Water, sediments and biota: why continuity is key for healthy rivers

Fernando Magdaleno (CIREF)

Centro Italiano per la Riqualificazione Fluviale

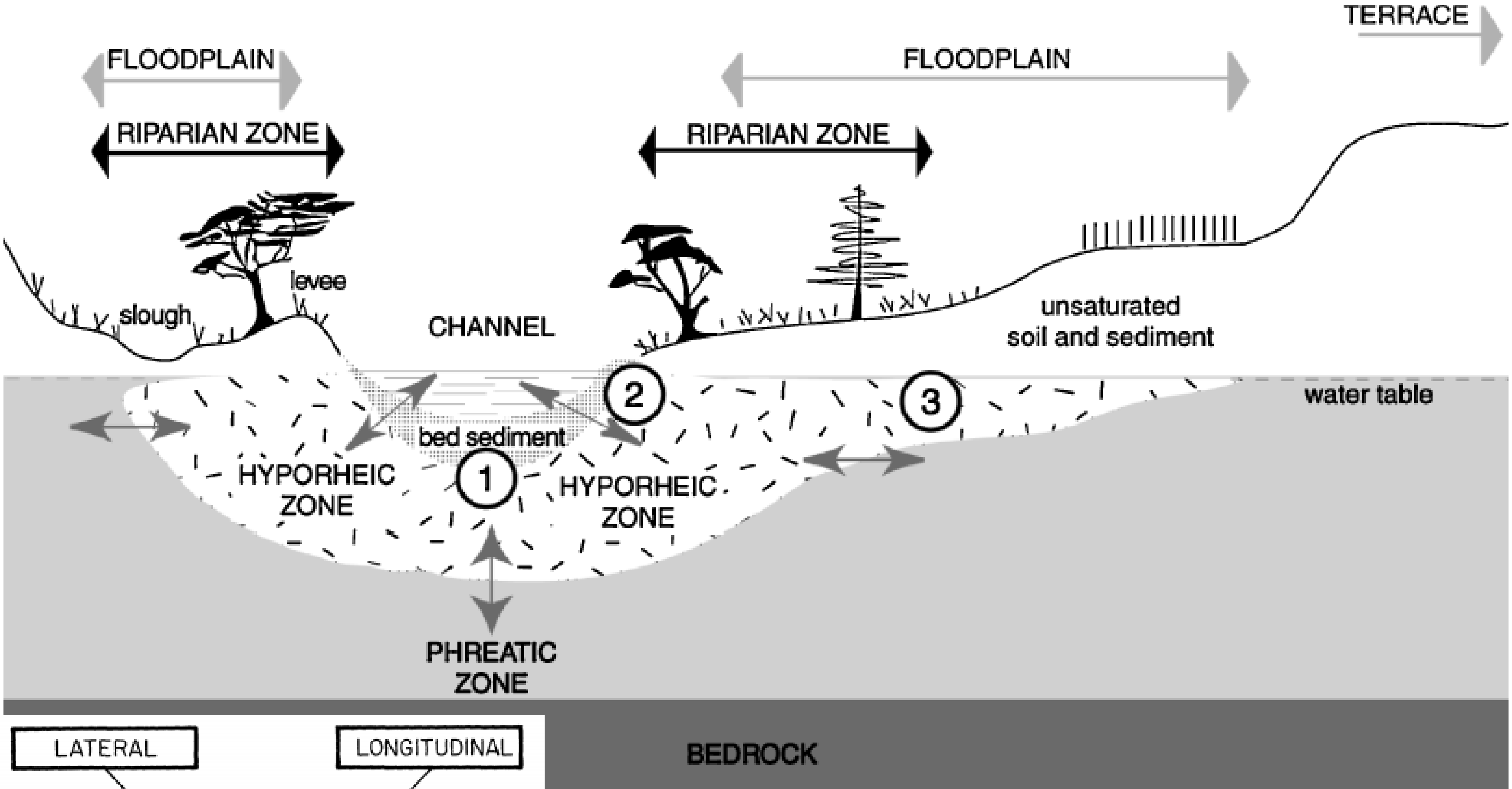
Wetlands International

This webinar series was supported by the European Commission through LIFE NGO funding

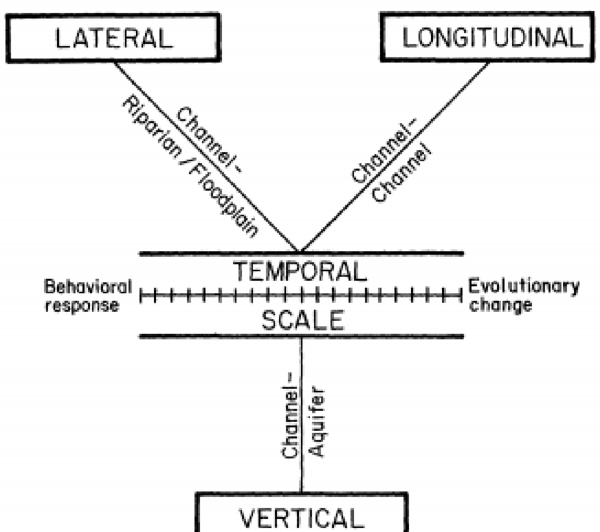
Overview

1. **Rivers as complex systems**
2. **How are river dynamics and connectivities threatened?**
3. **Some approaches to improving water-sediments-biota interactions**
4. **Other (positive) examples in urban areas**
5. **Conclusions**

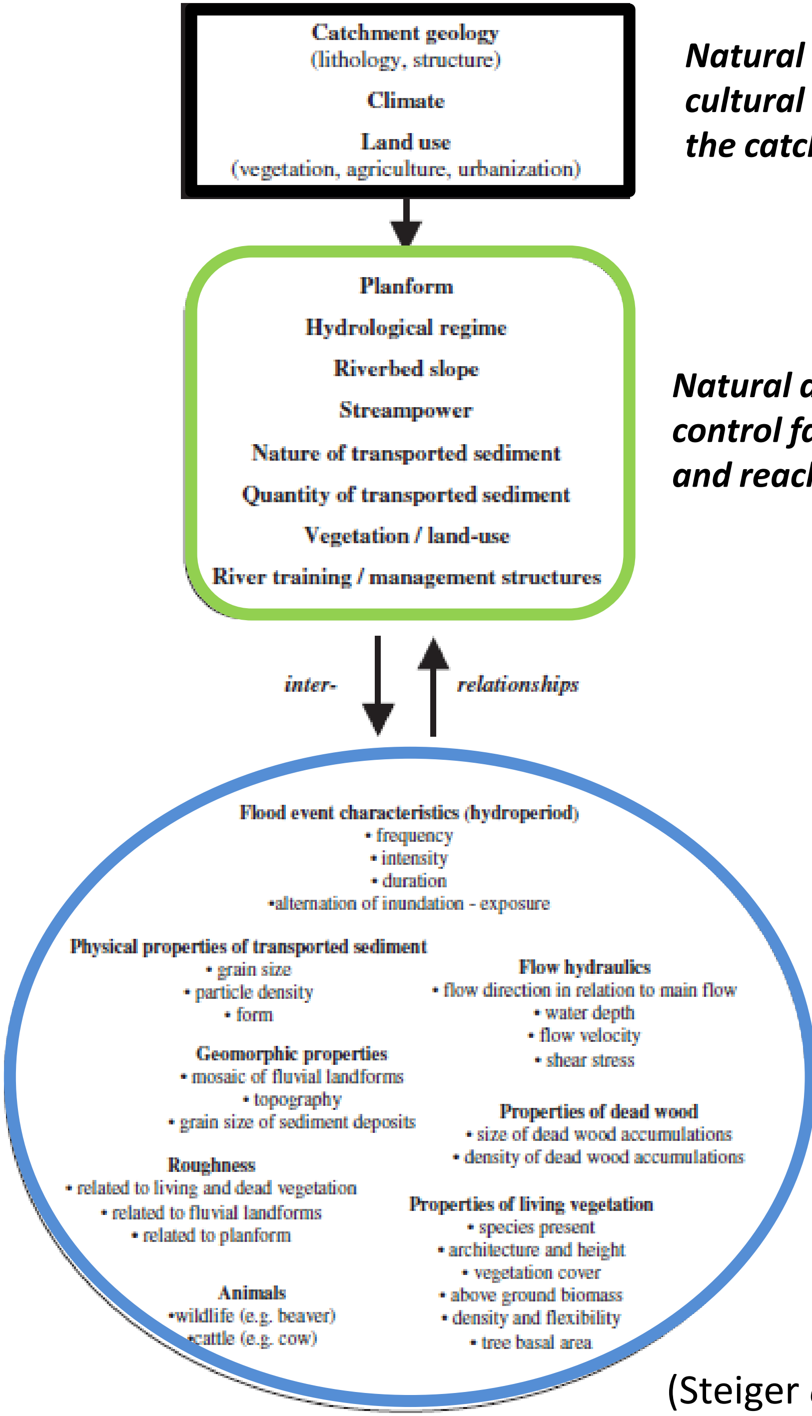
1. Rivers as complex systems



(Naiman *et al*., 2000)



(Ward, 1989)



Natural and cultural context of the catchment scale

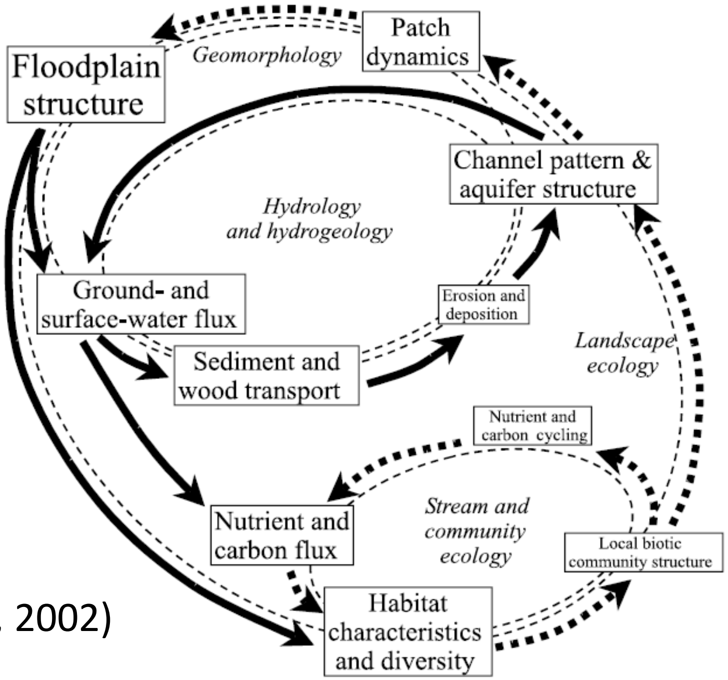
Natural and anthropogenic control factors at the river and reach scale

Primary factors interacting at the local scale

(Steiger *et al.*, 2005)

How do rivers work?

1. River continuum concept (Vannote *et al.*, 1980)
2. The serial discotinuity concept (Ward & Stanford, 1983, 1995)
3. The natural flow regime paradigm (or the predictible diversity) (Poff *et al*., 1997)
4. Intermediate disturbance hypothesis (Ward & Stanford, 1983)
5. Flood pulse concept (Junk *et al*., 1998)
6. The hierarchical classification of rivers (Frissell *et al*., 1986)
7. The hyporheic corridor concept (Stanford & Ward, 1993)
8. Network Dynamics Hypothesis (Benda *et al*., 2004)
9. Nutrients spiraling (Newbold *et al*., 1981)
10. Channel – floodplain - basin interactions

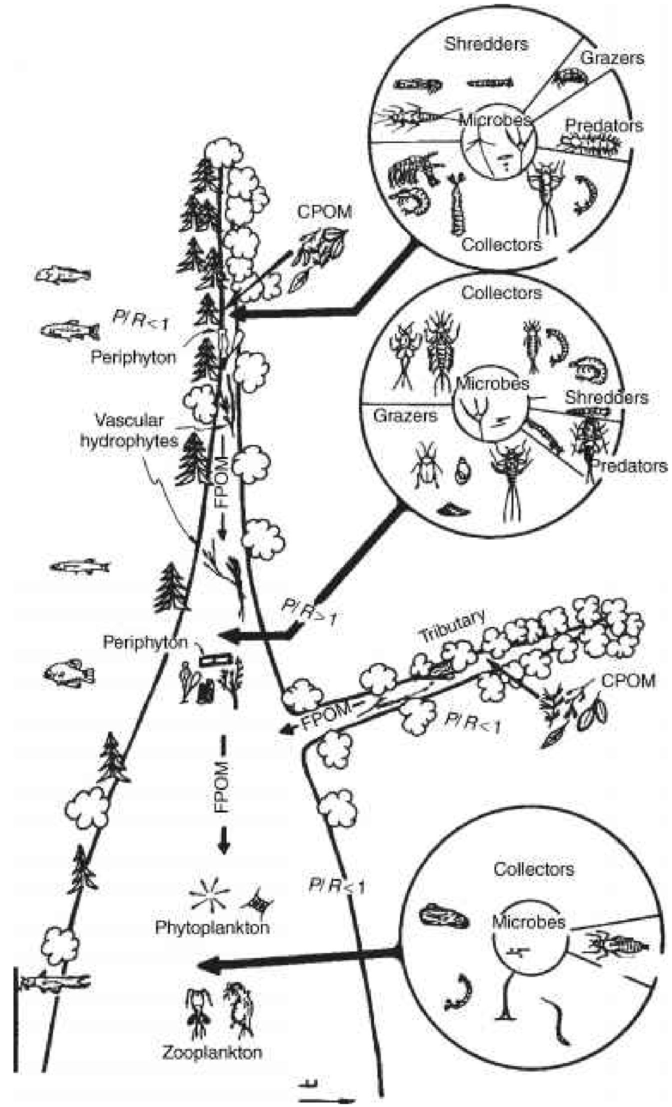


(Poole, 2002)

How do rivers work?

- **Principle 1: River Continuum Concept**

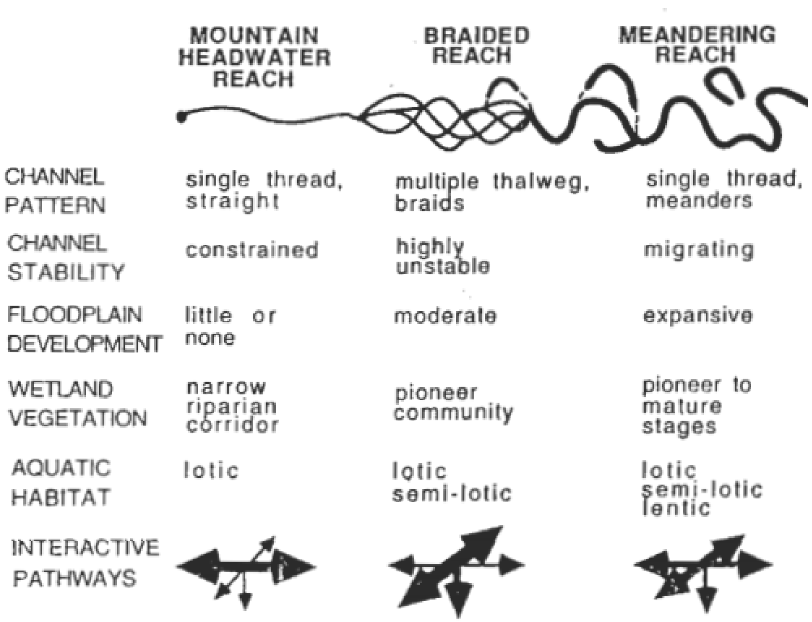
(Vannote *et al.*, 1980)

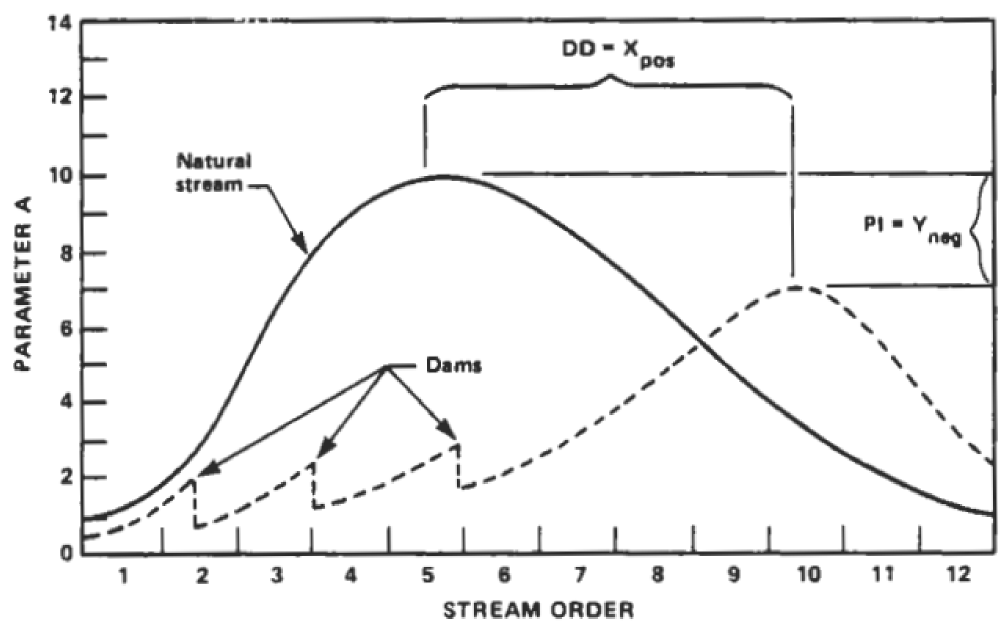


How do rivers work?

