

Limiting the development of riparian vegetation in the Isère River: A physical modelling study

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Abstract. Physical modelling experiments are conducted to investigate if a modification of the Isère River (French Alps) hydrology by changing dams management is able to foster riverbed morphodynamic and, thus limiting riparian plant development. The experimental setup is a 1:35 scale, undistorted movable bed designed to ensure the Froude number similarity and initial conditions for sediment particle motion. The physical model is 35 m long, 2.6 m wide, with a sand mixture composed of three grain size classes. Two runs with different flow and bed load conditions are simulated. Preliminary results show an intense riverbed activity when the system reaches a dynamic equilibrium state. Under these conditions, bar mobility is strong enough to limit vegetation encroachment only when water discharges are higher than the discharge of a 5-years flood during more than 10 days. These results indicate that the hydrological characteristics of the Isère River and the actual configuration of the hydropower structures could be not able to release annually the flow conditions needed to control riparian plant development.

1. Introduction

Many rivers worldwide have been strongly modified during the 19th and 20th centuries by human activities, such as channelization, sediment dredging and damming [1]. These perturbations limit or stop the lateral divagation of the riverbed and modify the channel planform, disrupt the sediment transfer and decrease the sediment supply [2], and adapt the flow regime by reducing flood intensity and increasing flow discharge during low flow periods [3]. Consequently, the riverbed is significantly altered, leading to channel incision [4], to a decrease in submersion frequency of bars (also named macroforms) and to an intense development of riparian vegetation on the bars (Fig. 1) [5]. Moreover, vegetation encroachment on macroforms reduces bed sediment mobility, promotes fine sediment deposition [6], triggers bar aggradation and elongation [7] and modifies further the river morphology [8]. Furthermore, the colonization of the active channel by plants increases the flood risk due to a reduction of the flow conveyance of the river [9], and degrades the ecological status of the river by a homogenization of the habitat diversity [10].

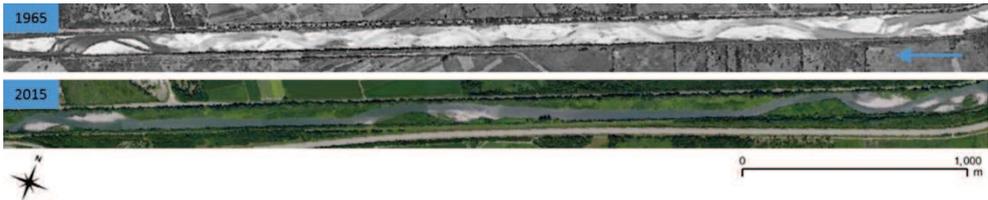


Fig. 1. Evolution of the Isère River between 1968 and 2013.

To face these issues, river managers traditionally remove mechanically the above ground part of plants. However, the efficiency of such method has not been demonstrated since in some case a propagule dispersion is promoted, leading to a speed up of vegetation development and growth [11]. Therefore, regular removing is necessary to limit plant encroachment in anthropized rivers, which constitute a non-perennial and expensive solution. Under this context, new management options have emerged such as environmental flows which correspond to artificial floods aiming at restoring mobility of bed materials and bars in order to limit vegetation encroachment within river channels, and maintain a diverse habitat [12, 13].

In this study, physical modelling experiments are conducted to investigate the influence of several flow conditions on bar mobility in a restored reach of the Isère River (French Alps). The objective is to propose a modification of the current river hydrology, mainly controlled by dams, to foster riverbed morphodynamic and, thus to limit the riparian plant development.

2. Material and Method

2.1. Study site

The study site is located in the French Alps on the Isère River, 1 km upstream of the Isère-Arc confluence. The reach studied is 1.2 km long and 100 m wide. The riverbed slope is 0.0016 m/m. The flow discharges for 2, 5 and 10-year floods are 209 m³/s, 291 m³/s and 345 m³/s, respectively. For these flow conditions, the width-to-depth ratio varies between 65 and 50. No measurement of bed load transport rates is available on this part of the Isère River. The initial channel includes long and elevated vegetated bars (Fig. 2a). Plants grow on a layer composed of a mixture of fine sands and silts. These fine sediments are deposited on a coarser substrate composed of 87 % of gravels, 12 % of sands and 1 % of cohesive particles. The D_{16} , D_{50} and D_{84} diameters of this coarse layer are 12 mm, 28 mm and 55 mm, respectively. Restoration works have been carried out during the winter 2017 consisting in removing plants and the layer of fine sediments, and reshaping 1.2-km long vegetated bars into 0.3 km-long central gravel bars (Fig. 2).

