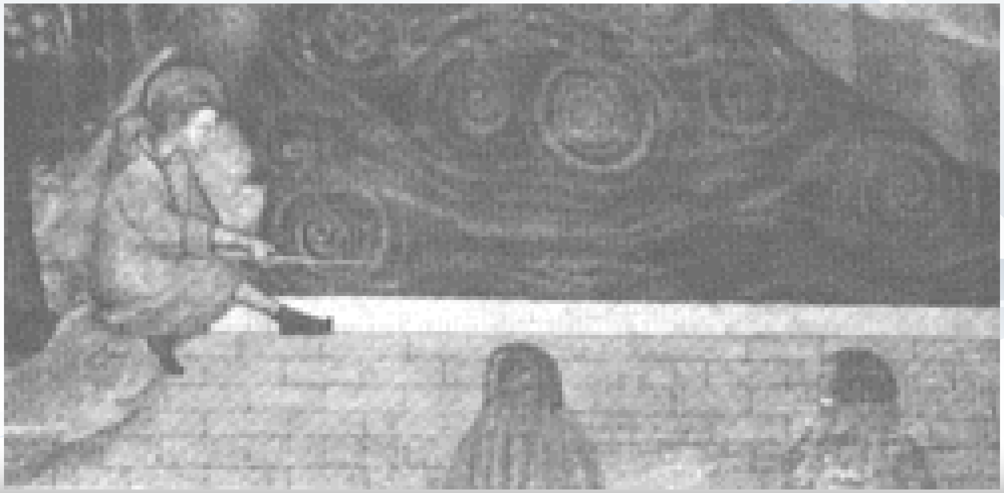
Environmental and recreational issues of dams and river modifications

Historical Impact of Dams

- Farmers in Mesopotamia may have been the first dam builders, 8000 year old irrigation canals have been found
- Earliest dams that have remains were built around 3,000 BC as a water supply system for the town of Jawa in modern-day Jordan



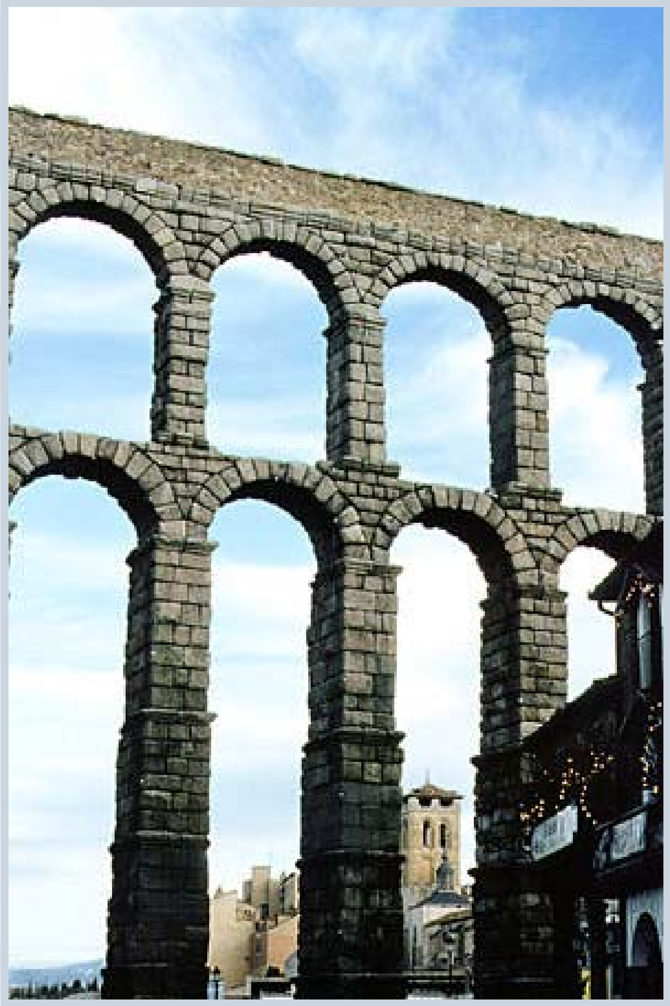
Painting from 1428 showing St. Benedict fishing from the crest of the 40 m high Subiaco Dam in Italy, built by Emporer Nero in about AD 60.

Historical Channel Modification

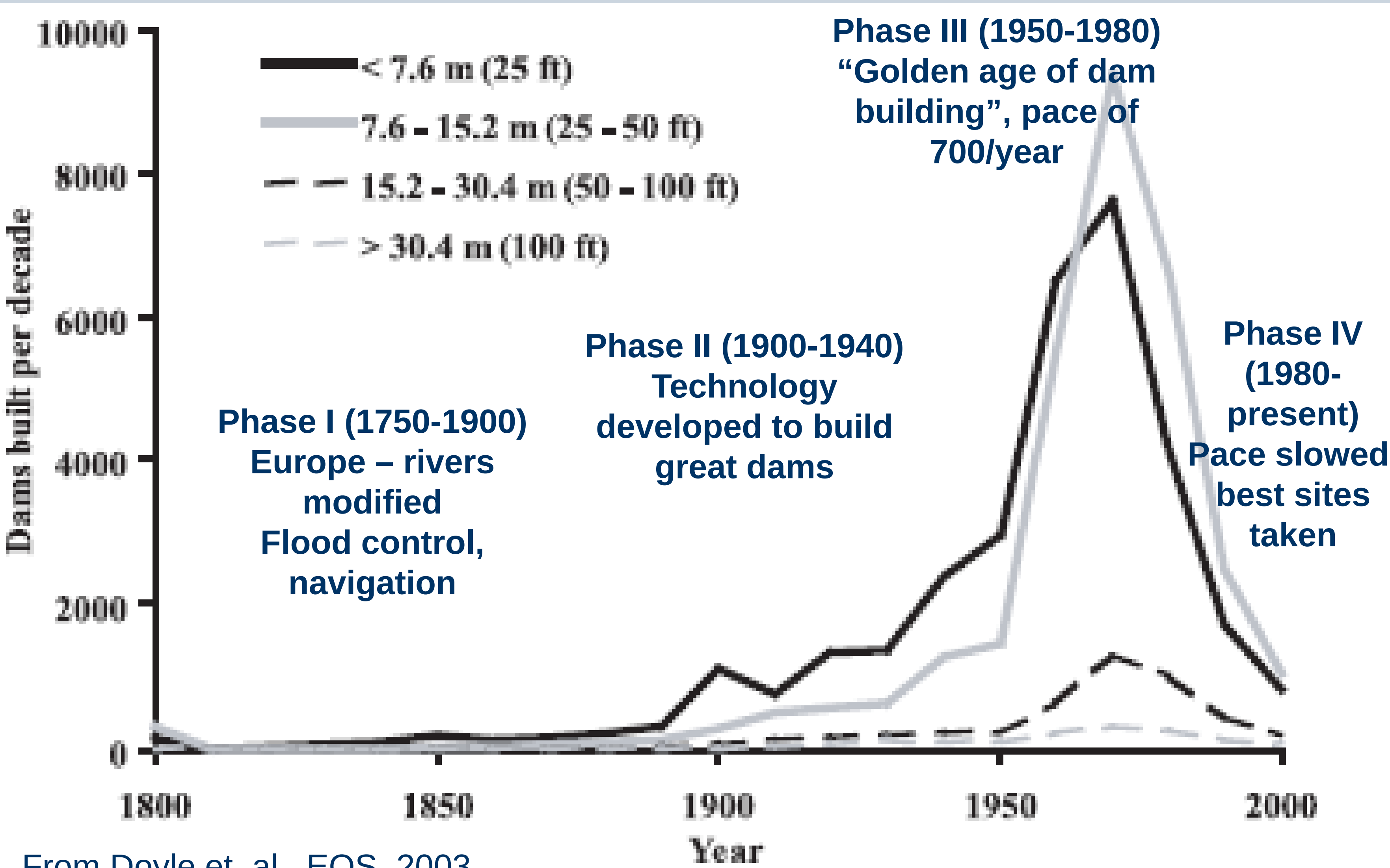
- In Roman times, engineering of water flow changed water distribution

Aqueduct = man-made conduit for carrying water (Latin aqua, "water," and ducere, "to lead").

Romans also created drainage tunnels to carry away Rome's wastes, 6th century B.C.



The golden age of dam building



From Doyle et. al., EOS, 2003.

