Paper title

Removing small dams: and now, what do I do with the sediment? Lessons learned (Démolition de petits barrages: et maintenant, que dois-je faire avec des sédiments? Leçons apprises)

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RÉSUMÉ

Quatre études de cas sont présentées pour illustrer la manière dont la gestion des sédiments a été planifiée dans la Démarcation Hydrographique de la Catalogne lors de la suppression de petits barrages. Le barrage de Bojons a été démoli en une seule phase. Avant sa démolition et à titre préventif, 15 % du volume total de sable accumulé dans le réservoir a été retiré. Malgré cela, une mobilisation massive de matériaux s'est produite avec un impact temporaire sur un tronçon de rivière de 600 m. Au barrage de Ritort, entre 60 % et 70 % du total des sédiments retenus par le barrage ont été éliminés mécaniquement par excavation. Il a été constaté par la suite que cette mesure préventive n'aurait pas été nécessaire en raison de l'absence d'impact sur l'écosystème fluvial. La démolition du barrage de Sant Salvador est réalisée en deux phases différentes, chacune impliquant l'élimination mécanique d'une partie des sédiments. Les sédiments ont été déplacés vers différentes sections du lit du fleuve où l'on s'attend à ce que le fleuve lui-même mobilise les sédiments lors des crues. Le barrage de Sentmenat est entièrement rempli. Compte tenu de son ampleur, la réponse de l'ensemble sédimentaire et du lit de la rivière à différents scénarios de démolition a été modélisée afin de sélectionner la meilleure alternative.

ABSTRACT

Four case studies are presented here to illustrate different sediment management approaches carried out in the Catalan basin district, NE Spain, during the demolition of small dams. The Bojons dam was dismantled in a single phase. Prior to its demolition and as a preventive measure, 15% of the total volume of sand accumulated into the reservoir was removed. Even so, a massive mobilization of material occurred with a temporary impact on a 600-m river reach. At the Ritort dam, between 60% and 70% of the sediment retained was mechanically extracted during the overthrow works. After the demolition, it was determined that this preventive measure was unnecessary, as the river ecosystem downstream remained unaffected. The demolition of the Sant Salvador small dam is being carried out in two phases, each involving partial sand removal through mechanical methods. The sediment extracted during the first phase was relocated to different sections of the river channel where it is expected to be mobilised during floods. The Sentmenat dam is fully filled. Given its magnitude, the response of both the sedimentary package and the riverbed to different demolition scenarios has been modelled to select the best alternative.

KEYWORDS

Case studies, dam removal, sediment management, impacts, Mediterranean rivers (études de cas, démolition de barrage, gestion des sédiments, impacts, rivières méditerranéennes)

1 INTRODUCTION

The removal of small dams allows the restoration of the river system hydro-sedimentary dynamics while the sediment package trapped by the dam is released, and then, progressively eroded by the river flow. The velocity in which the sediment will be evacuated, as well as the volume of mobilized material, will depend on several factors such as, the slope of the river channel, the height of the dam, the geometry of the weir basin, the volume and composition (granulometry) of the sediment package and the hydrology of the river; among others. If these factors are not considered, there is a risk of a massive mobilization of sediment with serious effects on the morphology of the river and the river ecosystem. For this reason, it is crucial to design sediment management plans prior to the demolition of the dam, and adapt the plan as needed during the process. In this context, we present 4 case studies in the Catalan Basin District, 3 of which have been completed and 1 is currently being developed. Together, they illustrate different sediment management scenarios undertaken during the demolition of small dams and the corresponding hydromorphological response of the river system.

2 STUDY CASES

2.1 The small dam of the Bojons Mill

The demolition of the "Molí de Bojons" dam, located in the Riera Major River was initially planned in 2015. To minimize the mobilization of the impounded sediment and its potential adverse impacts on the downstream riverine environment, a 3-phased demolition approach was adopted, involving a gradual lowering of the dam over multiple years. In addition, the removal of 340 m^3 out of the total of 9,300 m^3 of medium and coarse sand retained into the reservoir, was also contemplated. However, due to administrative reasons the demolition project was delayed. Finally, the dam was demolished in October 2017 in a single phase and around 1,400 m^3 of sediment were removed mechanically as a preventive measure. Nevertheless, a massive mobilisation of the material package occurred, rapidly impacting a ~375-m river reach. This led to the total modification of the riverbed with marked consequences on the ecosystem. The impacted reach extended to 520 m after 3 months and up to 600 m after 4 months. The material released from the dam was observed within a 5 km- reach. As a corrective measure, three sediment traps were built to slow the advance of the sediment wave and prevent further damage. The traps were located immediately upstream of the demolished dam, and downstream at 450 m and 1,000 m. Traps were checked weekly and emptied by excavator when water discharge allowed.

A monitoring study undertaken in June 2018 concluded that: (i) a significant part of the sediments stored in the old dam arm was transported during the first 9 months after the dam's demolition; (ii) the bulk of the sediment package transferred downstream was located approximately 500 m from the former dam site; (iii) the front of the sediment wave had not yet reached 1,200 m, but an incipient tendency towards sedimentation was observed. In despite of this, it was recommended to discontinue the use of traps. Therefore, in September 2018 (when about 1,800 m^3 of sediment were dredged), the use of traps was discontinued. Later on, in October 2018 and January 2021, a flood slightly lower than the bankfull and an extraordinary flood, allowed the total transit of the material released from the dam's demolition, resulting in the complete recovery of both the channel morphology and the river ecosystem.

