

River Resilience and Dams in Mountain Areas

Die Belastbarkeit von Gebirgsflüssen mit Talsperren

Carmen de Jong

Abstract

Most dams worldwide are constructed in mountainous upstream parts of river basins with the most active sediment transport rates and largest discharge variability. Precise knowledge of river resilience to dams is lacking due to absence of interdisciplinary approaches to dam planning and their long term impacts. A toolbox to analyse basin-wide resilience of impounded rivers is suggested taking into account climate change.

Zusammenfassung

Die meisten Staudämme der Welt befinden sich im Oberlauf von Einzugsgebieten mit sehr hohen Transportraten von Sedimenten und hoher Abflussvariabilität. Genaue Kenntnisse über die Belastbarkeit von Flüssen mit Staudämmen fehlen wegen dem Mangel an interdisziplinären Forschungsansätzen bei der Planung von Dämmen und ihre langfristigen Folgewirkungen. Eine „toolbox“ wird zur Analyse der einzugsgebietsbezogenen Belastbarkeit von aufgestauten Flüssen unter Berücksichtigung von Klimaveränderungen vorgeschlagen.

1 Introduction

River resilience can be defined as the capacity of a river system to tolerate disturbance without collapsing into a qualitatively different state. In theory a resilient river system can withstand sudden changes such as dam construction or dam removal and recover itself (after Resilience Alliance). Most dams worldwide are constructed in the mountainous upper river basins which coincide with the most active sediment transport rates and largest discharge variability. **Figure 1** indicates that for Europe, the strongest concentration of dams is found in the Alps, Pyrenees, Western Highlands of Scotland, Scandes, Carpathians and the Mediterranean mountain islands. Most dam construction occurred prior to the 1970's and was often associated with hydro-social politics [1]. Therefore, the natural lifespan of dam reservoirs will confront us with issues of dam abandonment or removal within the next 50 years. Nowadays few of our mountain rivers are still natural since they have been significantly impacted by large and small dams. On average, discharge has been reduced by 70% and sediment load by up to 90% compared to unregulated reaches [2]. A precise knowledge of river resilience to dams is lacking both in the long term and at the catchment scale, due to a lack of interdisciplinary approaches to dam planning and monitoring. Interdisciplinary tools are necessary for environmental management and policy concerning dams in mountain catchments [3] in particular for monitoring sediment transport [4].

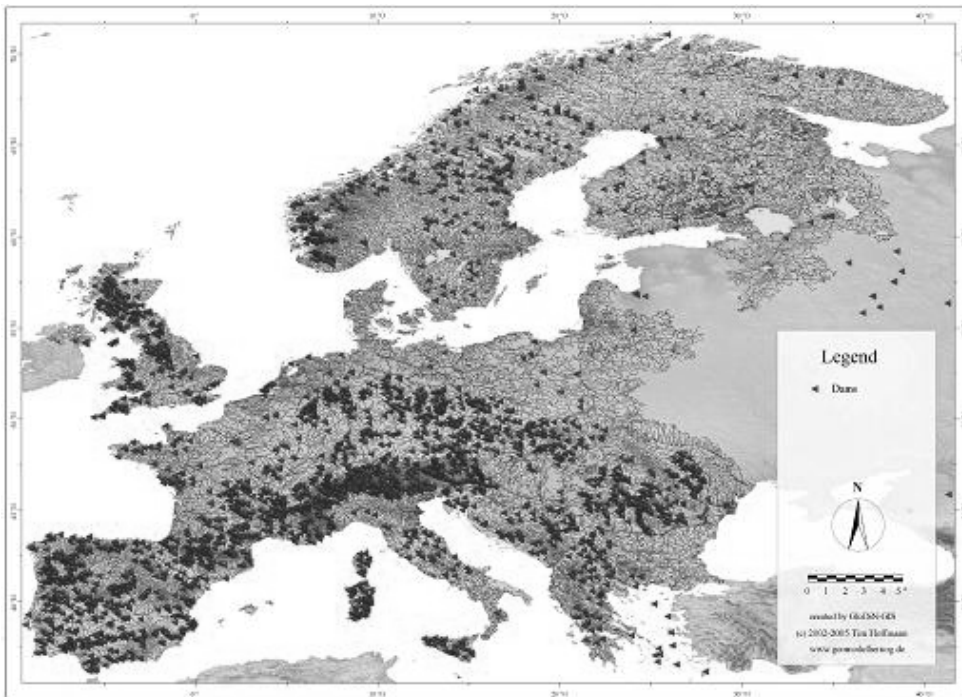


Figure 1: Distribution of dams in Europe showing strongest concentration in mountainous areas (based on ICOLD database 1998 processed [11])