US participated in Golden Age of dam building

- U.S.A. has 14% of world’s large dams
- U.S. estimate is over 2.5 million total dams (National Research Council), 75,000 that are >5m, 6500 that are >15m.
- Most in the U.S. are privately owned
- “That means we have been building, on average, one large dam a day, every single day, since the Declaration of Independence.” - Secretary of the Interior Bruce Babbitt

River channelization

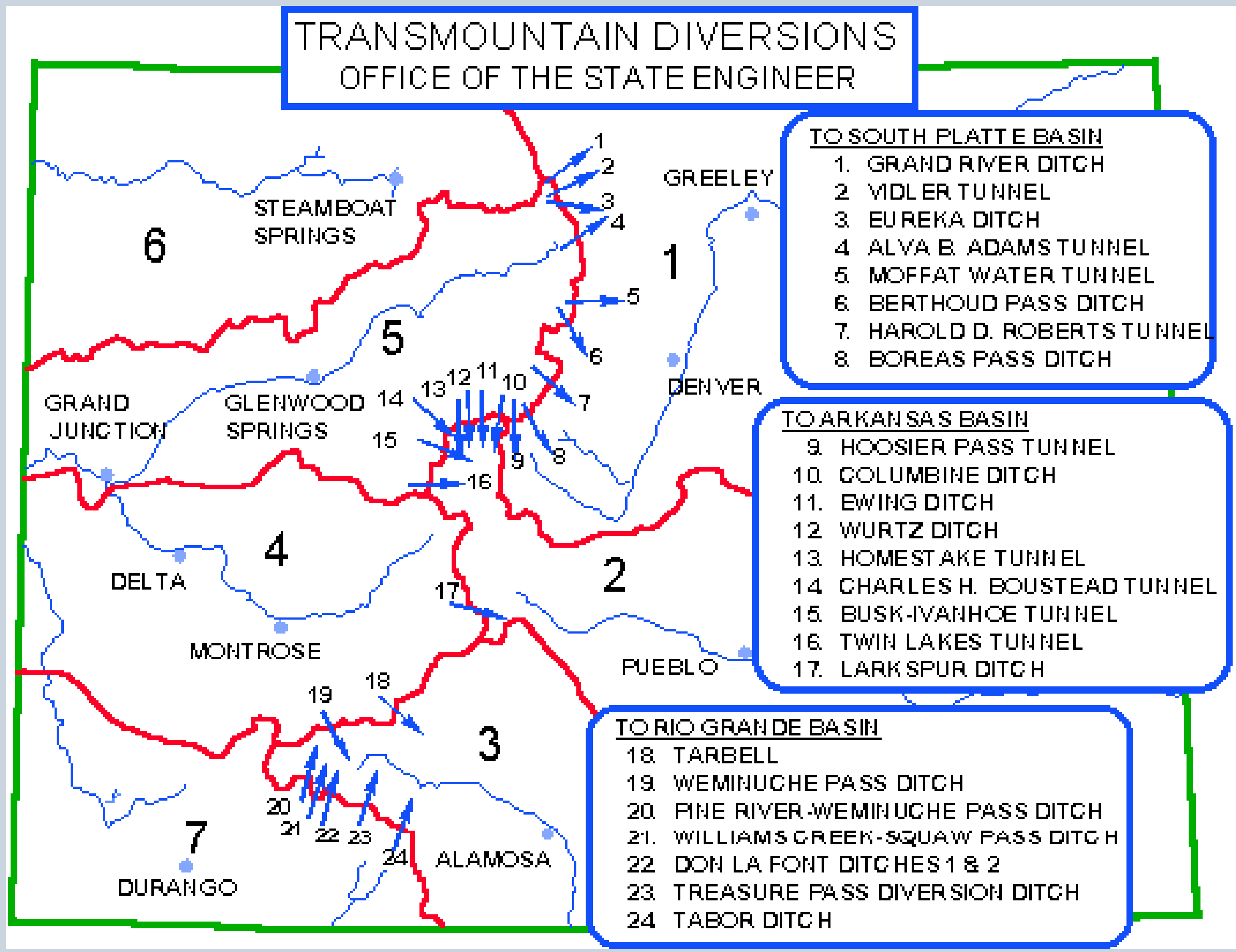
Kissimmee River (Everglades) water management project *(flood protection for neighboring developments):*

1. Kissimmee River prior to channelization, 1961
2. Kissimmee River during construction, 1961
3. Kissimmee River after extensive channelization, 1965.

1992, Kissimmee River Restoration Project began

Photos courtesy of South Florida Water Management District.

Colorado Interbasin Water Transfer



Transformations of the land

- Draining of floodplains
- timber harvest
- road building
- intensification of agriculture
- spreading of human development

Land use change has important consequences for stream processes

- Often result in degradation or fragmentation of aquatic habitat

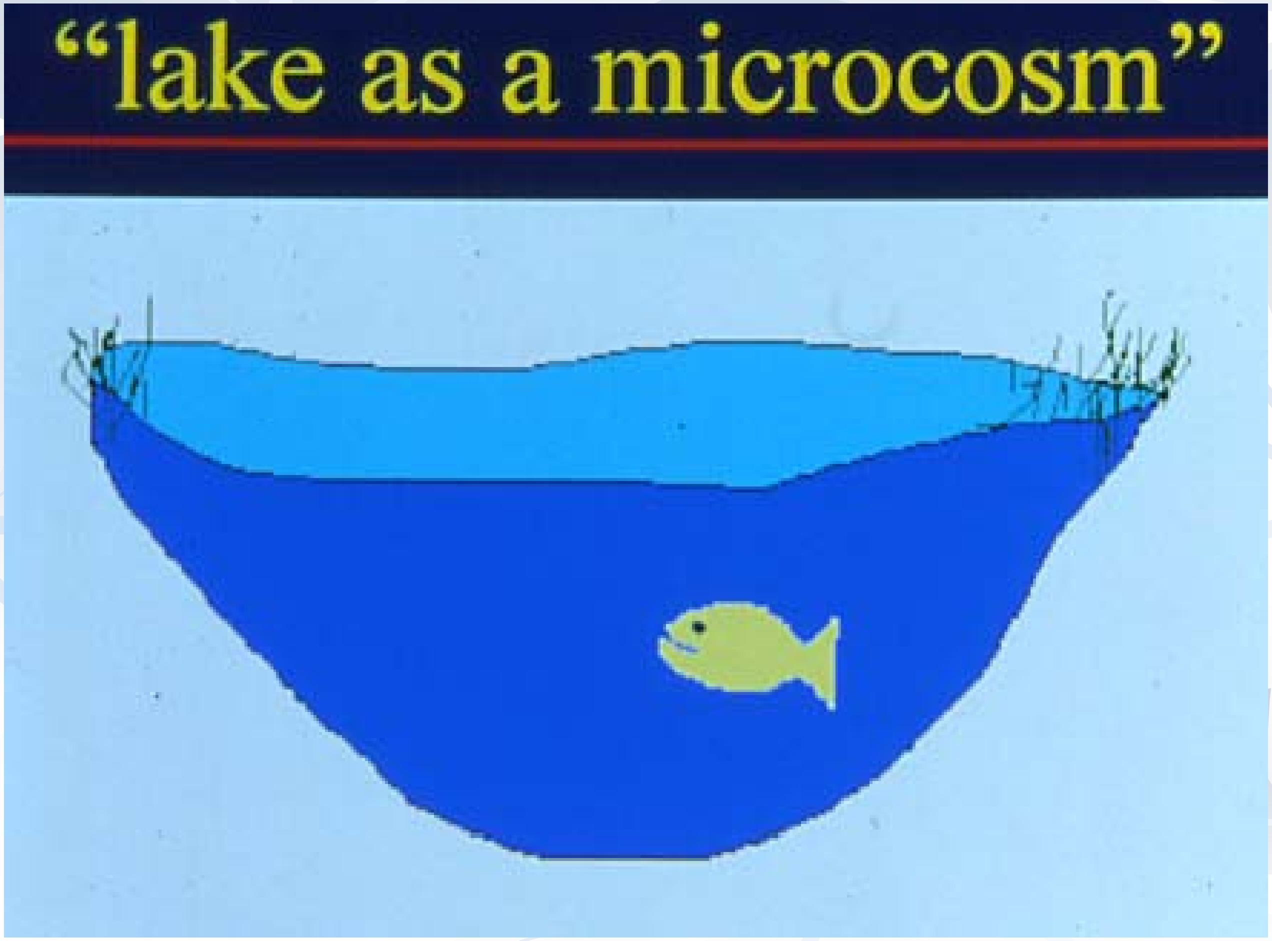
Adapted from Allan, 1995.

Challenge: Large scale changes in river systems

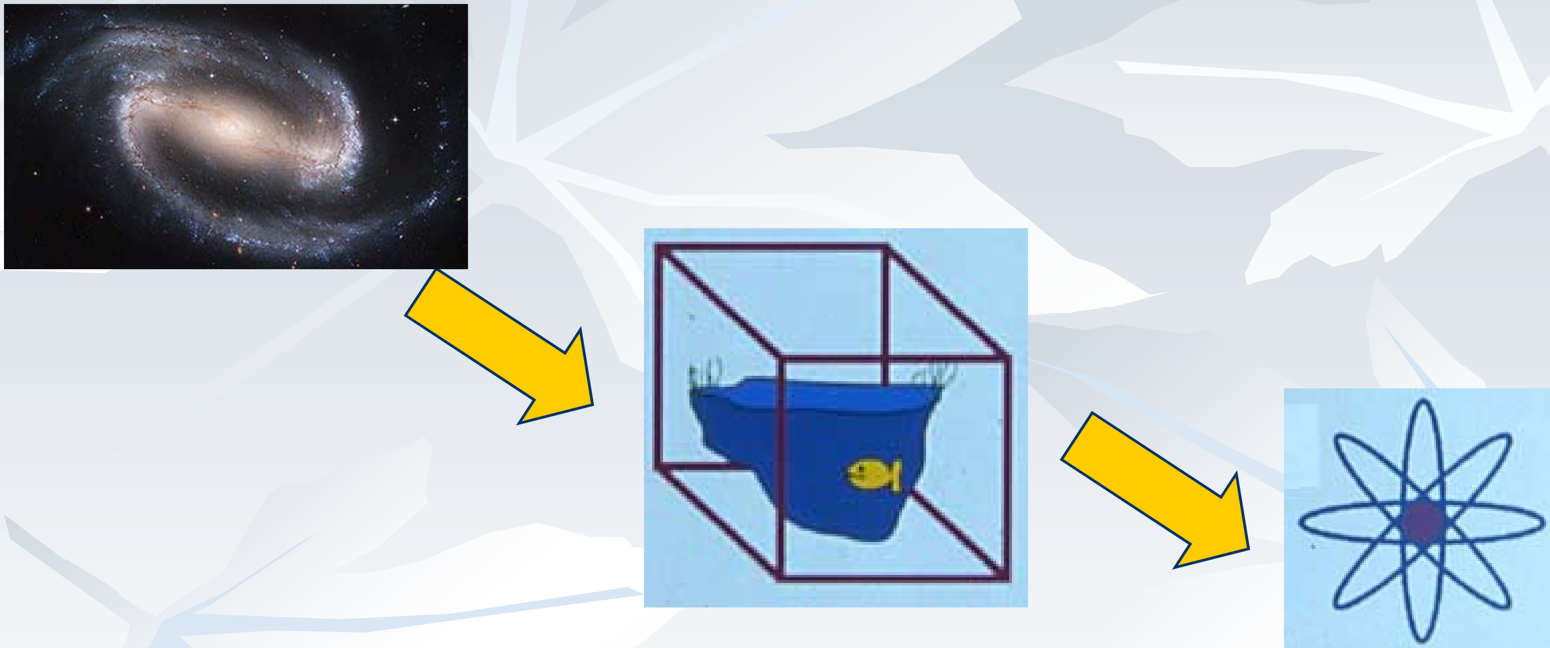
- Transport of C & N in surface waters is coupled to movement of water and sediments across gradients in biogeochemical activity
- River ecosystem structure changes with modification and nutrient availability
- Approaches for “scaling up” to river networks