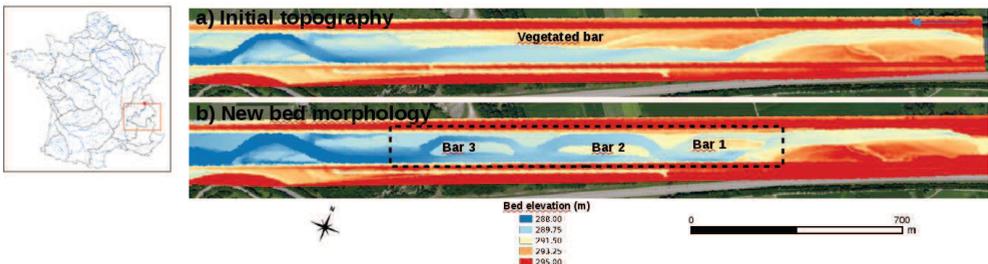


Fig. 2. Study site location and topography before (a) and after (b) restoring works. Dotted lines indicate the reach modelled in the physical model.

2.2. Physical model

The experimental setup is a 1:35 scale, undistorted movable bed designed to ensure the Froude number similarity and the initial conditions for sediment particle motion. The physical model is 35 m long, 2.6 m wide with a sand mixture composed of three grain size classes ($D_{16} = 0.65$ mm, $D_{50} = 1.4$ mm and $D_{84} = 2.3$ mm). The density of the bed material of the model is equal to 2650 kg/m^3 . The scales on the particle diameter and the non-dimensional critical shear stress are presented Table 1. A tank located downstream the model includes a sediment trap to collect exiting sediments and a weir to control the water surface elevation. Initial bed topography corresponds to the restored riverbed configuration (with central bars) and is defined from theoretical building plans provided by river managers (Fig. 2b). The real topography obtained after the field works is not used because experiments and restoring actions are performed simultaneously. For the sake of simplicity, variables and results are given at the prototype (nature) scale in the next sections.

Table 1 : Scale on diameter and non-dimensional critical shear stress.

	D_{16}	D_{50}	D_{84}
Diameter in prototype - D_p (mm)	12	28	55
Diameter in model - D_m (mm)	0.65	1.4	2.3
Scale on diameter (D_p/D_m)	18.5	20	24
Non-dimensional critical shear stress in prototype - θ_{cp}	0.055	0.055	0.055
Non-dimensional critical shear stress in model - θ_{cm}	0.042	0.036	0.033
Scale on Non-dimensional critical shear stress in model (θ_{cp}/θ_{cm})	1.31	1.52	1.68

Two runs, named EGIS1 and EGIS2, with different flow and bed load conditions are simulated (Table 2). Runs are divided in 4 phases (Fig. 3). To test different sediment supply conditions, the model is sediment-feed either with transport rates estimated from the Meyer-Peter and Müller formula [14] adapted with the Egiazaroff formulation [15] to take into account hiding/exposure effects, or with low or null bed load transport discharges. Runs start with a first phase (P1) having flow discharges varying between 150 and 350 m^3/s (Fig. 3) to observe the adjustment of bar morphology after channel impoundment. Then, in EGIS1, water discharges ranging between 200 and 350 m^3/s are simulated during 2 phases: one with a low sediment-feed (P2) and one with a sediment-feed at bed load transport capacity (Fig. 3a). Flows are maintained steady for 6 days during P2 and 15 days for P3. These 2 phases allow to study the effect of sediment supply on bar mobility. Finally, in a last phase (P4) a flow discharge of 600 m^3/s is simulated for 1 day to investigate the morphodynamic of macroforms during large floods. In EGIS2, a combination of constant flow (at 250 m^3/s) and 3 different hydrographs with daily or semi-daily water discharge variations is modelled (Fig. 3b). The hydrographs last 5 days with flow discharges ranging between 114.5 and 315 m^3/s and mean water discharges equal to 250 m^3/s for H2 and H3, and 206 m^3/s for H4. The hydrographs correspond to potential hydrological conditions that could be regularly released by an optimization of the hydropower structures management in the upstream part of the Isère River. Constant flow discharge steps (H1) are simulated for 5 to 35 days. Sediment supply is set to zero during the second phase (P2) and equal to bed load transport capacity during last phases (P3 and P4). The phase P4 finishes with a step (H5) at 350 m^3/s for 18 days. The objective of EGIS2 is to compare the effect of different hydrograph shapes on bar mobility for several sediment supply conditions and bed configurations.

