Modelling Large Wood Dynamics in the Allier River
Modélisation de la dynamique des bois dans la rivière Allier

Wafae Ennouini[1], Elisabetta Persi[1], Diego Ravazzolo[1], Gabriella Petaccia[1], Stefano Sibilla[1], Borbála Hortobágyi[2], Hervé Piégay[2]

[1]Department of Civil Engineering and Architecture, University of Pavia (Italy)
[2]UMR 5600 Environnement Ville société, ENS de Lyon, CNRS, Lyon (France)

wafae.ennouini01@universitadipavia.it (corresponding author)

RÉSUMÉ
La dynamique du bois dans les rivières est étroitement liée aux processus géomorphologiques, écologiques et hydrauliques, qui influencent, et sont en retour influencés par, le transport et le dépôt du bois. Ces interactions complexes rendent souvent difficile la compréhension des effets mutuels. Un effort collaboratif est donc nécessaire, combinant données de terrain, recherches analytiques et modélisation numérique, afin de clarifier les dynamiques pertinentes. Les modèles numériques de transport du bois peuvent être particulièrement utiles pour simuler des scénarios inconnus ou futurs, à condition qu'ils reproduisent fidèlement les processus les plus significatifs. Leur calibration à partir des données de terrain disponibles est donc essentielle. Dans cette contribution, le modèle ORSA2D_WT est appliqué à un tronçon de la rivière Allier, pour lequel des données hydrologiques et topographiques sont disponibles, ainsi que des observations de terrain sur le transport et le dépôt du bois. Après une première phase de calibration du modèle hydraulique, la dynamique du bois sera modélisée pour (i) calibrer et étendre les capacités du modèle d'entraînement, avec une attention particulière au bois stable, et ensuite (ii) analyser l'effet de la morphologie fluviale sur la rétention du bois.

ABSTRACT
Wood dynamics in rivers is strongly connected to geomorphological, ecological and hydraulic processes, which are affected, and in turn affect, wood transport and deposition. Such intricate influences often prevent a clear understanding of the mutual effects. Collaborative effort is thus required, combining field data, analytical research and numerical modelling to clarify the relevant dynamics. Numerical models of wood transport may be particularly helpful in simulating unknown or future scenarios, provided that they can accurately replicate the most relevant processes. Their calibration on available RFID wood monitoring field data is thus critical. In this contribution, the model ORSA2D_WT is applied to a reach of the Allier River, for which hydrological and topographical data are available, together with field observations about wood transport and deposition. After the first phase of hydraulic model calibration, the wood dynamics will be modelled, to (i) calibrate and extend the capabilities of the entrainment model, with particular attention to stable wood, and then to (ii) analyse the effect of river morphology in influencing wood entrapment.

KEYWORDS
Wood transport dynamics, Entrainment thresholds, Numerical Modeling, Two-dimensional simulation, RFID wood monitoring.

Dynamiques des bois, Seuils de mobilité, Modélisation numérique, Simulation bidimensionnelle, Suivi des bois par RFID

INTRODUCTION

Entrainment, transport and deposition are key wood dynamics in rivers, playing a crucial role in shaping riverine systems and influencing both ecological and hydraulic processes (Collins and Montgomery, 2002; Gurnell et al., 2002). The movement of wood through river networks is mainly governed by complex interactions between the characteristics of the wood (e.g., size, density, and rootwads), flow hydraulics, and channel morphology (Mao et al., 2020). Understanding these dynamics is essential for predicting how wood behaves during flood events, which has implications for ecosystem, flood risk management, and infrastructure protection (Schmocker and Weitbrecht, 2013). The process begins with the recruitment of wood and continues with its entrainment (Braudrick and Grant, 2000), i.e., in-channel wood mobilization by hydrodynamic forces that overcome resisting forces as those due to, for example, to sediment burial, or channel morphology (Wohl and Scott 2016). Once entrained, wood is transported, a phase influenced by flow conditions, interactions with channel boundaries, the presence of vegetation, and collisions with other pieces of wood or structures. Eventually, wood may undergo deposition, becoming stationary due to shifts in flow conditions or interactions with channel characteristics (Ruiz-Villanueva et al., 2016a).

However, a key question in understanding wood dynamics is whether wood is mobilized at all. The threshold conditions for entrainment, influenced by the interactions between flow regime, wood properties, and river morphology, are critical to determining wood fluxes (i.e., number of wood elements transported per unit time). An accurate quantification of wood fluxes is crucial for understanding fluvial processes and recommending river and flood management practices. To this point, numerical models are becoming important in advancing the understanding of wood dynamics. In fact, they allow the simulation of wood entrainment, transport, and deposition under varying flow conditions, providing insights into processes that are often challenging to observe directly. In addition, these models can predict individual log behaviour or simulate the movement of bulk wood volumes, addressing both deterministic and stochastic aspects of wood transport. However, the development of reliable models requires rigorous calibration with field data to ensure accuracy and applicability to real-world scenarios (Ruiz-Villanueva et al., 2016b). Field measurements, including log dimensions, density, and hydrodynamic conditions, are critical for validating hydraulic components of these models. Moreover, integrating field surveys of in-channel wood provides a basis for assessing whether the numerical model aligns with observed conditions, whether the in-channel wood has moved or not. This coupling of hydraulic calibration with wood surveys helps in evaluating the model’s ability to predict wood movement and deposition accurately (Ennouini et al., submitted).