Ecosystem framework

- **Forbes- 1892**



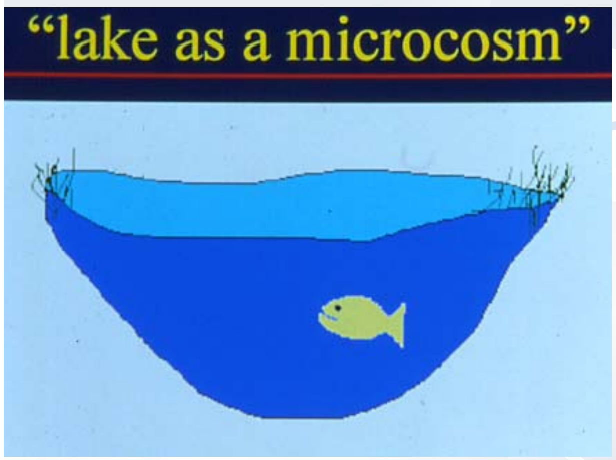
Ecosystems: fundamental units of nature



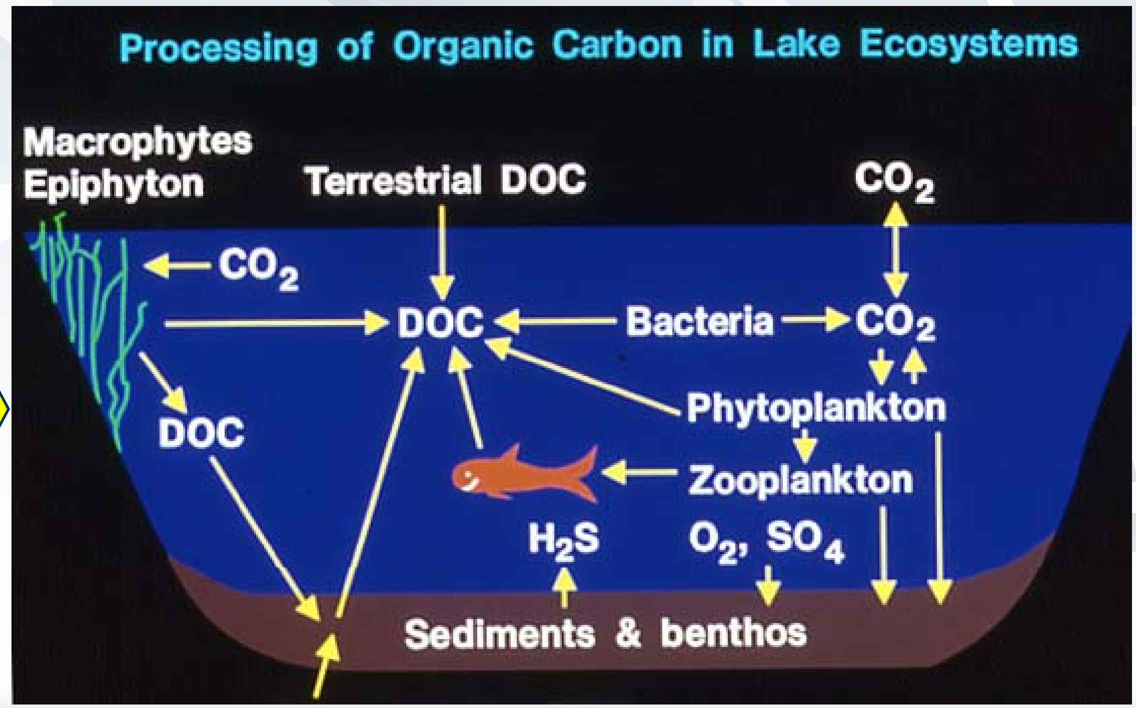
- **Tansley 1935**: Ecosystems as a fundamental unit of nature along continuum from atoms to galaxies

Ecosystem framework

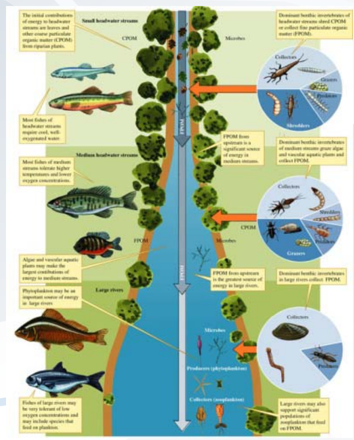
- Lindeman (1953): Trophic Dynamics Concept, addressing the cycling of C in ecosystems

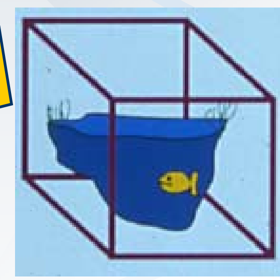


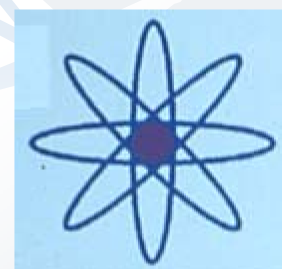
Forbes- 1892



Ecosystems: fundamental units of nature

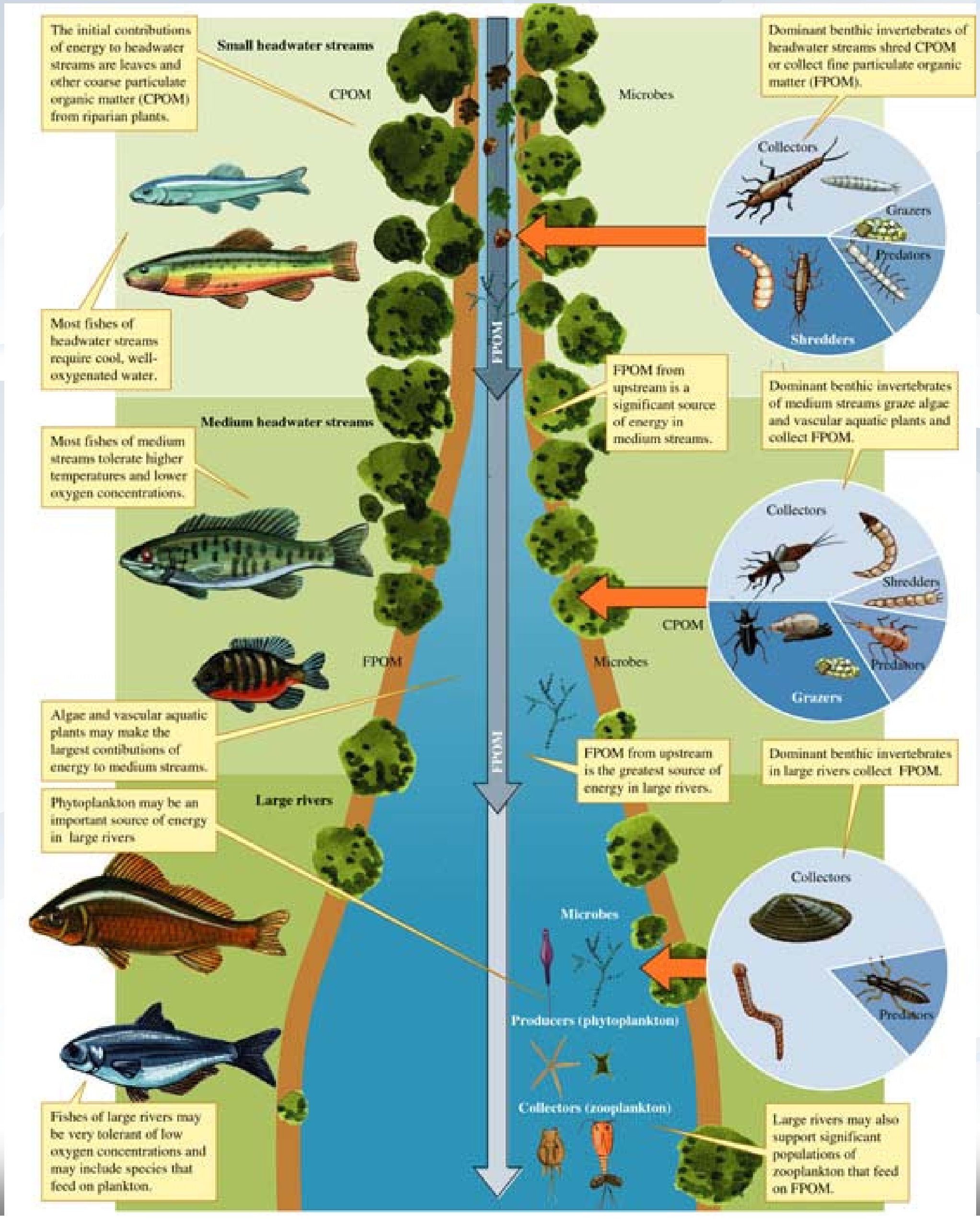






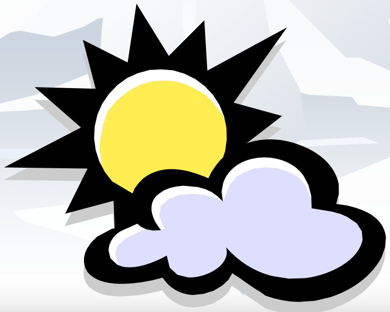
River Continuum concept places river ecosystems within the basic scientific foundation for ecosystem science

