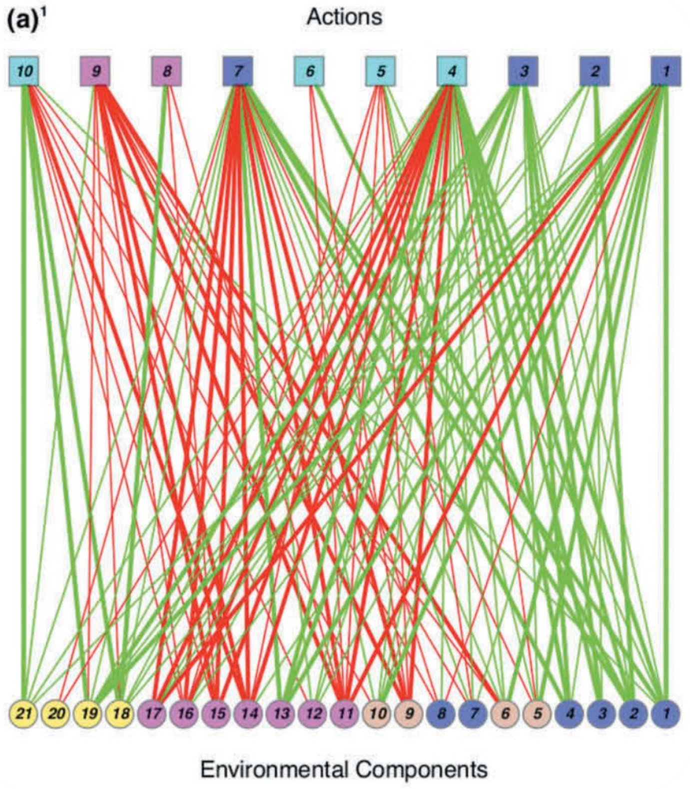
Water Resources Engineering and Management

(CIVIL-466, A.Y. 2024-2025)

5 ETCS, Master course

Prof. P. Perona

Platform of hydraulic constructions



Lecture 8-1: Environmental issues of dams and elements of Environmental Impact Assessment

Environmental issues of dams

- Transport of sediment along the river is altered. Erosion in the downstream part of the river (countermeasure: release of flow and sediment from the bottom gates).

- Alteration of fish migration (countermeasure: fish ladder).

- Alteration of hydrologic cycle because of lake evaporation.

- Salinization of water especially in tropical or equatorial zones (high ET)

- Alteration of the natural flow regime in the downstream section of the river, e.g. hydropeaking, etc. (countermeasure: release of minimum flow or more advance sequence of releases).

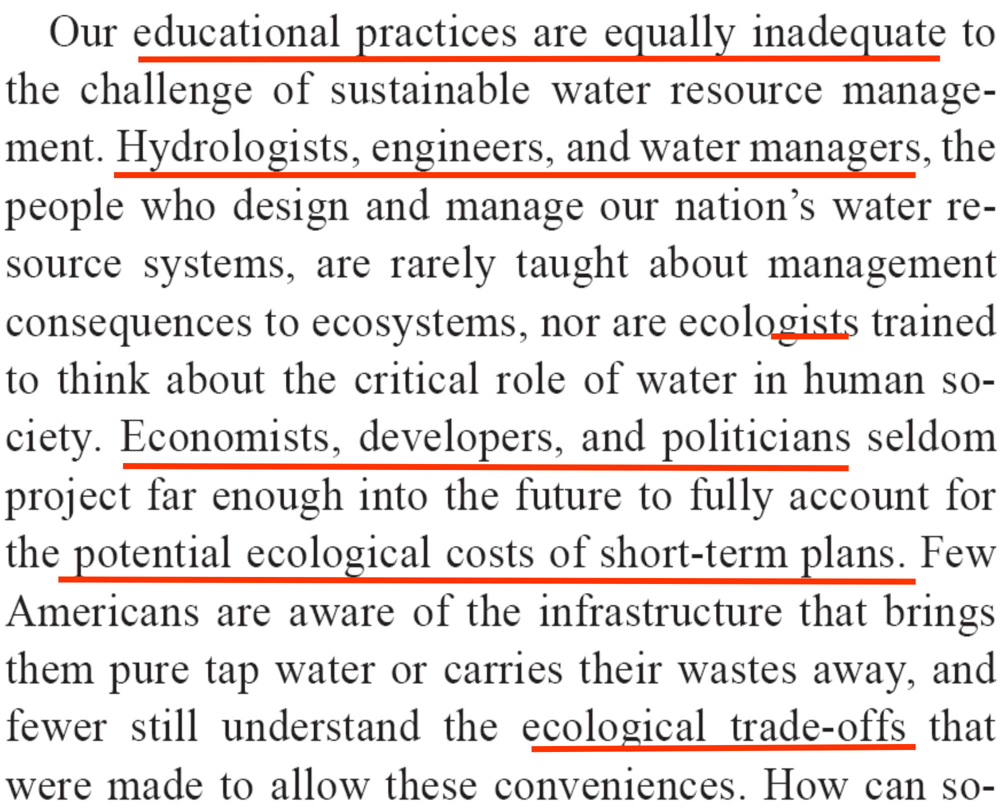
- Alteration of water temperature, e.g. thermopeaking (usually colder).

- The lake can increase incidence of diseases related to water like malaria, schistosomiasis and cholera.

- Resettlement of people

- Greenhouse gas emission

Twenty years ago…



Our educational practices are equally inadequate to the challenge of sustainable water resource management. Hydrologists, engineers, and water managers, the people who design and manage our nation's water resource systems, are rarely taught about management consequences to ecosystems, nor are ecologists trained to think about the critical role of water in human society. Economists, developers, and politicians seldom project far enough into the future to fully account for the potential ecological costs of short-term plans. Few Americans are aware of the infrastructure that brings them pure tap water or carries their wastes away, and fewer still understand the ecological trade-offs that were made to allow these conveniences. How can so-