- **Principle 2: The serial discontinuity concept**

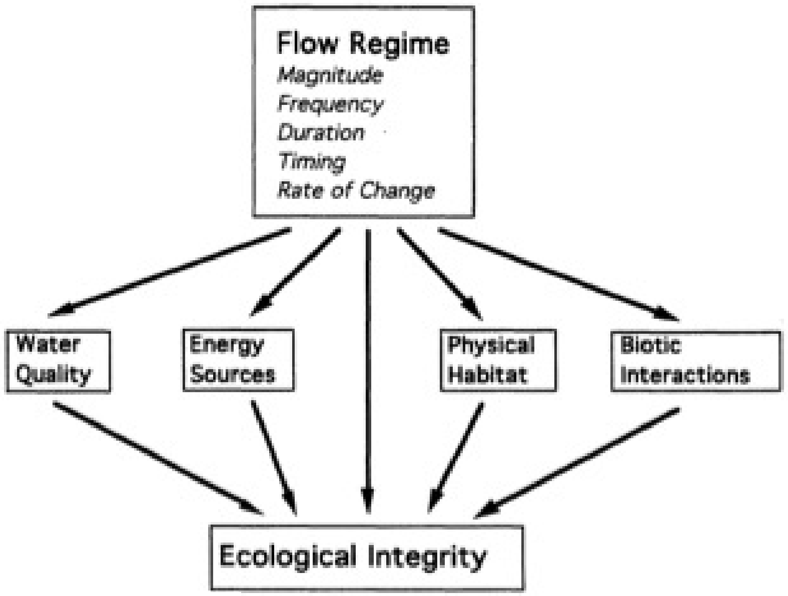
(Ward & Stanford, 1983, 1995)

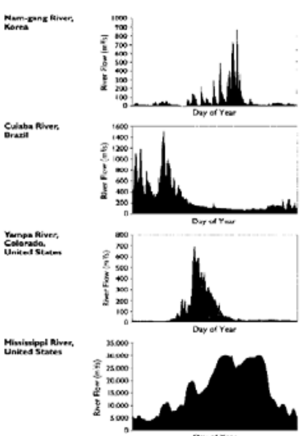


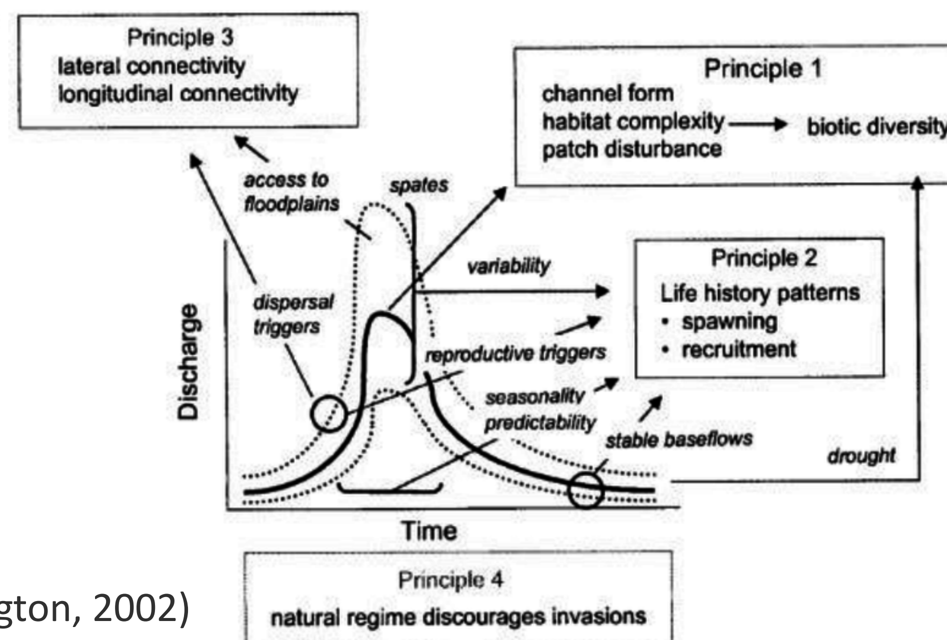


How do rivers work?

- **Principle 3: The natural flow regime paradigm (or the predictible diversity)** (Poff *et al.*, 1997)





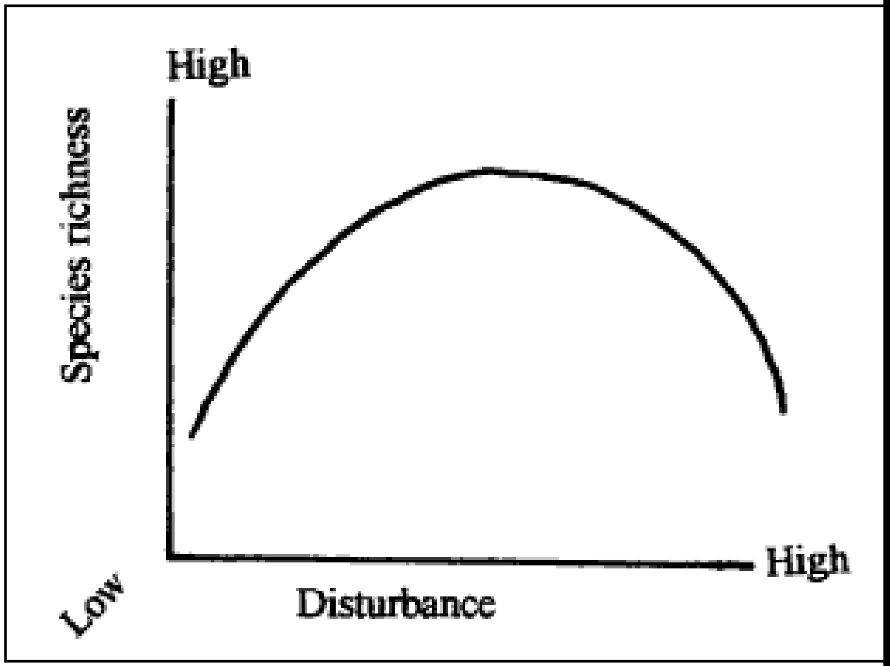


(Bunn & Arthington, 2002)

How do rivers work?

- **Principle 4: Intermediate disturbance hypothesis**

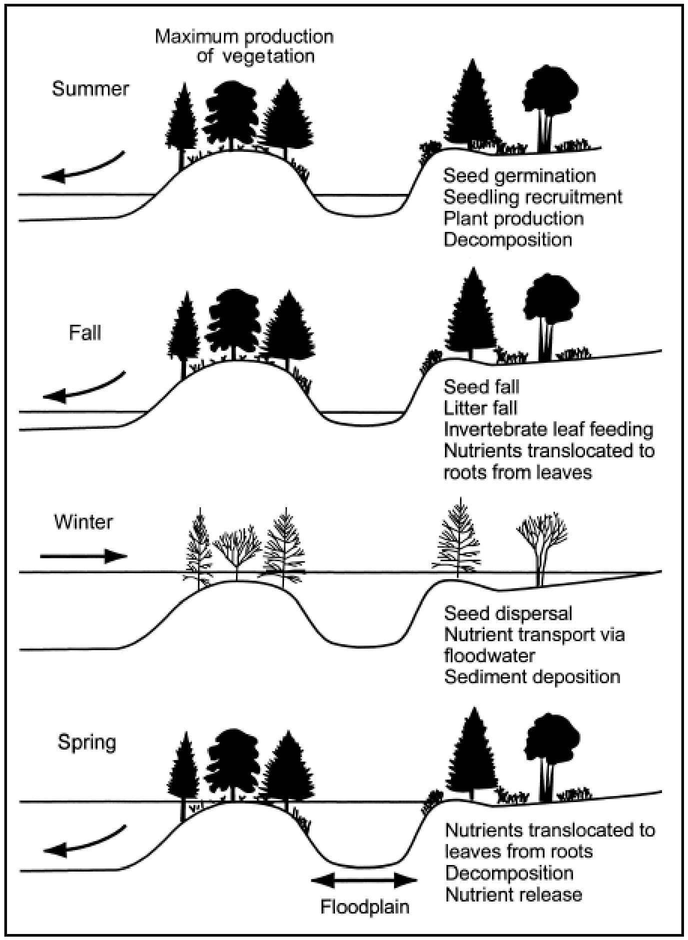
(Ward & Stanford, 1983)

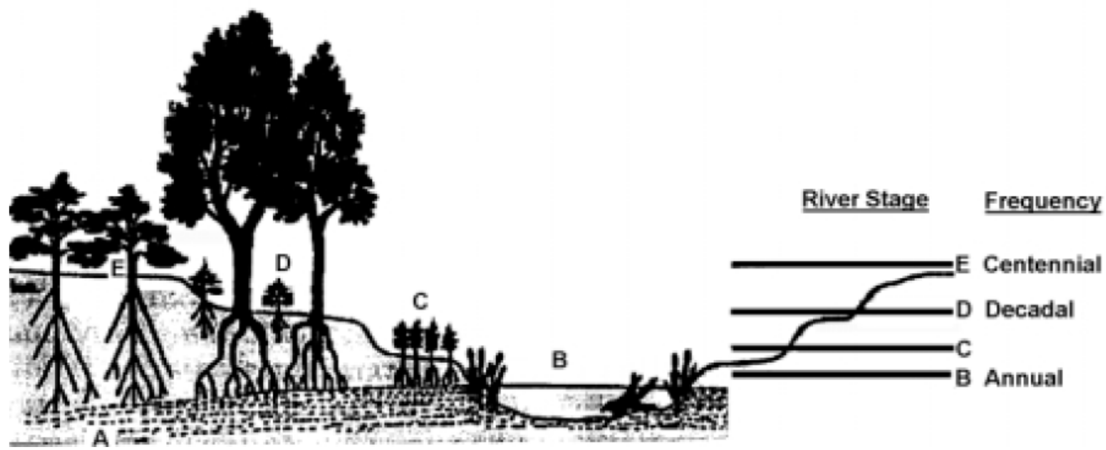


How do rivers work?

- **Principle 5: Flood pulse concept**

(Junk *et al.*, 1998)

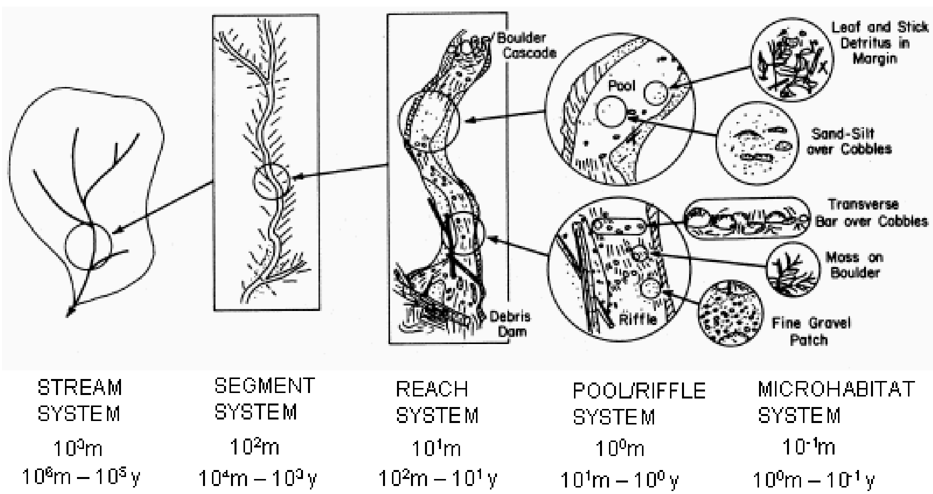


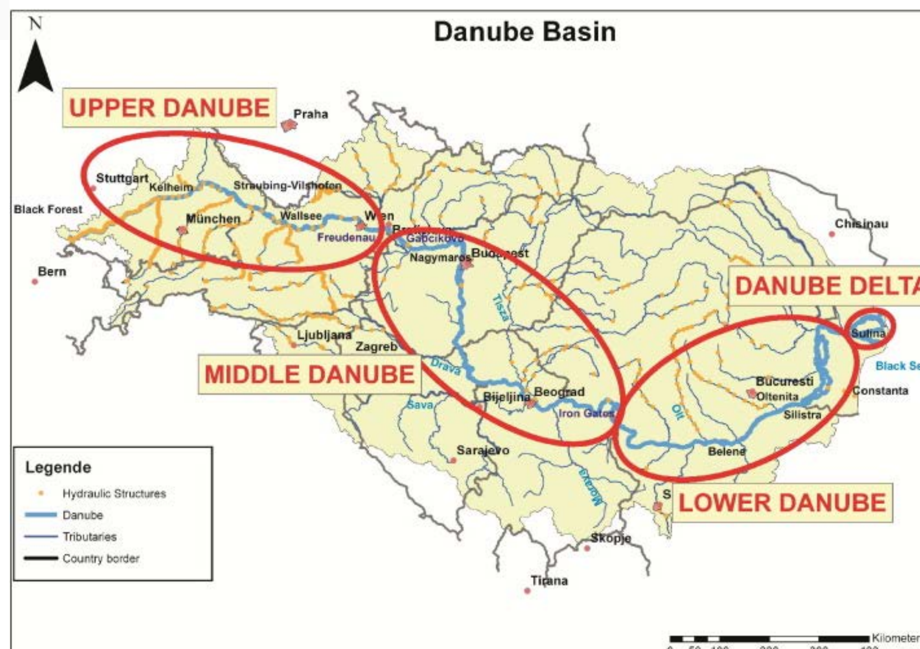


How do rivers work?

- **Principle 6: The hierarchical classification of rivers**

(Frissell *et al.*, 1986)

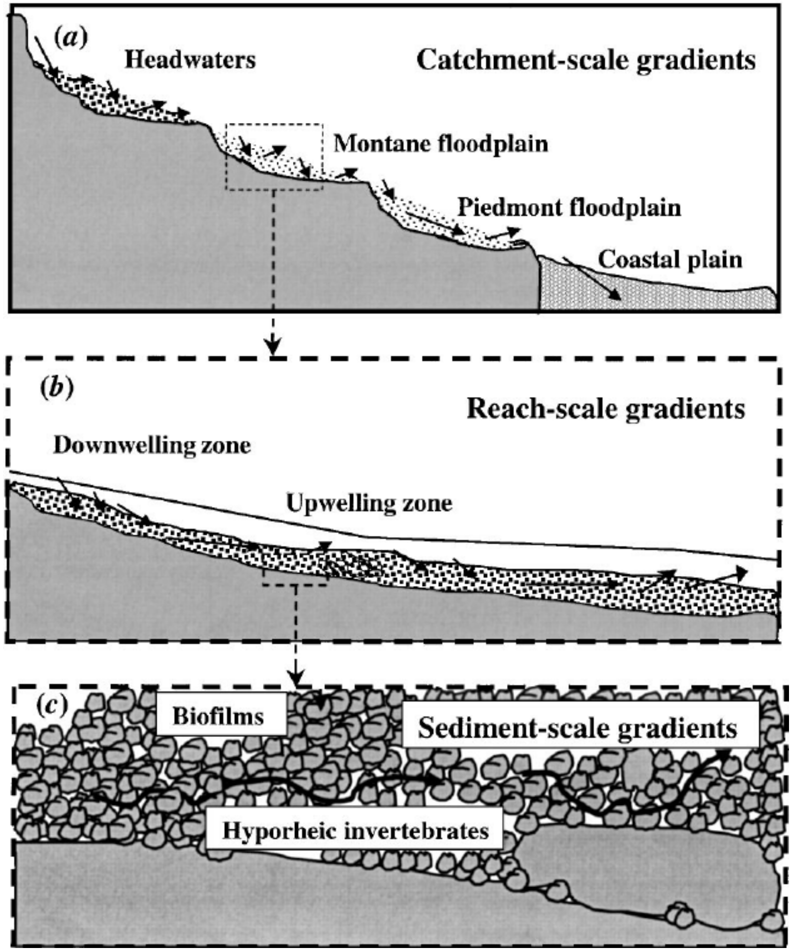




(Habersack *et al.*, 2016)

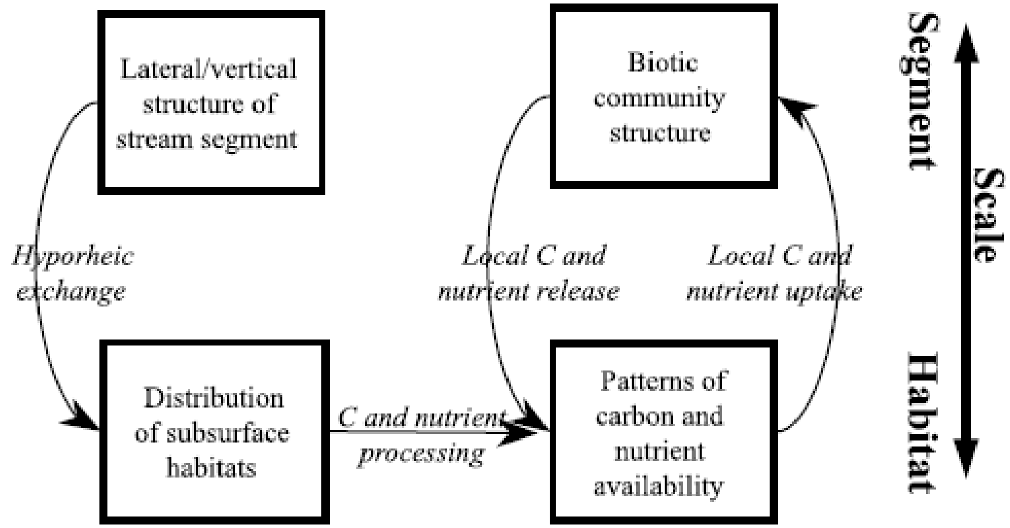
How do rivers work?

