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Challenges in the numerical modelling of flow, sediment and wood in rivers

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INTRODUCTION

Fluid flow and sediment transport models have been extensively used during the last decades; however, modelling of wood is still quite immature. Since the works from Braudrick and Grant (2000), providing the basic framework to approach wood motion modelling, several attempts have been made to combine wood transport analysis and numerical models (Mazzorana et al., 2010; Merten et al. 2010; Hafs et al., 2014).

The **numerical model** presented by Ruiz-Villanueva et al. (2014) is a deterministic model proposed to **simulate the transport of multiple wood elements** (assuming logs as cylinders) of different sizes under complex hydraulic conditions at short timescales and **fully coupled to the hydrodynamics** (Bladé et al., 2014). Keeping the approach as simple and robust as possible, while retaining the key elements for the description of the feedbacks between wood and hydromorphodynamics, the model describes the **initial motion** (based on a **force balance**) and movement of logs including two possible transport mechanisms (i.e. floating or sliding), and simulating **interactions between logs and the channel** configuration (including **infrastructures**) and among logs themselves. Two approaches have been developed, a **kinematic** approach where logs are transported based on the flow dynamics and a **fully dynamic** where logs transport is based on the acting forces.

The **coupling of wood transport and hydrodynamics** was solved by including drag forces in the governing flow equations as an **additional shear stress** term in the 2D Saint Venant equations.

KINEMATIC OR DYNAMIC?

Kinematic approximation: Water velocity threshold is based on the balance of forces (gravity, friction, drag force) in the direction of flow acting on a piece of wood situated in a water stream:

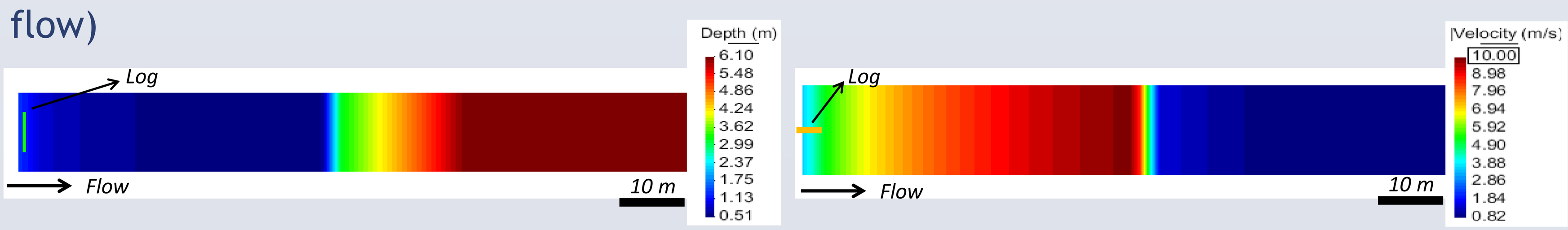
$$U_{\lim}^2=\frac{\left((g\cdot\rho_w\cdot L_w\cdot A_w)-(g\cdot\rho\cdot A_{sub}\cdot L_w)\right)\cdot(\mu_{bed}\cdot\cos\alpha-\sin\alpha)}{(0.5\cdot C_d\cdot\rho\cdot(L_w\cdot h\cdot\sin\theta+A_{sub}\cdot\cos\theta))}$$

And log velocity is: $U_{\log}=U-U_{\lim}$

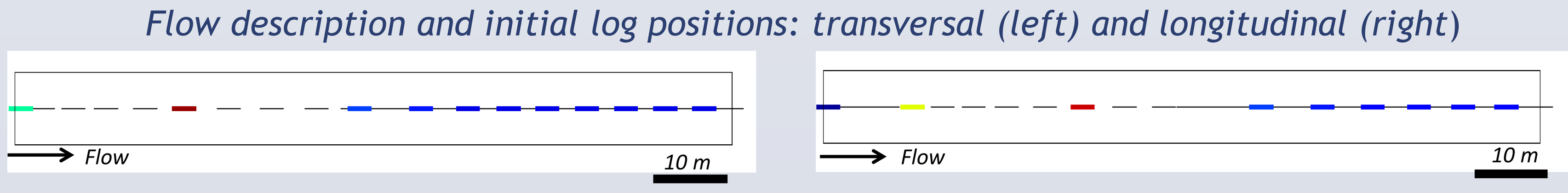
Dynamic approximation: the equations that describe the movement of a rigid solid are used:

