Morphodynamic modelling of historical modifications and present-day restoration strategies along two reaches of the Rhône River

Modélisation morphodynamique des modifications historiques et des stratégies de restauration actuelles sur deux tronçons du Rhône

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RÉSUMÉ

Le Rhône a subi d'importantes modifications au cours du 20ème siècle suite à la construction de digues (Casiers Girardon), de barrages de dérivation pour l'hydroélectricité, d'extraction de sédiments et de dragage. La somme de ces impacts a conduit à un lit pavé et à de faibles capacités de transport du charriage. Des réinjections de sédiments sont actuellement mises en œuvre le long de tronçons clés afin de restaurer la mobilité du lit. Nous avons utilisé une combinaison de modèles morphodynamiques 1D existants (le Spawning Gravel Refresher (Viparelli et al., 2011) et le Basement model (https://basement.ethz.ch/)) pour étudier l'évolution historique et la dynamique actuelle, et pour évaluer les impacts des réinjections de sédiments le long des tronçons PDR et DZM. Nous présentons les changements historiques dans l'élévation du lit et les distributions granulométriques le long de chaque tronçon et leur réponse à la restauration, ainsi que les capacités de transport actuelles par fraction granulométrique. Nous discutons également de l'adéquation des différents modèles aux études morphodynamiques à long terme ou à court terme et aux données disponibles.

ABSTRACT

The Rhône river has undergone significant changes during the 20th century as a result of embankments (Casiers Girardon), diversion dams for hydropower, sediment mining and dredging. The sum of these impacts has led to an armoured bed and low bedload transport capacities. Sediment reinjections are currently being implemented along key reaches in order to restore bed mobility. We used a combination of existing 1D morphodynamic models (the Spawning Gravel Refresher (Viparelli et al., 2011) and the Basement model (https://basement.ethz.ch/)) to study historical evolution and present-day dynamics, and to evaluate the impacts of sediment reinjections along the PDR and DZM reaches. We present historical changes in bed elevation and grain size distributions along each reach and their response to restoration as well as present-day transport capacities by grain size fraction. We also discuss the suitability of different models to long-term versus short-term morphodynamic studies and to available data.

KEYWORDS

1D Morphodynamic modelling, Sediment reinjections, GSD, Dams

1 INTRODUCTION

The Rhône river (France) has undergone several major phases of human modifications, beginning with channelization in the late 1890s (Casiers Girardon), followed by construction of multiple diversion dams for hydropower and intensive sediment mining starting in the 1950s. The sum of these has significantly affected the bed and sediment dynamics along the river and sediment reinjections are underway with the goal of breaking up bed armouring and increasing bed mobility in order to restore habitat.

2 STUDY REACHES

The study was conducted on the Péage de Roussillon (PDR) and Donzère-Mondragon (DZM) reaches of the Rhône River, France. Both reaches are bound between two dams and consist of an upstream bypassed sub-reach that runs parallel to a derivation canal and has a modified flow and sediment supply, and a “total Rhône” sub-reach downstream of the confluence of these that receives the natural discharge. A large fraction of the total Rhône sub-reach lies within the backwater of the downstream dam.

The 30 km long PDR reach is located 50 km downstream of Lyon between the Saint-Pierre-de-Bœuf dam (1977) and the Arras dam (1971). There is a weir (installed in 1978) approximately 7 km downstream that has a height of 3.4 m. A large volume of sediment (approximately 1 650 000 m3) was dredged downstream of the confluence in order to increase the hydraulic drop below the power plant.

The 40 km long DZM reach is located 170 km downstream of Lyon between the Donzère dam (1952) and the Caderousse dam (1975). The Ardèche, one of the major tributaries to the Rhône, flows into the bypassed reach. A total of between 3 200 000 and 3 900 000 m3 were extracted in sediment mining operations along the reach between 1969 and 1991.

3 METHODS

This study uses data collected and compiled as part of previous studies (e.g. Vázquez-Tarrío et al., 2019) conducted through the Rhône Sediment Observatory (OSR). These include historical and present-day channel bathymetry, present-day grain size distributions from samples collected along the channel bed and from the surface and sub-surface of bars, and present-day flow duration curves. It also uses water elevations from simulations using the 1D hydraulic model Mage (Inrae) and estimates of sediment mining volumes based on a study conducted by the Compagnie National du Rhône.

The most robust numerical simulations are based on initial conditions from a period in which they are well known and for which it can be assumed the system was in equilibrium. As such, our boundary conditions and initial conditions were based on the channel at the end of the 19^{th} century prior to the construction of embankments. We implemented these in the Spawning Gravel Refresher using a simplified rectangular grid with fixed slope. To reconstruct the historical sediment supply and bed material we used an empirical bedload transport equation based on current channel conditions (slope, Q, width, GSD of the surface) to estimate the flux per grain size fraction weighted over the hydrograph and we used an analytical approach (Blom et al., 2017) to back calculate the grain size distribution of the surface layer. Once the simulated pre-management channel achieved equilibrium, we used these initial conditions to simulate the impacts of embankments, dams and mining.

