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Dam reservoir backwater alters hydrodynamics of a mountain river

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ABSTRACT

2D numerical modelling indicated that backwater fluctuations of the Czorsztyn Reservoir increase floodwater depth (up to 255%) and decrease flow velocity (up to 72%) and bed shear stress (up to 80%) in the backwater zone of the mountainous Dunajec River. They also trigger further morphological changes, which additionally modify the initial river hydrodynamics, even in the period when backwater fluctuations do not occur.

1. Introduction and study area

Natural flow regime is a key factor shaping abiotic and biotic components of river ecosystems and human life in riverine landscapes. Large dam reservoirs profoundly disturb this regime affecting river functioning downstream and upstream from them. Backwater fluctuation-induced disturbance of river hydrodynamics may be particularly important for the functioning of mountain rivers, because it may induce intensive in-channel sedimentation and related morphological changes which may additionally influence river hydrodynamics, flood hazard and river ecology, even in the periods when backwater fluctuations do not occur (Liro, 2019). This hypothesis was positively verified by a previous remote sensing analysis of the Dunajec River in the backwater fluctuation zone of the Czorsztyn Reservoir (Liro 2016), but it has not been tested quantitatively up to now. In this work we aim to quantify the scale and spatial extent of changes in water depth, flow velocity and bed shear stress created by backwater fluctuation during low (1-year), medium (2-year) and high (20-year) floods, and to quantify the effects of channel widening and the formation of large bars documented in the backwater zone (Liro, 2016) on the river hydrodynamics, even in the periods when backwater fluctuations do not occur.

2. Methods

In order to analyse backwater fluctuation effects on river hydrodynamics, we defined 6 scenarios, with three steady inlet discharges with recurrence intervals of 1 year (43 $m^3 s^{-1}$), 2 years (205 $m^3 s^{-1}$) and 20 years (604 $m^3 s^{-1}$) and two reservoir levels (527.5 m a.s.l. – no backwater effect within the study reach, and 532.35 m a.s.l. – maximal backwater effect) as boundary conditions. We used two-dimensional numerical model *Iber* (Bladé et al., 2014) to compute water depth, flow velocity, water elevation and shear stress for each scenario. Output raster files for each parameter were then analysed with GIS software using automatic measurements along 90 cross-sections covering the whole study reach. We implemented a homogeneity test to determine a longitudinal extent of disturbances in the hydraulics of flood flows caused by backwater fluctuations of the dam reservoir.

3. Results

The analysis indicated that backwater fluctuations of the dam reservoir influence hydrodynamics of the studied river during 19% of the time (75 days/year) by increasing floodwater depth by 83–255% (Fig. 1) and decreasing flow velocity by 41–72% and bed shear stress by 68–80%. During the remaining 81% of the time, backwater fluctuation-induced changes in river morphology decrease flow velocity by 34–52% and bed shear stress by 13% and increase overbank flow depth by 32%. These changes reach 1.3-1.35 km upstream from the reservoir for water depth increase, and 2.05-2.15 km and 1.4-1.45 km upstream from the reservoir for the decrease in flow velocity and bed shear stress, respectively.

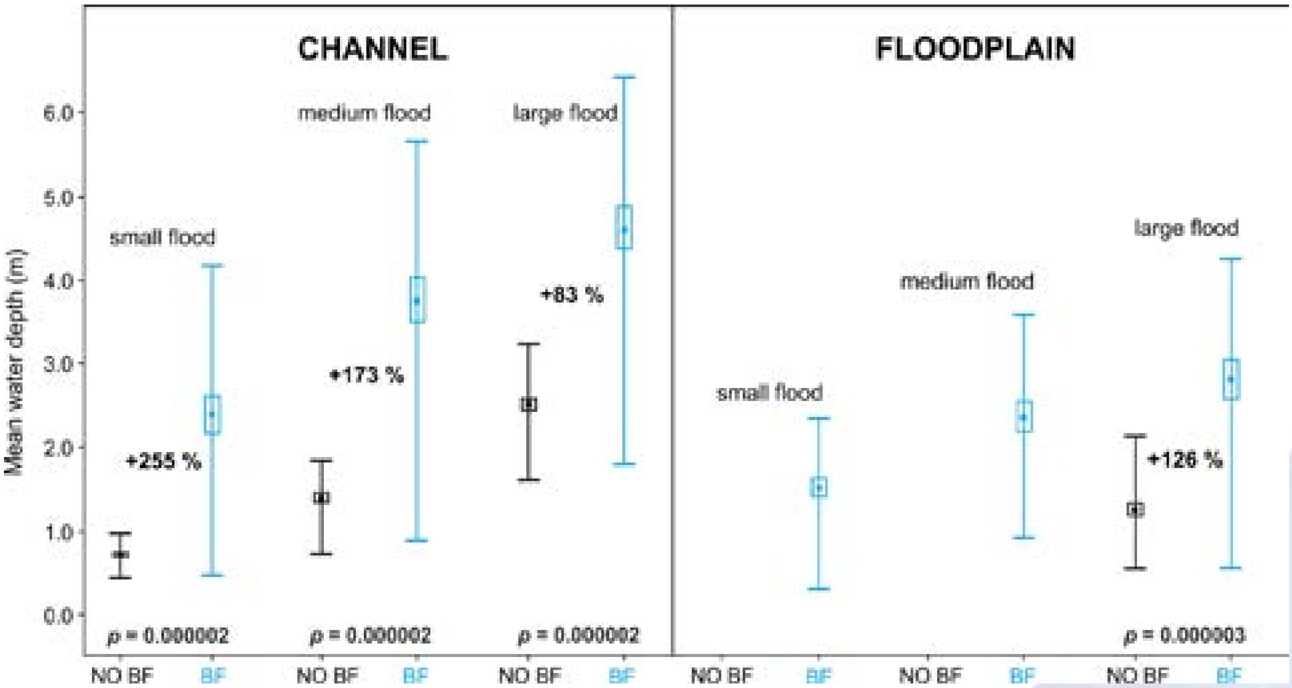

Fig. 1. Mean water depth measured in the channel and on the floodplain of the Dunajec River within the backwater fluctuation zone of the Czorsztyn Reservoir during floods of different magnitude (large flood: Q = 604 $m^3 s^{-1}$, RI = 20 years; medium flood: Q = 205 $m^3 s^{-1}$, RI = 2 years; small flood: 43 $m^3 s^{-1}$, RI = 1 year) with (BF) and without backwater inundation (NO BF). Statistically significant *p*-values and percentage changes of the means are indicated in bold.

4. Conclusions

This study supplements existing knowledge on dam's effects on river flow, demonstrating that a dam reservoir influences river hydrodynamics not only in its downstream sections but also in the upstream section affected by backwater fluctuations.

The study demonstrates that in the case of a mountain river with coarse bed sediments, reservoir backwater triggers feedbacks between flow hydraulics and river morphology, which operate even in the periods when backwater fluctuations do not occur. It also confirms that the operation of this feedback may be detected via remote sensing analysis.

Hydromorphological changes initiated by backwater seem to have positive ecological impacts on mountain rivers, especially in the case of previously channelized rivers affected by sediment deficit and channel incision, such as the studied Dunajec River.

We estimated that ca. 14% of dams in the world were built on mountain rivers (>1000 m a.s.l.) and findings from this study may be useful for their management.

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