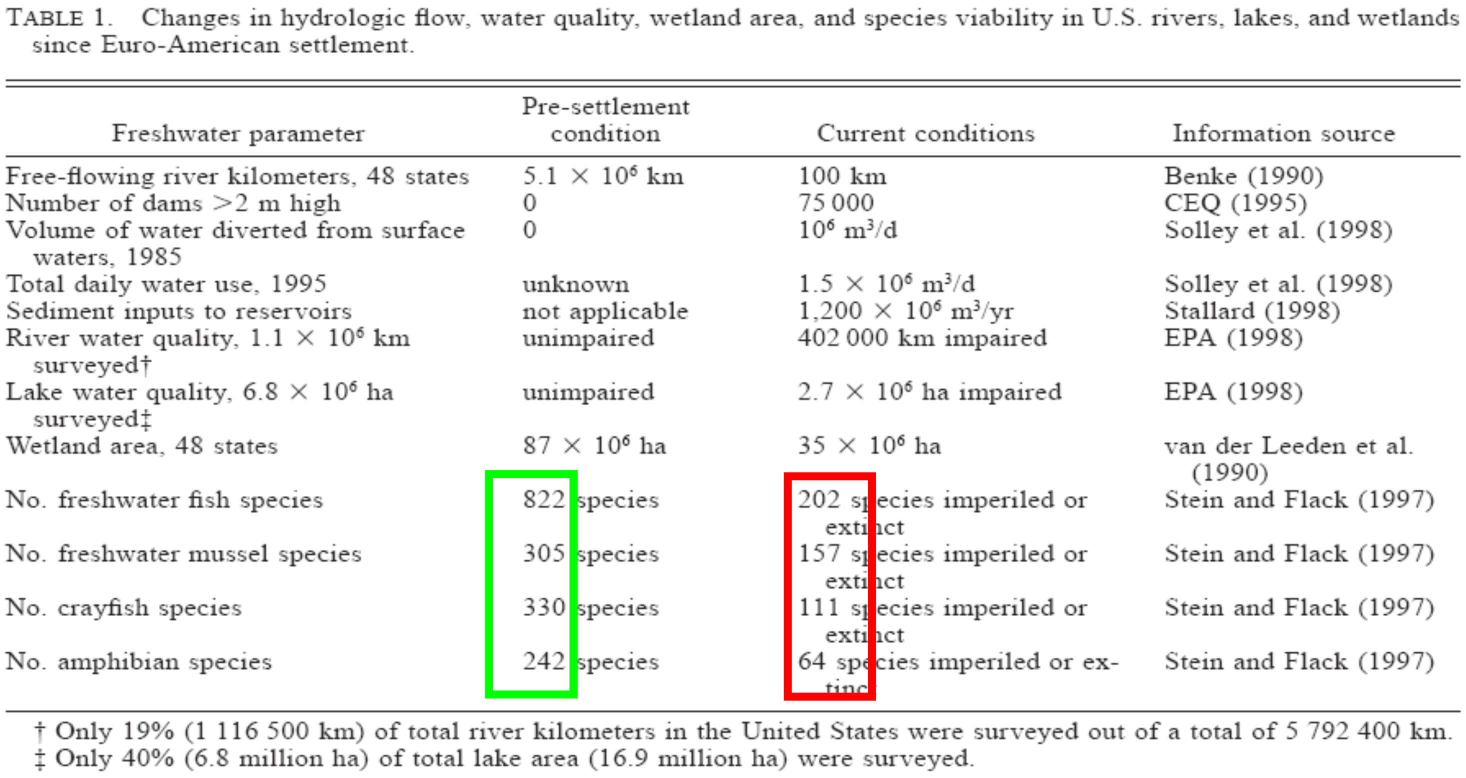


TABLE 1. Changes in hydrologic flow, water quality, wetland area, and species viability in U.S. rivers, lakes, and wetlands since Euro-American settlement.

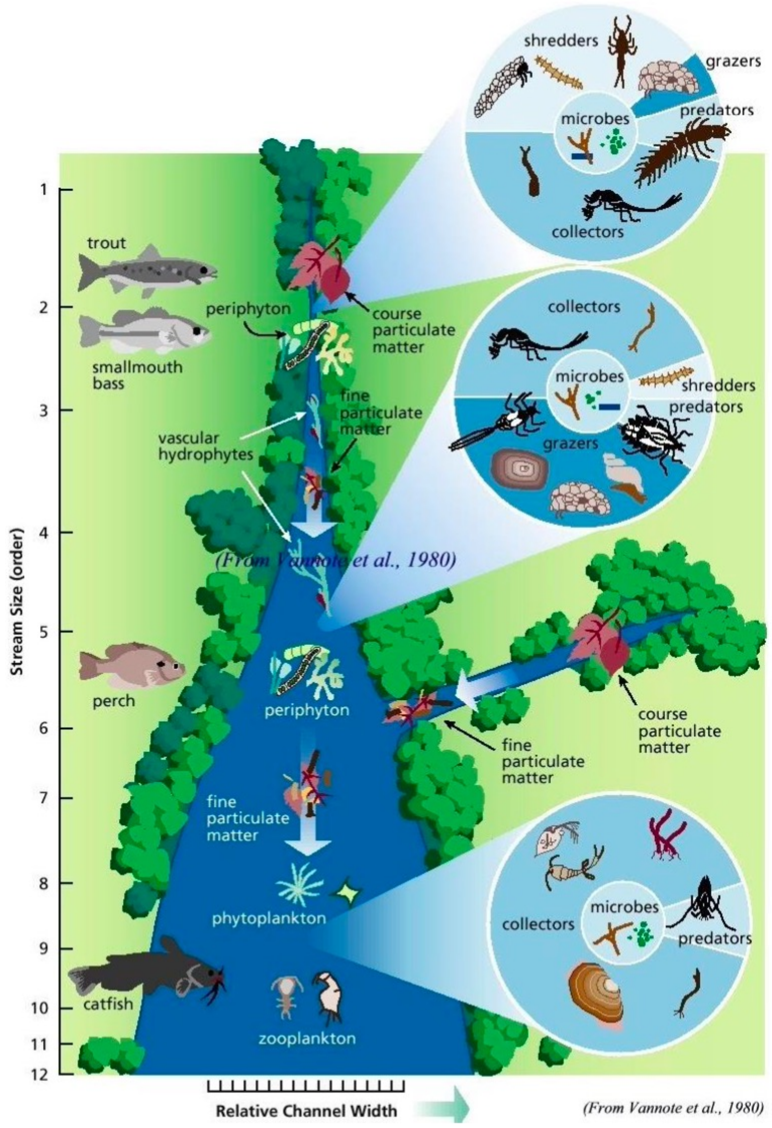
Freshwater parameter	Pre-settlement condition	Current conditions	Information source
Free-flowing river kilometers, 48 states	5.1×10^6 km	100 km	Benke (1990)
Number of dams >2 m high	0	75 000	CEQ (1995)
Volume of water diverted from surface waters, 1985	0	10^6 m³/d	Solley et al. (1998)
Total daily water use, 1995	unknown	1.5×10^6 m³/d	Solley et al. (1998)
Sediment inputs to reservoirs	not applicable	$1{,}200 \times 10^6$ m³/yr	Stallard (1998)
River water quality, 1.1×10^6 km surveyed†	unimpaired	402 000 km impaired	EPA (1998)
Lake water quality, 6.8×10^6 ha surveyed‡	unimpaired	2.7×10^6 ha impaired	EPA (1998)
Wetland area, 48 states	87×10^6 ha	35×10^6 ha	van der Leeden et al. (1990)
No. freshwater fish species	822 species	202 species imperiled or extinct	Stein and Flack (1997)
No. freshwater mussel species	305 species	157 species imperiled or extinct	Stein and Flack (1997)
No. crayfish species	330 species	111 species imperiled or extinct	Stein and Flack (1997)
No. amphibian species	242 species	64 species imperiled or extinc	Stein and Flack (1997)

† Only 19% (1 116 500 km) of total river kilometers in the United States were surveyed out of a total of 5 792 400 km.
‡ Only 40% (6.8 million ha) of total lake area (16.9 million ha) were surveyed.

Source: Baron et al. (2002) *Ecol. Applications* 12(5)

Instream flows based on Minimal Flow policy have produced a phenomenon called homogenisation

Non-traditional uses: Environmental flows

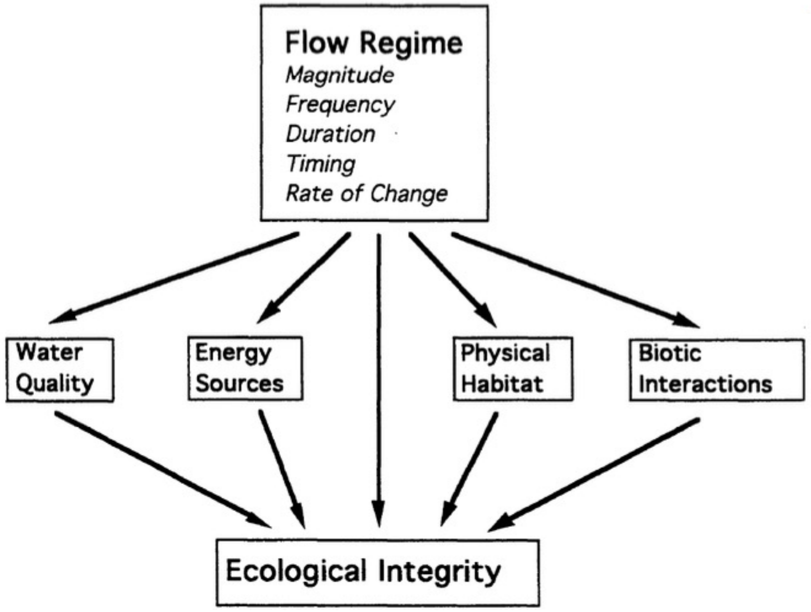


(From Vannote et al., 1980)

Principal components of a riverine ecosystem:
food web and carbon cycling and how they change along the river continuum from upstream to downstream (The River Continuum concept, Vannote et al. 1980).