- **Principle 7: The hyporheic corridor concept** (Stanford & Ward, 1993)



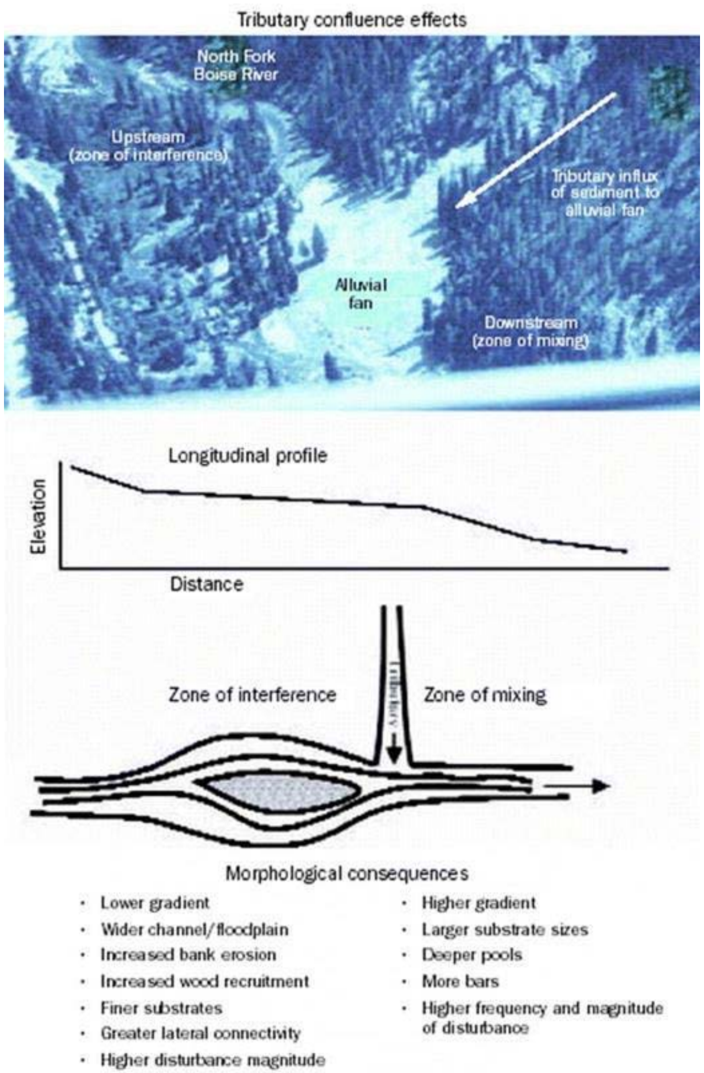
(Boulton *et al.*, 2003)

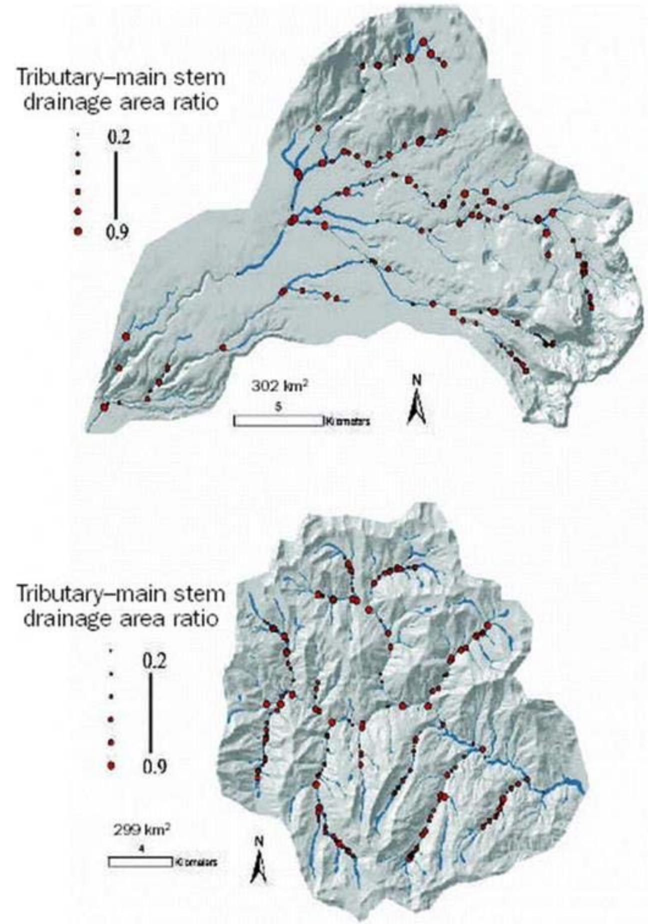
(Poole, 2002)



How do rivers work?

- **Principle 8: Network Dynamics Hypothesis**
  (Benda *et al*., 2004)

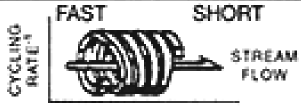
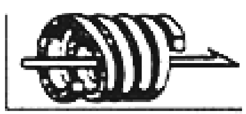
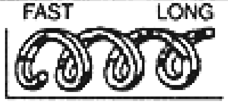
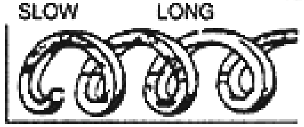




How do rivers work?

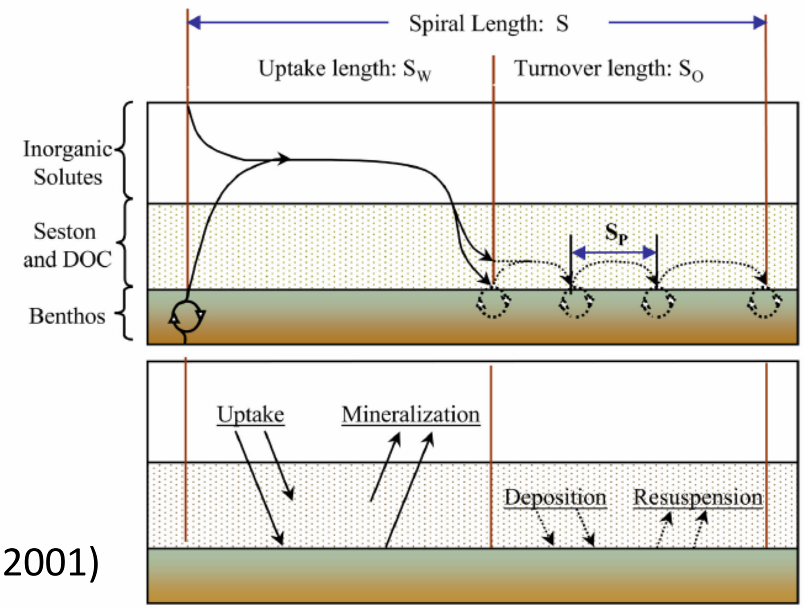
- **Principle 9: Nutrient spiraling**
  (Newbold *et al*., 1981)

<u>*Nutrient cycling + Downstream transport*</u>
Spiraling length influenced by abiotic attributes (flow, sediment, physical-chemical transformations), but also by biotic aspects (abundance of periphyton, abundance of heterotrophic microbes, uptake rates, composition of the animal community).

	Mechanism		Effect on Nutrient Cycling				
	Retention	Biological Activity	Rate of Recycling	Distance Between Spiral Loops	Ecosystem Response to Nutrient Addition	Ecosystem Stability	Categorization of study Streams
A.	HIGH	HIGH	FAST	SHORT 	CONSERVATIVE (I>E)	HIGH	MI 2,3 PA 1,2,3
B.	HIGH	LOW	SLOW	SHORT 	STORING (I>E)	HIGH	OR 1,2 ID 1 MI 1
C.	LOW	HIGH	FAST	LONG 	INTERMEDIATELY CONSERVATIVE < A but > D	LOW	ID 3 MI 4 PA 4
D.	LOW	LOW	SLOW	LONG 	EXPORTING (I≈E)	LOW	OR 3,4 ID 2,4

(Minshall *et al*., 1983)

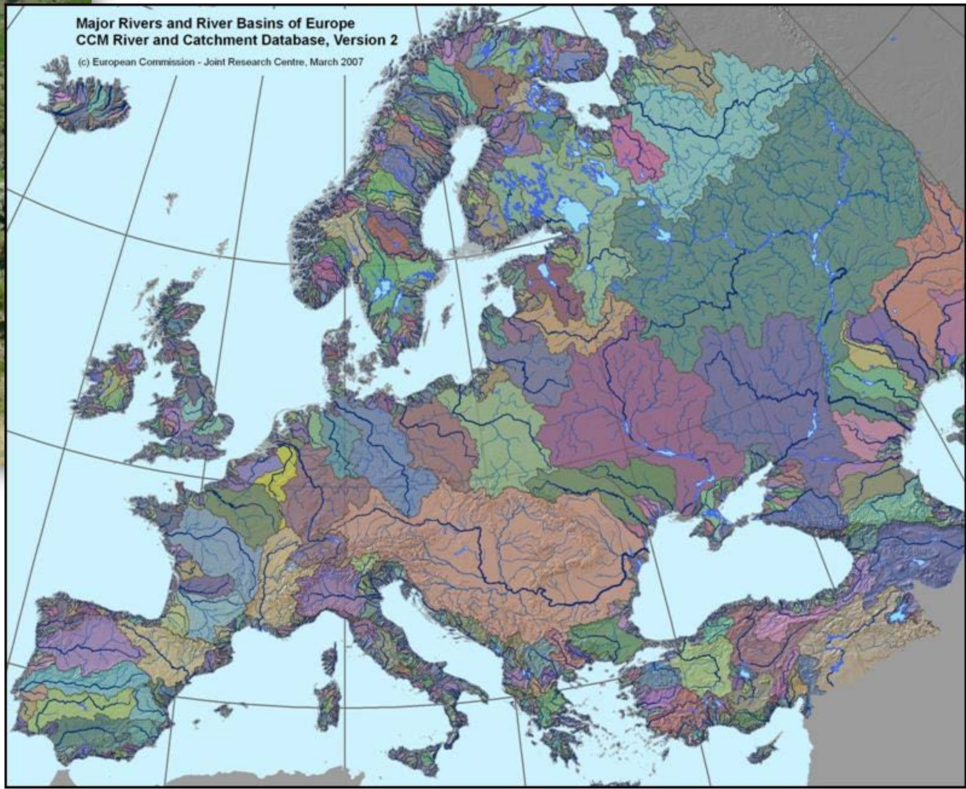
Carbon, nitrogen, phosphorus, silicon: top elements for organisms as nutrients



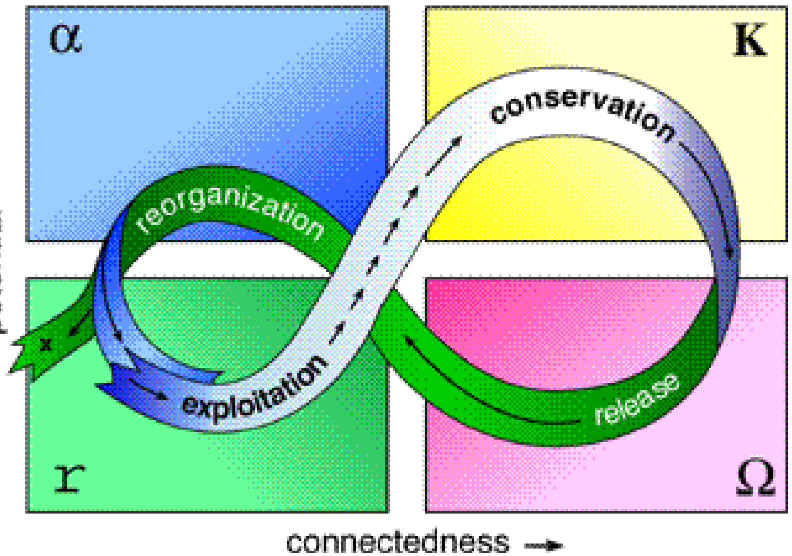
(Thomas *et al*., 2001)

How do rivers work?

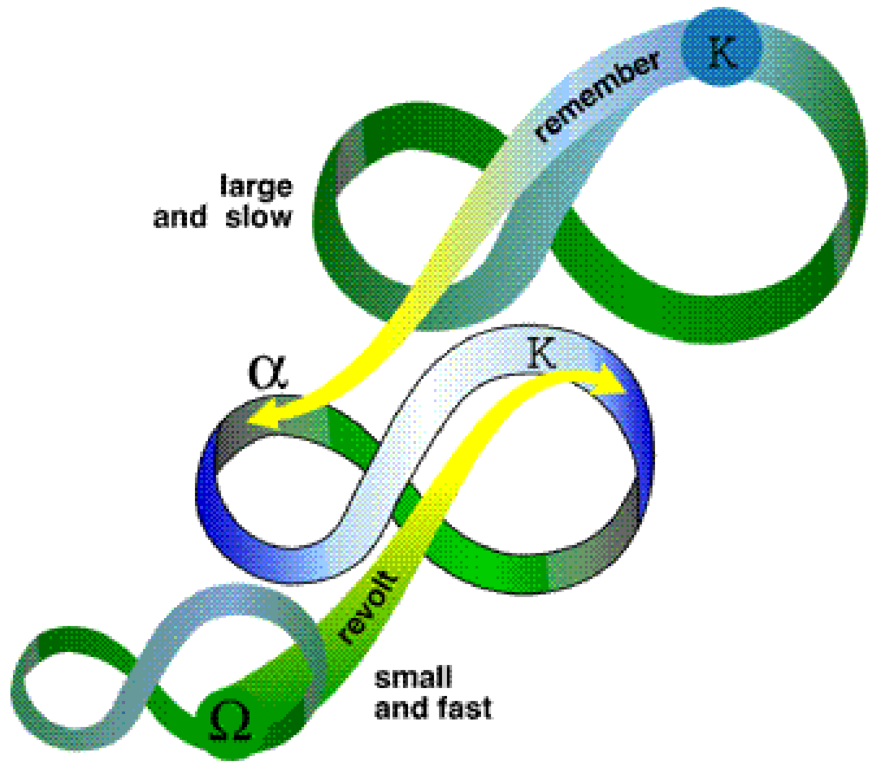
- **Principle 10: Channel – Floodplain – Basin interactions**



How do rivers work?



Panarchy in rivers



- Changes are episodic, modulated by interactions between fast and slow variables
- Non-linear processes reorganize processes across levels
- Ecosystems do not have a single equilibrium; multiple equilibria are frequent.

(The Sustainable Scale Project)

What do rivers offer?