River Continuum Concept: Vannote et al. 1980



Connections from upstream to downstream habitats control flow of energy and carbon in fluvial ecosystems, as well as the species of aquatic organisms

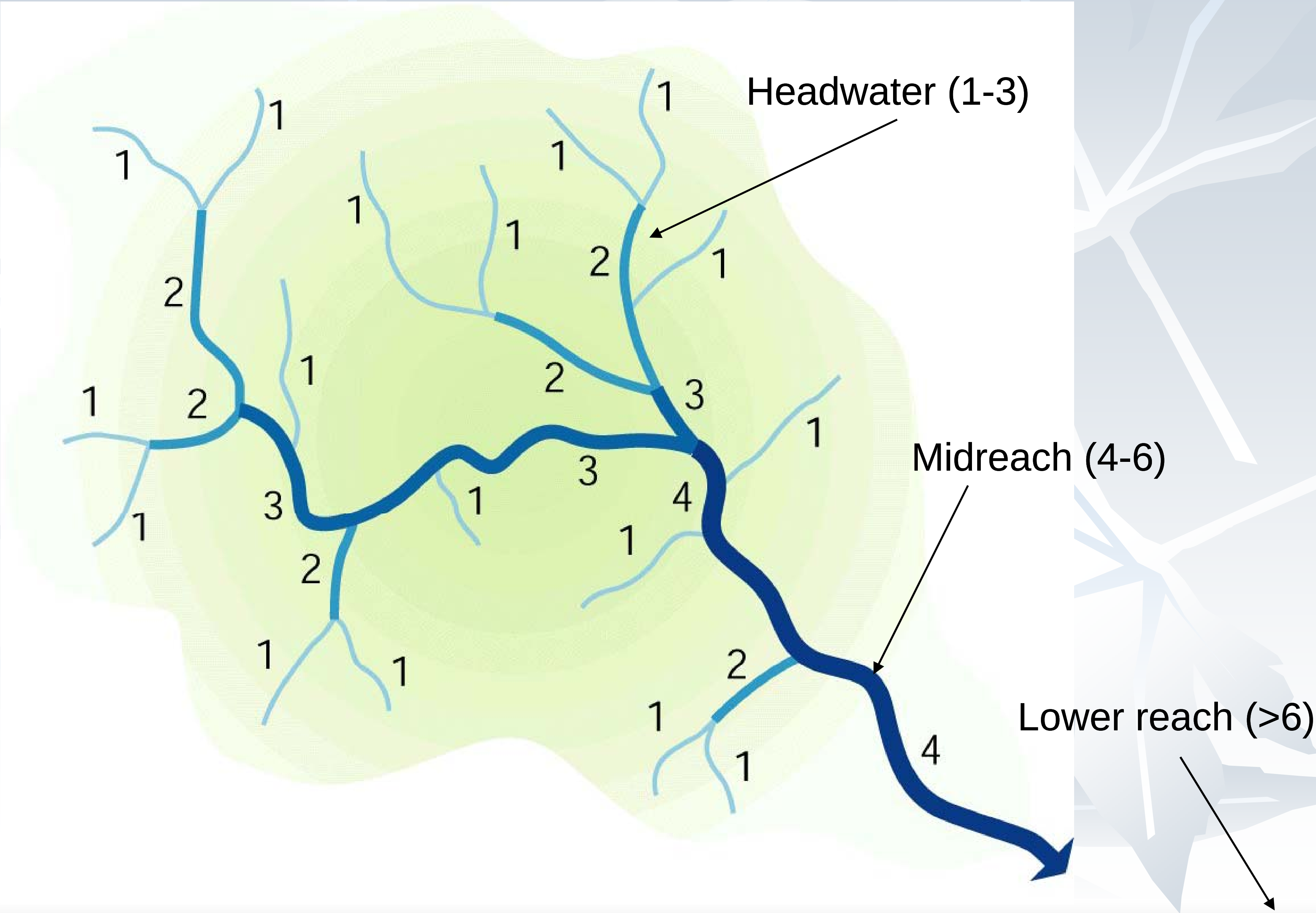
Theme: importance of light availability in controlling in situ production (e.g. P/R)



The River Continuum Concept (RCC)

- The River Continuum Concept (RCC) : presents testable hypitheses for physical, chemical and biological changes that occur on a longitudinal gradient from headwaters → lower reaches of a stream/river system
- Based on fluvial geomorphology: **Physical stream network is in a quasi-equilibrium.**
- **This equilibrium is defined by hydrologic *means* and *extremes***
- Specific predictions based on patterns from northern temperate streams and rivers
- 1980- R. L. Vannote, G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. Can. J. Fish. Aquatic. Sci. 37:130–137

Stream Ordering



Types of organic matter

- Particulate organic matter
  - **CPOM**-Coarse particulate organic matter
    - Woody material & leaves (> 1 mm)
  - **FPOM**-Fine particulate organic matter
    - Leaf fragments, invertebrate feces, and organic precipitates (50um – 1 mm)
  - Ultrafine (UPOM)
    - Even smaller fragments (0.5 – 50um)

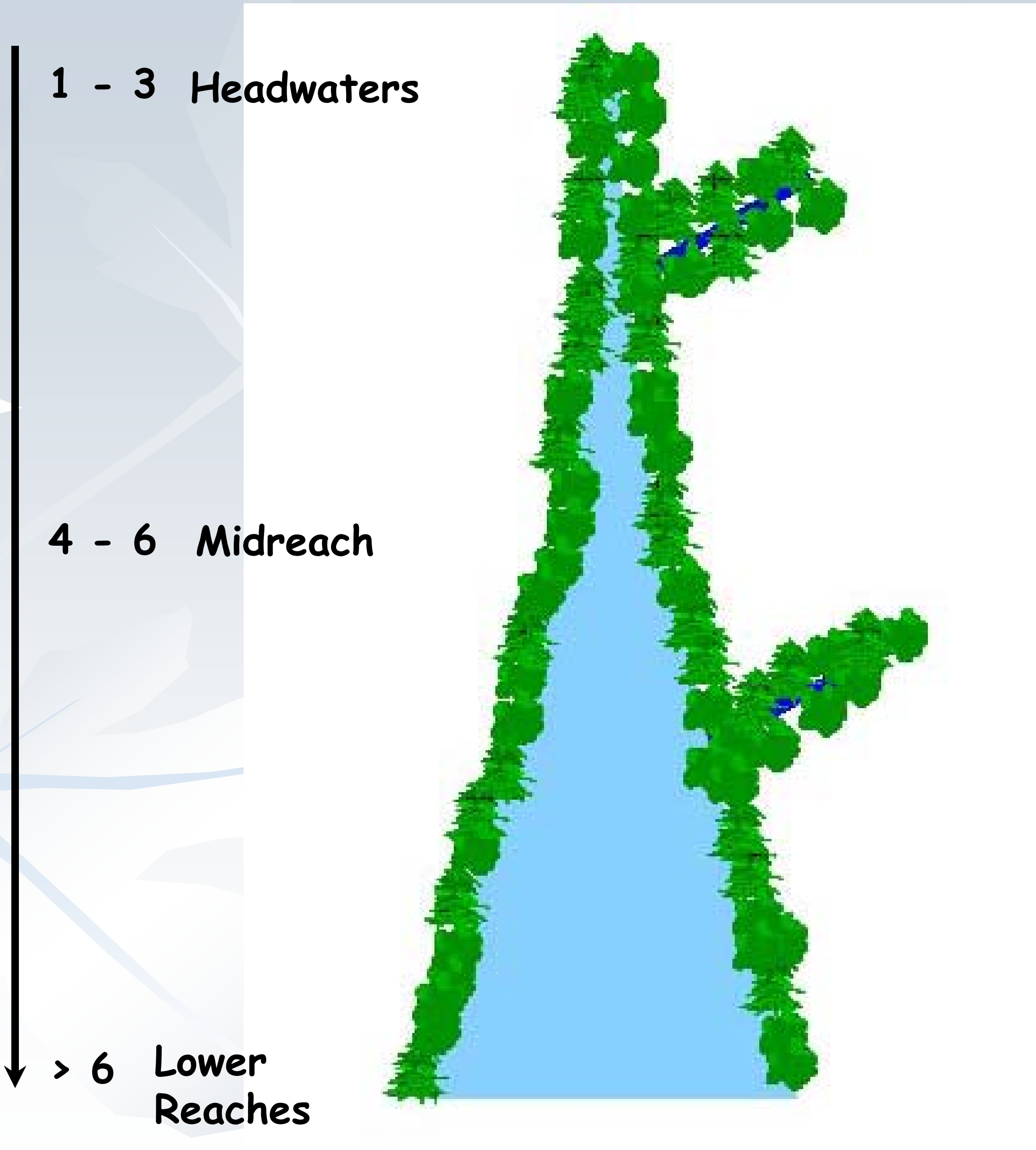
Types of organic matter

- **DOM**- Dissolved organic matter
  - Soluble organic compounds (<0.5 um) that leach from leaves, roots, decaying organisms, and other terrestrial sources
  - Microbial sources: algal exudates, senescent bacteria
  - 50% is humic material- **HDOM**
  - Largest pool of organic matter in streams

