Trajectorial BACI approach to address the complexity of river response to run-of-the-river dam operation in a multi-driver context (Upper Garonne)

Utilisation d'une approche BACI trajectoriel en vue d'évaluer les effets d'un barrage au fil de l'eau dans un contexte de pressions multiples (Garonne amont)

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RÉSUMÉ

Nous évaluons les changements morphologiques associés au barrage du Plan d'Arem (1970), un ouvrage au fil de l'eau sur la Garonne amont, au moyen dune approche Before-After-Control-Impact (Marteau et al., 2020), un cadre spatio-temporel et hypothetico-déductif visant à distinguer l'effet du barrage de ceux des autres facteurs. Les potentiels réductions des flux liquides (Q_L) et solides (Q_S) liées à ces pressions ont été évaluées, en parallèle d'une caractérisation des changements morphologiques en plan (1942 – 2019), verticaux (1922 – 2014), et la granulométrie du chenal. Les résultats montrent que la rivière était en cours d'ajustement au début de la période d'étude suite à la réduction hydrologique de la fin du PAG et à la reforestation du bassin amont, avec rétraction du chenal actif de 0,6 à 1,2 % an^{-1} sur l'ensemble du linéaire étudié. L'aval du Plan d'Arem a complété ses ajustements dans les années 1960, alors que la rétraction s'est poursuivie sur l'amont sous l'effet des barrages amont et la poursuite de la reforestation. Les effets liés au Plan d'Arem ont commencé environ 15 ans après sa construction, et ont consistés en une rétraction de la largeur active de 0,9 % an^{-1} jusque dans les années 2010. La crue centenale de juin 2013 s'est traduite par un ré-élargissement du chenal actif sur l'ensemble des secteurs. Les actions de transparences entreprises depuis 2014 se révèlent efficaces pour la restauration de la continuité sédimentaire au travers de l'ouvrage et la préservation des débits en crue, se traduisant par un maintien de la morphologie post-crue à l'aval du Plan d'Arem.

ABSTRACT

We evaluate morphological changes related to the Plan d'Arem dam (1970), a run-of-the-river (RoR) dam located on the Upper Garonne (central Pyrenees) using a Before-After-Control-Impact approach, a space-time framework that allowed the stating of four hypotheses distinguishing the effects of the considered dam from other pressures. We first examined the potential reduction to the flow regime (QL) and bedload transport (QS) from these pressures, then assessed planimetric changes (1942–2019), vertical evolution (1922–2014), and sediment size within the channel. The results show the river completed adjustments related to post-LIA climate change and catchment afforestation at the beginning of the study period, with channel narrowing affecting the whole study reach and ranging from 0.6% to 1.2% yr^{-1}. Downstream the Plan d'Arem, morphological adjustments completed during 1960's, whereas channel narrowing is still observed on the upstream reach after this date under the effects of upstream dams and catchment afforestation. The effects of the Plan d'Arem started a decade after its construction, with channel narrowing at a rate of 0.9% yr^{-1} until the 2010's. The exceptional flood of June 2013 resulted in channel widening over the entire study reach. Flushing actions since 2014 allowed to maintain the post-flood morphology downstream the Plan d'Arem dam.

KEYWORDS

BACI approach; By-passed reach; Channel adjustments; Dam management; RoR dam; Upper Garonne River