This research focuses on modelling wood dynamics in rivers, with an emphasis on the processes of entrainment, transport, deposition and the quantification of wood fluxes. At the current stage, the hydraulic components of the model are being calibrated with field data. The next phase will involve integrating this hydraulic information with wood transport to assess whether the model can accurately replicate observed patterns of wood mobility. In particular, the key aspect of the research is to understand which characteristics of logs or channel geometry, if any, have the greatest influence on the non-mobility or entrapment of wood. By advancing the understanding and modelling of wood dynamics, this work aims to improve flood risk management strategies while preserving the ecological benefits of wood in river systems.

1 MATERIALS AND METHODS

1.1 Case Study description

The Allier River, a major tributary of the Loire River in central France, is one of the last free-flowing rivers in Europe. Spanning 421 km, it is characterized by its meandering dynamics, braided channels, active floodplains, and dynamic sediment and wood transport.

The overall Field study focuses on a 32 km reach downstream of “Pont ferroviaire de Contigny,” intensively monitored since 2020. Annual field campaigns have tracked large wood (LW) dynamics using RFID-tagged logs to document movement, deposition patterns, and key characteristics such as dimensions, root or branch presence, involvement in jams, and burial status.

Within this general reach, an 8 km section downstream of Châtel-de-Neuvre was selected for detailed numerical analysis. A high-resolution Digital Terrain Model (DTM, 0.5 m) from 2023 was combined with 2020 cross-sectional surveys to create a comprehensive representation of the floodplain and riverbed. Recent tracking data from August 2024 showed that, of 29 logs tagged in 2023, 9 were transported, 4 remained stable, and 16 were lost, likely exiting the area. The numerical domain was discretized with a triangular mesh (2 m in the active channel, up to 20 m in outer areas), and Manning coefficients were assigned using land use data and grain size analysis. This setup ensures accurate hydraulic simulations for understanding LW transport dynamics.

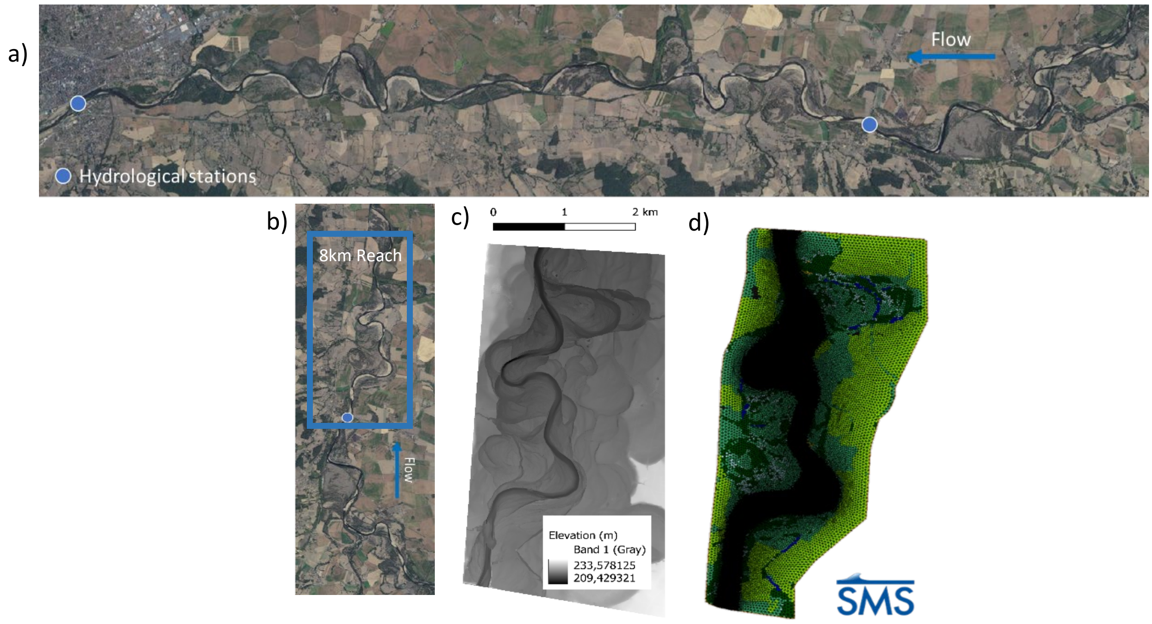

Figure 1. a) Reach of the Allier River subject to LW monitoring; b) 8 km reach for LW transport modelling; c) detail for the 8 km reach of the DTM with bathymetry and d) resulting numerical domain.