RCC and Dynamic Equilibrium

- Stream forms equilibrium between physical parameters (width, depth, velocity, and sediment load, both means and extremes) and biological factors
  - SEASONAL: Uniform energy processing over time; different species exploit different available organic substrates as efficiently as possible
  - SPATIAL: Energy loss from upstream = energy gain/income for downstream

STREAM ORDER

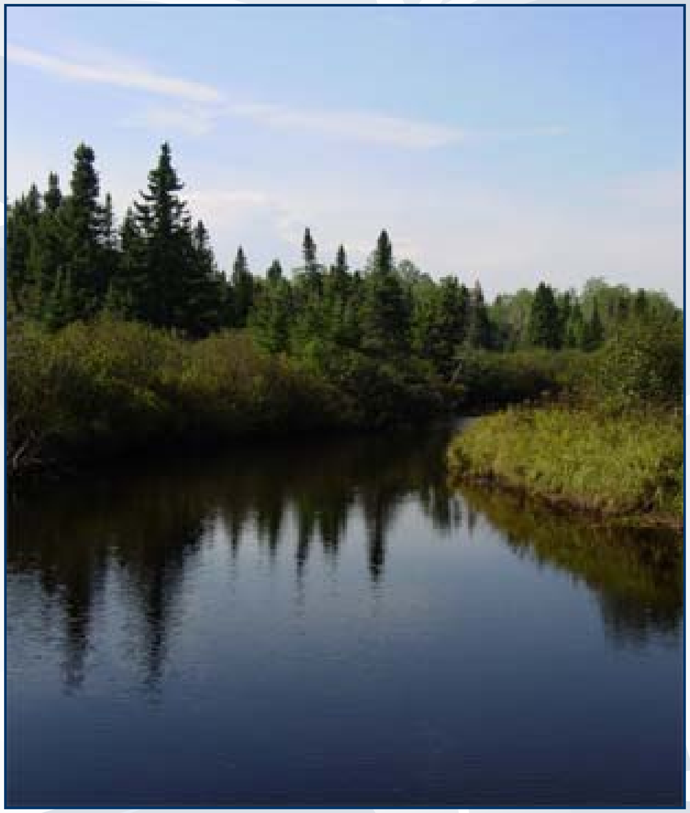


Energy Sources- Headwaters

- Shading: Riparian vegetation, limits light to stream, low autotrophic production
- Photosynthesis/Respiration (P/R) ratio will be **less than 1** (heterotrophic stream)
- Lots of CPOM: **allochthonous** carbon/energy sources (leaves from watershed)
- Low temperture

Energy Sources- Midreach

- Stream broadening, more light
- **P/R** > 1, autotrophic production (phytoplankton, periphyton, macrophytes)
- More **FPOM**, b/c CPOM processed upstream
- Energy source is **autochthonous**.
- High temp variation

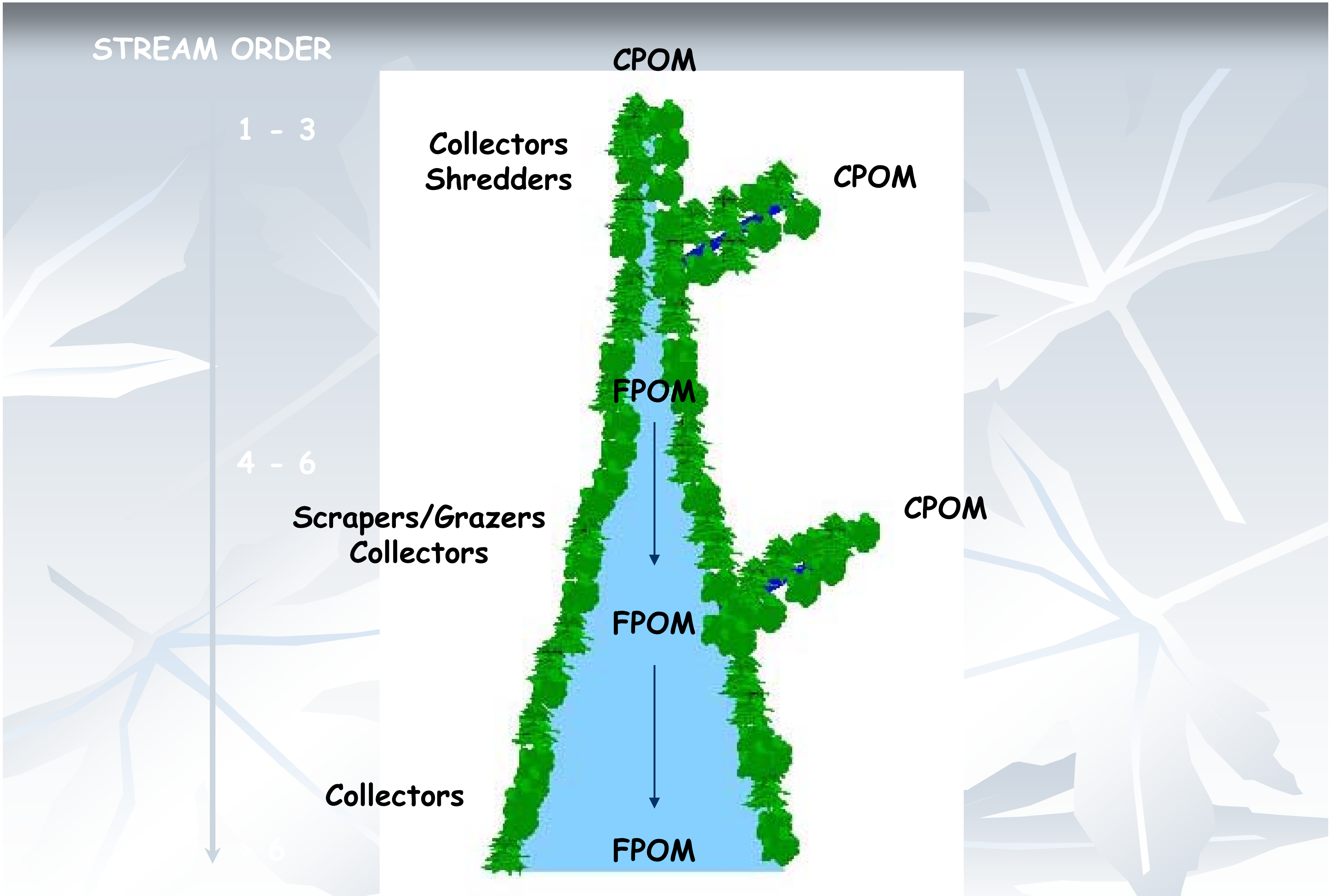


Energy Sources- Lower Reaches

- Increasing turbidity, even wider stream, increased macrophytes
- **P/R** < 1, net heterotrophic
- Mostly **FPOM** (vs. CPOM in the headwaters)
- High phytoplankton, **not enough** to cause the river to become autotrophic
- Large volume, low temp