$$U_{\log}^{n+1}=U_{\log}^{n}+\Delta t\cdot a \qquad a=\frac{F_g+F_f+F_d}{\rho_w\cdot L_w\cdot A_w} \qquad X_{\log}^{n+1}=X_{\log}^{n}+\Delta t\cdot U_{\log}^{n}+\frac{1}{2}a\cdot\Delta t^2$$

Comparison of methodologies shows small difference in log velocity for transversal logs, but differences may arise if log is oriented in the flow direction. The test case consists of a steep channel (10% slope) followed by a horizontal one (supercritical to subcritical flow)

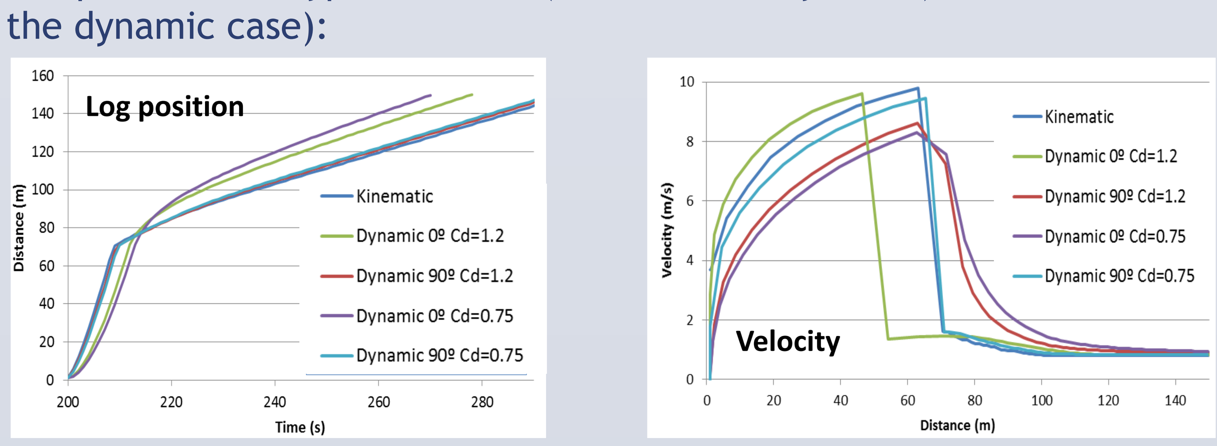


Flow description and initial log positions: transversal (left) and longitudinal (right)



Log position a t=0s,5s,10s,20s,30s,40s: Kinematic model (left), dynamic model (right)