2.2 The Ritort Hydroelectric Power Station dam

The Ritort Hydroelectric Power Station dam was located on the Ritort River, in the Pyrenees. In October 2020, the 8-meter-high dam, fully filled by approximately 4,000 m^3 of gravel and pebbles, was demolished in a single phase (see video). However, the demolition project did not include a sediment management plan. In this case, no preliminary study was done to evaluate the potential mobility of the sediment during floods after the dam removal and the length of the river that could be affected. Consequently, as a preventive measure, between 60 and 70% of the total sediment trapped by the dam was extracted before the demolition. Concurrently, the longitudinal slope of the river in the former reservoir was softened and a low-water channel was built. When de demolition works began, a biological and geomorphological monitoring was carried out (see document). The results obtained showed that removing the sediment from the dam would not have been necessary since the river by itself adjusted its channel and slope progressively to the new flow and sediment conditions without major fluvial ecosystem impacts.

2.3 The Sant Salvador small dam

The Sant Salvador dam is placed in the lower parts of the Riera de Santa Coloma River. This structure is made up of two consecutive dams: the first with a height of about 2 m and a length of 20 m, and the second with a height of 1.7 m and about 30 m long. In January 2021, the Riera de Santa Coloma River registered the most significant flood since 1995, which led to an enormous mobilization of sediments throughout the river basin. As a result, the dam acted as a sediment trap and the reservoir was filled, mainly by medium and coarse sand. The barrier effect of the dam led to the accretion of the first 700 m of the riverbed located immediately upstream of the dam, with a direct impact on the riparian forest and aquatic habitats. Bed accretion exceeded one meter in elevation at specific points. It was then when the City Council considered the possibility of demolishing the dam.

Prior to the dam's demolition, a hydraulic and sediment transport model of the river was developed to evaluate the response of the sedimentary package and assess the potential sediment impacts under different demolition scenarios and flow discharges. This study concluded that a phased demolition strategy was the most suitable approach and included an initial 33% reduction in dam height and the mechanical removal of 1,400 m^3 of sediment (from a total volume of 4,500 m^3 within the first 350 meters upstream of the dam). Sediment extracted was relocated downstream in sections of the active channel where ordinary floods could mobilize it. These sections were identified following an analysis of the existing orthophotos taken after the extraordinary flooding that occurred in 2021. The first phase of the demolition was carried out throughout 2023. The second phase is expected to occur within the next 2 to 5 years.

2.4 The Colonia Rio small dam

The Colonia Rio dam (Fig. 1a), a 5.6-meter-high and 56-meter-long dam located in the Calders River, was an obstacle for the sediment transport continuum since around 13,000 m^3 of sediment was trapped into the reservoir, causing a strong sediment deficit downstream of the dam. Due to sediment exhaustion, sections of the riverbed within the first 400 meters of the downstream river channel were exposed bedrock.

A single-phase demolition of the dam and diversion canal was conducted in 2023. The reservoir sediments, composed mainly of sand, gravel, and pebbles (see video), suggested a low probability of mass movement. Nevertheless, uncertainties remained concerning the hydro-morphological response of the sediment package. When the dam wall was demolished, an abrupt discontinuity (break slope) was generated in the longitudinal profile of the river (Fig. 1b). Therefore, during the demolition process, part of the sediment retained in the reservoir was relocated immediately downstream, where the former dam was placed, to reduce the slope of the channel. Also, a portion of the sediments retained in the former dam reservoir were relocated at the front of the sedimentary package while a new morphology of the river channel was traced to facilitate the creation of the new fluvial channel. Results from a geomorphological monitoring program indicated a rapid response of the morphological system after the occurrence of small flood events. The sediment deficit downstream was compensated by riverbed accretion up to 50-100 cm (recovering the bedrock riverbed) with the sediment eroded from the sedimentary package, which also facilitated the formation of a braided channel with a complex riverbed morphology.

3 FINAL REMARKS

Preliminary studies evaluating sediment management options while considering the potential effects downstream are crucial prerequisites for the execution of dam removal projects. Sediment management options may include: (i) leaving the sediment in situ (so that the river itself gradually redistributes the material downstream); and (ii) extract part or all of the retained sediment.

It should be noted that there are many factors that determine both the mobility of the material and the river length that might potentially be affected. Therefore, case-by-case studies must be carried out for each dam to identify the best management strategies for each individual case. The chosen option should define both the demolition methodology (phased or single-phased approach) and demolition type.

Sediment management is a complex challenge where zero risk does not exist. The possibility of negative impacts on the river ecosystem, infrastructure, goods, and services proximate to the demolition area is ever-present. However, in most cases, impacts are limited both in space and time and should be understood as short to medium term effects within the restoration process. In this sense, we should become aware that the riverbed material (sediment), joint with the sediment processes and dynamics are key aspects for the correct functioning of the

entire fluvial system, being the basis of the structure of the biological communities and the river biodiversity. Therefore, sediment extraction from the reservoir should be considered a last resort due to ecological and economic concerns and should only be proposed when a significant, long-lasting impact is anticipated.

Figure 1.- View of the Colonia Rio dam before (a) and after (b) the demolition of the barrier.