Later Poff et al., (1997) investigated the ”Natural Flow Regime” and concluded that: “Streamflow can be considered a "master variable" that limits the distribution and abundance of riverine species and regulates the ecological integrity of flowing water systems. Until recently, however, the importance of natural streamflow variability in maintaining healthy aquatic ecosystems has been virtually ignored in a manag

Remember at this point the “River attributes”



Flow Regime
Magnitude
Frequency
Duration
Timing
Rate of Change

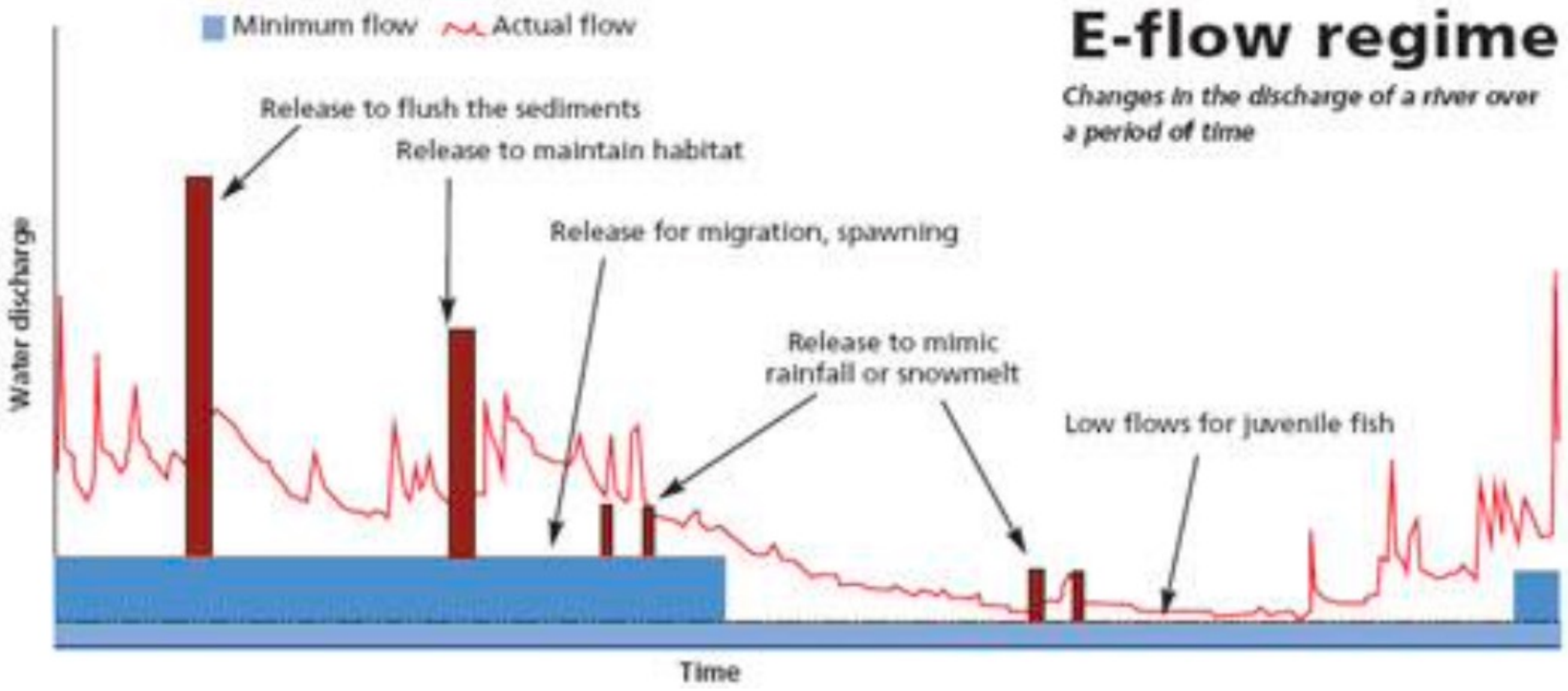
Water Quality
Energy Sources
Physical Habitat
Biotic Interactions

Ecological Integrity

Environmental flows

Environmental flows describe the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well being that depend on these ecosystems services.

Achievement of a flow regime, or pattern, that provides human uses and maintains the essential processes required to support healthy river ecosystems. Environmental flows do not necessarily require restoring the natural, pristine flow patterns that would occur in absence human development, use, and diversion but, instead, are intended to produce a broader set of values and benefits from rivers than from management focused strictly on water supply, energy, recreation, or flood control.



Dynamic Environmental Flows

- Relatively new concept (but difficult to accept and implement)
- The challenge is to obtain a natural-like variability

Proportional (to incoming flow) releases

Non-proportional (to incoming flow) releases

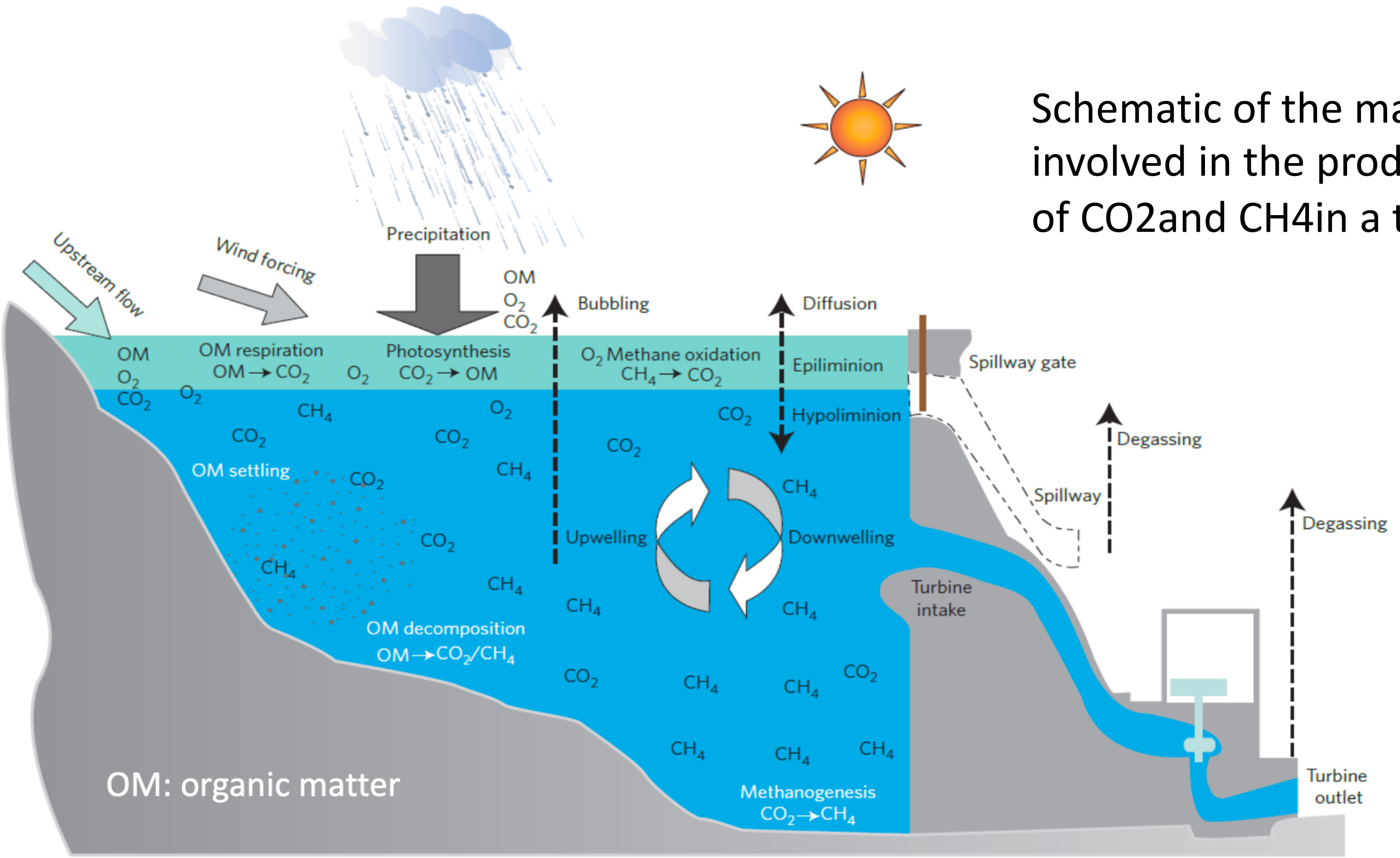
- A theoretical basis has been sought so to include the environmental use of water either as an additional user or as a criteria in optimization procedures (see next Lectures)

