Bed elevation along the Rhone river (France): a spatio-temporal overview

Elévation verticale du lit dans le linéaire du Rhône (France) : une perspective spatio-temporelle

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RÉSUMÉ

Le caractère géomorphique du Rhône actuel est fortement influencé par les modifications humaines récentes dont il a fait l'objet : travaux destinés à promouvoir la navigation au début du XXème siècle et construction de toute une série de barrages au fil de l'eau dans la deuxième moitié du XXème siècle. Par ailleurs, des extractions sédimentaires massives ont eu lieu simultanément à l'installation des aménagements hydroélectriques. Cette étude se focalise sur la caractérisation des changements dans l'évolution verticale du lit en réponse aux différentes phases d'aménagement, en s'appuyant sur l'analyse des profils longitudinaux compilés à partir des données bathymétriques disponibles. Les résultats de cette analyse différentielle nous montrent des taux d'incision verticale assez variables en réponse aux différentes phases d'aménagement, et souligne des tendances amont-aval intra-tronçon et une forte variabilité inter-tronçon.

ABSTRACT

The geomorphic character of the present-day Rhône river is heavily influenced by its recent history of human modifications consisting of river training in the early 1900s and the construction of a series flow diversions during the second half of the XXth century. Widespread gravel mining coincided with the period of dam construction. This study is focused on characterising changes in bed elevation in response to different management phases based on the analysis of long profiles compiled from bathymetric data. The results of differential bed elevation analysis show variable rates of bed incision in response to different management phases and highlights downstream trends in bed elevation within reaches as well as variability in bed evolution amongst different reaches.

MOTS CLES

Long profiles, Rhone River, river training, hydropower dams, gravel-mining

1 INTRODUCTION

The present-day Rhône River (France) owes its geomorphic character to several major periods of human modifications carried out in the main channel over the past 150 years. The first, in the late 1900s, consisted of classic river training aimed at improving navigation. The second, starting in 1948, involved the construction of a series of canals that bypass the main channel, diverting flow to dams for hydroelectric production. Finally, gravel mining was widespread from the 1950s until the 1990s. The net result of these works is an incised channel characterised by almost continuous embankments along the lowermost 300 km and multiple segments of by-passed channel characterised by reduced flood frequencies and reduced average discharges. We present results of a study carried out within the framework of the Rhône Sediment Observatory (OSR) aimed at characterising the vertical response of the bed in time and space to different management phases.

2 MATERIALS AND METHODS

Long-profiles of the river bed were compiled from CNR bathymetric data and historical maps in order to characterise the bed at different times (Parrot, 2015): i) at the beginning of the 20th century, and therefore considered to represent the bed before it adjusted to the Casiers Girardon works, ii) corresponding to the construction of the hydro-electric dams and therefore considered to represent the bed after it responded to river training but before its response to the dams, iii) a profile based on the most recent bathymetric data available (2006 – 2010) representing the present day bed that is post-adjusted to the dams, and iv) and v) two profiles constructed before and after the occurrence of large flood events in 2002 – 2003 (Q50 – Q100) providing insight as to how today's bed is mobilised in response to large hydrologic events. Data from a recent CNR compilation of mining volumes (Coeur, 2017) were used to adjust bed elevations in order to estimate incision rates without the impact of mining. In order to compare downstream trends in bed elevation amongst reaches of different lengths, distances along each reach were normalised by a common scaling factor.

3 RESULTS

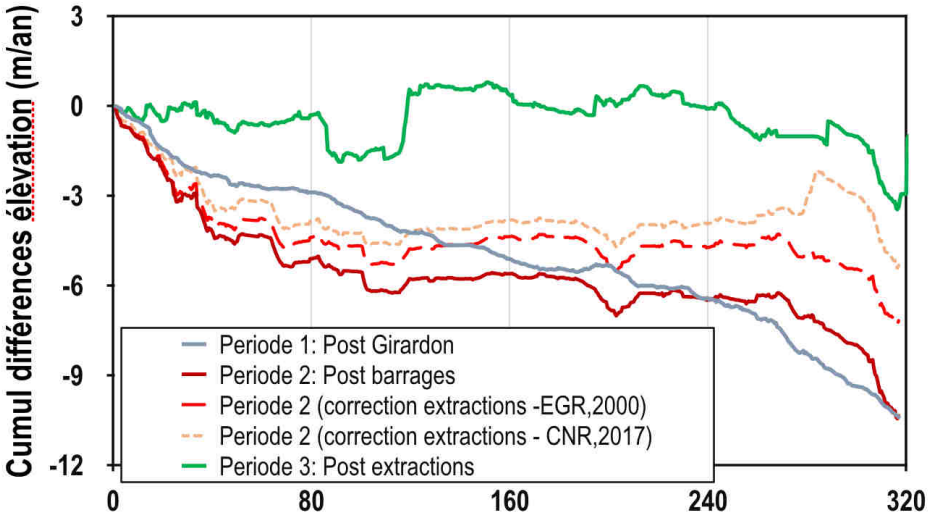

Figure 1. Cumulative differences in bed elevation in response to different periods of human interventions.