Ecosystem service	Benefits
Provision of water supplies	More than 99 percent of irrigation, industrial and household water supplies worldwide come from natural freshwater systems
Provision of food	Fish, waterfowl, mussels, clams, and the like are important food sources for people and wildlife
Water purification / waste treatment	Wetlands filter and break down pollutants, protecting water quality
Flood mitigation	Healthy watersheds and floodplains absorb rainwater and river flows, reducing flood damage
Drought mitigation	Healthy watersheds, floodplains and wetlands absorb rainwater, slow runoff, and help recharge groundwater
Provision of habitat	Rivers, streams, floodplains, and wetlands provide homes and breeding sites for fish, birds, wildlife, and numerous other species
Soil fertility maintenance	Healthy river-floodplain systems constantly renew the fertility of surrounding soils
Nutrient delivery	Rivers carry nutrient-rich sediment to deltas and estuaries, helping maintain their productivity
Maintenance of coastal salinity zones	Freshwater flows maintain the salinity gradients of deltas and coastal marine environments, a key to their biological richness and productivity
Provision of beauty and life-fulfilling values	Natural rivers and waterscapes are sources of inspiration and deep cultural and spiritual values; their beauty enhances the quality of human life
Recreational opportunities	Swimming, fishing, hunting, boating, wildlife viewing, waterside hiking, and picnicking
Biodiversity conservation	Diverse assemblages of species perform the work of natural (including all the services in this table), upon which societies depend; conserving genetic diversity preserves options for their future

(Postel & Richter, 2003)

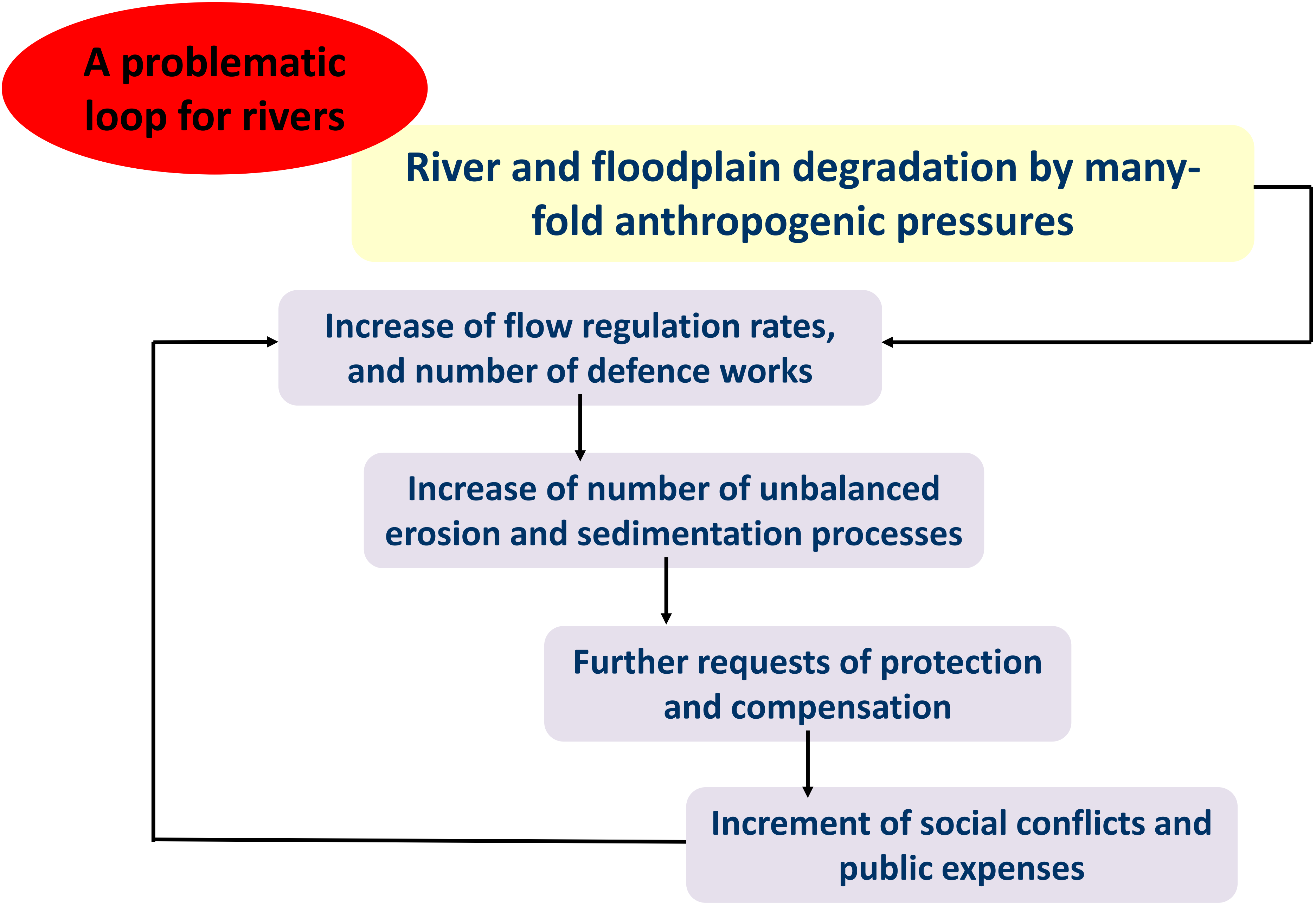
2. How are river dynamics and connectivities threatened?

Human activity	Impacts on ecosystems	Benefits/services at risk
Dam construction	Alters timing and quantity of river flows, water temperature, nutrient and sediment transport, delta replenishment; blocks fish migrations	Provision of habitat for native species, recreational and commercial fisheries, maintenance of deltas and their economies, productivity of estuarine fisheries
Dike and levee construction	Destroys hydrologic connection between river and floodplain habitat	Habitat, sport and commercial fisheries, natural floodplain fertility, natural flood control
Excessive river diversions	Depletes streamflows to damaging levels	Habitat, sport and commercial fisheries, recreation, pollution dilution, hydropower, transportation
Draining of wetlands	Eliminates key component of aquatic environment	Natural flood control, habitat for fish and waterfowl, recreation, natural water purification
Deforestation / poor land use	Alters runoff patterns, inhibits natural recharge, fills water bodies with silt	Water supply quantity and quality, fish and wildlife habitat, transportation, flood control
Uncontrolled pollution	Diminishes water quality	Water supply, habitat, commercial fisheries, recreation

Threats to Freshwater Ecosystem Services from Human Activities (Postel & Carpenter, 1997)

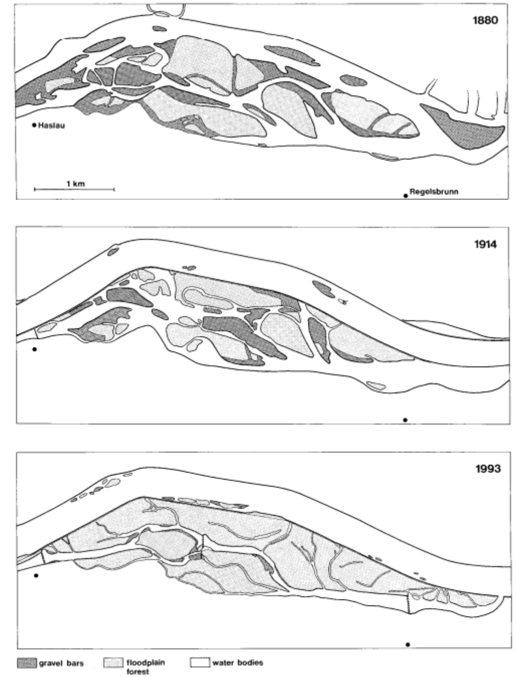
Human activity	Impacts on ecosystems	Benefits/services at risk
Overharvesting	Depletes species populations	Sport anc commercial fisheries, waterfowl, other biotic populations
Introduction of exotic species	Eliminates native species, alters production and nutrient cycling	Sport and commercial fisheries, waterfowl, water quality, fish and wildlife habitat, transportation
Releases of metals and acid-forming pollutants to air and water	Alters chemistry of rivers and lakes	Habitat, fisheries, recreation, human health
Emissions of climate-altering air pollutants	Potential for dramatic changes in runoff patterns from increases in temperature	Water supply, hydropower, transportation, fish and wildlife habitat, pollution dilution, recreation, fisheries, flood control
Population and consumption growth	Increases pressures to dam and divert more water, to drai more wetland, etc.: increases water pollution, acid rain, and potential for climate change	Places virtually all aquatic ecosystem services at risk

Threats to Freshwater Ecosystem Services from Human Activities (Postel & Carpenter, 1997) (cont.)

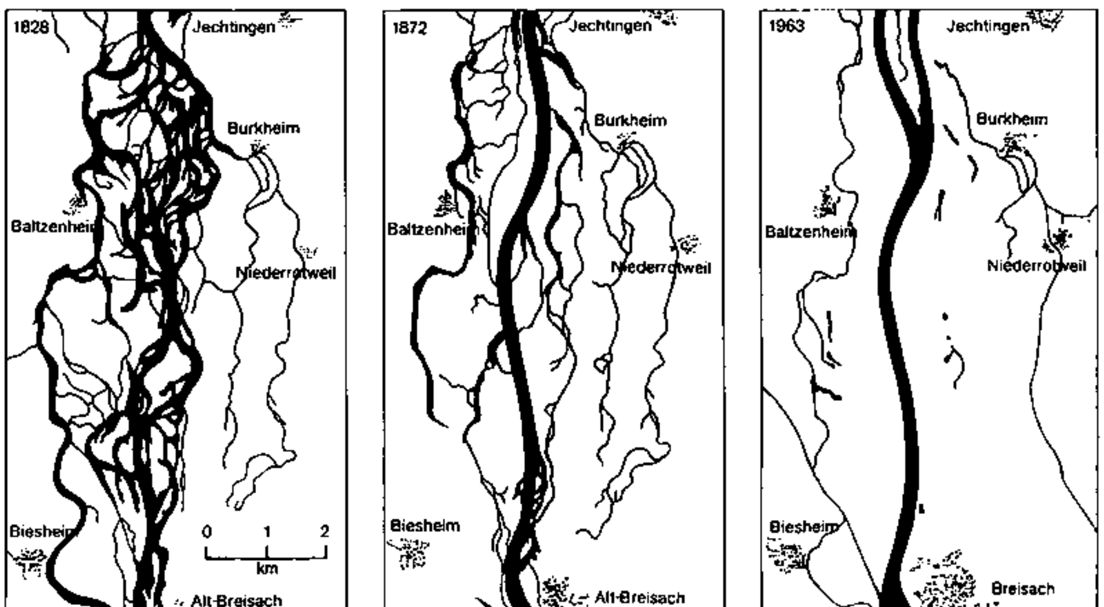

A problematic loop for rivers
River and floodplain degradation by many-fold anthropogenic pressures
Increase of flow regulation rates, and number of defence works
Increase of number of unbalanced erosion and sedimentation processes
Further requests of protection and compensation
Increment of social conflicts and public expenses

Aragon River. Source: Government of Navarre Region

Arga River. Source: Government of Navarre Region

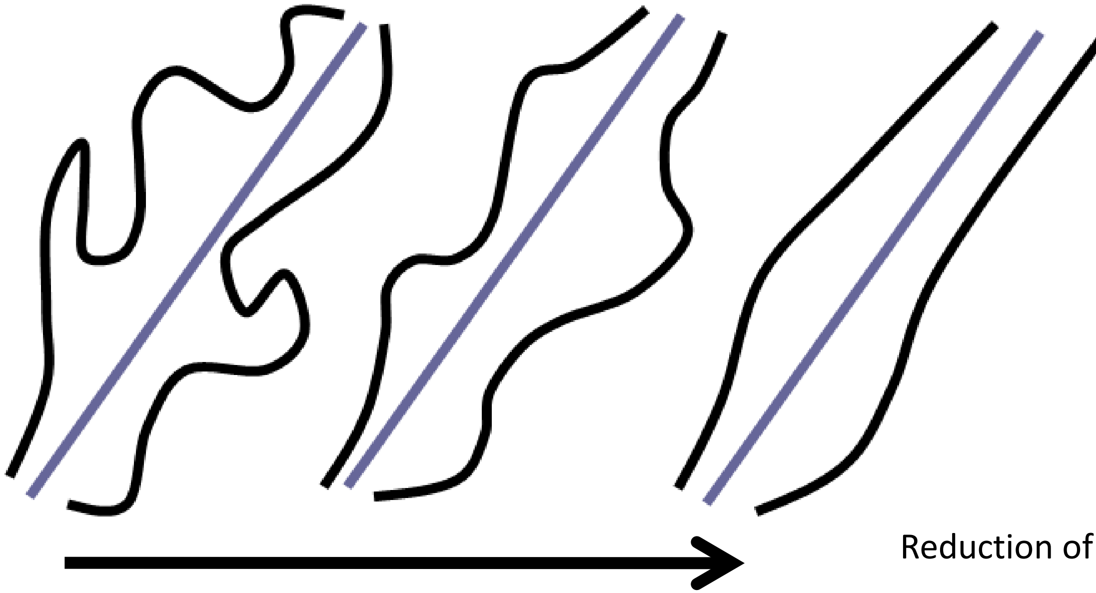


Danube River (Schiemer *et al*., 1999)

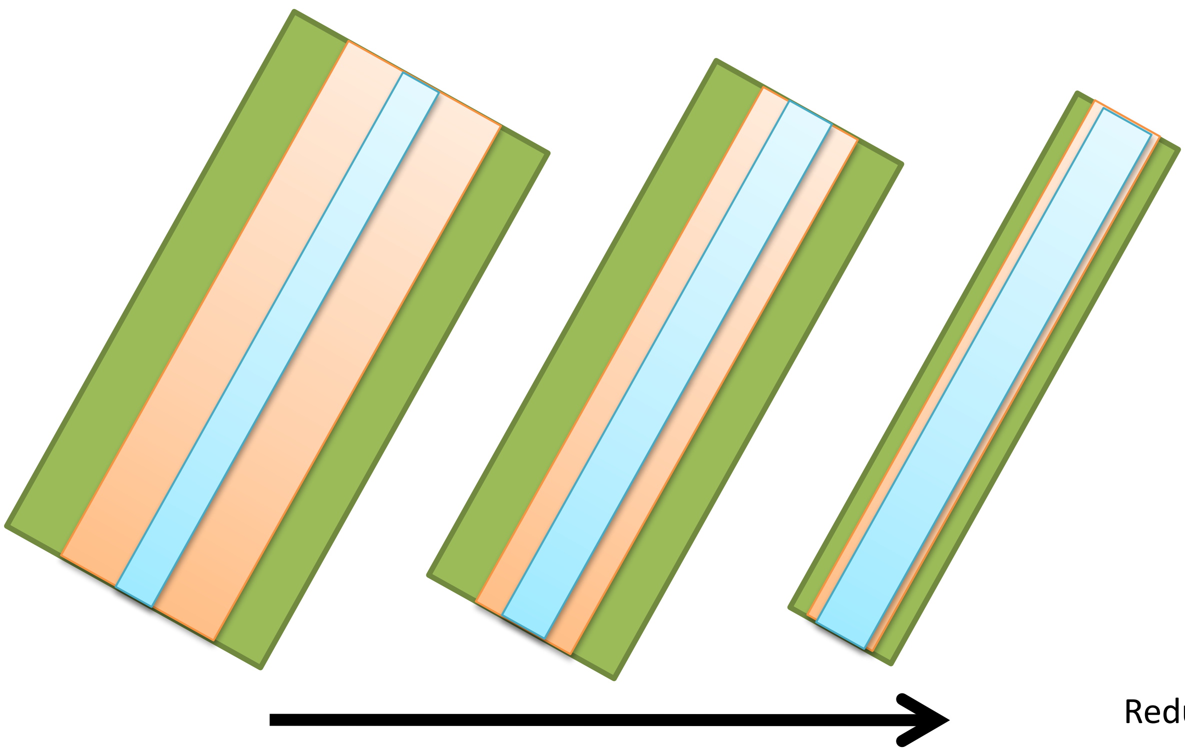


Rhine River (ICPR, 1991)