2 River Resilience

The resilience of rivers to upstream and downstream impacts of dams is essential since this has consequences on the local and regional geomorphology, ecology, economy and agronomy. The retention of coarse sediment and water in dam reservoirs impacts sediment dynamics, stream patterns, stream morphology, aquatic and riparian habitats or downstream delta and coastal zones. It is important to know how rivers impounded by dams can recover in space and time i.e. over a distance of several hundreds of km or over a time period of 30-40 years. **Figure 2** suggests a toolbox for analysing the resilience of rivers to dams using a basin-wide approach spanning different temporal phases from interdisciplinary dam planning to dam construction, dam monitoring and dam removal. The basin and river characteristics are illustrated over space beginning with the mountainous upper catchments and ending in the zone downstream of the dam. They include the pre-dam conditions, changing hydrological, groundwater and sedimentological conditions after dam construction and the effects related to climate change and abandoned dams ready for removal. In the upstream dam area, rivers are rarely resilient to change since they are inevitably subject to sedimentation in the newly formed reservoir delta as the river seeks to regain equilibrium to its newly imposed base level. This sedimentation continues rapidly within- and upstream of the reservoir with time as is the case for Carpathian mountain reservoirs [5]. Since water and sediment supply are considerably reduced over time and space downstream of dams, rivers respond by narrowing and vertical erosion. Together with the reduction in groundwater level this causes widespread abandonment of the floodplain and alteration or destruction of the floodplain forest. The newly gained area is colonised by infrastructural and urban development.