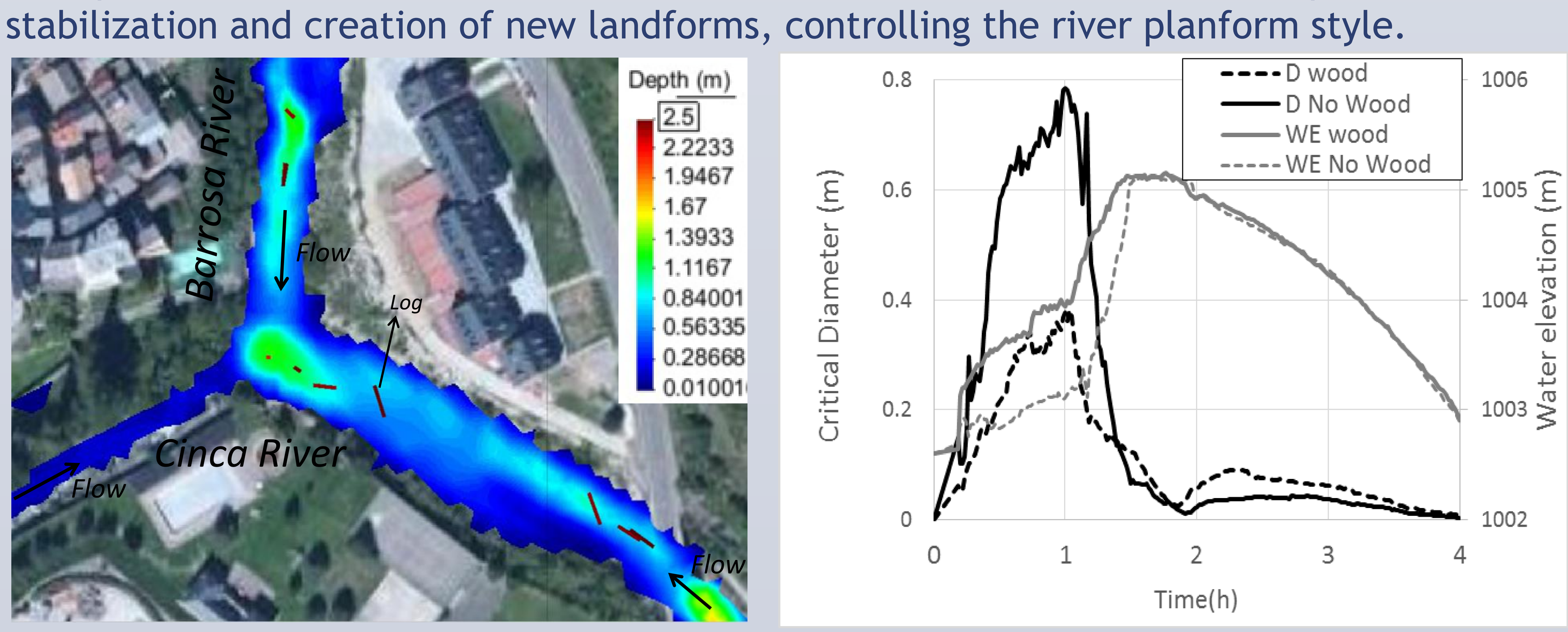
Log trajectories depend on the type of model (kinematic or dynamic) but also on the drag coefficient (in the dynamic case):



Log position and velocity at different time steps with kinematic, dynamic and different Cds values

FLOW AND WOOD INTERACTIONS

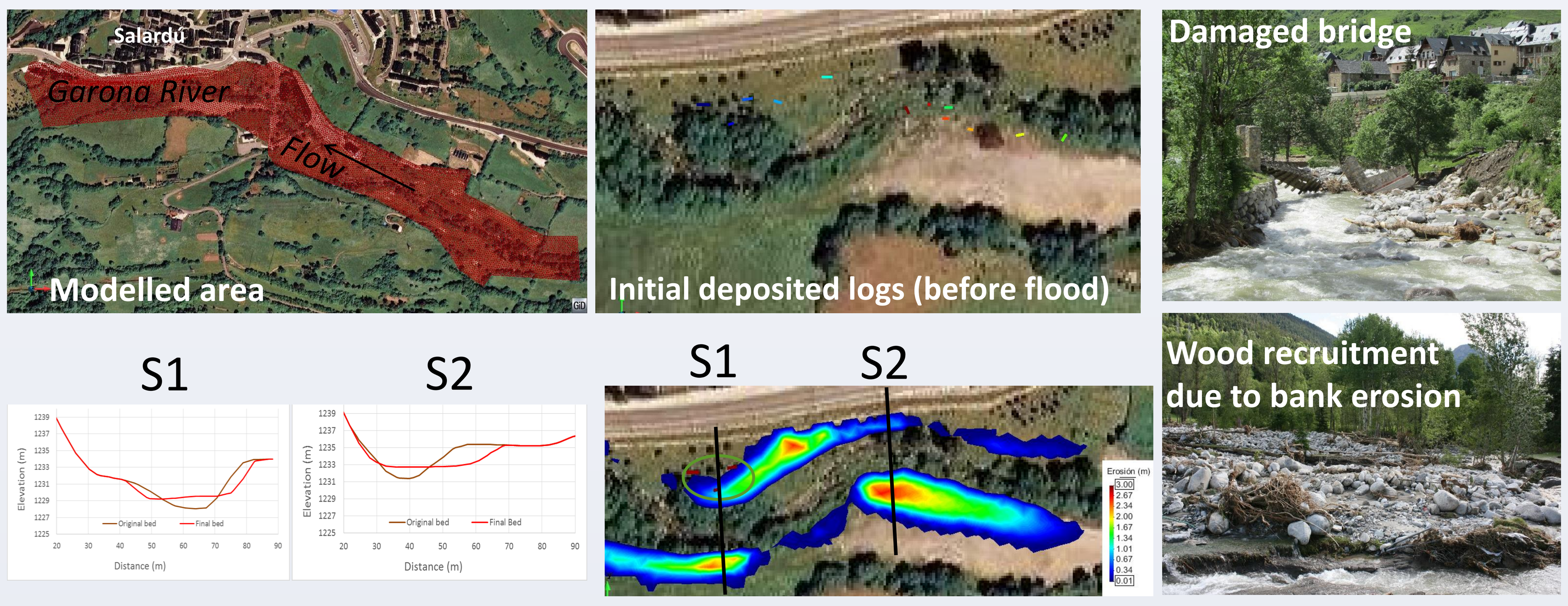
The presence of instream wood could be associated to sediment deposition, bank stabilization and creation of new landforms, controlling the river planform style.