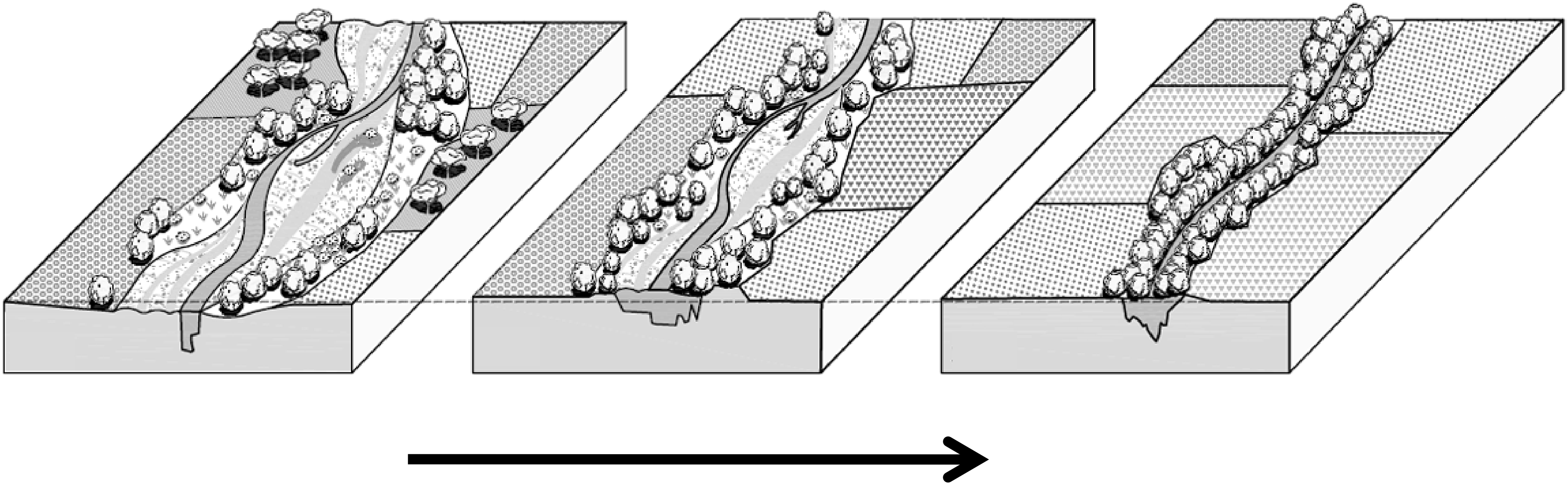
Jarama River



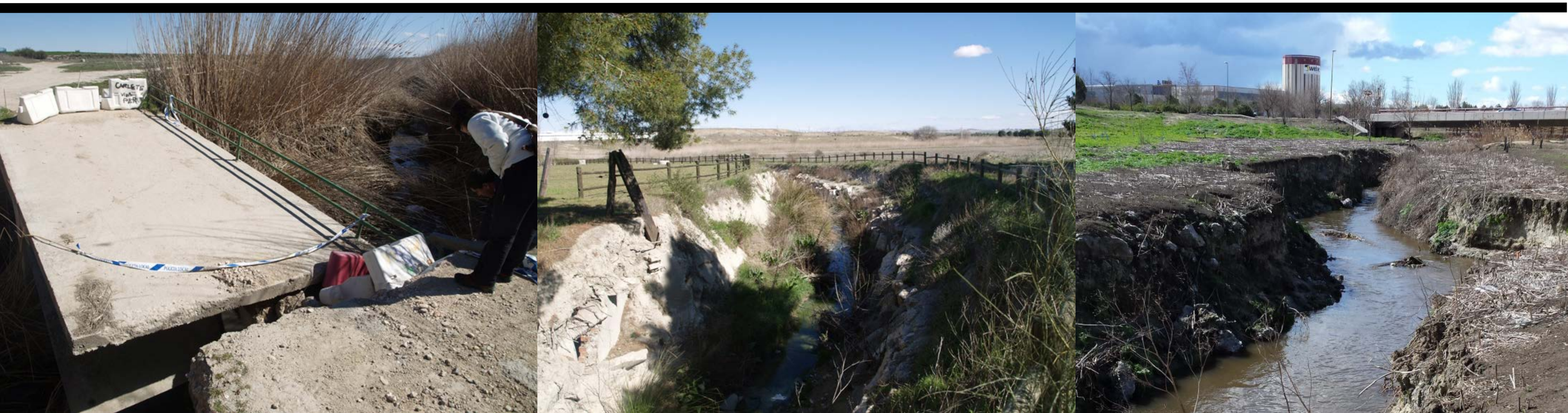
Reduction of banks complexity



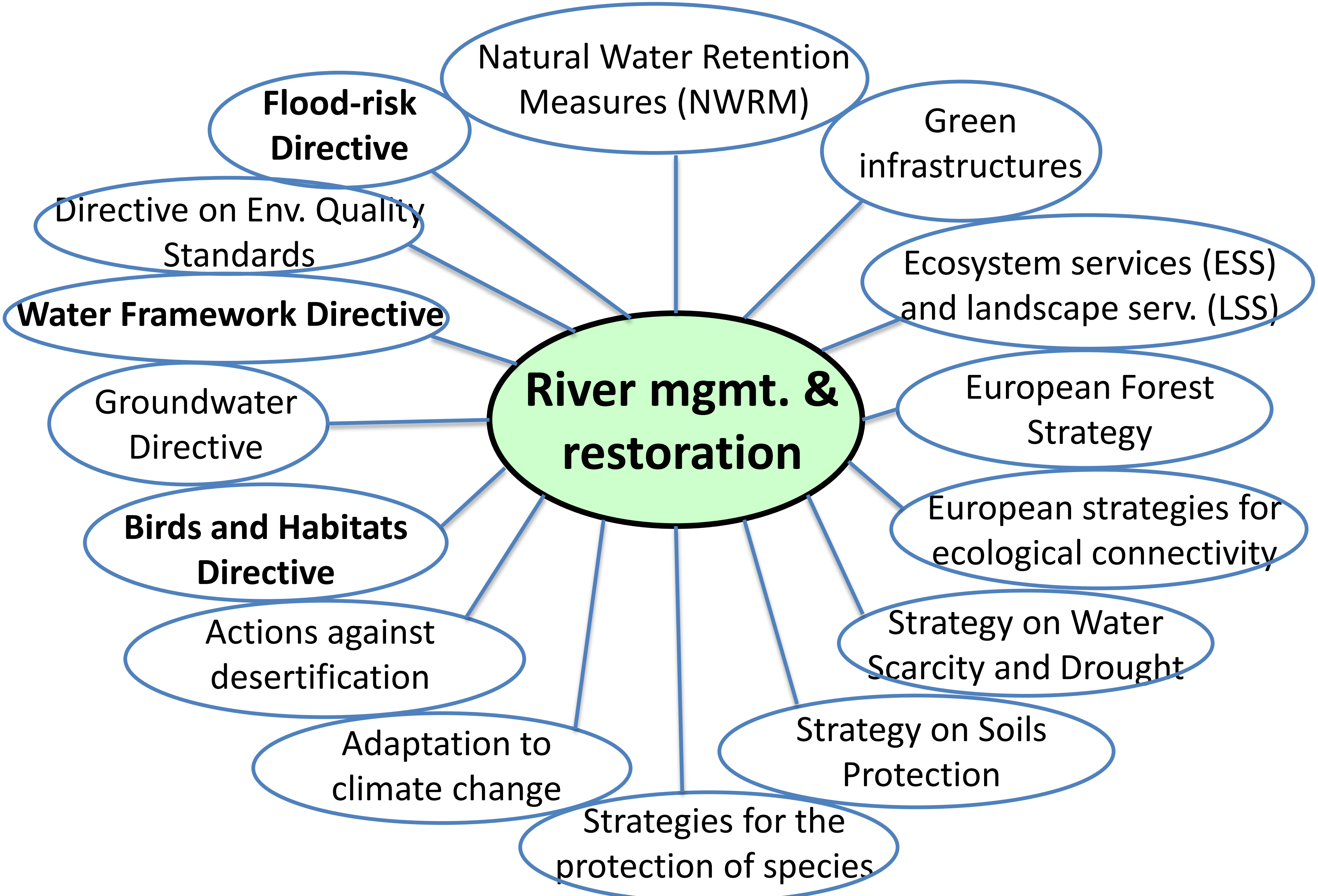
Reduction of river territory

Magdaleno *et al.,* 2017. *Physical Geography*



3. Some approaches to improving water-sediments-biota interactions



River mgmt. & restoration
Natural Water Retention Measures (NWRM)
Flood-risk Directive
Green infrastructures
Directive on Env. Quality Standards
Ecosystem services (ESS) and landscape serv. (LSS)
Water Framework Directive
European Forest Strategy
Groundwater Directive
European strategies for ecological connectivity
Birds and Habitats Directive
Strategy on Water Scarcity and Drought
Actions against desertification
Strategy on Soils Protection
Adaptation to climate change
Strategies for the protection of species

Approach to water-sediments-biota in the WFD

1.1. Quality elements for the classification of ecological status

1.1.1. Rivers

Biological elements

- Composition and abundance of aquatic flora
- Composition and abundance of benthic invertebrate fauna
- Composition, abundance and age structure of fish fauna

Hydromorphological elements supporting the biological elements

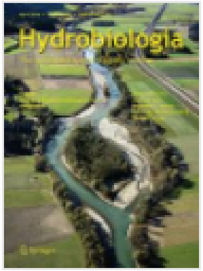
- **Hydrological regime**
  - **<u>quantity and dynamics of water flow</u>**
  - **<u>connection to groundwater bodies</u>**
- **River continuity**
- **Morphological conditions**
  - **<u>river depth and width variation</u>**
  - **<u>structure and substrate of the river bed</u>**
  - **<u>structure of the riparian zone</u>**

Ad-hoc Task Group on hydromorphology (ECOSTAT)

CEN Standards

Chemical and physico-chemical elements supporting the biological elements

- General
  - Thermal conditions
  - Oxygenation conditions
  - Salinity
  - Acidification status
  - Nutrient conditions
- Specific pollutants
  - Pollution by all priority substances identified as being discharged into the body of water
  - Pollution by other substances identified as being discharged in significant quantities (...)



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Assessing the societal benefits of river restoration using the ecosystem services approach

Authors | Authors and affiliations

Jan E. Vermaat, Alfred J. Wagtendonk, Roy Brouwer, Oleg Sheremet, Erik Ansink, Tim Brockhoff, Maarten Plug, Seppo Hellsten, Jukka Aroviita, Luiza Tylec, Marek Giełczewski, Lukas Kohut, Karel Brabec, Jantine Haverkamp, Michaela Poppe, show 4 more

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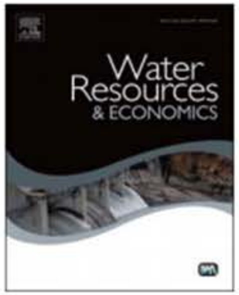
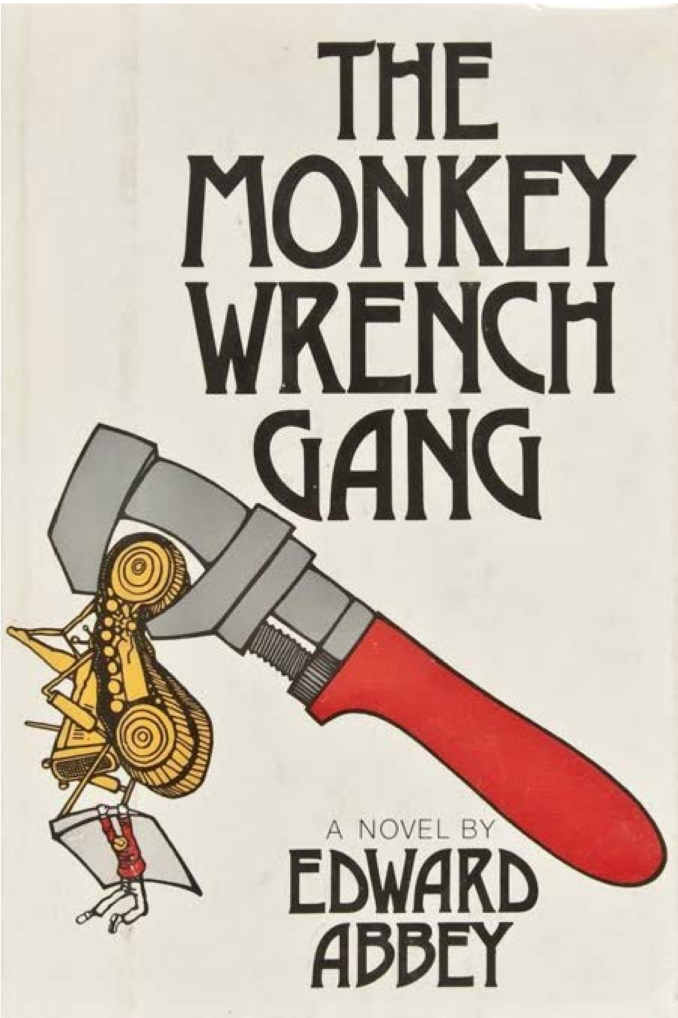


The economic value of river restoration

CrossMark

1. Introduction

BIG JUMP
FOR LIVING RIVERS
VOOR LEVENDE RIVIEREN
POUR DES RIVIERES VIVANTES



PERSPECTIVES

ECOLOGY

1000 dams down and counting

Dam removals are reconnecting rivers in the United States

By J. E. O'Connor,[1] J. J. Duda,[2] G. E. Grant[3]

Forty years ago, the demolition of large dams was mostly fiction, notably plotted in Edward Abbey's novel *The Monkey Wrench Gang*. Its 1975 publication roughly coincided with the end of large-dam construction in the United States. Since then, dams have been taken down in increasing numbers as they have filled with sediment, become unsafe or inefficient, or otherwise outlived their usefulness (*1*) (see the figure, panel A). Last year's removals of the 64-m-high Glines Canyon Dam and the 32-m-high Elwha Dam in northwestern Washington State were among the largest yet, releasing


USDA United States Department of Agriculture Forest Service

PNW Pacific Northwest Research Station

Science FINDINGS

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Rapid Recovery ... 4

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"Science affects the way we think together."
Lewis Thomas

Liberated Rivers: Lessons From 40 Years of Dam Removal

1975 → **2017**

40 years

confederación hidrográfica del SEGURA

ENCAUZAMIENTOS FLUVIALES EN LA CUENCA DEL SEGURA

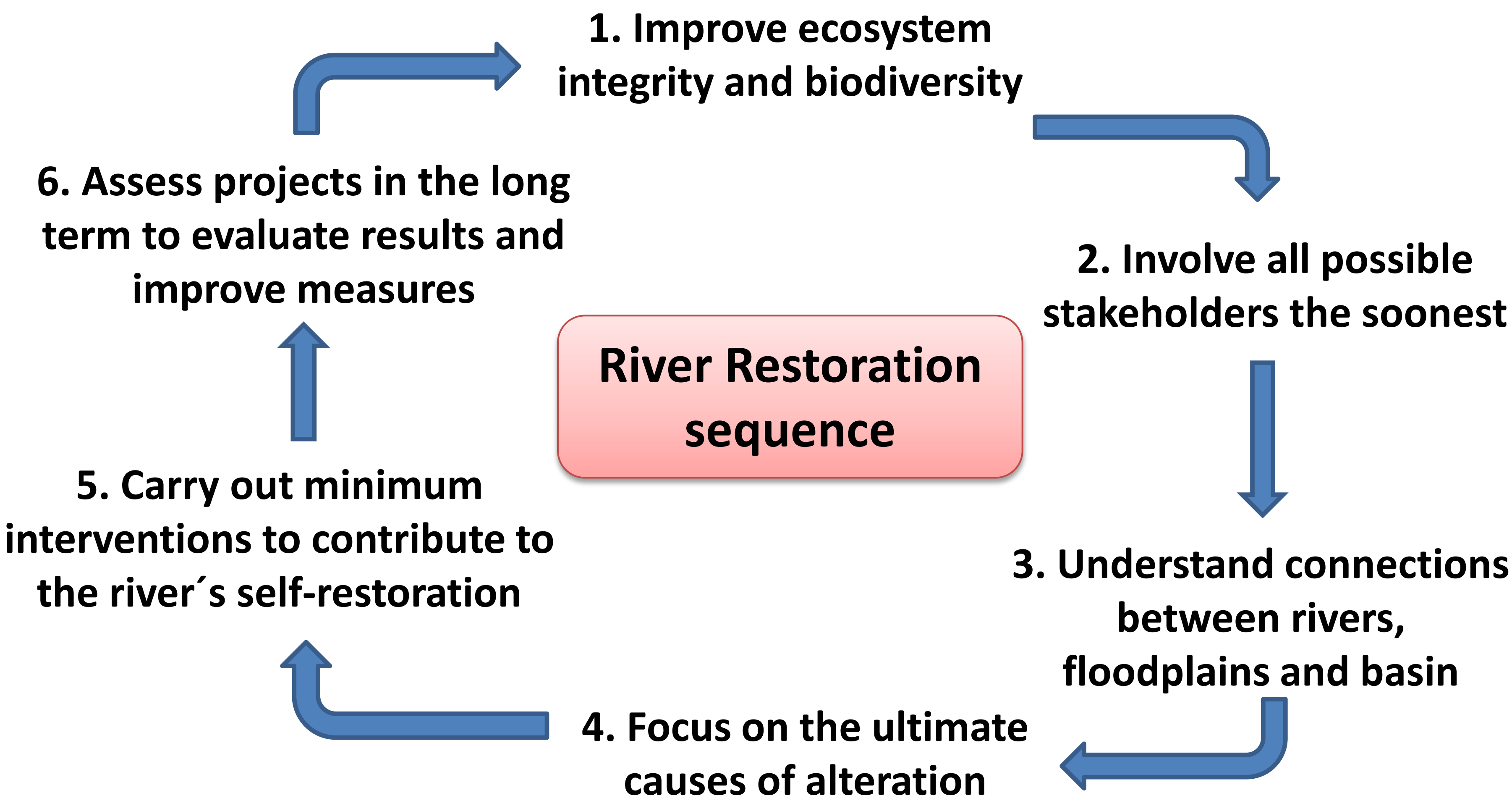
JORNADAS DE ENCAUZAMIENTOS FLUVIALES
Octubre 1990