Differences in bed elevation show that the Rhône River has undergone global incision in response to both periods of management works (casiers and dams) but that the average incision rate was lower post-dams versus post-river training (1.2 cm/yr versus 1.7 cm/yr respectively, Figure 1). When bed elevations were corrected for gravel mining (approximately 47.4 Mm3), post-dam incision reduced to

0.9 cm/yr. Incision since mining ceased is estimated to be on average 0.2 cm/yr. Analysis of bed elevation before and after large floods shows that the bed underwent global incision equivalent to a mean rate of approximately 3 cm/yr, suggesting that the relative impact of large hydrological events on the rate of change of the bed has the potential to be very large. Much of the incision is associated with the flushing of fines stored upstream of dams. A comparison of average erosion and deposition rates in the bypassed Rhone and Total Rhone highlights differences in the trajectories of these reaches following the construction of the dams with the Total Rhone characterised by higher rates of both erosion and deposition.

A detailed reach-by-reach analysis of differences in bed elevation between the present-day channel bed and the bed at the time of dam construction highlights that the global trends are the sum of a response that is highly non-uniform amongst the reaches and between the Total Rhone (RT) and bypassed Rhone (RCC; Figure 2). Many sectors of the RT show aggradation in the downstream direction, highlighting the storage effect of dams, while many RCC reaches appear stable, most likely due to armouring. Still, several sectors show strong incision, which is likely due to one or a combination of several causes: sediment deficits behind dams, residual effects of the Casiers Girardon, and gravel extractions.

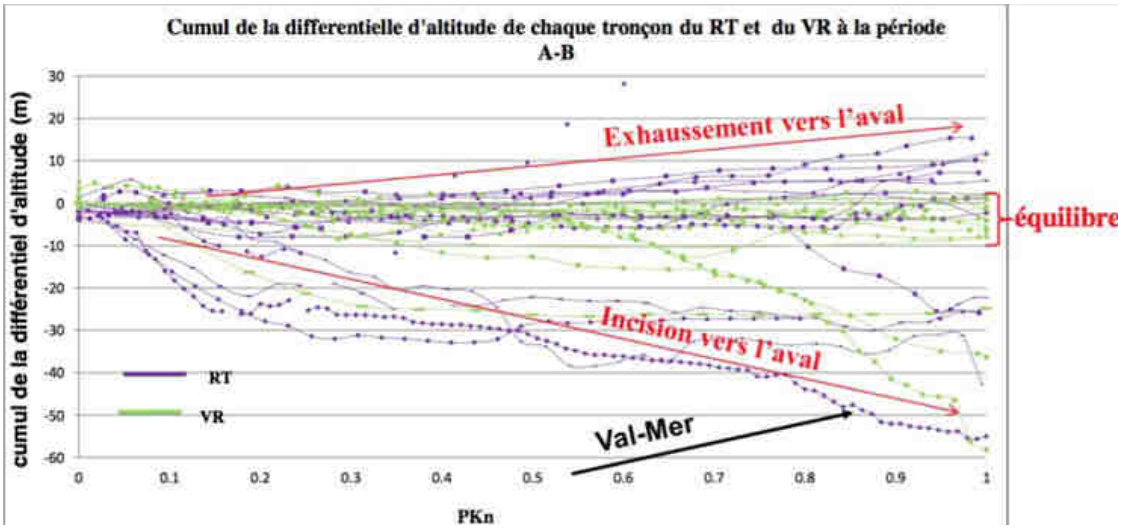

Figure 2. Bed evolution on a reach-by-reach basis following dam construction.

4 CONCLUSIONS

- The rate of bed incision was highest during the period following river training and was approximately half this rate during the period following dam construction.
- Incision rates since mining in the bed ceased are negligible
- Reaches of the Total Rhone show a marked difference in their vertical evolution following the construction of the dams
- Global trends in the Rhone's vertical evolution are the sum of a highly non-uniform response amongst reaches

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