Wood transport in a river confluence. Left: model results: water depth and transported logs. Right: water elevation and critical diameter evolution in the confluence with two different scenarios: presence of wood transport in Barrosa river or not. The effect of wood transport is observed only in the rising phase of the flood because of a delay in the hydrographs and the lack of logs in Cinca River as the study reach is immediately downstream of a dam.

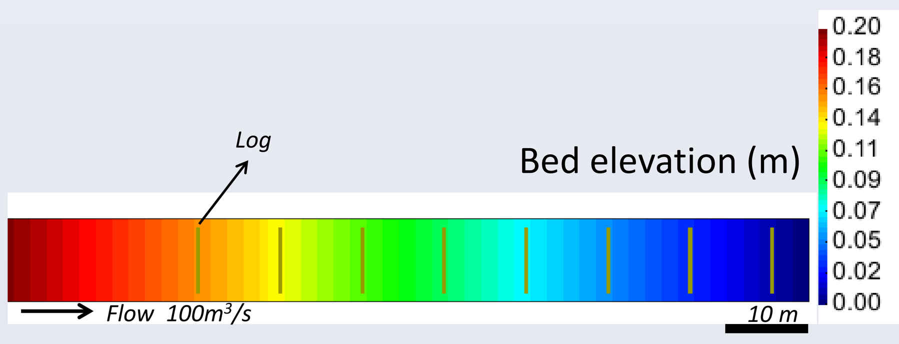
WOOD AND MORPHODYNAMICS INTERACTIONS

Severe floods in Garona River in Val d'Aran (Iberian Peninsula) in June 2013 caused by precipitation and snowmelt, with significant bank erosion and wood transport, damaged critical infrastructures. In Salardú, the maximum discharge was 60m³/s.

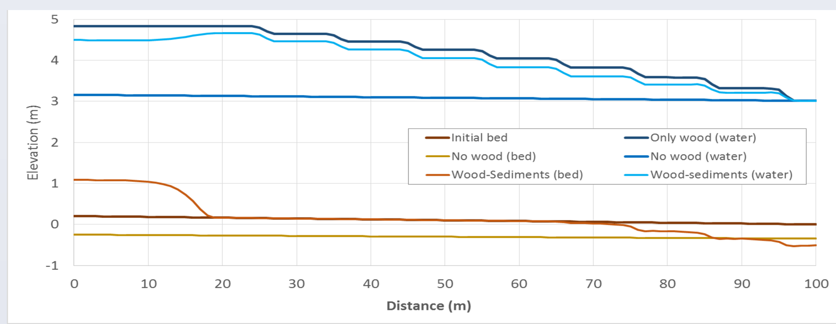


Eroded sections, model results: bank erosion and remaining logs after recruitment

The impacts of wood transport on bedload transport and morphodynamics are analyzed simulating a straight channel with erodible bed. The upstream solid discharge boundary condition is in all cases the bedload capacity without wood.