Ecosystem importance of streamflow variability

(Assumption: pristine biodiversity derives from the Natural Flow Regime)

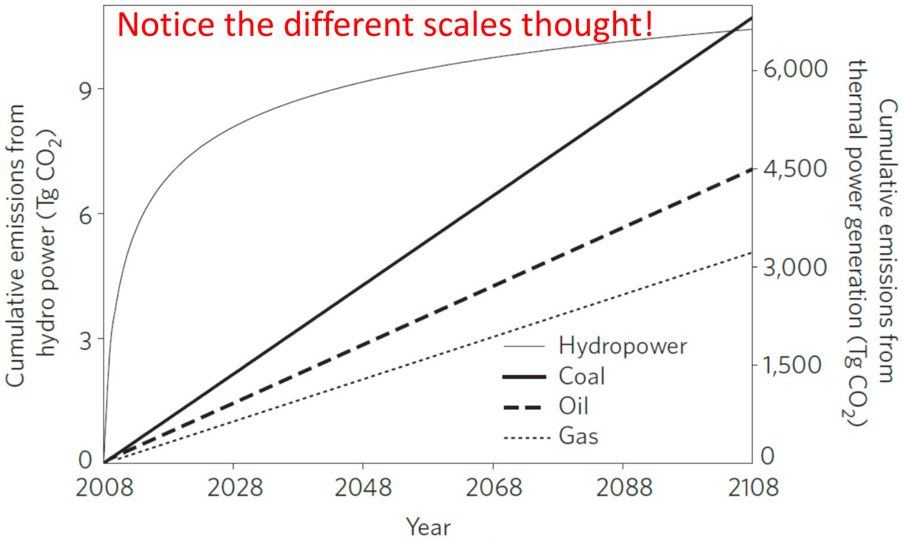
Gorla and Perona, 2013;
Niayifar and Perona, 2018
Razurel et al. 2018
Perona et al., 2021

Is hydropower really greenhouse gas-free?



Schematic of the major biological, chemical and physical processes involved in the production, consumption and atmospheric release of $CO_2$and CH_4in a typical deep reservoir.

Methane is particularly troublesome as it has more than 20 times the warming impact of CO_2.



Cumulative GHG emissions (in equivalent gCO2) from the Three Gorges Reservoir

Decomposition of organic carbon produces CO_2 and CH_4 (in anoxic conditions that can possibly occur in the Hypoliminion). Significant CH_4 emissions occur when the methane-rich water experiences drastic changes in pressure and temperature (e.g., in turbines) and in the drawdown areas that are seasonally exposed due to periodic flooding and draining of reservoirs.

Environmental Impact Assessment

Environmental Impact Assessment

Definition

EIA is a procedure that serves to provide information to authority planners, regulators and authorizing bodies about the effect on the environment of certain proposed project

Screening and ranking of a project is based on:

→ Technical feasibility

→ Environmental Impact Assessment

→ Financial and economical feasibility

→ Reliability analysis

EIA – SOME DEFINITION AND GLOSSARY

ES, Environmental statement	The document reporting the Environmental Impact Assessment
Mitigation	The complex of actions to avoid, reduce and remedy potential adverse impacts
Compensation	Actions aiming at replacing an adverse impact either in kind or something of a different nature to that which may be lost
Enhancement	Improving elements of the environment
Scoping	The process to identify key environmental issues
Screening	The process to decide if EIA is required

EIA is produced in form of report (Environmental statement), and should take place at different levels of the planning and design activities, i.e:

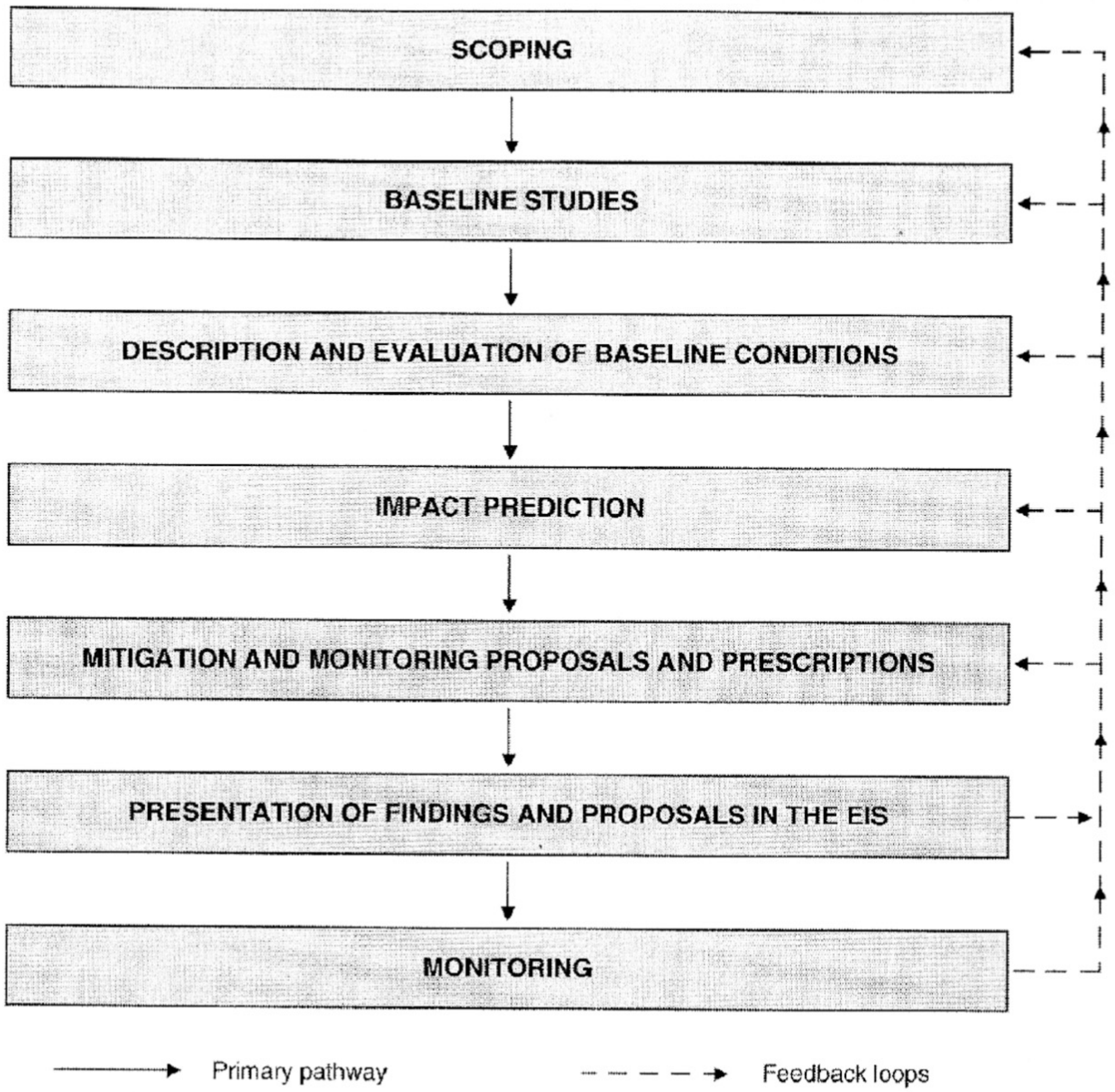
a) Early stage (feasibility) → TO EVALUATE THE OVERALL ENVIRONMENT COMPATIBILITY

b) Project alternatives → TO DISCRIMINATE AMONG ALTERNATIVES WITH DIFFERENT IMPACTS

c) Project implementation → TO MONITOR UNAVOIDABLE IMPACTS AND MITIGATE THEIR EFFECTS