SEGURA RIVERLINK
FRANQUEO FLUVIAL

INTERNATIONAL RiverFoundation
2016 European Riverprize Winner
SEGURA RIVER
SPAIN

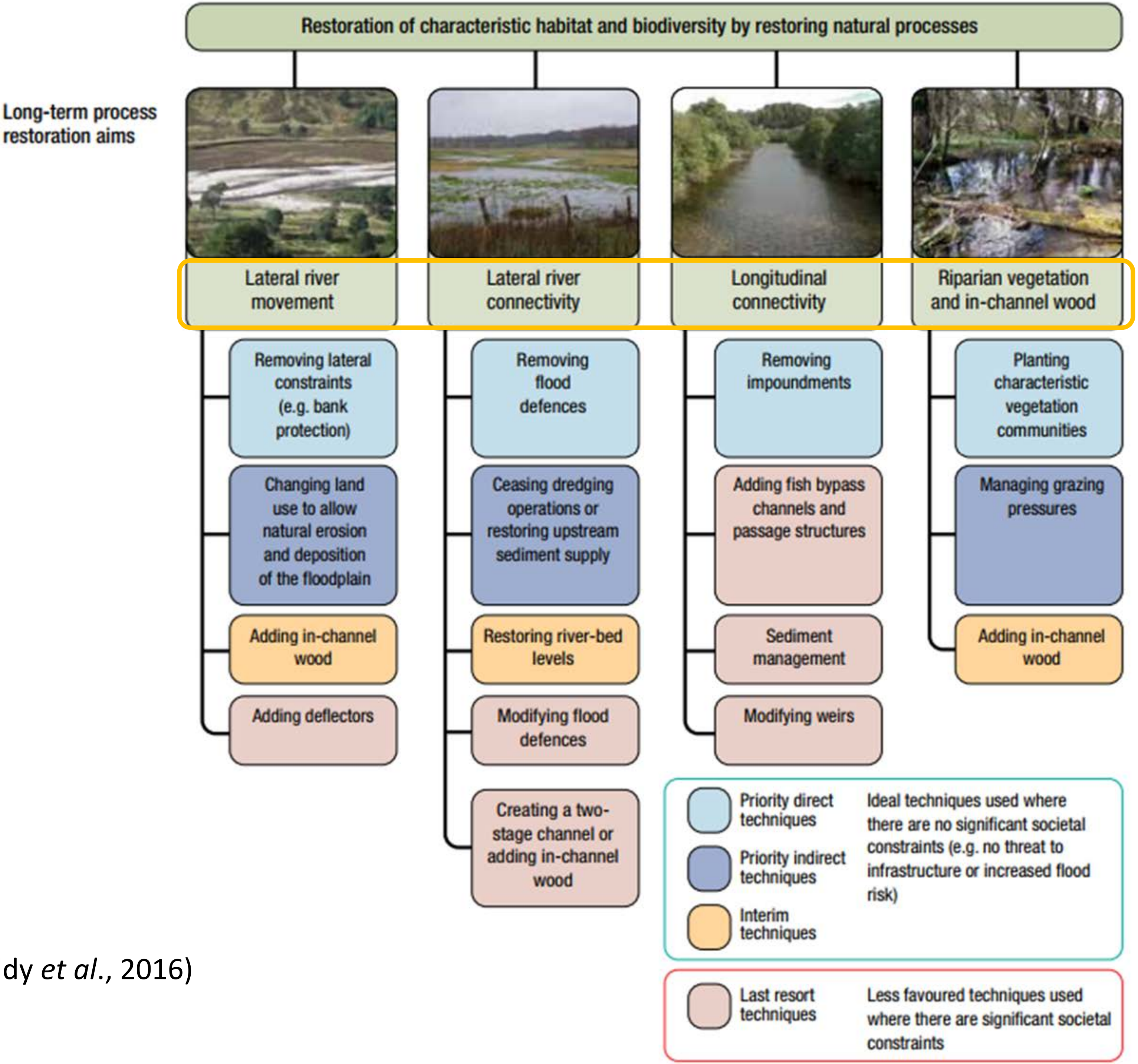
1990 ⟹ **2017**

25 years



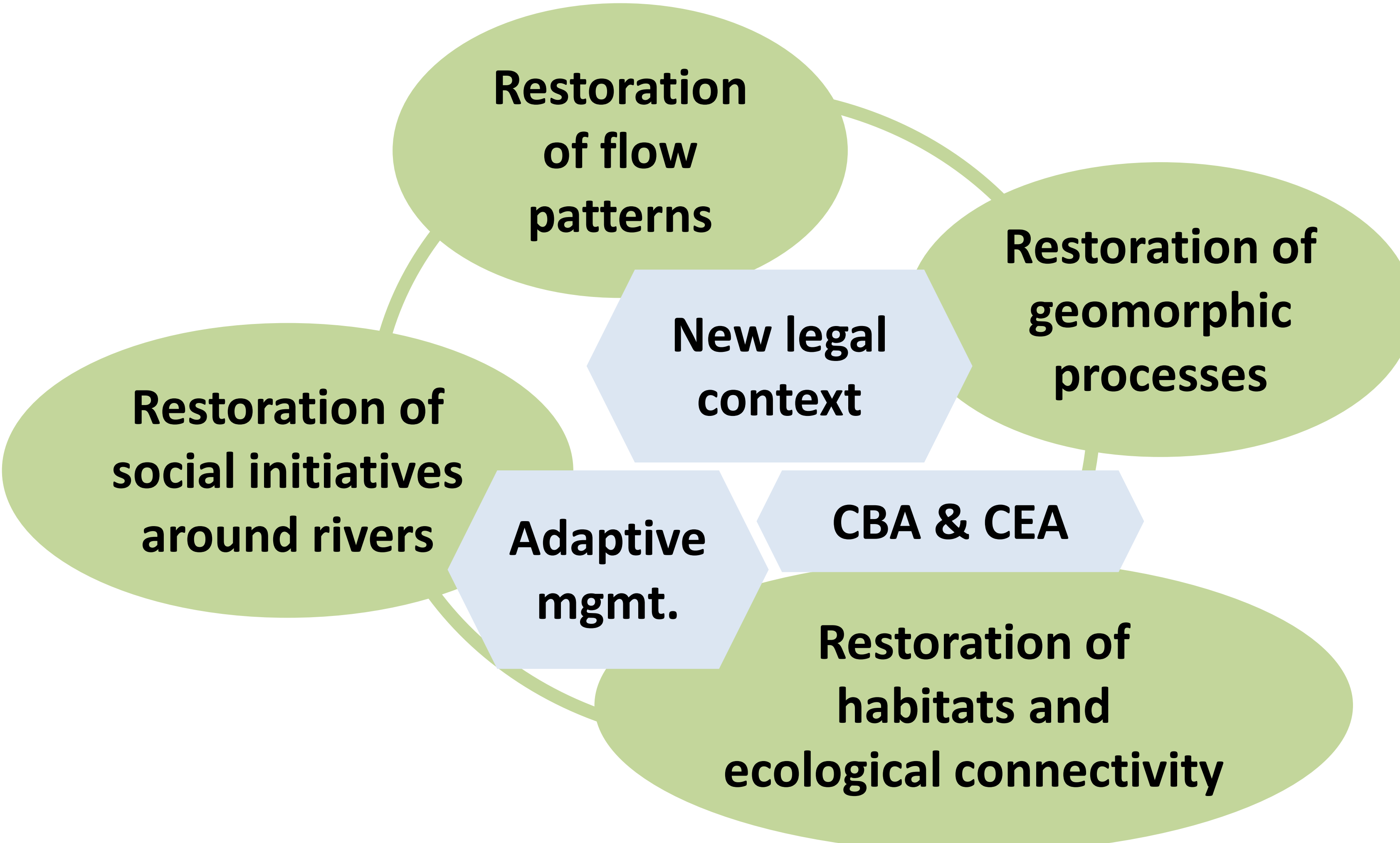
(Modified from: Addy *et al*., 2016)

Reference-based Vs. Objective-based restoration

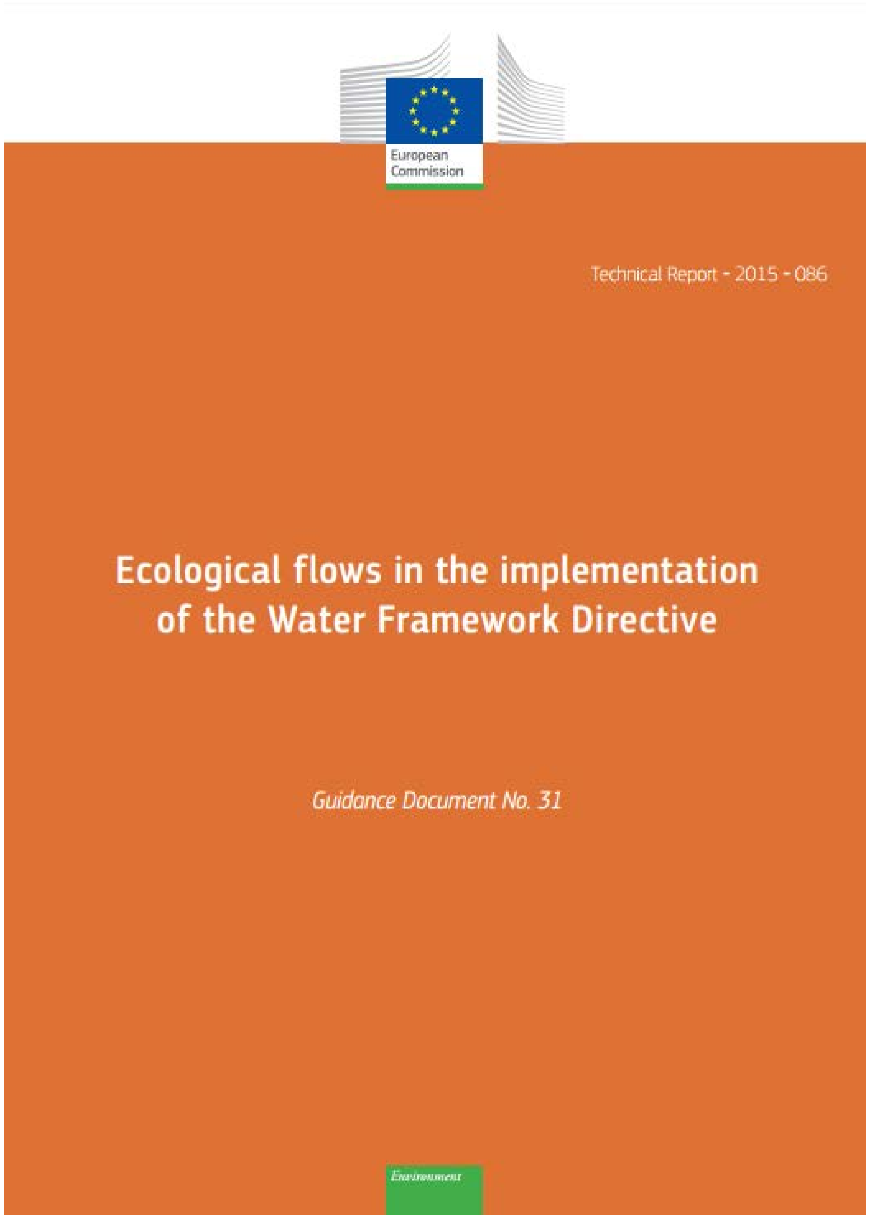


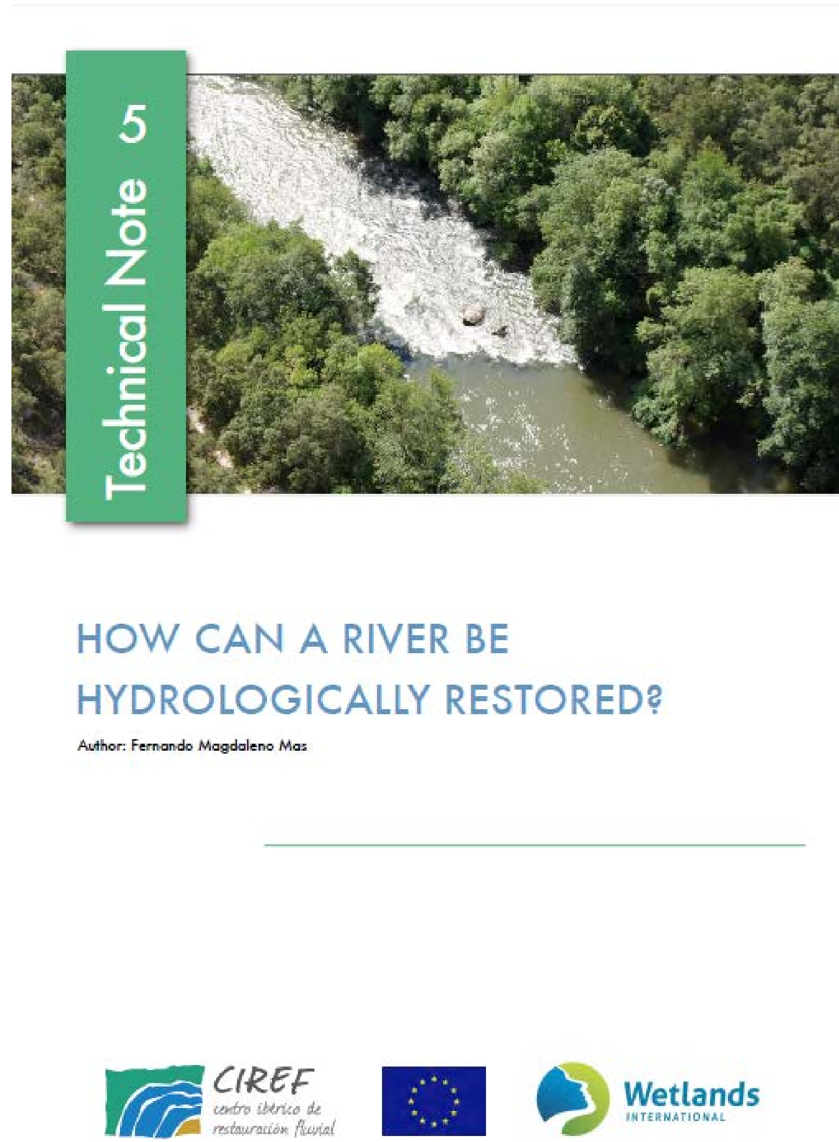
(Addy *et al*., 2016)

Main approaches to the restoration of degraded water-sediments-biota interactions