1.2 Numerical Model: ORSA2D_WT

The numerical model ORSA2D_WT couples the two-dimensional solution of the Shallow Water Equations with a dynamic Discrete Element Method for the transport of single cylinders, computing the hydrodynamic forces responsible for the transport and the planar rotation of LW. For the application to the Allier River, particular attention is given to the entrainment model, including sliding and rolling of LW, and not only floating. LW can slide, or roll, when the water depth is low, but the hydrodynamic forces are sufficient to overcome friction forces, while it can float when the hydraulic conditions allow for it, depending on wood density. The equations implemented in the model are based on Bocchiola et al. (2006) and Chen et al. (2020). Details on the transport and collision model, validated both on flume and real-scale experiments, can be found in Persi et al. (2019), Persi et al. (2020).

1.3 Preliminary Numerical Simulations

Two simulations were conducted, first simulation to calibrate the hydrodynamic model. The first was a steady-state simulation replicating hydraulic conditions on 27 August 2024, coinciding with a field survey during which water levels were measured using a sonar sensor (Deeper Sonar Pro 2.0). The discharge during this period was recorded as Q = 31 m^3 s^{-1} at the hydrological station. The second simulation modelled the unsteady conditions of the flood event from 9–20 March 2024. Terrain marks, such as mud deposits on trees indicating maximum water levels, were still visible in August 2024 along the floodplain. The upstream hydrograph for the simulation was derived from the hydrological station data with a peak discharge Q = 700 m^3 s^{-1}, while the downstream boundary condition was set using an appropriate Froude number.

2 PRELIMINARY RESULTS AND FUTURE WORK

Figure 2a, 2b,2c compares simulated and sonar water levels for two upstream profiles, showing similar trends with a maximum difference of 0.35 m. For the May 2024 flood event, the model underestimated water levels by about 0.4 m, likely due to discrepancies between the simulated (DTM 2023 and 2020 cross-sections) and actual bathymetry. However, tuning the Manning coefficients to better represent the riverbed roughness is required to improve the simulation accuracy, which is crucial for reliable LW dynamic Modeling.

Figure 2d illustrates the water depth results of the unsteady-state simulation for the March 2024 flood event, highlighting inundated areas under peak conditions.

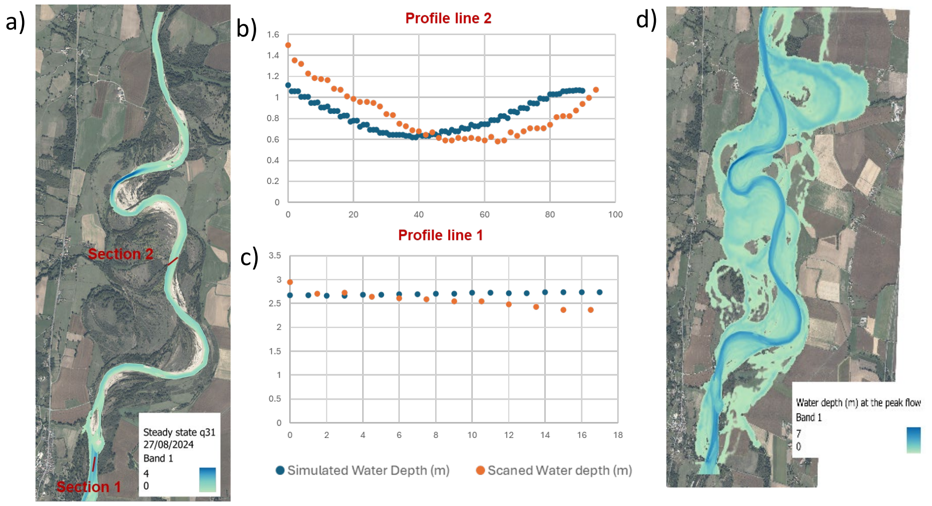

Figure 2. a) Location of the profiles and water level comparison for the b) profile 1, c) profile 2 and d) Water depth and inundation areas at the peak of the flood event March 2024.

Once the hydrodynamic model is calibrated, the next step will involve introducing LW elements into the ORSA2D_WT model. Future simulations will focus on enhancing the ORSA2D_WT model by incorporating a wider range of hydraulic scenarios and large wood characteristics. These simulations will include varying flood magnitudes (High and moderate flood events) to assess how changes in hydraulic conditions affect entrainment and transport dynamics. Additionally, simulations will explore the impact of environmental factors such as log burial, vegetation, and sediment interactions on log mobility. The model will also be tested under different log orientations and sizes to understand how these variables influence motion initiation.

The study is expected to improve the ORSA2D_WT model by refining entrainment predictions for large wood in rivers, incorporating field data and simulations to better represent real-world dynamics.

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