RCC and Stream Invertebrates

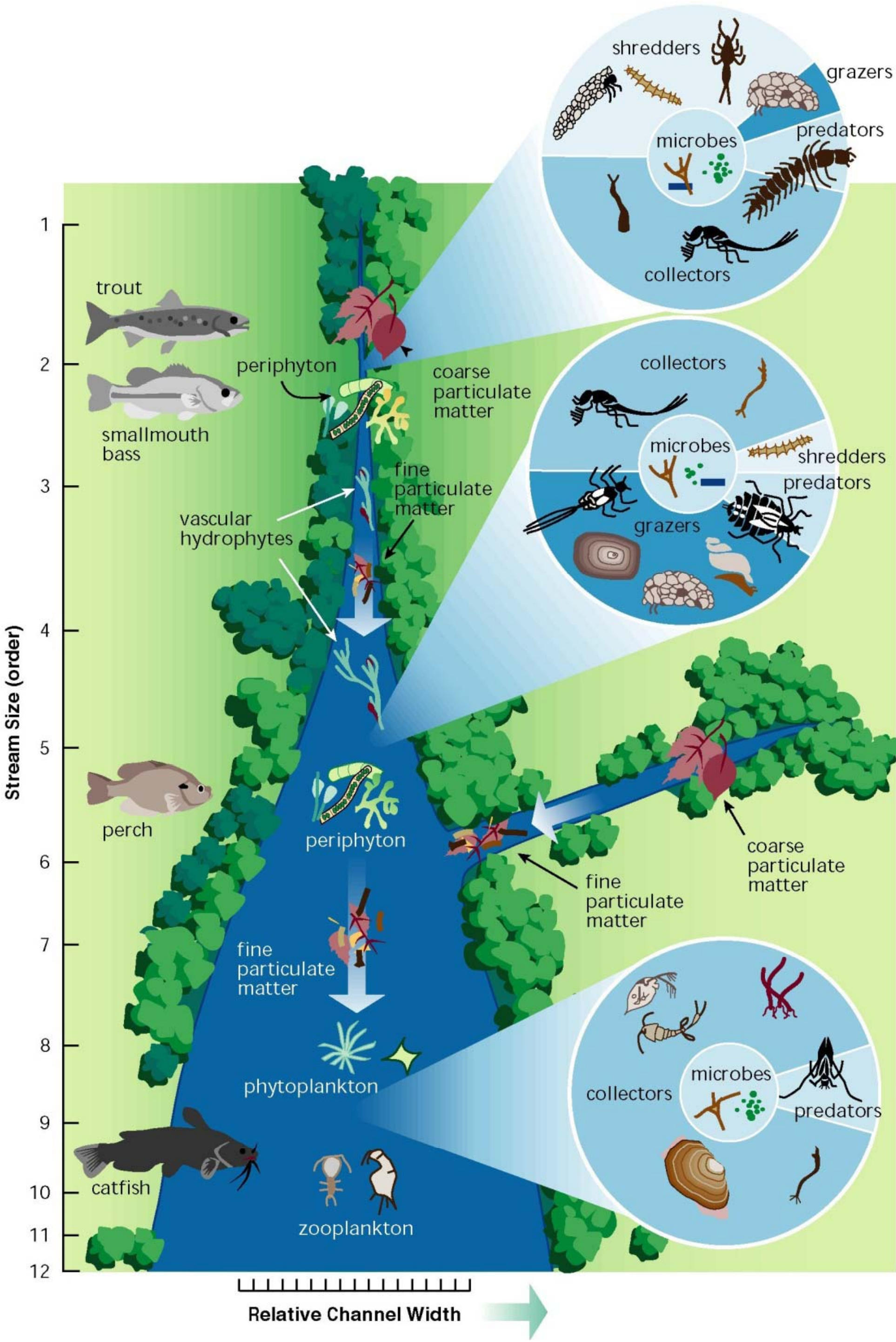
- **Stream invertebrates - longitudinal gradient community types, reflects the food availability in the different segments of the stream/river continuum**
- ***Shredders and collectors dominate the headwaters, in response to the CPOM, and derived FPOM***
- ***Shredders are replaced by scrapers/grazers in the mid-reaches (more periphyton) . . . Collectors are still abundant (more FPOM)***
- ***Most invertebrates in the lower reaches are collectors b/c of dominance of FPOM***
- ***Predator abundance changes relatively little with stream order***



TESTABLE HYPOTHESIS- Taxonomy is the tool to measure this

RCC and Fish Communities

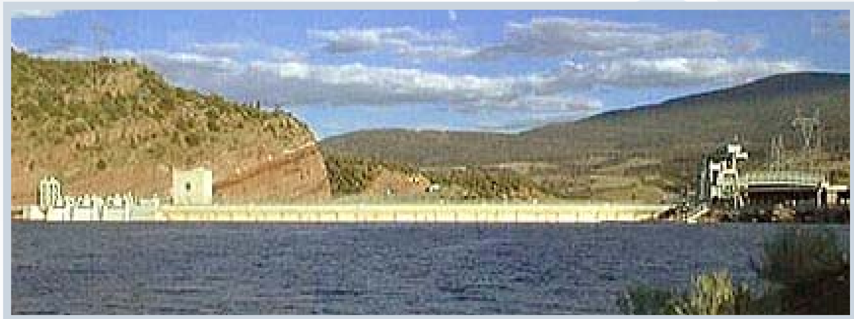
- **Headwaters**: cool water species (e.g., trout)
- **Lower reaches**: warm water species (e.g., carp)
- Most headwater fishes feed on invertebrates
- Mid to lower reaches, piscivorous species are also abundant
- Lower reaches, planktivorous species may be present



Construction of a dam changes the means and extremes to which the stream biota are adapted

Construction of a dam can correspond to a "resetting" of the river continuum, by trapping material and making sunlight more available to support autotrophic growth.

Why do we build dams?



Generating electricity

- One-third of countries in the world rely on hydropower for ½ of electricity supply (www.dams.org)
- Hydropower converts the energy in flowing water into electricity
- A typical hydropower plant includes a dam, reservoir, penstocks, a powerhouse and an electrical power substation
- The greater the flow and head, the more electricity produced

Types of Hydropower Plants

- **Run-of-river plants—**These plants use little, if any, stored water to provide water flow through the turbines
- **Storage plants—**These plants have enough storage capacity to off-set seasonal fluctuations in water flow and provide a constant supply of electricity throughout the year.
- **Pumped storage---**During off-peak hours (periods of low energy demand), some of the water is pumped into an upper reservoir and reused during periods of peak-demand

Irrigation

- Half of world's large dams (>15m high) – built for irrigation (www.dams.org)
- Return flows are often a fraction of the applied water
- Loaded with fertilizers, pesticides, herbicides

Flood Protection

- Floods can cause severe damage
- In many areas, people have developed traditional floodplain areas
- Reservoirs / Dams are used to buffer against large flows

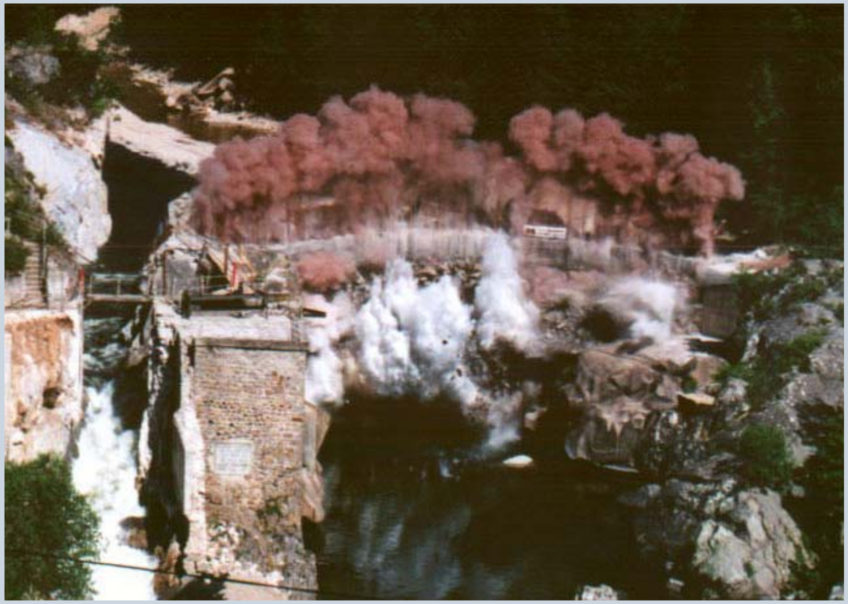
Other human uses…

- Municipal water sources- Front Range supplied by dozens of trans-continental divide water projects (Dillon Reservoir, etc…)
- Flat-water recreational opportunites (Lake Powell, Lake Mead…)

Federal Energy Regulatory Commission (FERC)

- Determines if and how most non-federal hydroelectric dams are built and operated
- Must comply with several laws including Federal Power Act, Electric Consumers Protection Act, ***Endangered Species Act, and National Environmental Policy Act***
- Project owner must apply for new FERC license to continue dam operation at end of term
- FERC has the authority to require decomissioning (including removal) at the end of license term

Why remove dams?



Not all dams have to go…

- dam removal is NOT appropriate for all dams
  - many continue to serve public and private functions (flood control, irrigation, hydropower)
  - many could be operated in a fashion that reduces negative impacts on the river (fish ladders, environmentally-sound release regimes, etc…)

…but many dams have outlived their intended purposes

- supplied power to mills that fueled industrial age
- often abandoned by original owners
- thousands of US dams built in the 1930s and 1940s are nearing the end of their design life and there is a need for guidelines for the retirement of these projects." *-Hydrowire* (newsletter of the hydoelectric industry)

Which dams are candidates?

- dams have finite lifetimes, so dam removal is an option for dams which:
  - no longer provide any benefits
  - have significant negative environmental impacts that outweigh the dam's benefits
  - are too old and unsafe, too much money to maintain

Old dams are beautiful…

- dams are subjected to stresses that lead to deterioration and limits the lifetime of dams
  - the danger of failure becomes a serious concern
  - many dams have aged beyond their planned life expectancy
    - average life expectancy of a dam is 50 years
    - 25% of US dams on the National Inventory of Dams are now more than 50 years old, and by 2020 that figure will reach 85%

Economic Reasons for Removal

- As a dam ages, many things can make it less cost effective
  - traps river sediments, reservoir impounds less water, decreases effectiveness of dam
  - sediment can block penstocks
  - flooding ramifications of sedimented-in reservoir
- Need for structural upgrades and operational modifications to comply with current regulatory requirements (FERC)
- Potential liability for dam failure
- Removal costs are often less than repairing an unsafe dam

Environmental Reasons for Removal

Dams change the physical, chemical, and biological processes of rivers

- Inundating wildlife habitat
- Reducing river levels
- Blocking or slowing river flows
- Altering timing of flows
- Altering water temperatures
- Decreasing water oxygen levels
- Obstructing movement of gravel, woody debris, and nutrients
- Impacting negatively the aesthetics and character of natural settings

The myth of “clean power”