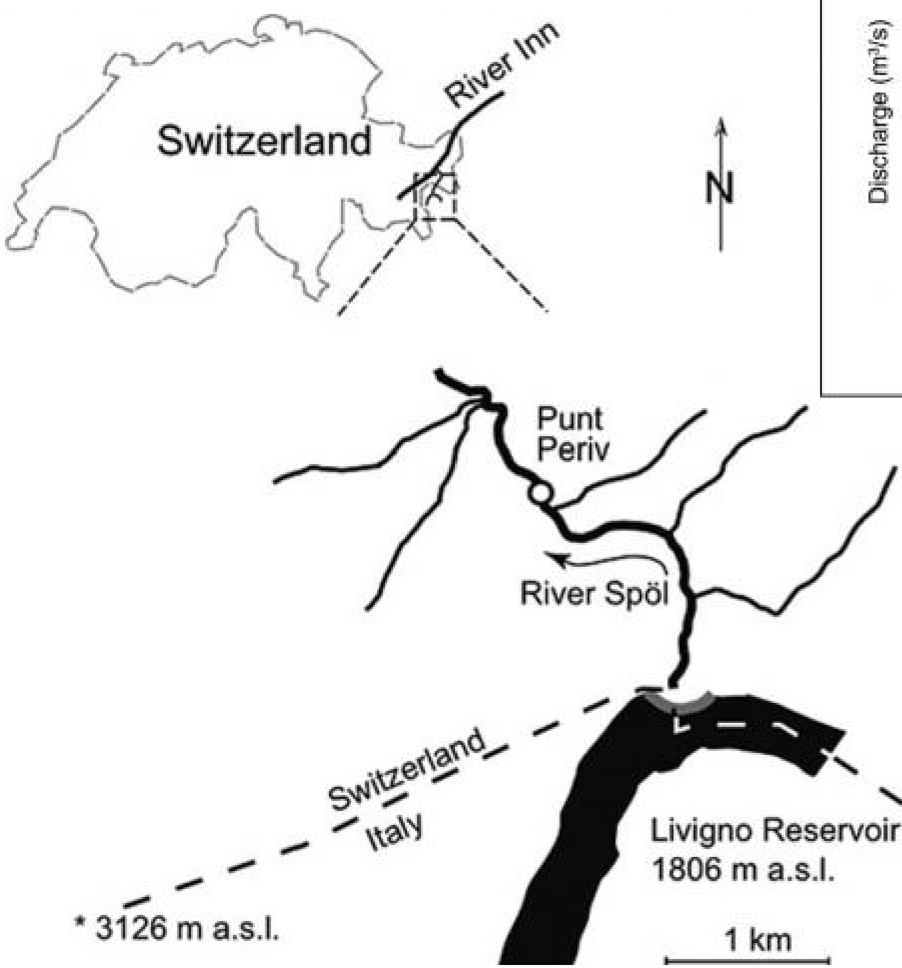


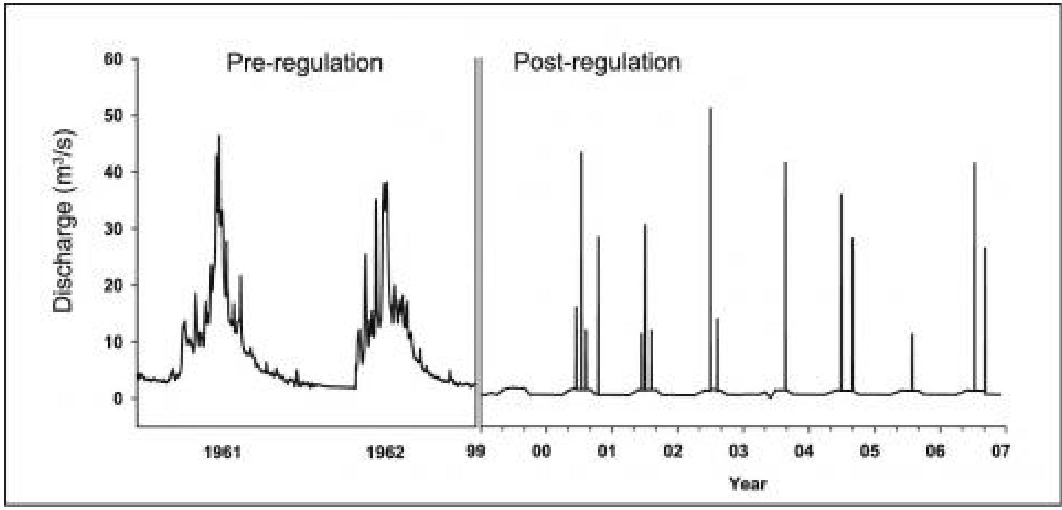
1. Restoration of flow patterns

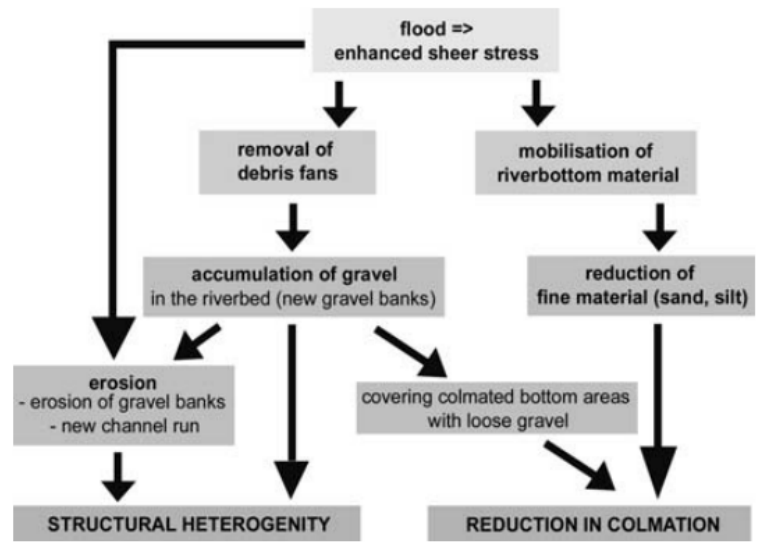




1. Restoration of flow patterns

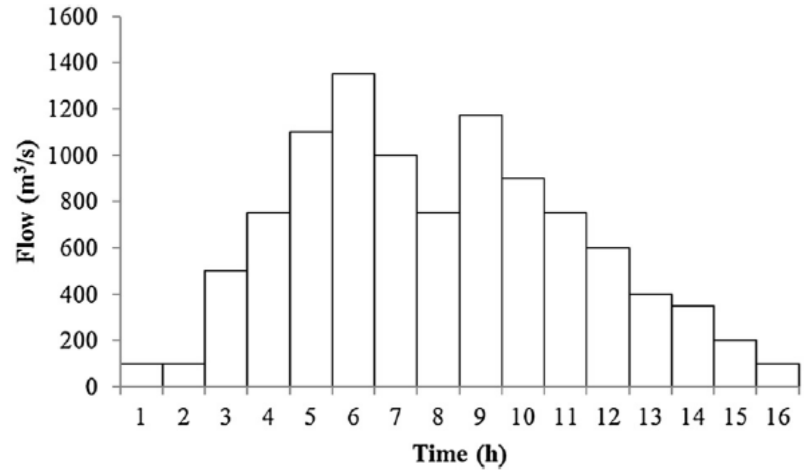






Spöl Reservoir (Mannes *et al.,* 2008)

Flix Reservoir.
Source: Flix City Hall



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Experimental floods: A new era for Spanish and Mediterranean rivers?

CrossMark

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Centre for Studies and Experimentation on Public Works (CEDEX), Alfonso XII, 3, 28014 Madrid, Spain

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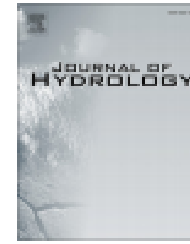

Tradeoffs in river restoration: Flushing flows vs. hydropower generation in the Lower Ebro River, Spain

Carlos M. Gómez [a,b], C. Dionisio Pérez-Blanco [a,b,*], Ramon J. Batalla [c,d,e]

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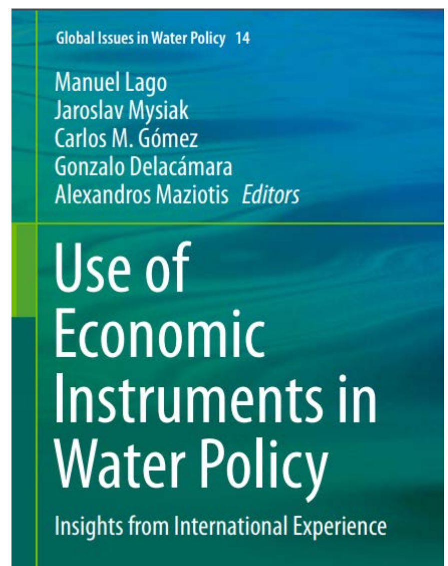
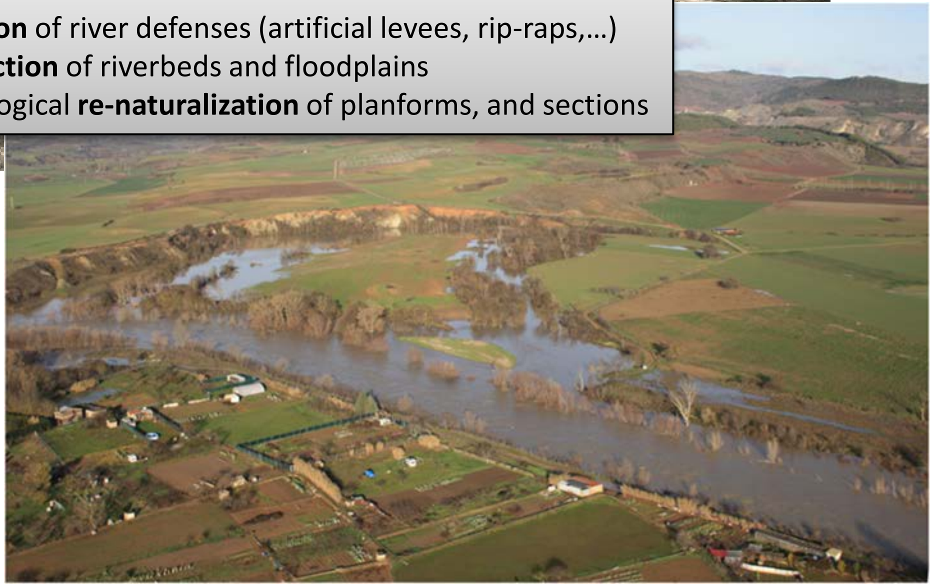
Chapter 26
Voluntary Agreement for River Regime Restoration Services in the Ebro River Basin (Spain)

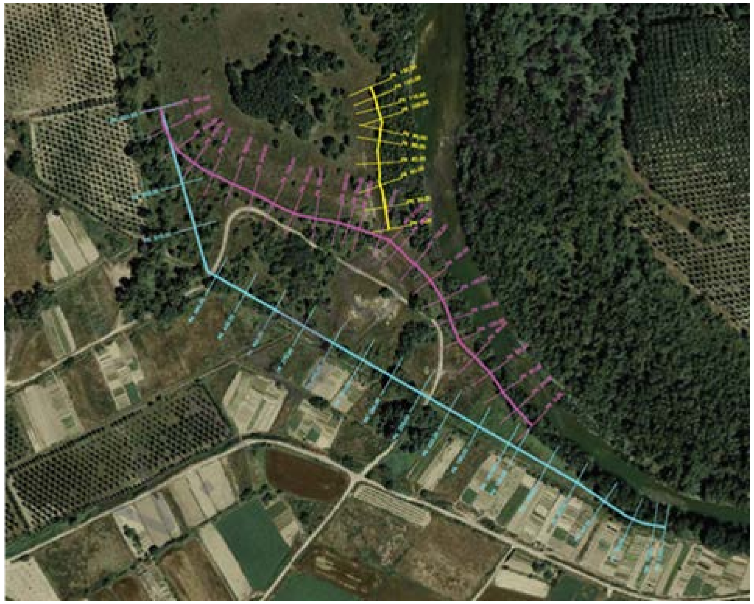
Carlos M. Gómez, Gonzalo Delacámara, C. Dionisio Pérez-Blanco, and Marta Rodríguez



2. Restoration of geomorphic processes

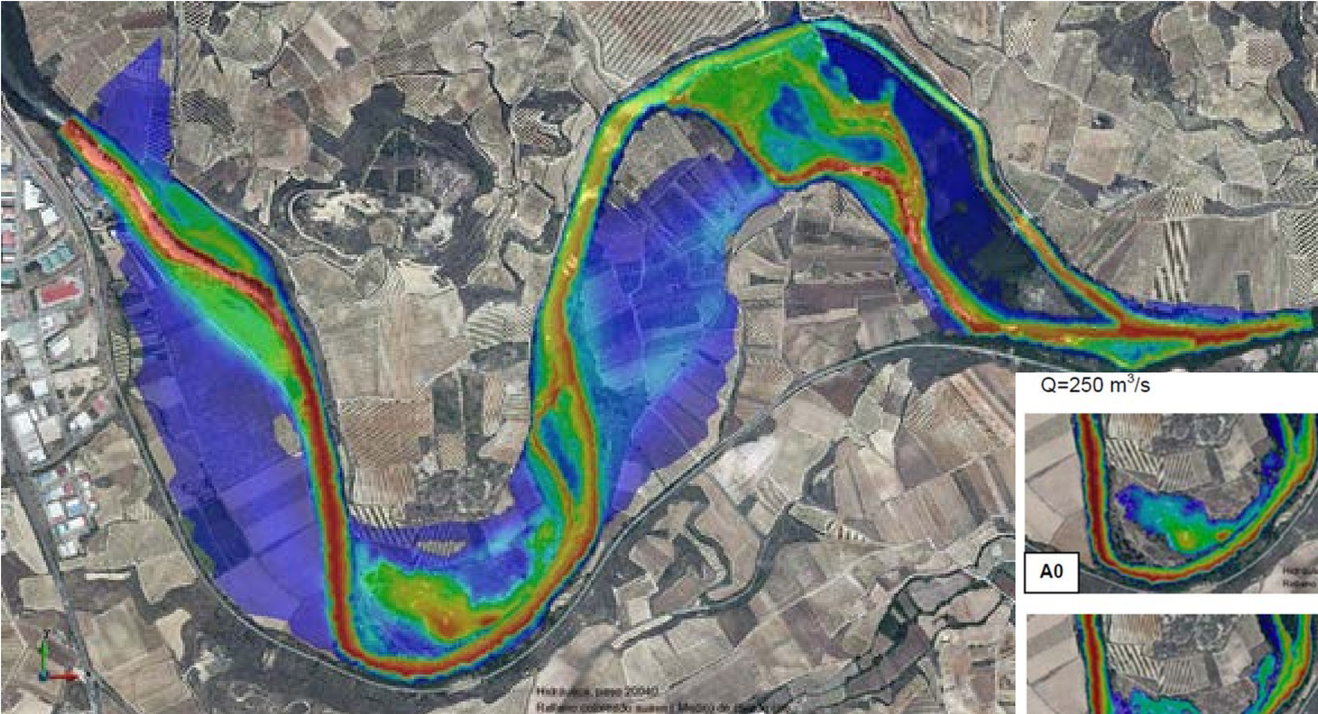
- **de-channelization** of river reaches
- **re-location** of river defenses (artificial levees, rip-raps,…)
- **reconnection** of riverbeds and floodplains
- morphological **re-naturalization** of planforms, and sections

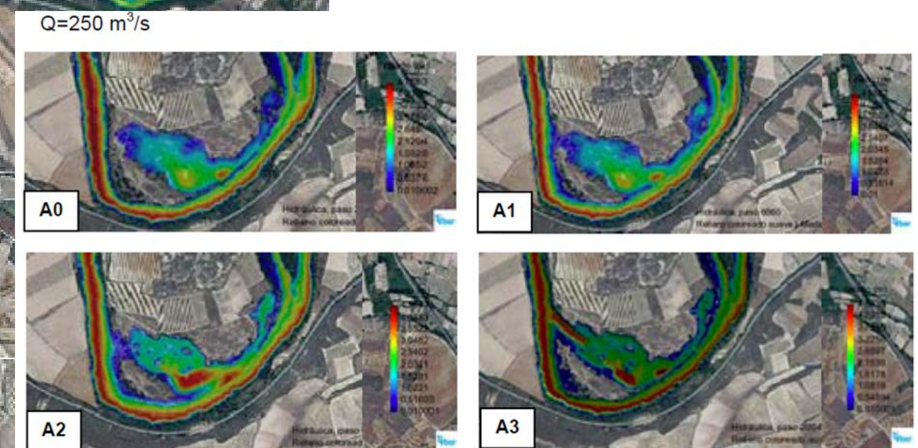


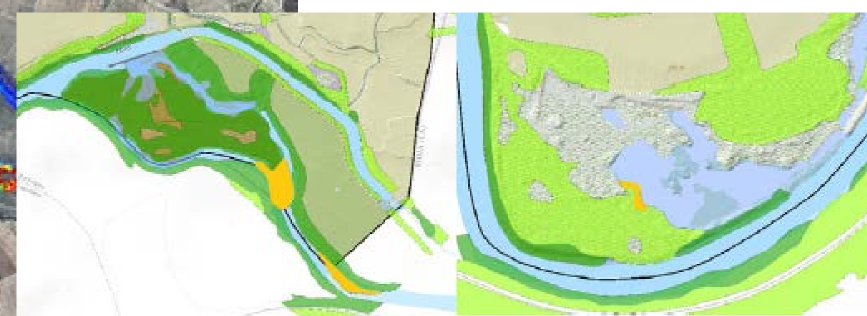


Arga-Aragón River System, Government of Navarre Region

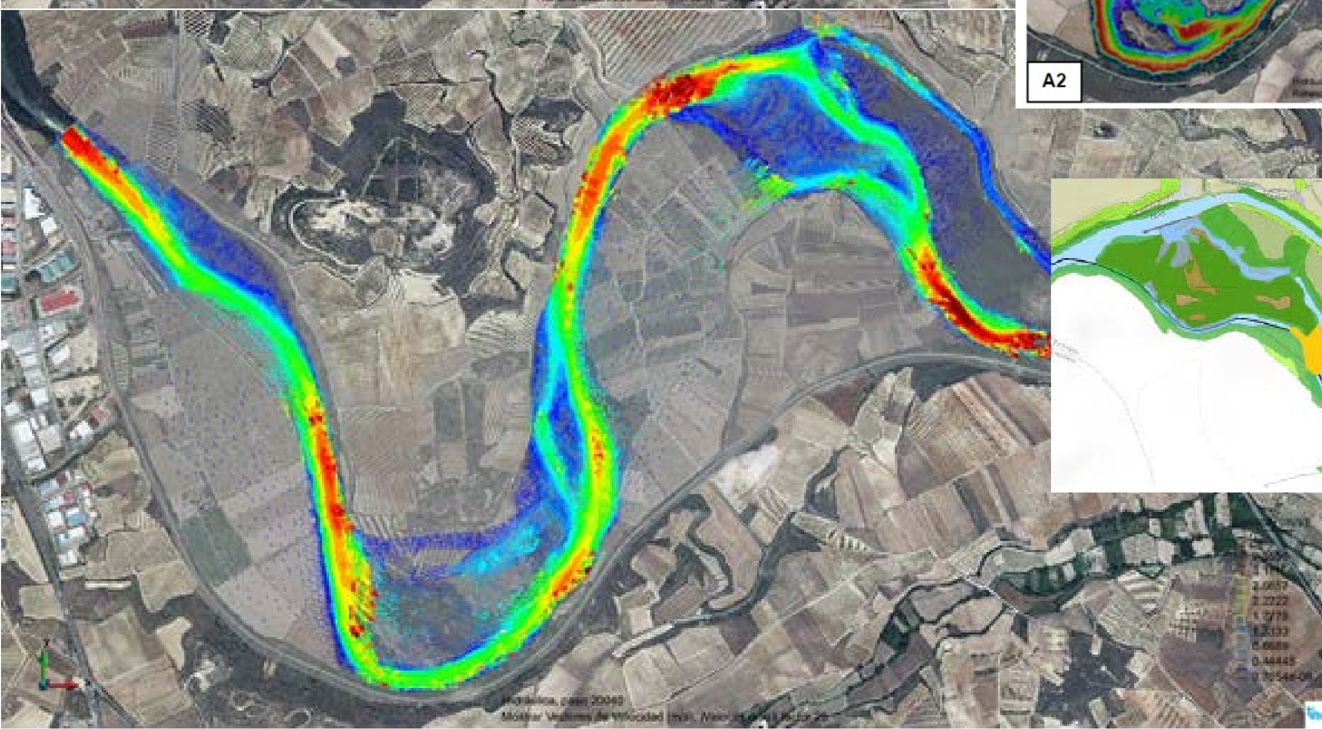
Depth and velocity distributions under different extreme events and restoration scenarios (Ebro River, Spain) (Source: CEDEX)