The **Environmental Statement** should include: i) a <u>description</u> of the site and the project; ii) an <u>outline</u> of the main alternatives studied; iii) an <u>analysis</u> of significant direct and indirect effects; iv) <u>measures</u> to prevent, reduce or affect significant adverse effects

The EIA process can be seen in form of flowchart to assess the role and importance of environmental components



(A) SCOPING AND (B) BASELINE STUDIES

Is an essential first step in the assessment of a component (or environmental factor) such as for instance sedimentation, channel morphology, root change, etc.

Form the backbone of component assessments

A starting point is offered by the technical, economical and reliability studies

Scoping aims at:

- → early stage identification of key receptors
- → providing a ground plan for subsequent steps by making a preliminary assessment of project’s milestones

Preliminary assessment must target:

→ project's potential impact on component receptors, estimated from the project description and the nature of components and receptors

→ Impact area and/or zones

→ possible mitigation measures

→ The need and potential for monitoring

→ the methods and level of study to assess the above issues

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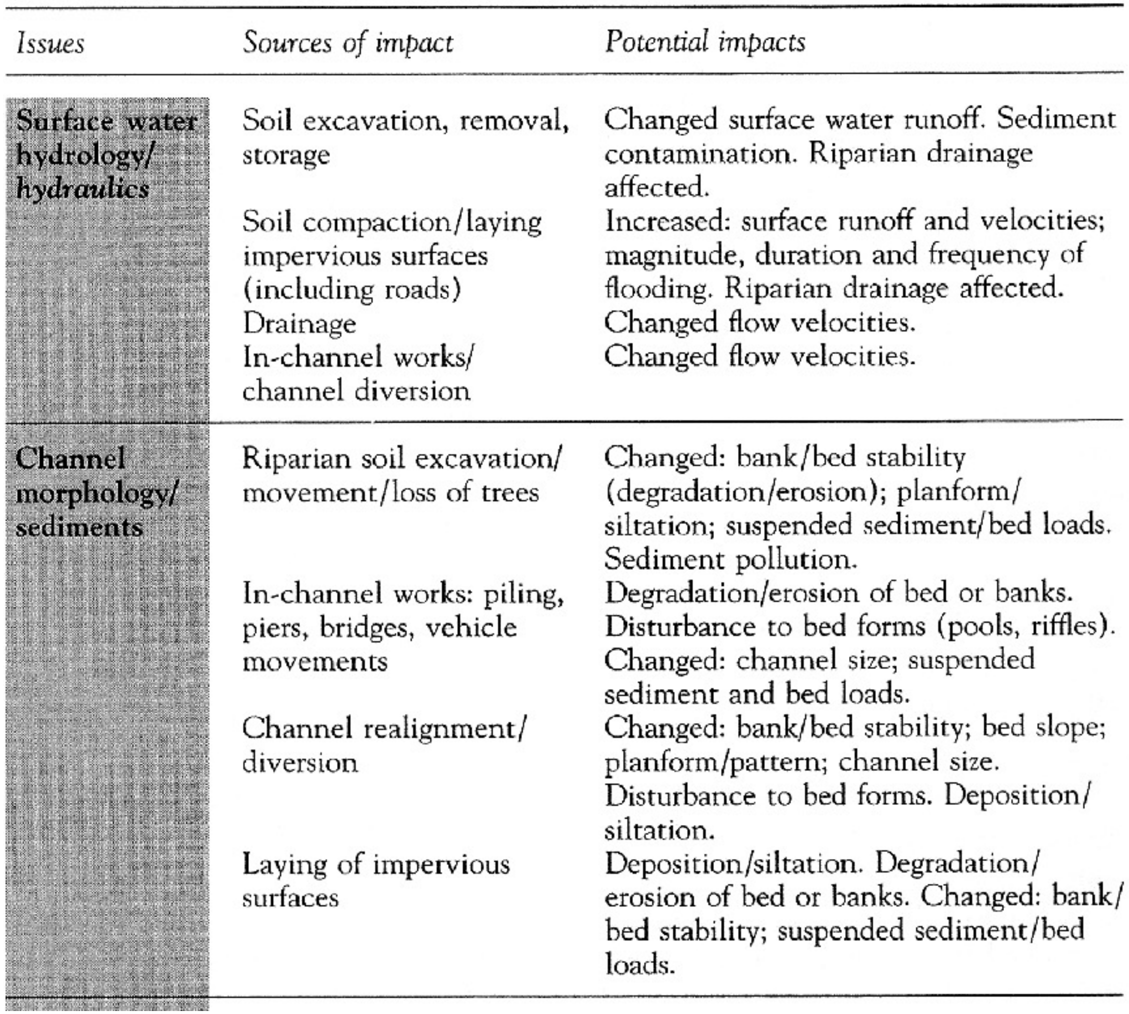
SCOPING CHECKLIST, SIMPLE INTERACTION MATRIX, STEPPED INTERACTION MATRIX,

SPATIAL REPRESENTATION (e.g., GIS)

Example of scoping in water related projects

Impact area may be confined to the project site and its immediate surroundings, but open hydrological impacts are likely to be widespread (e.g., dam construction).

Example of
scoping checklist



Issues	*Sources of impact*	*Potential impacts*
Surface water hydrology/ hydraulics	Soil excavation, removal, storage	Changed surface water runoff. Sediment contamination. Riparian drainage affected.
	Soil compaction/laying impervious surfaces (including roads)	Increased: surface runoff and velocities; magnitude, duration and frequency of flooding. Riparian drainage affected.
	Drainage	Changed flow velocities.
	In-channel works/ channel diversion	Changed flow velocities.
Channel morphology/ sediments	Riparian soil excavation/ movement/loss of trees	Changed: bank/bed stability (degradation/erosion); planform/ siltation; suspended sediment/bed loads. Sediment pollution.
	In-channel works: piling, piers, bridges, vehicle movements	Degradation/erosion of bed or banks. Disturbance to bed forms (pools, riffles). Changed: channel size; suspended sediment and bed loads.
	Channel realignment/ diversion	Changed: bank/bed stability; bed slope; planform/pattern; channel size. Disturbance to bed forms. Deposition/ siltation.
	Laying of impervious surfaces	Deposition/siltation. Degradation/ erosion of bed or banks. Changed: bank/ bed stability; suspended sediment/bed loads.

