Increase of hydraulic habitat diversity downstream of dams with sediment replenishment and artificial flooding

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Sediment and flow dynamics, meaning the regular disturbance of habitats and turnover of sediments, are key drivers for floodplain functionality. Dams may interrupt the sediment continuum and alter discharge in the downstream river segments. In alpine rivers, magnitude and frequency of flood events therefore is often highly reduced and pauperization of the geomorphology of residual flow reaches happens. While sediment is entrained but not supplied, river bed incision may happen, affecting lateral connectivity and in worst cases even the groundwater table. This research describes a measure conducted at the Sarine floodplain in western Switzerland, aiming at counteracting this problematic. The study took place downstream of the 83 m Rossens dam that was constructed in 1948 impounding a 200 mio m^3 reservoir with the purpose of hydropower production. The dam has released about 3 m^3s^{-1} to its meandering downstream river segment. The large reservoir volume makes the activation of the spillways rare. Based on laboratory experiments, an approach of an artificial flood release combined with sediment replenishment was applied. Therefore 1000 m^3 of sediment was excavated from the floodplain and placed in four deposits in the river. Then, a flood with a return period of about 1 year was released from the Rossens dam. The flood was not powerful enough to change river morphology to a large extent. However, it transported a large part of the replenished sediment. The restoration measure increased the hydraulic habitat diversity by more than 20% in the 850 m long observed river segment around the replenishment site. This change in hydraulic habitat diversity was analysed with the hydro-morphological index of diversity (HMID) a robust tool for habitat assessment. It was calculated based on 200 measurements of flow depths and velocities from both, before and after the flood event. Since this was the first flood event in the Sarine river little can be said about the long-term evolution of the replenishment. Results from laboratory experiments with a similar sediment replenishment configuration are promising.

1. Background

1.1 Problematic of missing sediment dynamics

Flow and sediment regimes are two key drivers of aquatic ecosystems and floodplains that host a large variety of habitats[1]. Reservoirs associated with dams have severe impacts on these drivers, causing residual flow conditions due to flow regulation. Large reservoirs retain almost all coarse sediment transported by rivers and the sediment continuum is often completely interrupted[2,3]. The absence of periodic flood events and sediment supply causes river incision in the downstream river bed and the loss of lateral fluvial connectivity. With time, gravel bars are colonized by species that prefer a more static environment such as hardwoods that are limited in dynamic riverine systems.

1.2 Engineering approach to reintroduce sediment dynamics

For maintenance reasons, reservoirs are flushed regularly by opening the bottom outlet[4,5]. Such reservoir operations can be designed accordingly to restore residual flow reaches. Combined with sediment replenishment, such an artificial flooding may contribute to restore river dynamics and hydraulic variability[6]. Lately, research efforts studying erosion, transport and deposition processes of sediment replenishment in the laboratory revealed the potential of an alternate deposition pattern of replenished sediment mimicking the repetition of sediment clusters which can favour geomorphological richness in the downstream river reach[7–9].

1.3 Case study

In the study presented here, the change in the variability of hydraulic habitats by sediment replenishment combined with an artificial flood was investigated at the Sarine river downstream of the Rossens dam in western Switzerland (Fig. 1a). The 83 m high Rossens dam is an arch-dam and was constructed in 1948 for hydropower generation. A constant residual flow of about 3 m^3/s is released by the Rossens dam, creating the Lake of Gruyère a reservoir of 200 mio m^3.