Present-day morphodynamic modelling was performed with the Basement model using measured cross sections spaced approximately every 500 m and an average of measured grain size distributions for the bypassed reach and the total Rhône. Q-H relationships from the 1D hydraulic model Mage were used for the downstream boundary condition and water lines were validated with those from Mage up to flows with a 10-year return period. Bedload transport rates and annual volumes were calculated per grain size fraction. Changes in bed elevation, grain size distribution of the surface and bedload transport capacities were analysed for different sediment reinjection scenarios 1-year and 50-years post-reinjection.

4 PRELIMINARY RESULTS

Figure 1 shows how bed elevation and surface grain size evolved along the PDR reach in response to a 75-year simulation using the Spawning Gravel Refresher model after we imposed embankments on the pre-management equilibrium bed. The result shows a negligible change in slope and slight fining of the bed surface.

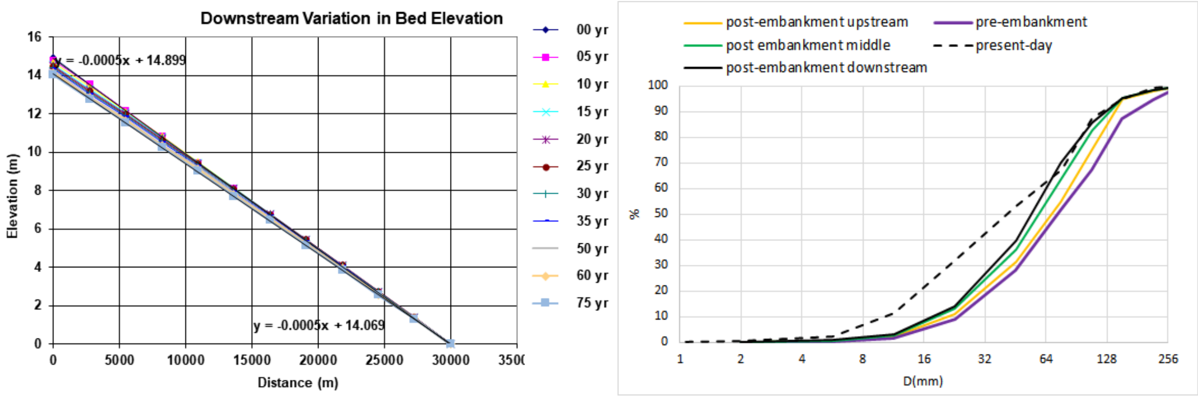

Figure 1: Evolution of bed elevation (left) and grain size distribution (right) from pre- to post-embankment

Figure 2 shows present-day transport volumes by grain size fraction and the cumulative transport volume along the PDR reach based on a simulation using actual cross-sections and an annual hydropgraph implemented in the Basement model. The result shows highest transport rates for D 16-32 mm upstream of the confluence and D 32-64 mm downstream of the confluence. Annual volumes are relatively low due to the impact of flow regulation.

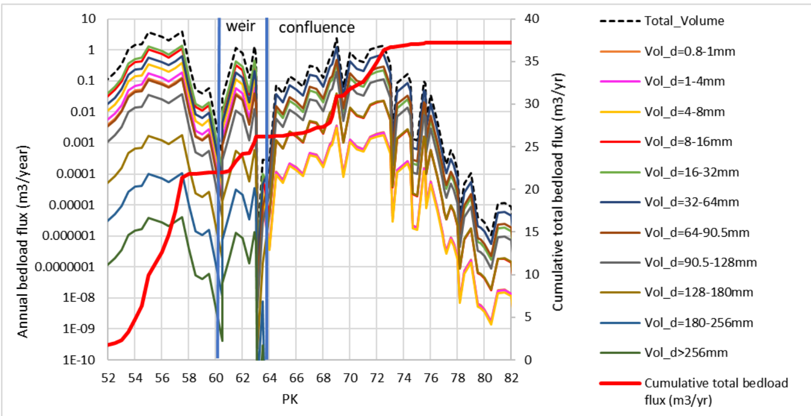

Figure 2: Annual volumes of bedload flux per grain size fraction and cumulative flux along the PDR reach.

5 PERSPECTIVES

Historical and present-day simulations using both models are currently in progress and the relationship between transport capacities and bed evolution are being analysed. We are evaluating the impacts of different sediment reinjection scenarios on the bed and the implications for habitat. The results of this study will be validated with tracer (RFID) measurements.

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