(C) DESCRIPTION AND EVALUATION OF BASELINE CONDITIONS

This should include

→ Clear presentation of methods and results;

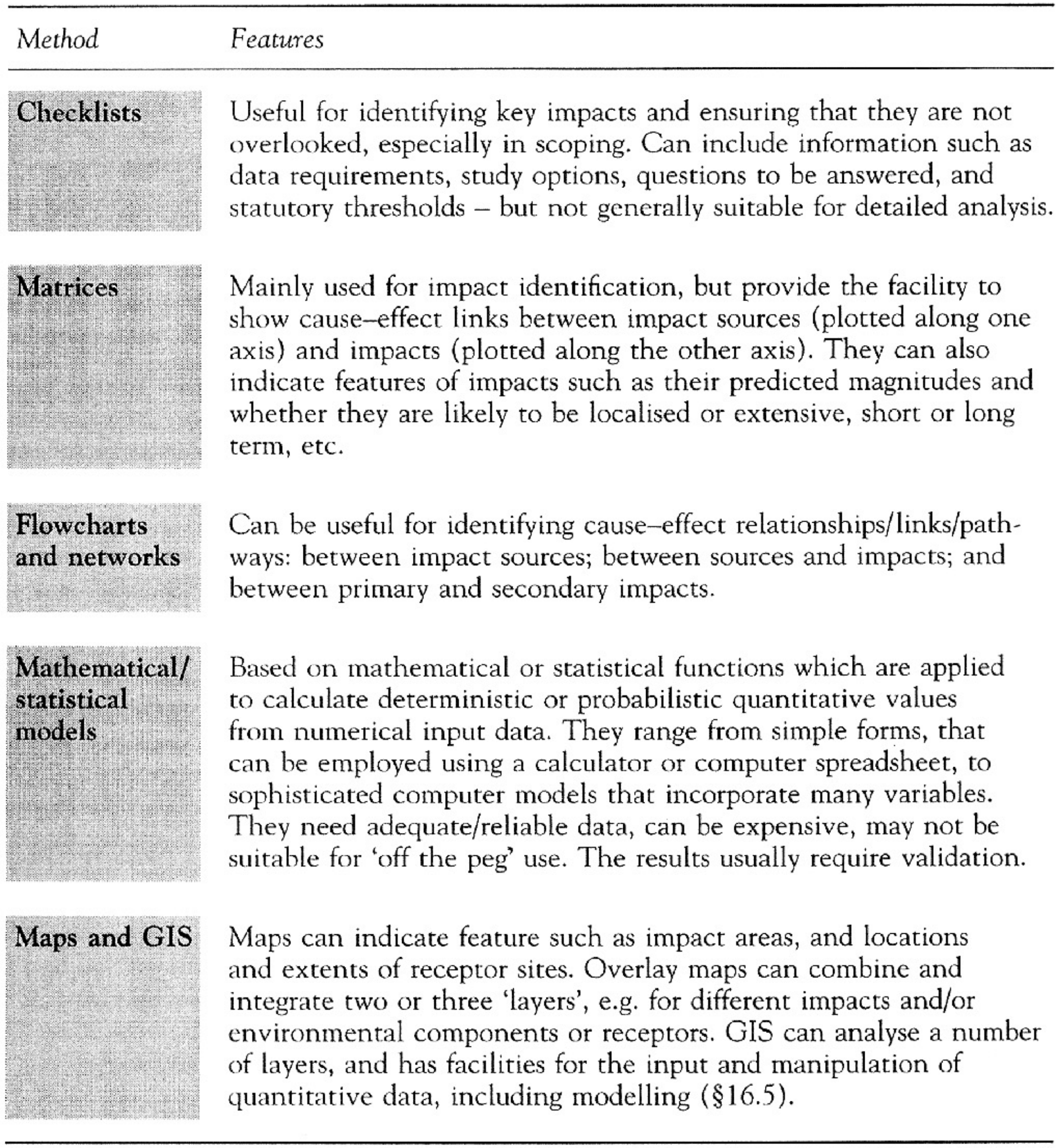
→ Indications of limitations and uncertainties (e.g., data accuracy, lack of information, …)

→ Assessment of the value of key receptors and their sensitivity to impacts (implicitly included in impact matrixes)

(D) IMPACT PREDICTION

This should include the assessment of

→ **Direct / primary impacts**	i.e., direct result of the projected development
→ **Indirect / secondary impacts**	i.e., cascade impacts or impacts that occur in other locations and/or as a result of a complex pathway
→ **Cumulative impacts**	i.e., those impacts that accrue over time and space from a number of developments or activities, and to which a new project may contribute



Method	*Features*
Checklists	Useful for identifying key impacts and ensuring that they are not overlooked, especially in scoping. Can include information such as data requirements, study options, questions to be answered, and statutory thresholds – but not generally suitable for detailed analysis.
Matrices	Mainly used for impact identification, but provide the facility to show cause–effect links between impact sources (plotted along one axis) and impacts (plotted along the other axis). They can also indicate features of impacts such as their predicted magnitudes and whether they are likely to be localised or extensive, short or long term, etc.
Flowcharts and networks	Can be useful for identifying cause–effect relationships/links/pathways: between impact sources; between sources and impacts; and between primary and secondary impacts.
Mathematical/ statistical models	Based on mathematical or statistical functions which are applied to calculate deterministic or probabilistic quantitative values from numerical input data. They range from simple forms, that can be employed using a calculator or computer spreadsheet, to sophisticated computer models that incorporate many variables. They need adequate/reliable data, can be expensive, may not be suitable for 'off the peg' use. The results usually require validation.
Maps and GIS	Maps can indicate feature such as impact areas, and locations and extents of receptor sites. Overlay maps can combine and integrate two or three 'layers', e.g. for different impacts and/or environmental components or receptors. GIS can analyse a number of layers, and has facilities for the input and manipulation of quantitative data, including modelling (§16.5).

All impacts must be graded:

Positive / negative
Short / Medium / Long term
Reversible / irreversible
Permanent / Temporary

Magnitude

Qualitative

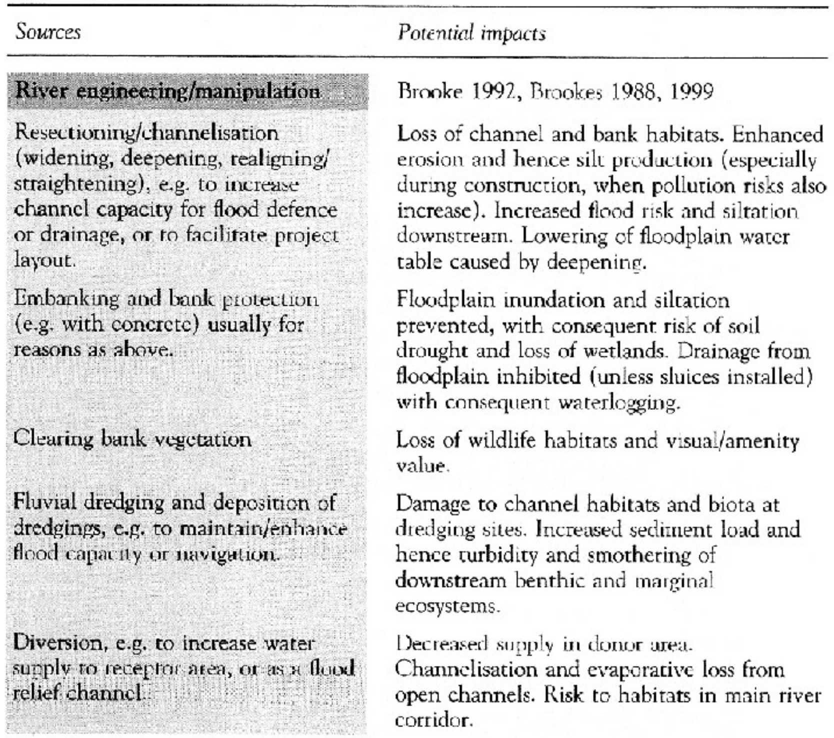
neutral	0
slight	$\pm 1/2$
moderate	± 1
Large	± 2