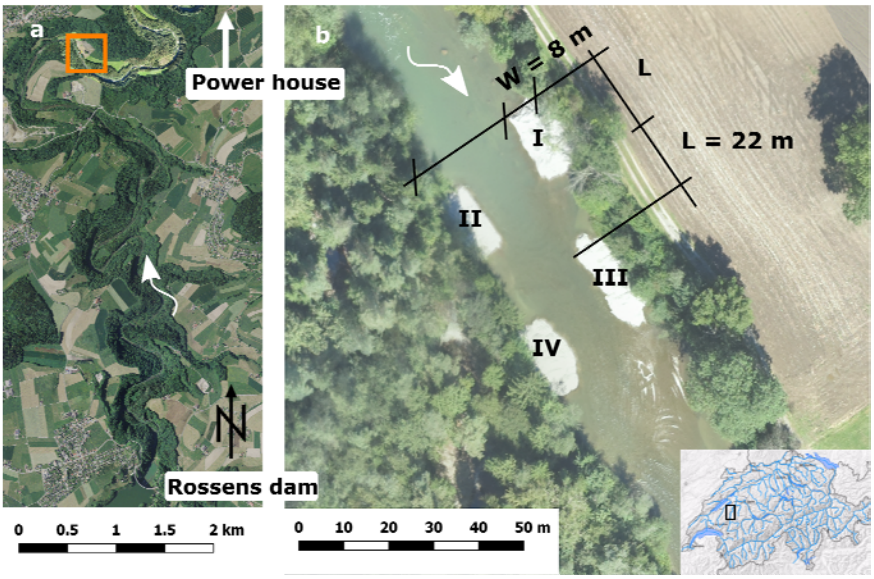

Fig. 1: (a) Situation of the Sarine river downstream of the Rossens dam in the canton Fribourg in western Switzerland. (b) Sediment replenishment with four deposits. Location of investigation is marked with an orange square in (a). Geodata © Swisstopo

2. Methodology

2.1 Sediment replenishment

The sediment replenishment consisted of 1000 m^3 of sediments, excavated from the floodplain and given to the river in four alternating deposits (Fig. 1b). The replenished sediment had the same grain size distribution as the river bed with a mean b-axis diameters of 60 mm (d_m) and 110 mm (d_{90})[10,11].

2.1 Hydraulic habitat diversity

The change in hydraulic habitat variability was investigated with the hydro-morphological index of diversity (HMID[12,13]), comprising of the normalized variations of flow depths and velocities (see Eq. 1). For calculations, about 200 measurements were taken before and after the flood using a handheld-ADV (FlowTracker from SonTek). Flow velocity was measured at 60% of flow depth. The detailed measurement locations were captured with a differential GPS, allowing the measurement on exactly the same locations after the flood event.

$$HMID_{segment} = (1+\sigma_v/\mu_v)^2 \cdot (1+\sigma_h/\mu_h)^2 \quad (1)$$

μ	mean value	
σ	standard deviation	
h	flow depth	[m]
v	flow velocity	[ms^{-1}]

2.2 Artificial flood

The artificial flood took place in September 2016 and lasted 28 hours. The peak discharge of 195 m^3s^{-1} lasted for two hours and corresponded to a flood event with a return period of 1 year. The decreasing limb of the hydrograph was less steep than the increasing to minimize fish-stranding (Fig. 2). Figure 3 shows the flood in the Sarine river.

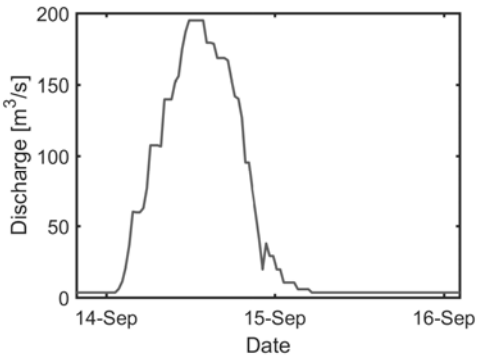

Fig. 2. Hydrograph released from the Rossens dam in September 2016.

Fig. 3. Air-view of the Rossens dam during the release of the artificial flood on 14 September 2016. Image © Research Unit Ecohydrology, ZHAW

3. Results and conclusions

The HMID value increased from 8.1 to 9.8 what is an improvement of the habitat richness of 21% in the 850 m reach of investigation. This change in hydraulic habitat variability reveals the potential of such a combined measure of sediment replenishment and triggered artificial flooding. This experiment represents the first investigated test at the Sarine with sediment replenishment and the first try of the multi-deposit replenishment optimized in the laboratory experiments[8,14]. Further tests will be needed to see the mid- and long-term evolution in the Sarine river, estimate the costs of such a measure and re-establish important sediment dynamics in hydropower impacted floodplains in general. The first ecological assessment of the restoration measures are promising[15].

Acknowledgements
This research project was part of the National Research Programme "Energy Turnaround" (NRP 70, www.nrp70.ch) of the Swiss National Science Foundation (SNSF, Project No. 153972). The first author has a complementary funding by the Swiss Federal Office of Energy (SFOE, Project No. 501673-01).

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