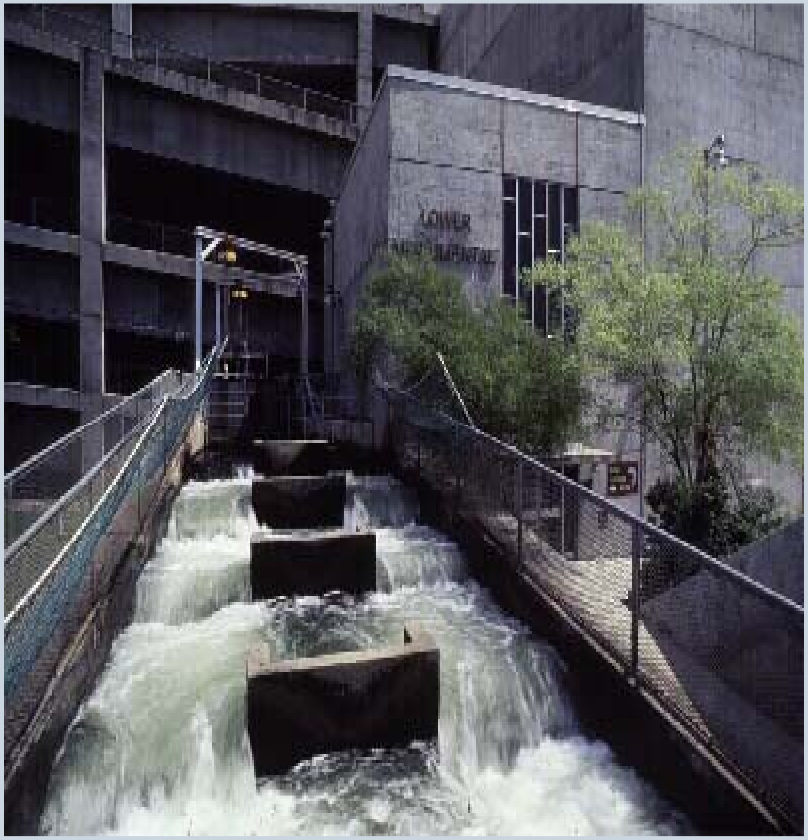
- Although classically considered “clean and renewable”, **hydropower** cannot always be considered a sustainable energy source
  - hydropower dams remove water needed for healthy instream ecosystems
  - release schedules (during peak demand periods) alternate between no water and powerful surges that lead to erosion of soils and vegetation
  - fish are often maimed or killed by power turbines

Which fish are affected?

- **Anadramous-** fish that are born in rivers, migrate to the ocean to live most of their lives, the migrate back up the same river to spawn and die
- **Catadramous-** migration in the opposite direction
- Salmon, steelhead, American shad, striped bass, sturgeon, alewife, herring, and American eel

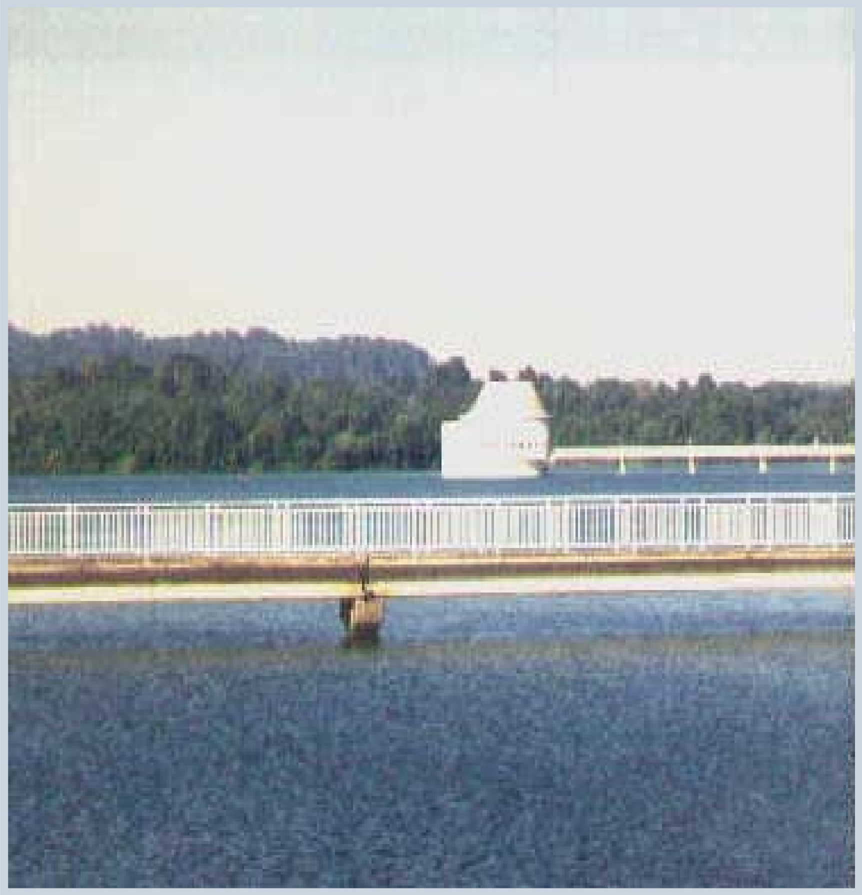
But aren't there fish ladders?

- Not always - no passage blocks access to spawning habitat above dam
- some fish can't find ladders, or water temperature too high in ladders
- fish often too exhausted once navigating past dam



Slow-moving reservoirs

- Delay juvenile migratory fish in journey to the ocean
- Physiological changes to prepare for salt-water cannot be delayed to accommodate delays in reservoirs
- Introduce new predators, disease, lethally high water temperatures



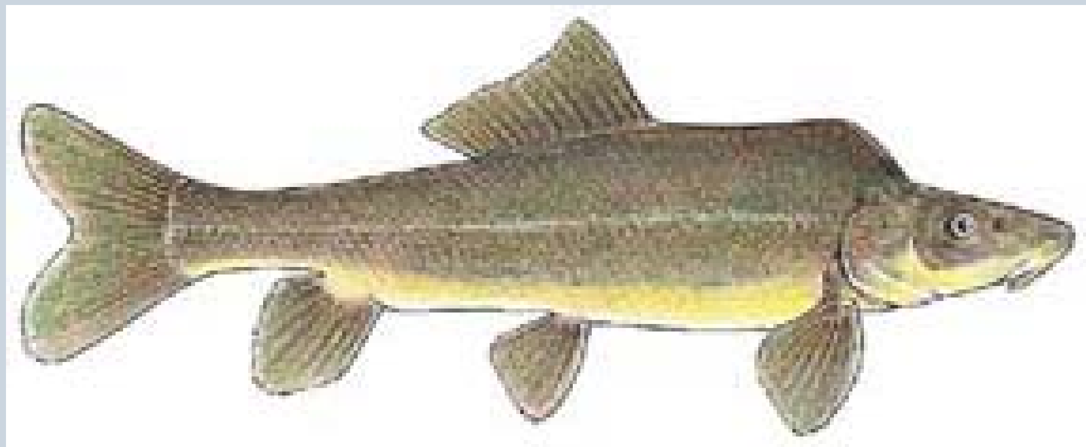
Native fish vulnerable to river modifications

- Endemic fish adapted to pre-dam conditions
- Endemic fish at competitive disadvantage under new conditions

Colorado Pikeminnow

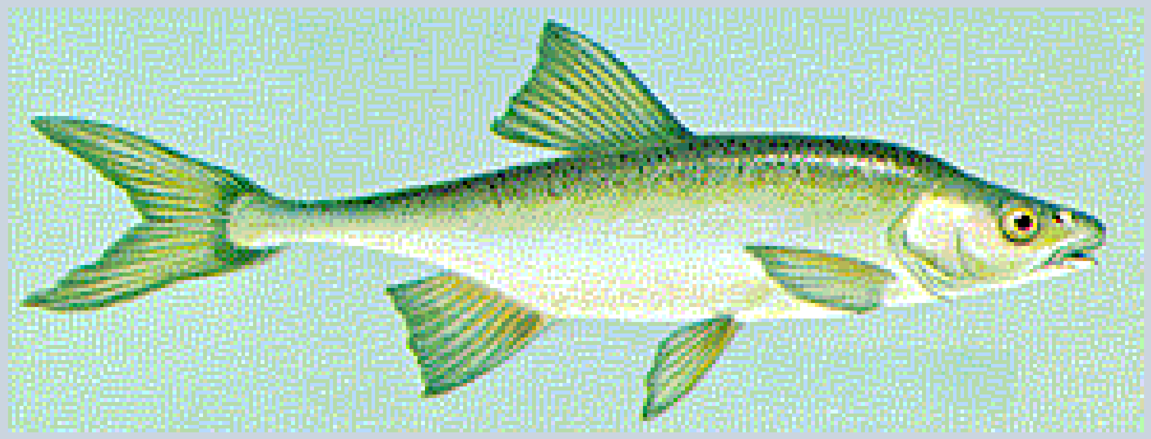
- Largest minnow in North America
  - can get nearly 6 feet long, 100 pounds
- Can migrate up to 200 miles to spawn
- Endangered under Colorado law since 1976
- Once abundant, now few stable populations exist

Razorback sucker



- One of the largest suckers in America
  - Can grow up to 18 pounds and 3 feet long
- Migrate long distances to congregate to spawn
- Wetland habitats are believed essential to the survival of young razorbacks

Bonytail chub



- Can grow to 24 inches or more, have been known to live 50 years
- Once common in these basins, now no reproducing populations in wild
- Rarest of endangered fish species in these basins
- Short-term recovery goal: prevent extinction

Humpback chub

- Can grow to nearly 20 inches
- Uses large fins to “glide” through slow-moving waters
- Lateral stripe is so sensitive, it can feel vibrations caused by nearby insects, and adaptation well-suited to life in muddy water

Considerations before dam removal?