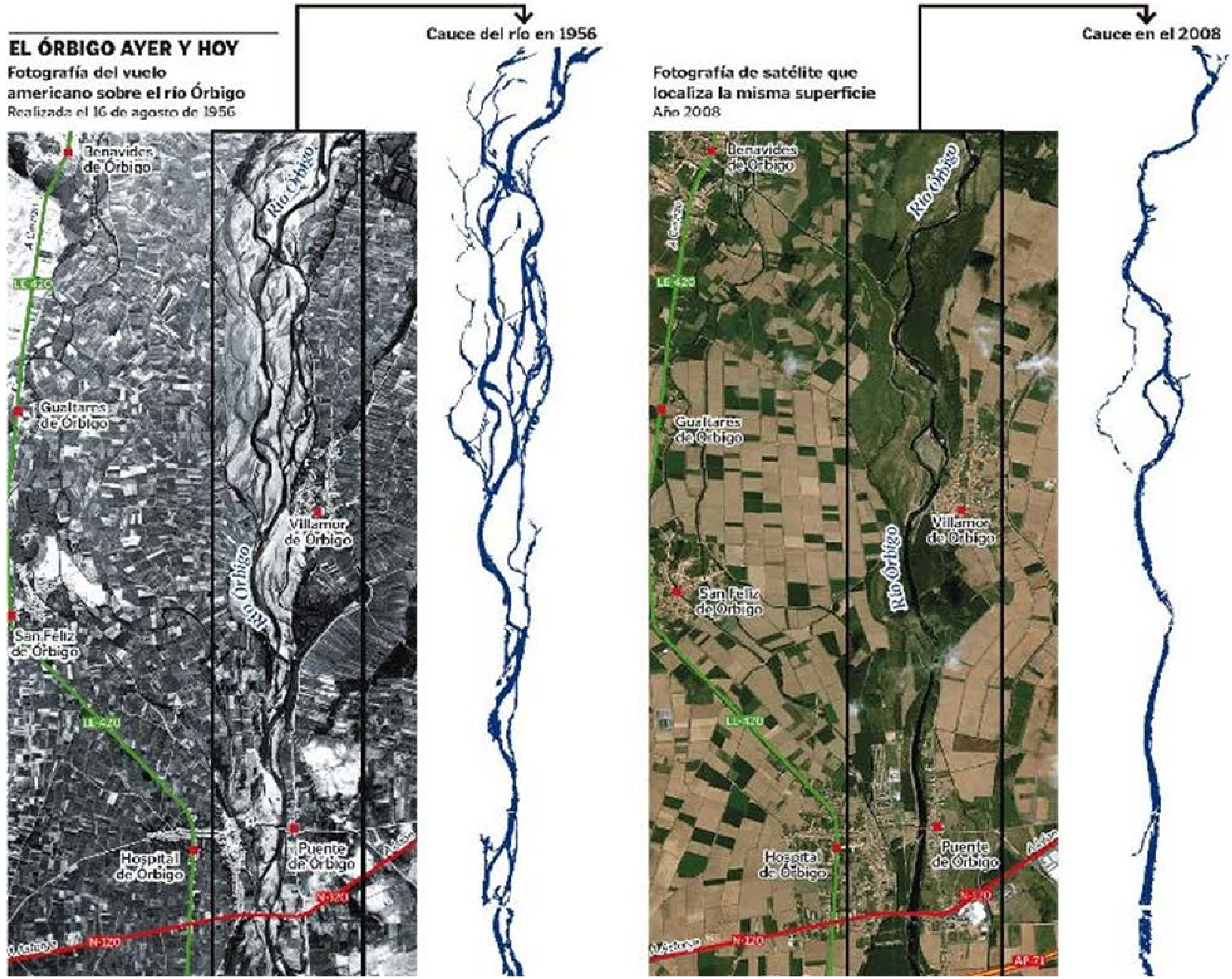




Ecologic modelization for each scenario



2. Restoration of geomorphic processes



Órbigo River, Duero Basin Authority

2. Restoration of geomorphic processes

Órbigo River, Duero Basin Authority

⇨ 2. Restoration of geomorphic processes

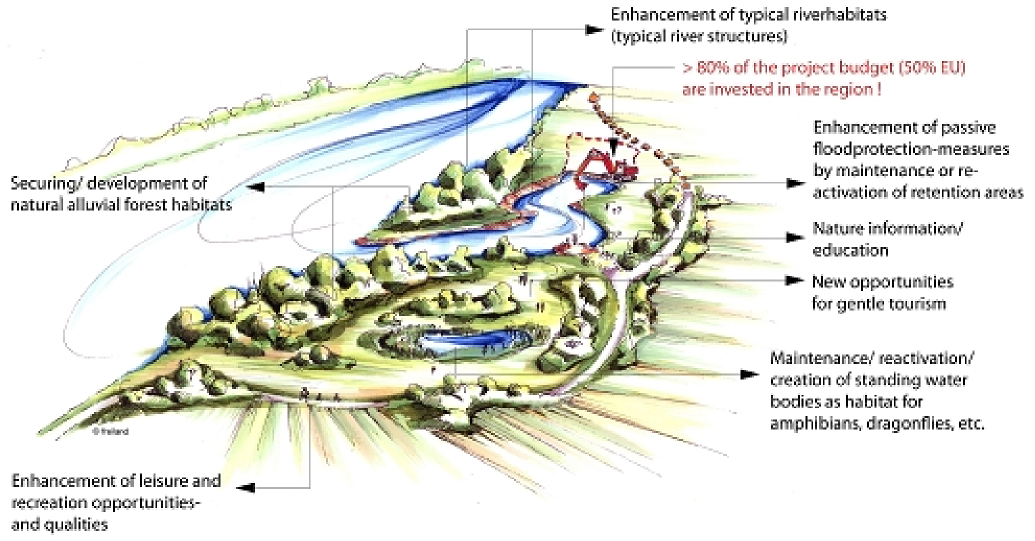
3. Restoration of habitats and ecologic processes

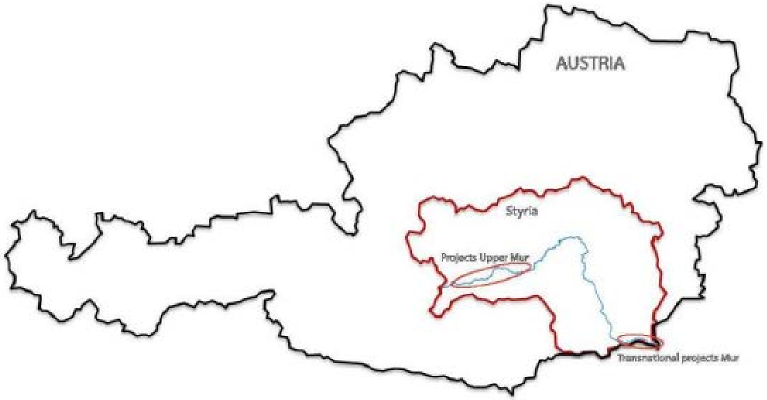
3. Restoration of habitats and ecologic processes

3. Restoration of habitats and ecologic processes

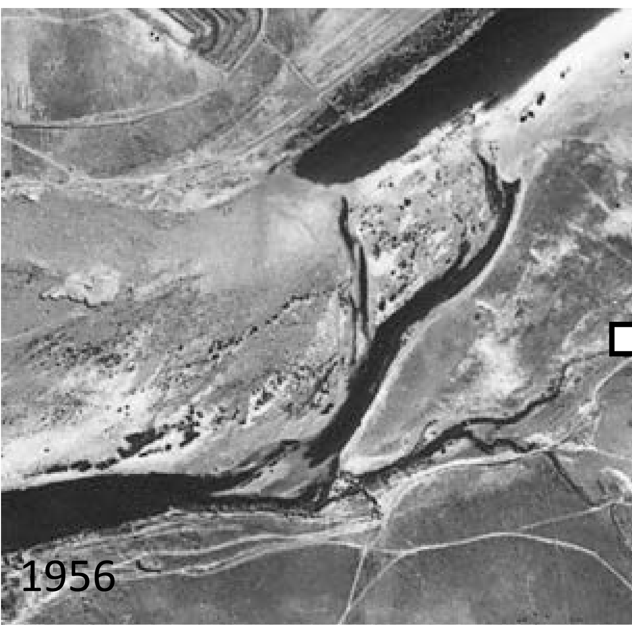
Mur River, Austria

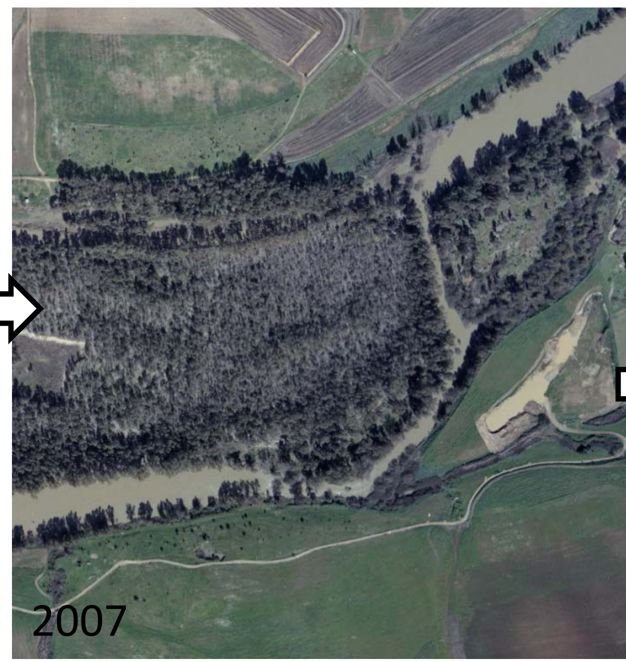
Results of river-restoration projects (LIFE)





Zújar River, SW Spain





4. Restoration of public processes and people-river connections

custodia fluvial

& RIVERS PEOPLE

4. Restoration of public processes and people-river connections

Whanganui, NZ (Source: Whanganui & Partners)

Ganga, IN (Source: GAP)

Yamuna, IN (Source: World Water Database)

4. Restoration of public processes and people-river connections

© Indra Giménez

© Martin Hill - Clutha River, Otago

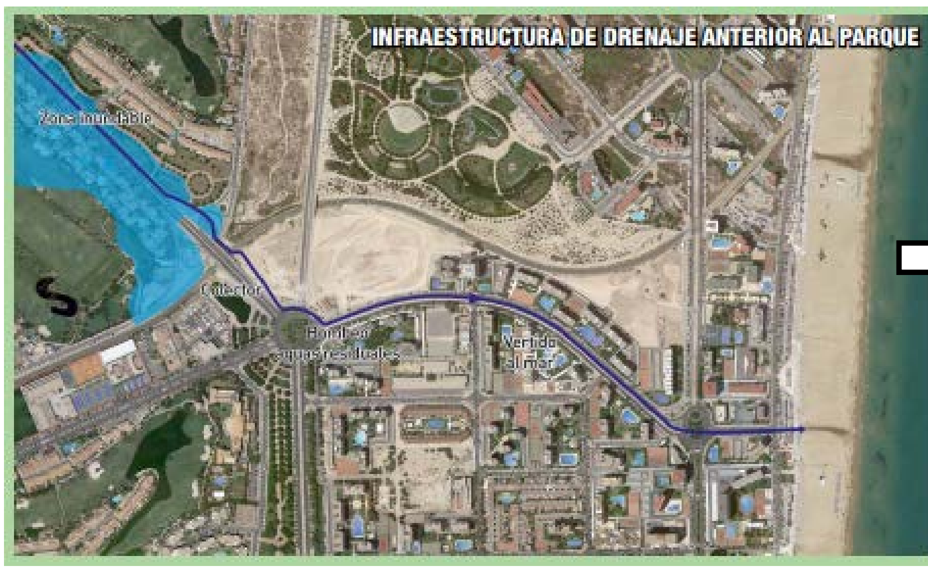
© Andy Goldsworthy

4. Other (positive) examples in urban areas

Arga River (Pamplona)

Manzanares River (Madrid)

Green infrastructure: La Marjal (Source: Alicante City Hall)

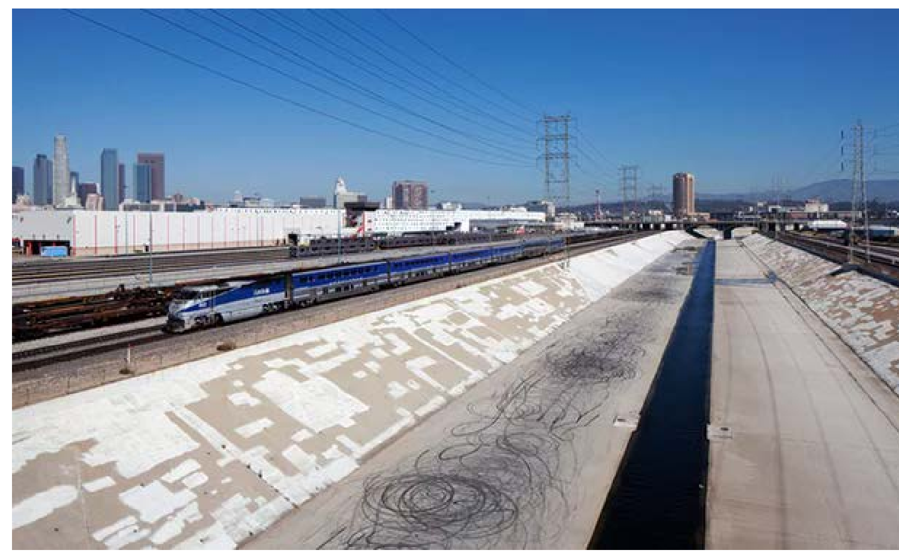


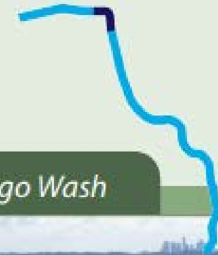
Storage: 45.000 m^3, T50

An international example: L.A. River (California)

(Curbed L.A.)

An international example: L.A. River (California)





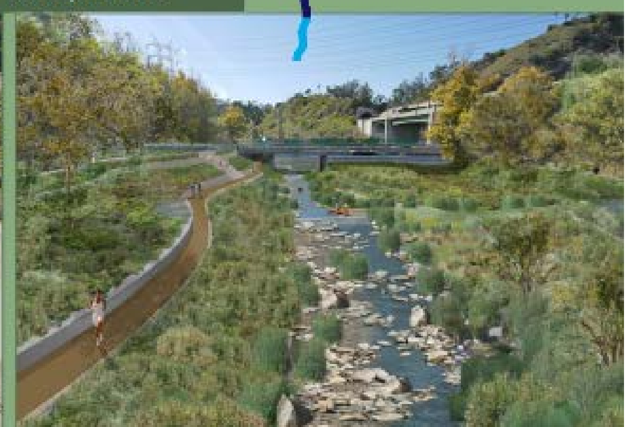
REACH 3 — *Verdugo Wash*

EXISTING CONDITIONS

AFTER PROJECT

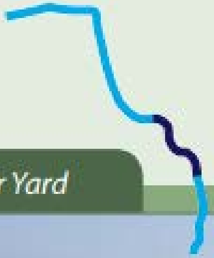
REACH 7 — *Arroyo Seco*

EXISTING CONDITIONS



AFTER PROJECT

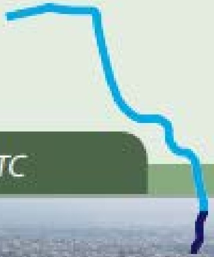
REACH 6 — *Taylor Yard*



EXISTING CONDITIONS

AFTER PROJECT

REACH 8 — *LATC*



EXISTING CONDITIONS

AFTER PROJECT

FIGURE H **Proposed Project Action Alternatives — Comparison of Cost and Benefits**

CRITERIA	Alt. 10	Alt. 13	Alt. 13v	Alt. 16	Alt. 20
Total Project Costs (October 2014 Price Levels)	$591 million	$708 million	$667 million[6]	$1.05 billion	$1.31 billion[6]
ECOSYSTEM RESTORATION BENEFITS					
Total Average Annual Habitat Units[7]	5,321	5,902	5,989	6,509	6,782
Percent Increase in Habitat over Existing Conditions	93%	104%	105%	114%	119%
CONNECTIVITY BENEFITS					
Nodal Connectivity[8]	Minor improvement	309% over Alt. 10	33% over Alt. 13	39% over Alt. 13v	120% over Alt. 16
Added Regional Connections to Significant Ecological Areas	Santa Monica Mountains	Santa Monica & San Gabriel Mountains	Santa Monica & San Gabriel Mountains, Elysian Hills	Santa Monica & San Gabriel Mountains	Santa Monica, San Gabriel & Verdugo Mountains, Elysian Hills
Total Acres Restored	528	588	598	659	719

FIGURE K **Cost Summary Table of the Recommended Plan: Alternative 20**

PROJECT ITEM	TOTAL COST ($1,000)
Lands and Damages (P.L. 91-646 Included)	$526,285
Utility/Facility Relocations	$228,562
Fish and Wildlife Facilities	$462,483
Recreation Facilities	$14,921
Pre-construction Engineering and Design (PED)	$85,135
Construction Management (S&A)	$39,222
Total First Cost	**$1,356,608**[9]

5. Conclusions

i. The new legal, scientific, technical and social context allows and requires a **new time for rivers**: more dynamic, heterogeneous, complex and people-bound rivers are crucial today

ii. Any restoration actions should be **multi-functional,** based on the many interactions between **water, sediments and biota,** and provide **multiple environmental services**

iii. **Effectiviness analyses** of the already fulfilled mitigation/restoration projects become indispensable to optimize future efforts

iv. Rivers are excellent living labs, fully linkeable with **knowledge transfer** processes

v. Integration of river management and restoration with **sectoral planning** is a must

vi. Emblematic and pilot experiences were and are still necessary, but not enough: we need to make restoration of water-sediment-biota interactions part of the **managerial routine** in the basins

vii. Difficult to imagine an effective and functional improvement of the much degraded drainage network without effective and functional **water & land policies** througout the continent

Thanks!

fernando.magdaleno@cirefluvial.com