Quantitative

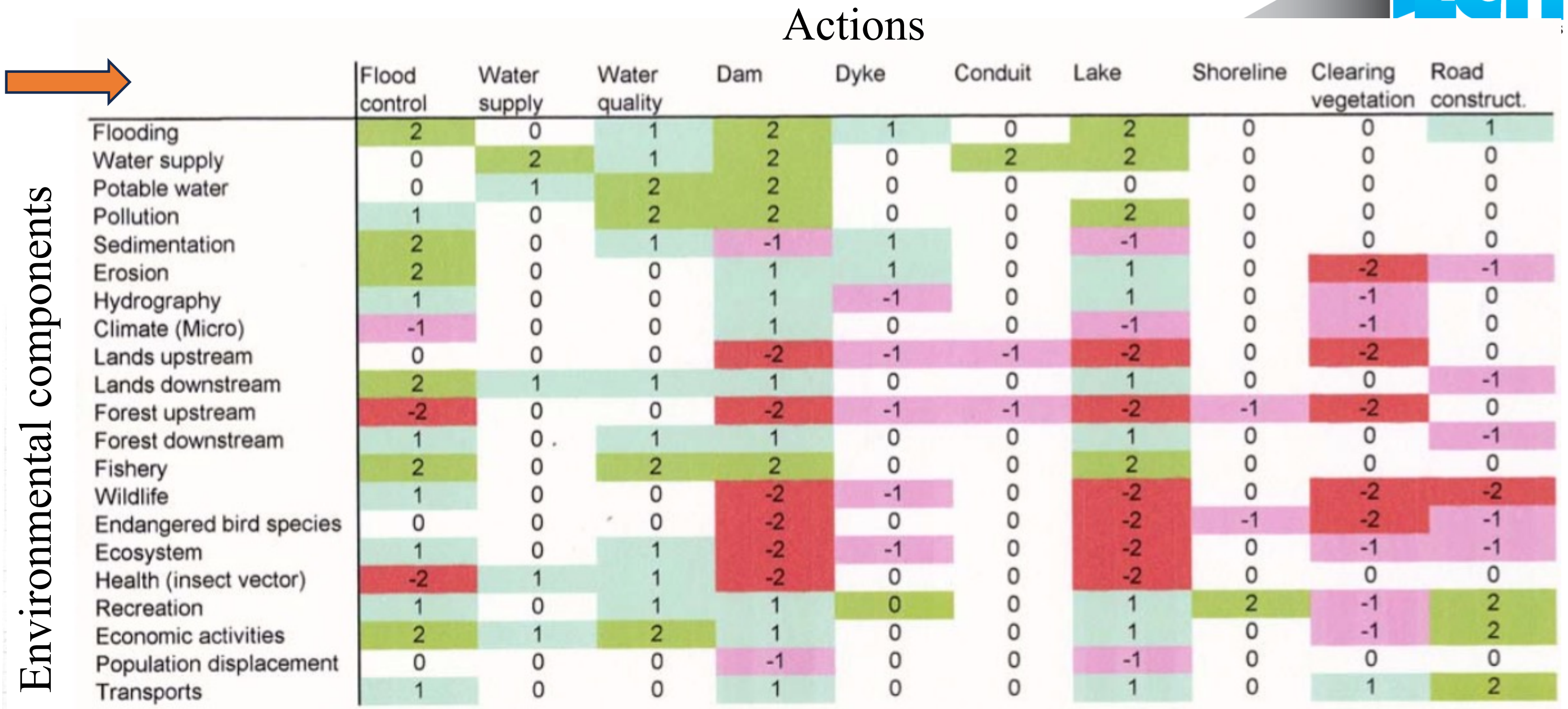
Component specific (e.g, % change)

Simple Interaction Matrix: it provides a summary of the EIA process steps from scoping to impact prediction and forms the basis for mitigation and monitoring actions

Interaction matrix example: **Tallahala Dam, Mississipi** (see also Schwemmle and Perona, 2019)



Sources	*Potential impacts*
River engineering/manipulation	Brooke 1992, Brookes 1988, 1999
Resectioning/channelisation (widening, deepening, realigning/straightening), e.g. to increase channel capacity for flood defence or drainage, or to facilitate project layout.	Loss of channel and bank habitats. Enhanced erosion and hence silt production (especially during construction, when pollution risks also increase). Increased flood risk and siltation downstream. Lowering of floodplain water table caused by deepening.
Embanking and bank protection (e.g. with concrete) usually for reasons as above.	Floodplain inundation and siltation prevented, with consequent risk of soil drought and loss of wetlands. Drainage from floodplain inhibited (unless sluices installed) with consequent waterlogging.
Clearing bank vegetation	Loss of wildlife habitats and visual/amenity value.
Fluvial dredging and deposition of dredgings, e.g. to maintain/enhance flood capacity or navigation.	Damage to channel habitats and biota at dredging sites. Increased sediment load and hence turbidity and smothering of downstream benthic and marginal ecosystems.
Diversion, e.g. to increase water supply to receptor area, or as a flood relief channel.	Decreased supply in donor area. Channelisation and evaporative loss from open channels. Risk to habitats in main river corridor.

