E., 1980. The river continuum concept. *Canadian journal of fisheries and aquatic sciences*, *37*(1), pp.130-137.

Image: https://stroudcenter.org/wp-content/uploads/2016/01/river-continuum-concept.jpg

Upstream-downstream connectivity: The river continuum concept

- Headwaters
  - Influenced by riparian vegetation, shaded
  - Energy from allochthonous sources (litter from riparian vegetation)
  - Shredders and collectors dominate to break down the debris into biomass
- Middle order
  - Wider channels, more sunlight enters the stream
  - Balance between allochthonous and autochthonous inputs
  - Dominated by grazers and collectors
- High order
  - Fine particulate organic matter dominant
  - Decrease in light penetration as depth increases
  - Dominated by collectors

Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R. and Cushing, C.E., 1980. The river continuum concept. *Canadian journal of fisheries and aquatic sciences*, *37*(1), pp.130-137.

Biologically relevant characteristics vary with stream order

•Headwater streams have maximum soluble organic compounds as they have the maximum interface with landscape

•These are the dominant accumulator, processor, and transporter of materials from the terrestrial system

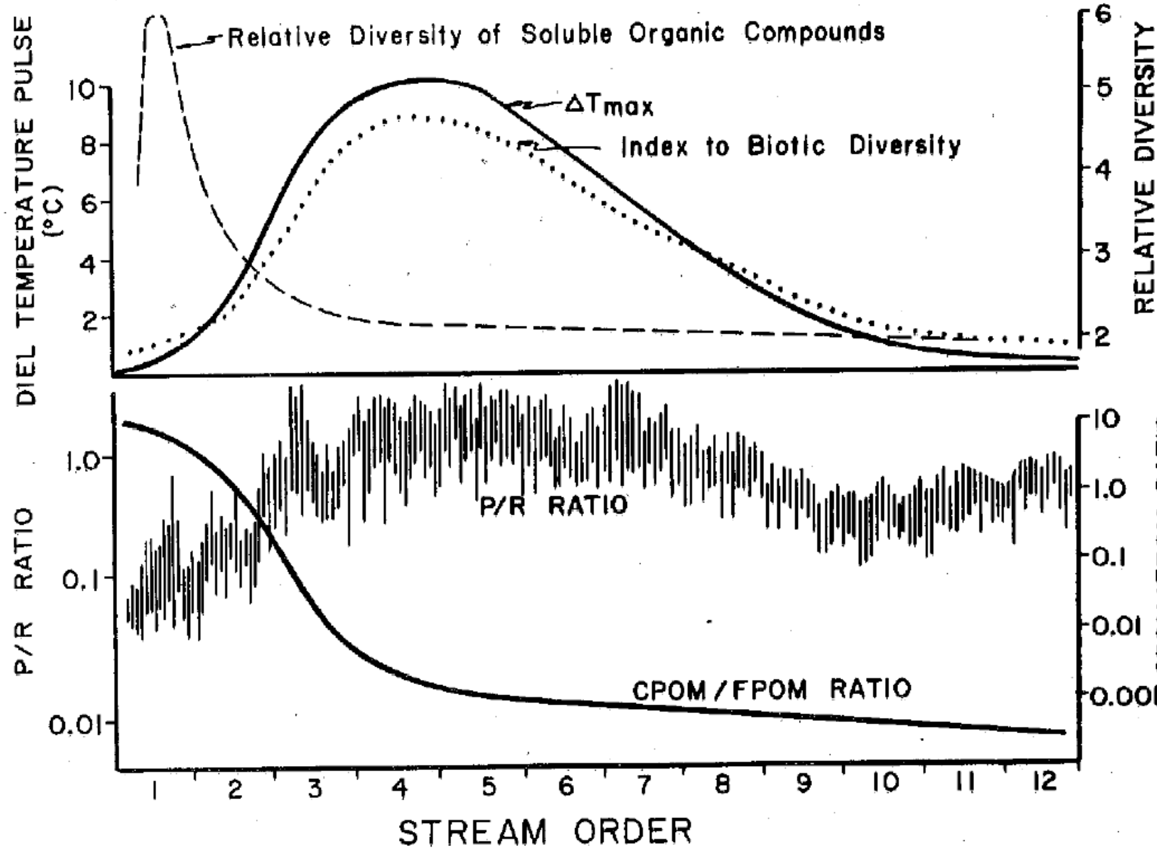


FIG. 2. Hypothetical distribution of selected parameters through the river continuum from headwater seeps to a twelfth order river. Parameters include heterogeneity of soluble organic matter, maximum diel temperature pulse, total biotic diversity within the river channel, coarse to fine particulate organic matter ratio, and the gross photosynthesis/respiration ratio.

Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R. and Cushing, C.E., 1980. The river continuum concept. *Canadian journal of fisheries and aquatic sciences*, *37*(1), pp.130-137.

Role of temperature

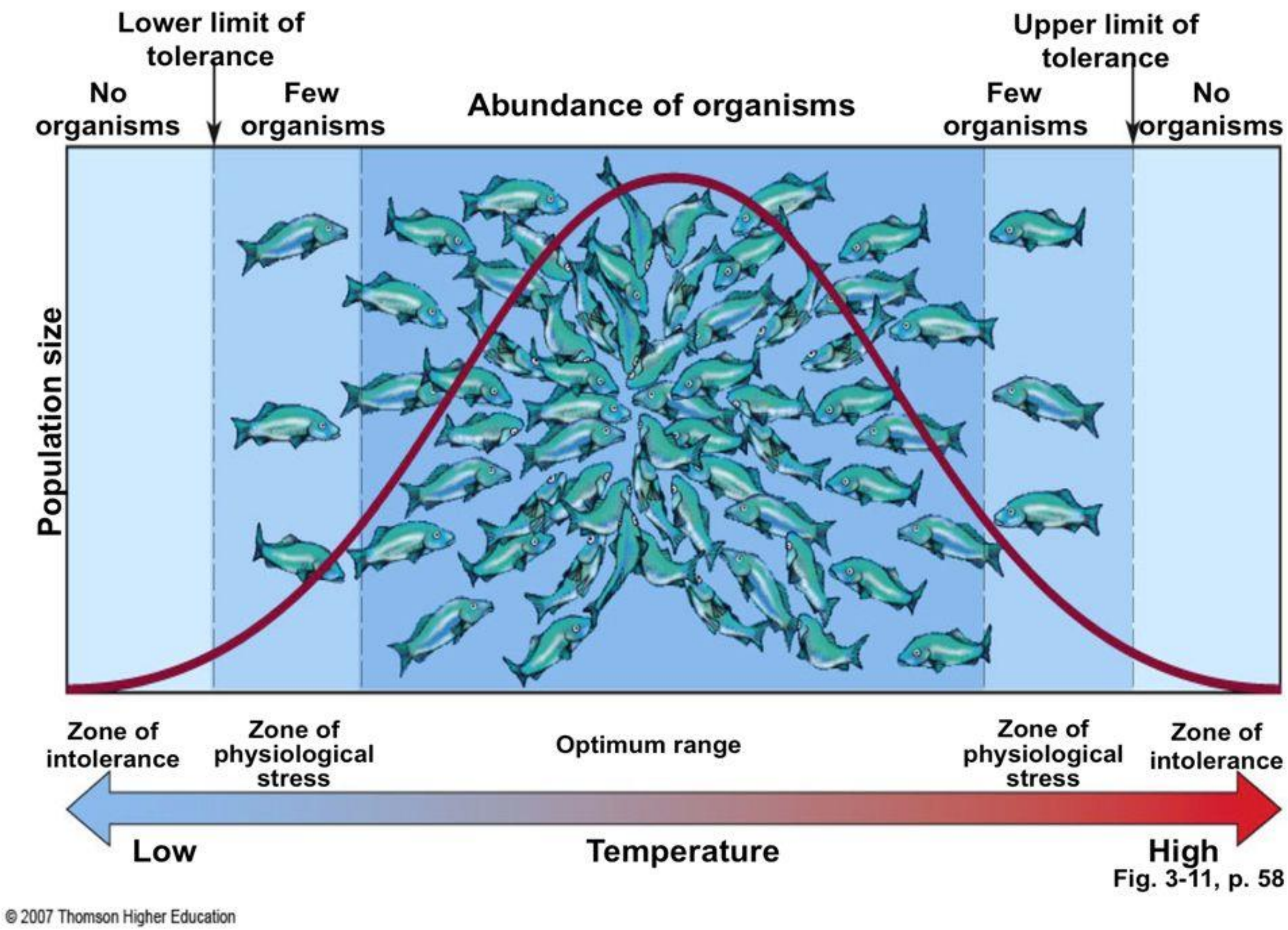


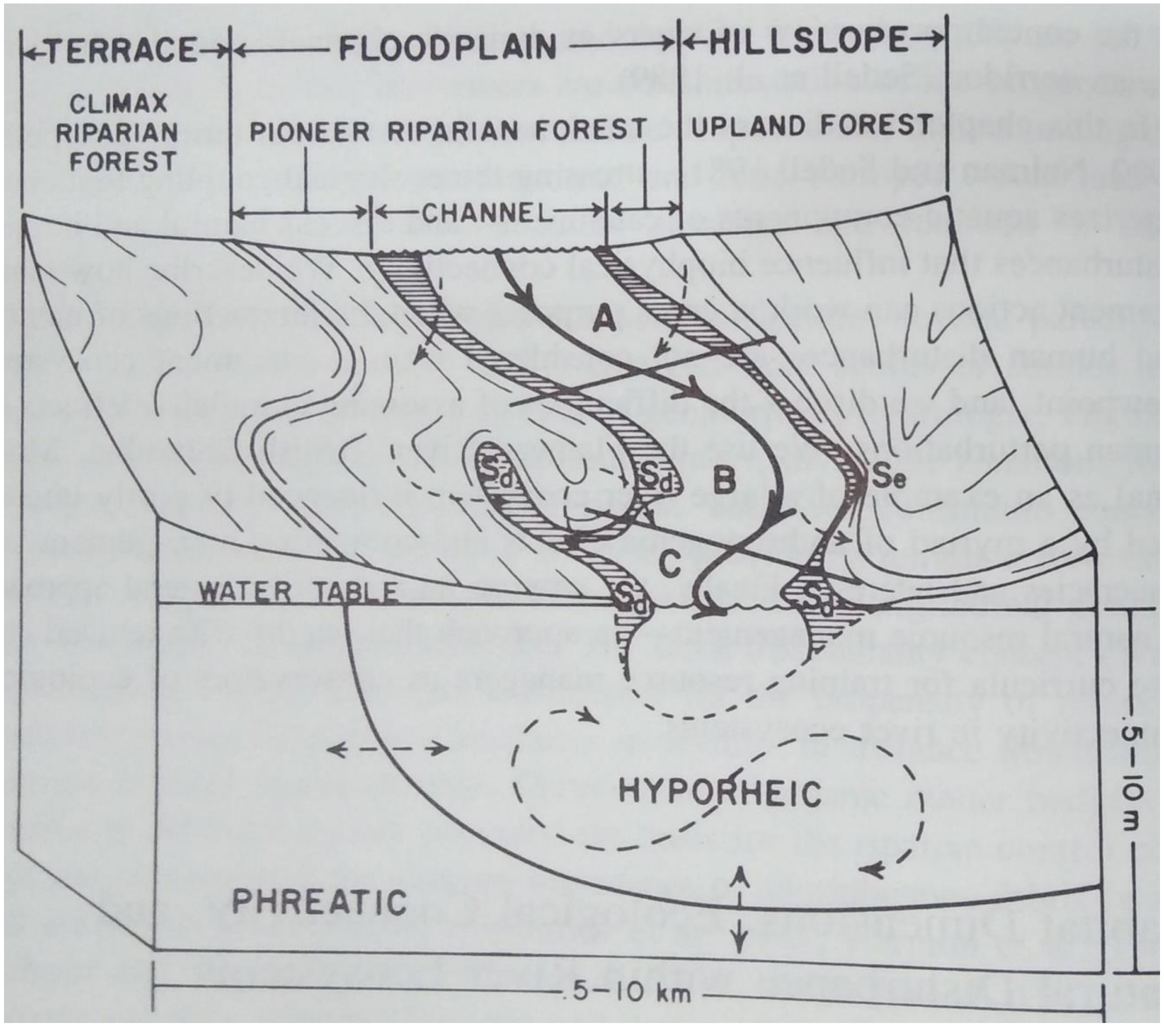
Image: http://slideplayer.com/slide/10493362/35/images/28/This+slide+shows+how+a+population+of+fish+distributes+itself+over+a+temperature+range..jpg

River ecosystem stability

- Stability:
  - Maintain community structure and function in the face of environmental variation
  - Coupling of stability of the biological system vs. stability of the physical system
- When physical systems are stable
  - Biotic contribution to ecosystem stability is less critical
  - Stability maintained despite low biotic diversity
- In widely fluctuating environments (floods, temperature fluctuations, microbial epidemics)
  - Biota is critical in stabilizing the entire system
  - High species diversity or high complexity in species function to maintain stability
  - Eg. Large diel temperature range includes optima for many species

Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R. and Cushing, C.E., 1980. The river continuum concept. *Canadian journal of fisheries and aquatic sciences*, *37*(1), pp.130-137.