The evolution of the channel topography is monitored with laser-scanning carried out with a FOCUS 3D – FARO that ensures an accuracy of the order of one millimetre on the vertical axis (Fig. 3). This task is performed with the empty model. During these steps, the sediments deposited in the downstream trap are collected, and their volume is measured to assess the average bed load transport rates exiting the model. Flow velocities are estimated from video images analysed with the Large Scale Particle Image Velocimetry (LSPIV) method.

Table 2 : Flow and sediment supply conditions during the experiments.

Run	Discharge Q_m (L/s) - model scale	Discharge Q_p (m ³ /s) - prototype scale	Sediment supply ($\times 10^{-3}$ L/s) - model scale	Sediment supply ($\times 10^3$ m ³ /s) - prototype scale	Duration (h) -model scale	Duration (j) prototype scale
EGIS1_P1	13.8 to 48.3	100 to 350	0.03 to 2.2	0.1 to 16	44	11
EGIS1_P2	27.6 to 48.3	200 to 350	0.14 to 0.75	0.9 to 5.4	96	24
EGIS1_P3	27.6 to 48.3	200 to 350	0.5 to 2.5	3.5 to 18.1	240	60
EGIS1_P4	82.8	600	7.9	56.7	4	1
EGIS2_P1	20.7 to 48.3	150 to 350	0.5	3.6	72	18
EGIS2_P2	15.8 to 43.5	114.5 to 315	0	0	20	5
EGIS2_P3	15.8 to 43.5	114.5 to 315	0.5 to 2.3	3.8 to 16.3	20	5
EGIS2_P4	15.8 to 43.5	114.5 to 315	0.5 to 2.3	3.8 to 16.3	372	93

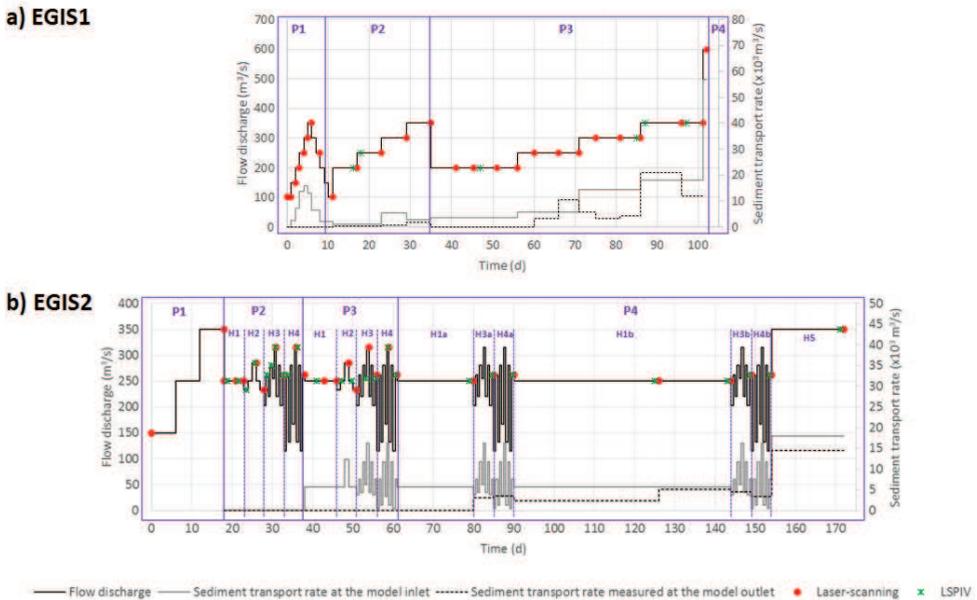


Fig. 3. Flow discharges and bed load transport rates simulated in the physical model during the runs a) EGIS1 and b) EGIS2. Laser-scanning and LSPIV measurements are indicated on the hydrographs.

3. Results

Riverbed topographies obtained during EGIS1 and EGIS2 are presented in Fig. 4. Bed evolutions are shown in Fig. 5. The areas presenting bars eroded or raised more than ± 0.3 m are presented in Fig. 6. Above this threshold, seedlings mortality rates are sufficiently increased to limit the colonization of a surface by riparian plants [16, 17].

The analysis of bed evolution indicates that bar mobility and river morphodynamic are negligible for flow discharges lower than $350 \text{ m}^3/\text{s}$ when the sediment supply is zero or low (Fig. 5b to e, l and Fig. 6). Riverbed dynamic is more intense and complex when the system is sediment-fed with high sediment transport rates (Fig. 5f to j, m to t and Fig. 6). Therefore, bar mobility is partly conditioned by the sediment supply magnitude in the study reach.