1 METHODOLOGICAL FRAMEWORK FOR WORKING HYPOTHESIS FORMULATION (FIG. 1)

- *Before - Control (H1)* : In response to climate change, rural depopulation, grazing area abandonment, and afforestation, the catchment experienced a reduction-effect on sediment supply (***Q_S1***). The Garonne probably responded with a decrease in channel width and bed incision, and all reaches would have been affected (**UP1, BPR1, DO1**).
- *Before – Impact (H2)* : Construction of the upstream chain of dams may have resulted in a reduction in peak flows (***Q_L1***), and especially a disruption to sediment transfer (***Q_S2***). Bypassing on the rest of the upstream reach may have affected the hydrology, which would also result in channel width reduction (**UP2**) by reducing peak and base flows (***Q_L1***).
- *After – Impact (H3)* : Because of its position on the main course of the Garonne, the Plan d'Arem dam has disrupted river sediment continuity (***Q_S3***) and reduced the magnitude of peak flows (***Q_L2***). The By-Passed Reach experienced channel width reduction (**BPR3**) after the dam construction. The downstream reach (**DO2**) may not see the same pattern of channel width reduction in response to the restoration of transport capacity as soon as the operated discharge is back-delivered to the main stem of the river.
- *After – Impact (H4)* : Between 2014–2020, flushing actions targeting peak flows were performed. H4 therefore states that peak-flows and sediment continuity were maintained, with no-effect on channel morphology (**BPR3** and **DO2**).

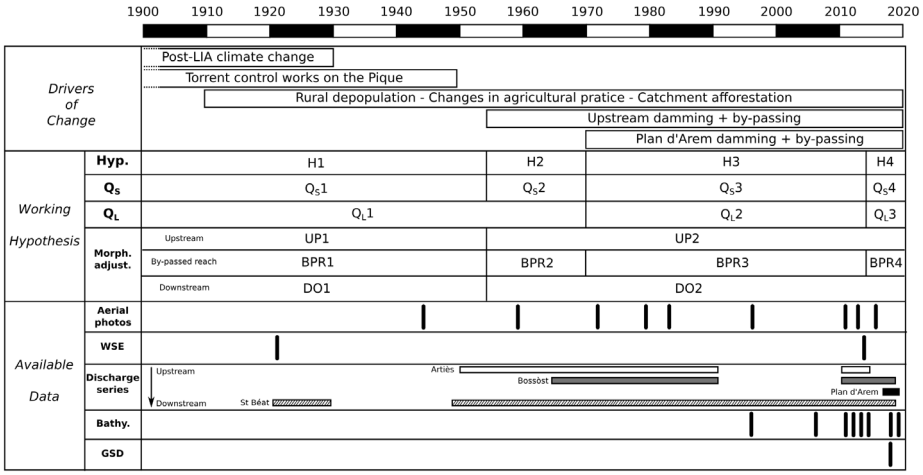

Figure 1. Chronology of drivers, expected changes in ***Q_S***, ***Q_L***, and river morphology, and available datasets (Boutault, 2020). WSE: Water surface elevation. Bathy.: Bathymetry of the Plan d'Arem lake. GSD: Grain size distribution.

2 RESULTS AND CONCLUSIONS (FIG. 2)

- Hypothesis *H1* and *H2* were related to the pre-dam period, and stated that the channel was already responding to land use changes and upstream damming. We validated those hypotheses by highlighting the important afforestation of the upstream catchment, the hydrological reduction through upstream damming and by-passing, and the channel narrowing.
- Hypothesis *H3* stated that the Plan d'Arem dam, through its sediment depletion and hydrological reduction effects, induced channel narrowing on the BPR. This hypothesis was validated, but we showed that hydrological reduction was the main driver, because channel changes did not propagate downstream of the HPP water return.
- Hypothesis *H4* stated that dam management can buffer the effect of the dam on ***Q_S*** and ***Q_L***. We

showed that drawdown flushing actions allowed the post-flood morphological activity to be maintained, whereas the upstream reach shows a new phase of channel narrowing after the catastrophic 2013 flood that completely refurbished the channel planform, especially in the upstream reaches.