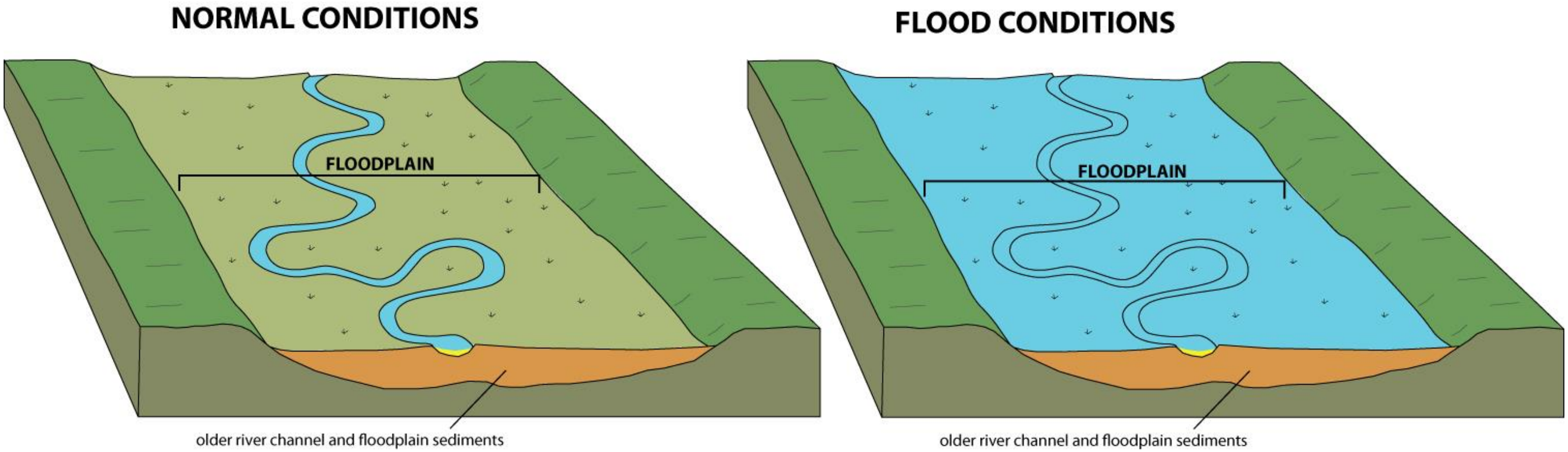
Channel-hyporheic connectivity



The Hyporheic Zone:
>connects surface water and groundwater ecosystems
>a zone of exchange of water, nutrients, and organic matter
>Exchange can be from surface water to ground water or vice-versa depending upon the prevailing hydrologic conditions
>can extend in metres vertically and in kilometres laterally
>can act as sink, storage, or source

Figure 5.1 in Naiman. Biota may reside in riparos (streamside or riparian), benthos (channel), hyporheos (river-influenced ground water), and phreatos (groundwater). Hatched area is periodically watered and dewatered. (A) run, (B) riffle, (C) pool are major channel features