Morphodynamic of the restored bed configuration is first characterized by large deposits in the channels and an erosion of the upstream part of bars for the phases 1 (Fig. 5a and k). This bed evolution corresponds to an adaptation of the bar geometry toward a more hydrodynamic/steady state. Then, phases with a high sediment supply show mainly deposition processes due to the filling of one of the two thalwegs surrounding central bars thanks to initiation and migration of high and long bedload sheets (Fig. 5f, g and m to p). An elongation and a widening of the bars is observed simultaneously (Fig. 4d and i). Mobility of initial restored bars is limited and probably not sufficient to prevent plant colonization. This sedimentation step has a duration between 41 and 52 days. The deposit phase ends when the system reaches a dynamic equilibrium state characterised by a balance between bed load transport rates at the inlet and the outlet of the model. The dynamic equilibrium state is attained during the step at $250 \text{ m}^3/\text{s}$ of EGIS1 P3 and the hydrograph H3a during EGIS2 P4 (Fig. 3).

For the dynamic equilibrium configuration, when water discharges are lower or equal to $250 \text{ m}^3/\text{s}$, macroforms continue to growth even though a bed dynamic is achieved with local areas of erosion and deposition (Fig. 5q, r and s). Bars wavelength become longer, with a higher amplitude (Fig. 4d and j,) presenting a weak mobility, that is insufficient to limit vegetation encroachment. For flow discharges higher than $300 \text{ m}^3/\text{s}$, riverbed morphodynamic increases significantly with the appearance of large erosion and deposit mechanisms on macroforms (Fig. 5h to j and t). These strong evolutions spread over 2 % of the bar area per day of discharge (Fig. 6). After a longer period of time (10 to 15 days), a substantial modification of the bed morphology is observed (Fig. 4e, f and k). For these hydrologic conditions, bar mobility may be sufficiently high to limit plant development on $\frac{1}{4}$ of their surface. Finally, an alternate bars system is formed with an upstream large macroform close to the right bank and a second downstream one near the opposite bank (Fig. 4f and k). The wavelength of bars is of the same order of magnitude than those estimated theoretically [18] and measured on historical aerial photos on the Isère River [18].

The erosion and deposition processes recorded during hydrographs follow similar trends in terms of location and magnitude (Fig. 5m to p, r and s). Morphological evolutions are too small to distinguish clearly the hydrograph which triggers the most intense dynamic. This behaviour is due to the flow discharges modelled during the hydrographs (mainly lower than $300 \text{ m}^3/\text{s}$) and their short duration. Furthermore, with the tested hydrographs only 4.5 % of the total bar area is impacted by strong sedimentary processes (Fig. 6). Thereby, the environmental flows that can be potentially released in the Isère River seems to not be able to limit significantly the bed colonization by riparian plants.

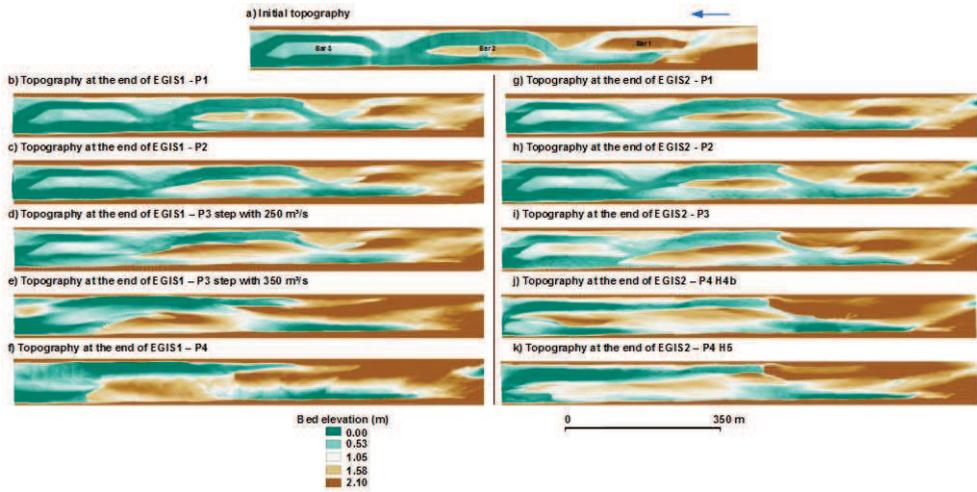


Fig. 4. a) Initial riverbed topography, b) to f) bed topographies obtained during EGIS1, g) to k) bed topographies obtained during EGIS2.