Geometry and initial log distribution

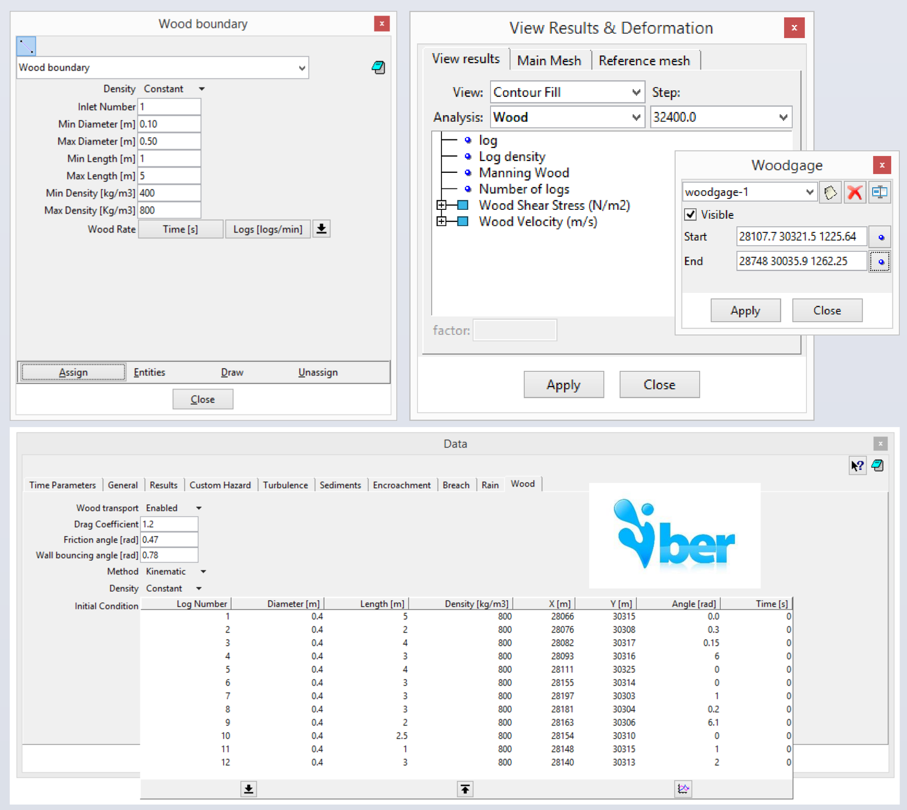


Bed and water elevation

INTERFACE OF THE WOOD MODEL

Iber Wood Interface:

- *Initial conditions for logs: dimensions, density, position, angle, time*
- *Constant/variable density*
- *Kinematic/Dynamic method selection*
- *Multiple log entities*
- *Wood properties definition by ranges*
- *Wood gates to count logs and wood weight*
- *Results visualization while calculating*
- *Results of wood density, wood velocity, wood induced shear stress, etc.*
- *Wood and hydraulics in different layers for better visualization*



CONCLUSIONS

- **Numerical modelling** allows studying flow, sediment, and wood dynamics in a **controlled environment** and opens **new possibilities** for understanding and disentangling the complex linkages in the hydromorphological evolution of the fluvial system. Numerical modelling proved powerful to **test hypothesis and run scenarios**, which are **difficult** to observe or perform **in the field**.
- Model **validation** is still crucial, and field data is required. Although, combining physical and numerical modelling, which is a common practice for other river dynamics processes, could be an efficacious alternative.
- Another remaining challenge is to reproduce more accurately the **complex shape of wood** pieces, logs with rootwads, crowns and branches.
- Besides these limitations, numerical modelling allows for the investigation of the role of different **controlling parameters**, guiding future field observations. **Models can be used to test** results of restoration projects, and help in the evaluation of the potential hazards and risks at critical sections, such as bridges.
- After decades of modelling sediment transport in rivers, **knowledge is far from completed**, hence, there is still a long way and **promising challenges** to endeavor in regards to **wood transport**, even more for combining both processes.

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