Channel-floodplain connectivity



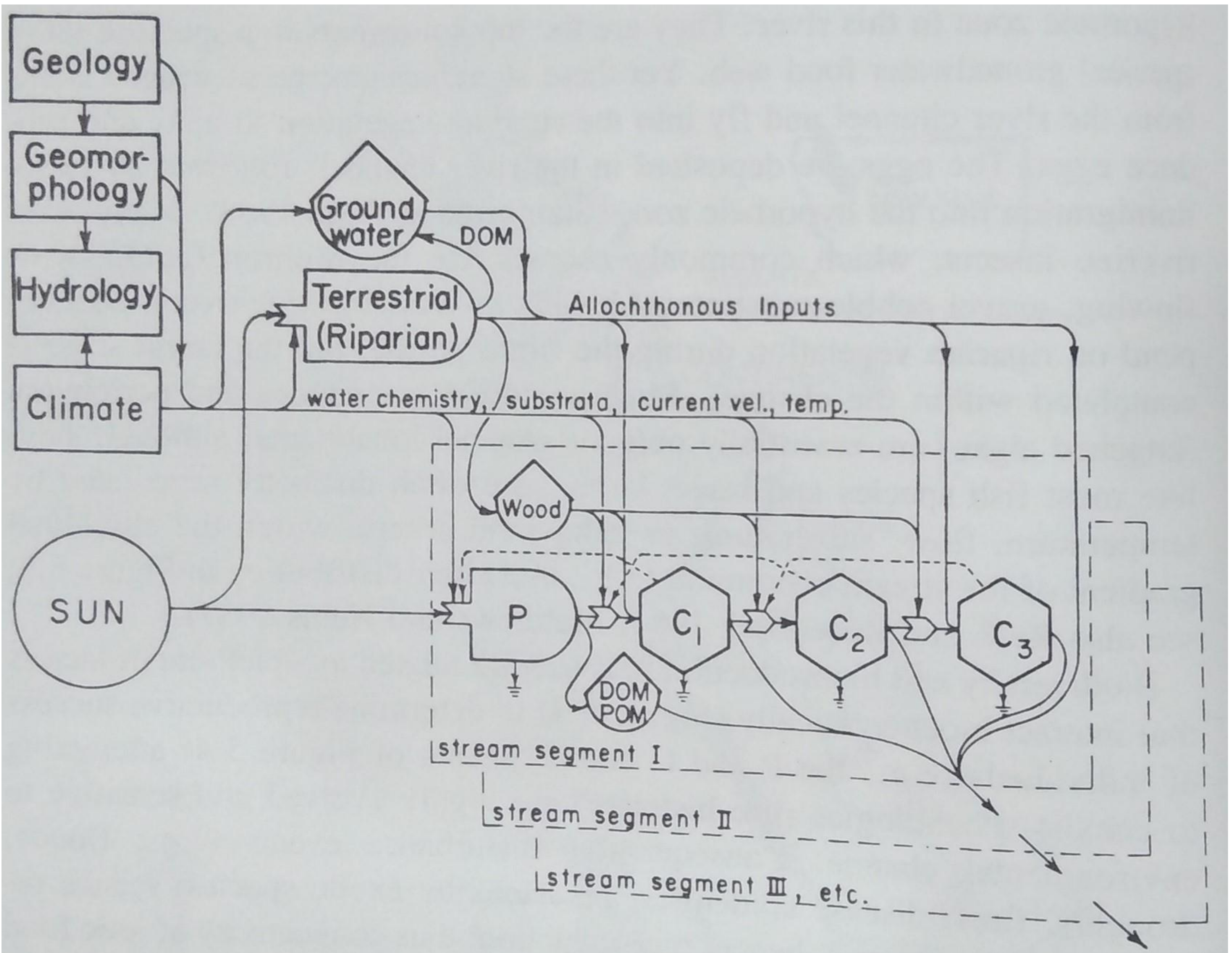
Floodplains:
>Rejuvenate soils during floods
>Control extremities of floods – energy and water is stored and released
>A mixture of land and water – rich in biodiversity
>Filter contaminants, so can improve water quality to an extent
>…

Image: https://www.villageofglencoe.org/document_center/Government/Village%20Forms%20and%20Documents/Public%20Work%20forms/floodplain1.jpg

Variations of connectivity across species

- High connectivity: species traverse all three spatial dimensions in the process of completing life cycles
  - Stoneflies reside within floodplain groundwaters during entire larval stage
  - Emerge as winged adults from the river channel and fly into the riparian vegetation to mate and produce eggs
  - Eggs are deposited in the river channel, followed by larval immigration into the hyporheic zone
- Low connectivity: restricted to any one dimension
  - Attached algae are channel inhabitants

Functional connectivity: flux of organic or inorganic materials and energy between consumer groups



For a particular species to survive, …, enough individuals must realize a net energy gain to meet phenological requirements which permit conservation of the gene pool

…tightly coupled systems are highly evolved, undistrubed, and essentially in equilibrium

…disturbance alteres structural and functional connectivity

Figure 5.4 in Naiman. Autotrophs in the stream use solar energy directly to create food, or food is input via terrestrial system as woody debris. Consumers are C1, C2, C3. Solid arrows are energy flows or energy regulators. Dashed lines are biotic feedback regulators.