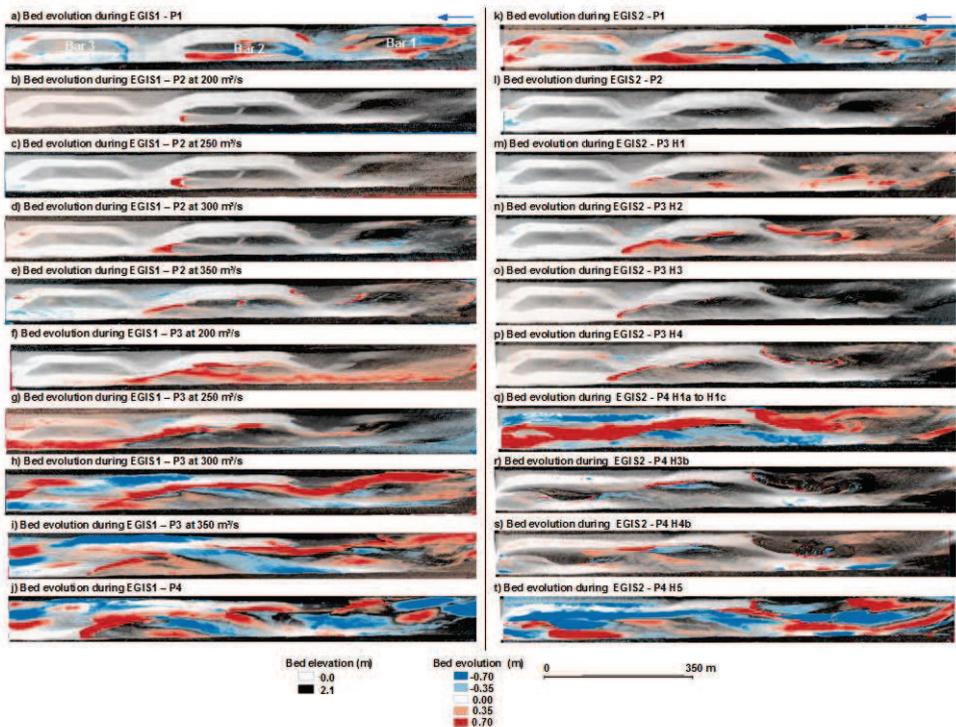


Fig. 5. Bed evolution during the two runs: a) to j) for EGIS1 and k) to t) for EGIS2.

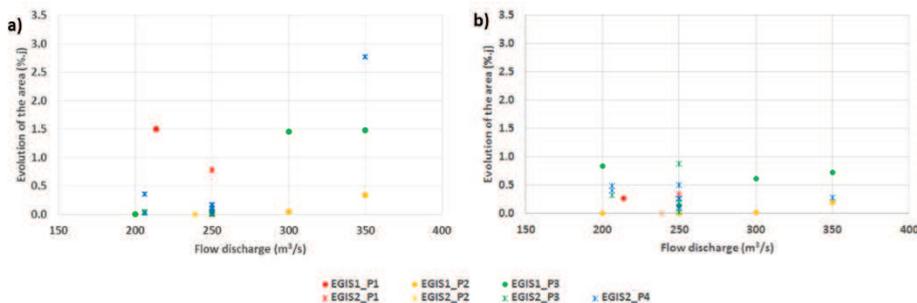


Fig. 6. Area of the bars a) eroded more than 0.3 m, b) raised more than 0.3 m.

4. Conclusion

Physical modelling experiments are conducted to investigate bars mobility in a restored reach of the Isère River (French Alps). The objective is to propose a modification of the current river hydrology, mainly controlled by dams, to foster riverbed morphodynamic and, thus limiting riparian plant development.

The experimental setup is a 1:35 scale, undistorted movable bed designed to ensure the similarity of Froude number and initial conditions for sediment particle motion. The physical model is 35 m long, 2.6 m wide with a sand mixture composed of three grain size classes. Two runs with different flow and bed load conditions are simulated.

Preliminary results show that bed evolution magnitude is partly controlled by rates of sediment-feed. A high sediment supply triggers a more intense and complex channel dynamic. Riverbed morphodynamic becomes significant once the system reaches a dynamic equilibrium state. In this configuration, bar mobility is sufficient to limit vegetation encroachment only when water discharges are higher than the discharge of a 5-years flood during last more than 10 days.

The results indicate that the natural hydrologic context of the Isère River and the technical capacities of the hydropower structures could be not able to provide annually flow conditions needed to limit riparian plant development. Other complementary practises may be considered as vegetation removing by goats or sheeps or by devices such as deflectors, to locally enhance bar mobility. Extrapolation of our observations to the prototype is underway.

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