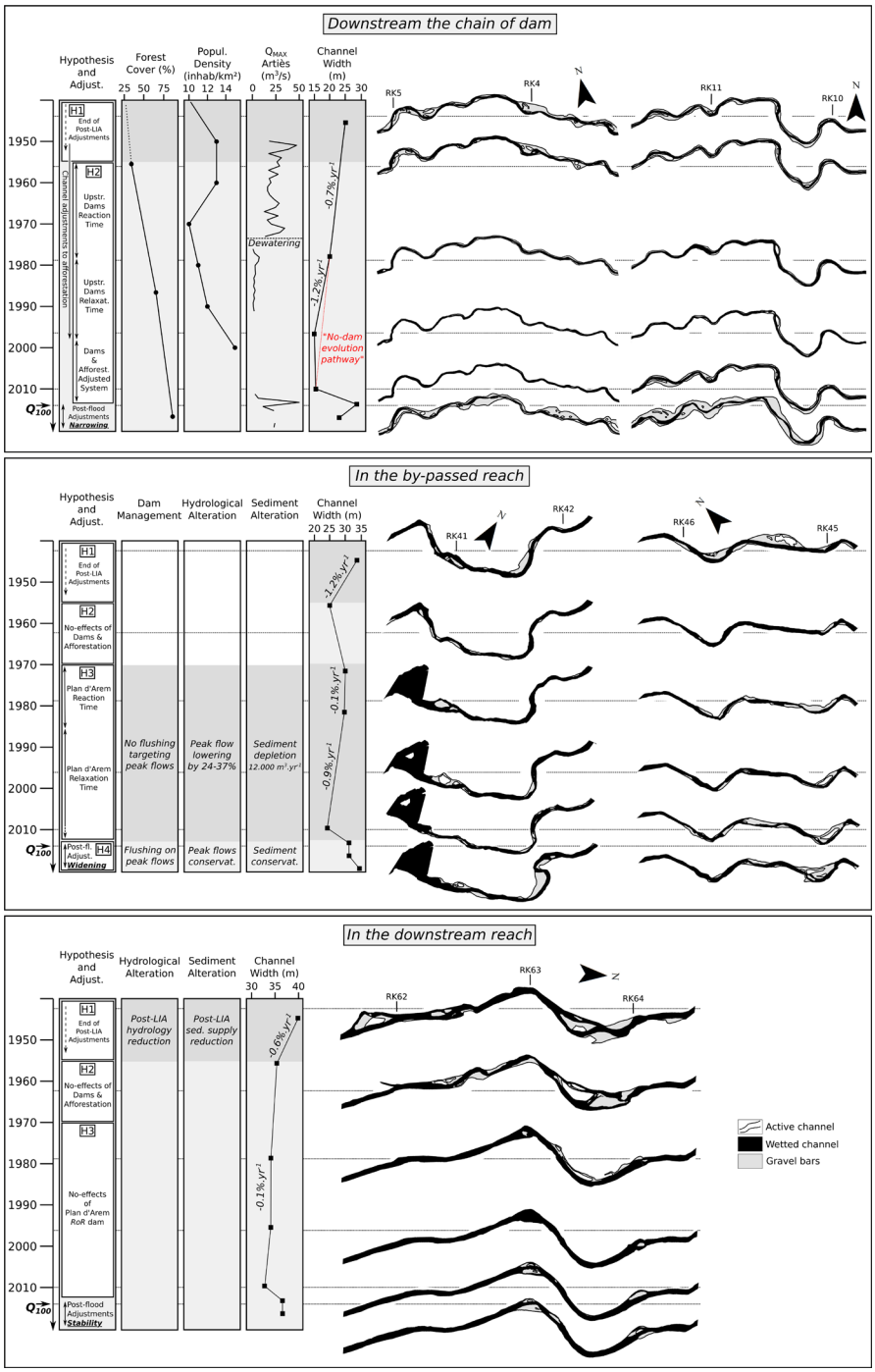

Figure 10. Synthesis of a working hypothesis and changes in drivers and associated morphological responses in upstream, by-passed, and downstream reaches. Morphological maps highlight the role of the catastrophic 2013 flood on refurbishing the channel planforms, mostly in the upstream reach.

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