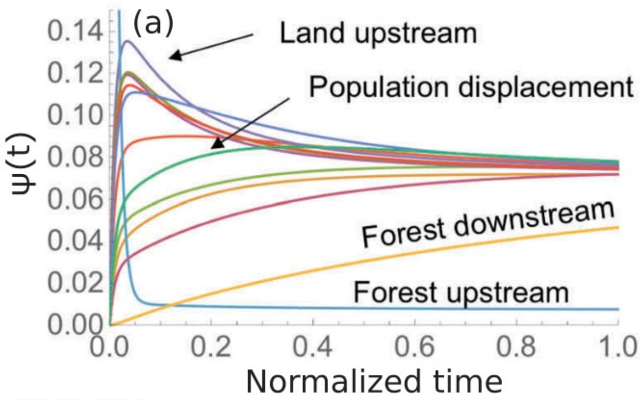


Actions

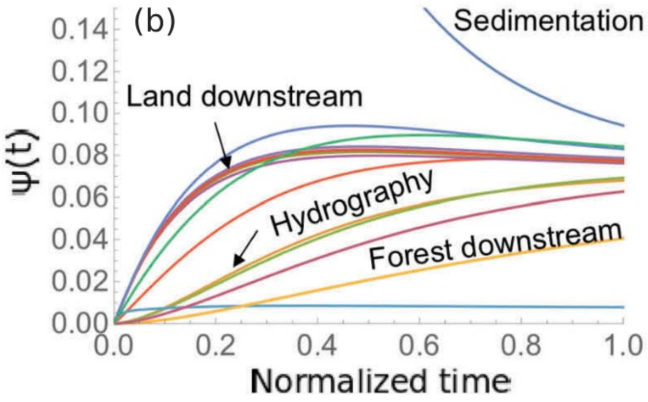
Environmental components

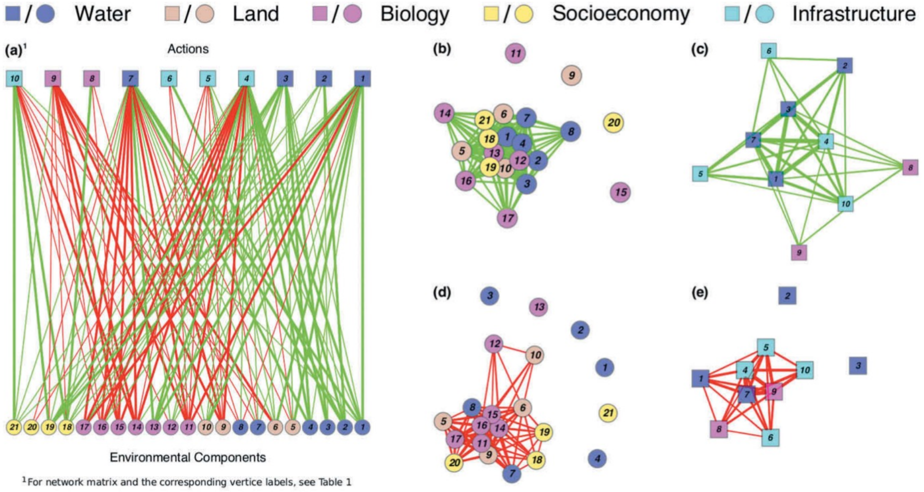
	Flood control	Water supply	Water quality	Dam	Dyke	Conduit	Lake	Shoreline	Clearing vegetation	Road construct.
Flooding	2	0	1	2	1	0	2	0	0	1
Water supply	0	2	1	2	0	2	2	0	0	0
Potable water	0	1	2	2	0	0	0	0	0	0
Pollution	1	0	2	2	0	0	2	0	0	0
Sedimentation	2	0	1	-1	1	0	-1	0	0	0
Erosion	2	0	0	1	1	0	1	0	-2	-1
Hydrography	1	0	0	1	-1	0	1	0	-1	0
Climate (Micro)	-1	0	0	1	0	0	-1	0	-1	0
Lands upstream	0	0	0	-2	-1	-1	-2	0	-2	0
Lands downstream	2	1	1	1	0	0	1	0	0	-1
Forest upstream	-2	0	0	-2	-1	-1	-2	-1	-2	0
Forest downstream	1	0	1	1	0	0	1	0	0	-1
Fishery	2	0	2	2	0	0	2	0	0	0
Wildlife	1	0	0	-2	-1	0	-2	0	-2	-2
Endangered bird species	0	0	0	-2	0	0	-2	-1	-2	-1
Ecosystem	1	0	1	-2	-1	0	-2	0	-1	-1
Health (insect vector)	-2	1	1	-2	0	0	-2	0	0	0
Recreation	1	0	1	1	0	0	1	2	-1	2
Economic activities	2	1	2	1	0	0	1	0	-1	2
Population displacement	0	0	0	-1	0	0	-1	0	0	0
Transports	1	0	0	1	0	0	1	0	1	2

Perturbation: vegetation clearing



Perturbation: sediment interception





¹For network matrix and the corresponding vertice labels, see Table 1

(E) MITIGATION/COMPENSATION

Aim: to avoid, minimize or remedy/compensate for the predicted adverse impacts

Priority

- Identify alternative project developments / locations
- Modify design features, including site boundaries and features (e.g., landscape)
- Minimise operational impacts (e.g., pollution and waste)
- Specific measures, eventually outside the development site or administrative/nonsrtructural, to minimize/compensate losses (EG, discuss the KWO example for hydropower production)

Mitigation measures should consider both

The construction phase

and

The operational phase

RESIDUAL IMPACT
that remains after having operated
mitigation or compensation

Precautionary principle

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Mitigation should be based on the possibility of a significant impact before there is conclusive evidence that it will occur

Environmental enhancement

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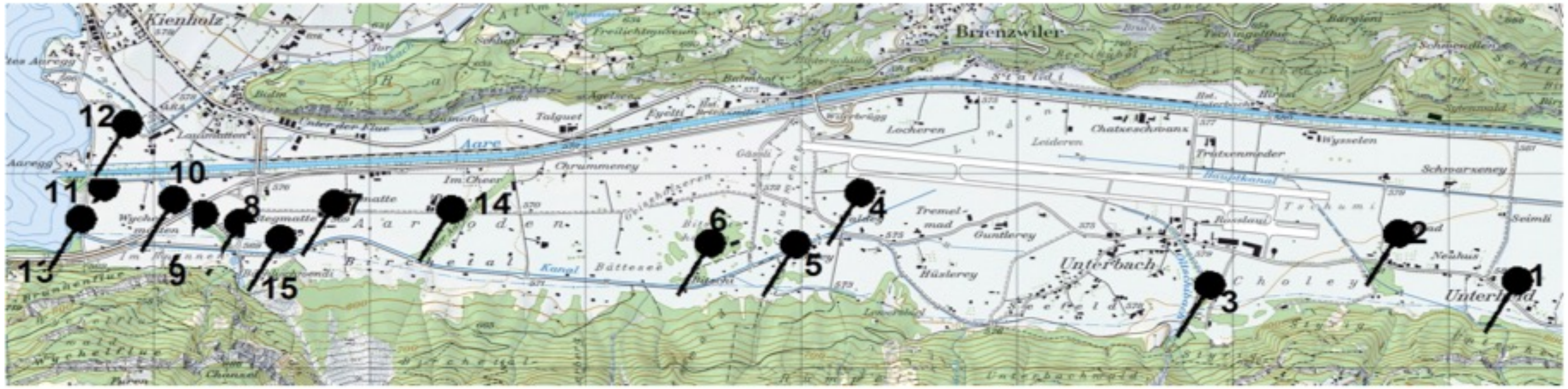
Additional task to mitigation (improvement of current environmental conditions)



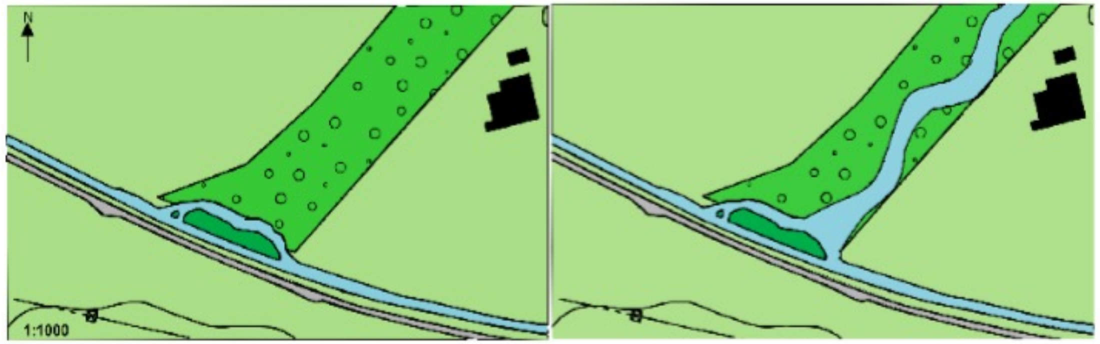
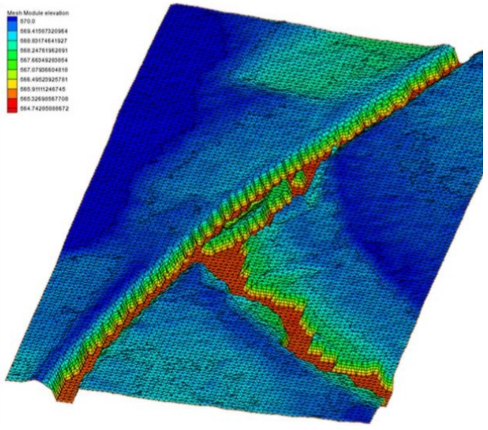


Figure 12: Revitalization measure (left: current situation, right: application of measure)



(F) EIS (ENVIRONMENTAL IMPACT STATEMENT)

The EIS is an integrate document that can be understood by “non-experts”, without compromising the integrity of the Environmental Impact Assessment.

As such it must be:

- Transparent to limitations and uncertainties;
- Including assessment of each component in relation to other (relartive importance)
- Addressing the conflicts of interests

(G) MONITORING

Systematic collection of specific data in time and space for the continuous assessment of environmental and socio economic variables related to a project development

baseline monitoring	Time and space observations to quantify ranges of variations relevant to impact prediction and mitigation (additional to existing data, e.g. hydrological)
compliance monitoring	Aimed at checking that specific conditions and standards are met
impact and mitigation monitoring	Aimed at comparing predicted and actual (residual) impacts.