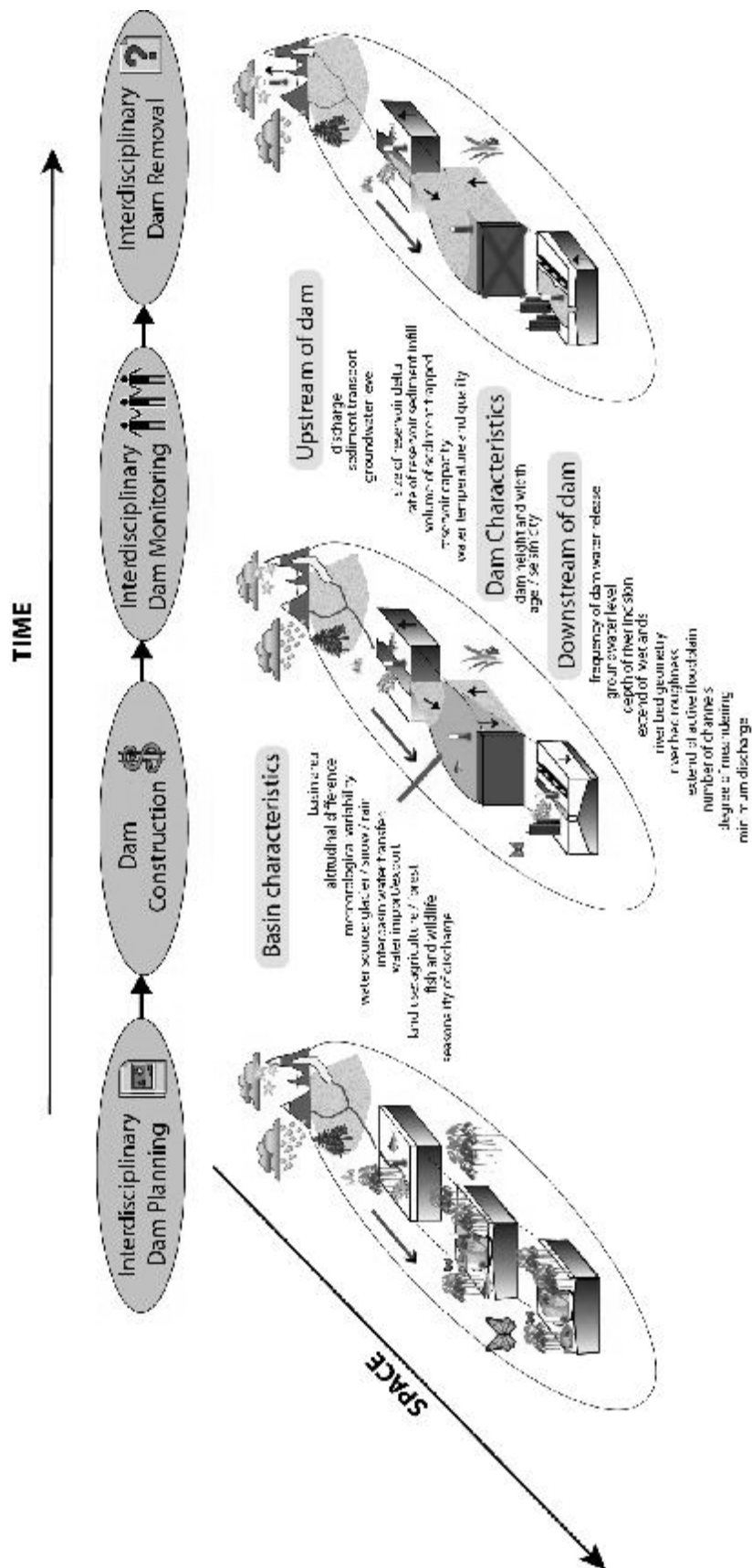


Figure 2: A toolbox for analysing the resilience of impounded rivers using a basin-wide conceptual approach. The temporal sequence includes interdisciplinary dam planning, dam construction, interdisciplinary dam monitoring and interdisciplinary dam removal. The spatial sequence includes three sections of the river system: upstream-, dam- and downstream section.

3 River resilience and climate change

3.1 Renewable energy

The discussion on water availability and dams as renewable energy is limited under the context of climate change. Renewable energy relies on the fact that the natural resources e.g. water is continually renewable in the future. However, it is predicted that glaciers and snow cover will continue to recede at an unprecedented rate due to global warming. This will have repercussions both on available water quantities and on sediment release from the newly exposed areas. In the discussion on renewable energy, the renewable characteristics of coarse stream sediments trapped behind dams is rarely discussed.

Climate change scenarios indicate that temperature increase will be relatively high at high altitudes which are the major source areas for dams [6]. The impacts will be threefold:

- Firstly, for reservoirs that are snow-fed, higher temperatures will decrease the ratio of snowfall relative to rainfall. A reduction in snow cover will decrease the storage buffering effects from snowmelt release during spring and summer time, thereby increasing the seasonal contrasts of discharge and increasing the uncertainty of dam infill during dry periods. The loss in volume of snow water equivalent will have direct impacts on reservoir replenishment and unless rainfall increases substantially relative to the present overall precipitation, water stress will result.
- Secondly, for reservoirs that are glacier-fed, higher temperatures will cause faster glacier retreat. It is estimated that if the present rate of glacier retreat continues, Alpine glaciers will have been reduced to one tenth of their volume within another 30 years. Glacier retreat will result in decreased dry season buffering and decrease in total water volume entering reservoirs within the next 20 years.
- Thirdly, for reservoirs that are both rain-fed, snow and glacier-fed, warmer temperatures will cause higher reservoir evaporation rates, thus decreasing stored water volumes.

It is also expected that the release of large amounts of coarse sediments from freshly exposed snow and ice-free areas will increase sediment supply into reservoirs and reduce dam capacity at higher rates than at present. To summarize, water amounts draining into dam reservoirs from glacierised or snow-fed catchments will be substantially reduced whereas sediment amounts will be increased thereby decreasing the security of reservoir infill within the next 2-3 decades. In future, it will be important to compare the climatological and hydrological conditions surrounding dams in semi-arid mountain regions [7] with the humid European environments.

3.2 Dam removal

The retention of increasingly sparse water in dam reservoirs in the upper parts of catchments will put additional stress on the river zones downstream of dams and cause them to be more vulnerable to aridity [8]. In the next 50-100 years, a large number of dams will have lost such high amounts of their capacity that dam removal will become an increasingly important issue [9]. The impacts of dam removal on mountain rivers is related mostly to sediment transport and river dynamics and has to be analysed from existing examples and laboratory experiments [10]. Since only a very small proportion of sediment can be removed from dam reservoirs by

excavation, river systems will have to cope with artificially high inputs of sediment in the post-dam era. Impacts will vary depending on whether dams are removed in a one- or multiple step process. The re-distribution of sediments from the former reservoirs into the floodplains will differ from pre-dam conditions since most floodplains have been heavily modified by infrastructure and urban development. The increasing groundwater levels together with sediments will have major impacts on the stability of the river system.

4 Conclusion

The resilience of river systems to dams is important considering the discussion on renewable energy and the sustainability of water and sediment. This is particularly relevant for the European Framework Directive which requires our rivers to be restored into a good ecological state by the year 2015. Since each river basin is subject to different environmental and human impacts, it is subject to different degrees of vulnerability and different degrees of recovery. More research and monitoring on these interdisciplinary aspects is essential to avoid ecological and economical loss and to optimise the planning of new reservoirs in Europe.

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Author's Name and Affiliation

Carmen de Jong, Prof. Dr. Habil, Dr.rer.nat, M.A.,
The Mountain Institute
Research Director
University of Savoy
Le Bourget du Lac
73376
HP7 3QZ
France
carmen.dejong@institut-montagne.org