- Dam removal can be a geomorphic disturbance to a quasi-adjusted riverine system
- Dam removal may wreak havoc on already disturbed systems:
  - Sediment released
  - Nutrients released
- Dams lie downstream of industrial sites, mines, other pollution sources:
  - Contaminants released (heavy metals, organic/inorganic compounds)
  - (PCB's released following removal of Ft Edwards Dam, NY Hudson River)
- Downstream communities affected - flooding

Adapted from Doyle et al. 2003)

Global perspective

What was the World Commission on Dams?

In response to the **growing opposition to large dams**, the World Commission on Dams (WCD) was established by the World Bank and IUCN in 1998.

The Commission's **mandate** was to:

- review effectiveness of large dams and assess alternatives for water resources and energy development
- develop internationally acceptable guidelines for the planning, design, appraisal, construction, operation, monitoring and **decommissioning** of dams.

WCD findings

“We believe there can no longer be any justifiable doubt about the following:

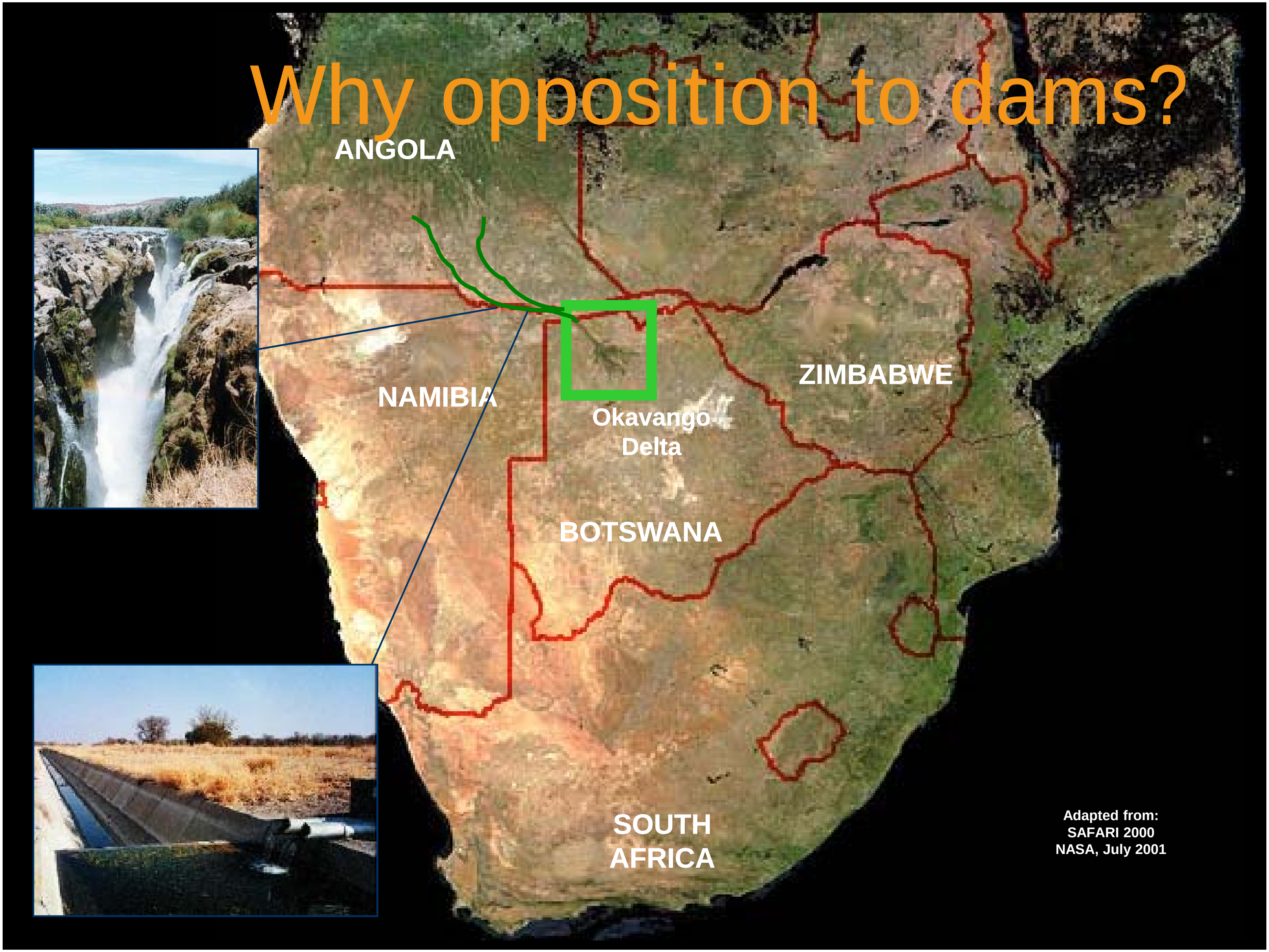
Dams have made an important and significant **contribution to human development**, and the benefits derived from them have been considerable.

In too many cases an unacceptable / unnecessary price has been paid to secure those benefits …by **people** displaced, by communities downstream, by taxpayers and by the natural **environment**.

Lack of **equity** in the distribution of benefits ...

Negotiating outcomes …eliminating unfavorable projects at an early stage, and by offering … only those options that key **stakeholders agree** represent the best ones to meet the needs in question."

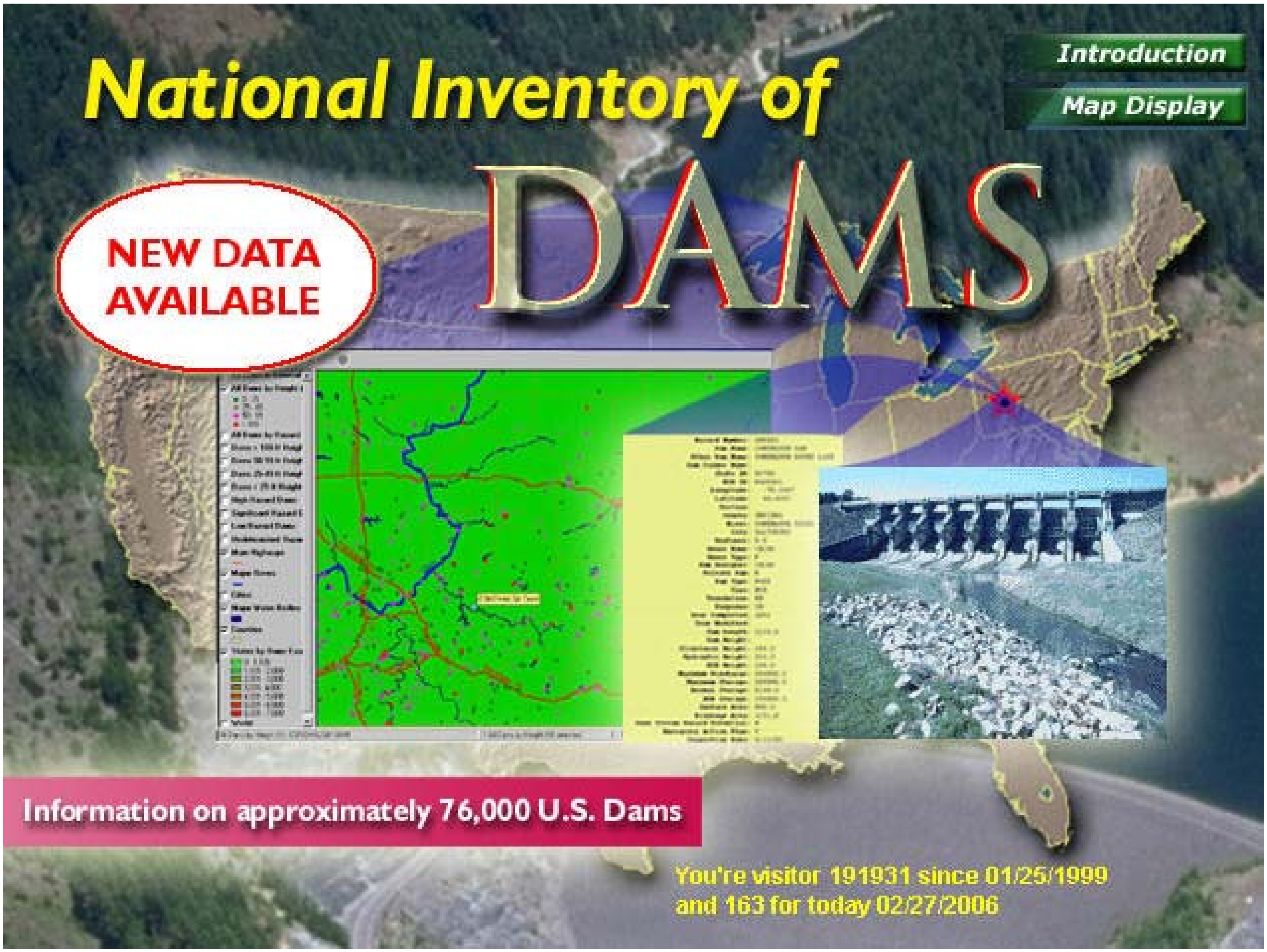
Why opposition to dams?



Hydropower dam issues Namibia and Botswana

UPSTREAM
•Loss of riverine forests
•Mosquitoes harbored = malaria
•Displacement of Himba people

DOWNSTREAM
•Channel straightening
•Sediment trapping
•Peak flood timing change



http://crunch.tec.army.mil/nid/webpages/nid.cfm