Understanding large wood deposition during floods: a modelling approach

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Abstract— **The aim of this contribution is to improve the knowledge about factors controlling large wood deposition in the Czarny Dunajec River in Poland, combining direct field observations, a 2D numerical modelling approach and GIS. Numerical modelling is a powerful tool to analyse different aspects that govern wood deposition, because models can be used to run scenarios and can be analysed fully at any space and time. We used a numerical model to simulate different flood magnitude events and to analyse wood deposition in two different river reaches. Preliminary results gave information about sites of preferential wood deposition, wood retention capacity and relationships with the river morphology. We found contrasting patterns regarding wood retention capacity in the single-thread and the multi-thread channels. We observed that the deposition of wood is not static but dynamic and significantly depends on the hydrological regime. The importance of flow depth in particular is confirmed by the fact that the elevation of deposited logs is strongly linked to the water level. Therefore, flood magnitude is the main factor controlling wood deposition.**

I. INTRODUCTION

Analysis of wood deposition in rivers has shown that complex river morphology and flow patterns play a crucial role in determining potential sites of wood retention [1]. Besides other parameters influencing wood distribution along the channels such as recruitment processes, forest stand and age and forest and river management, geomorphology is a major control on the distribution of large wood in rivers [2]. Flood frequency and magnitude are also significant factors influencing the distribution of large wood in rivers [3].

Nowadays there are still few direct observations of wood transport and deposition [4]. It is even more difficult to obtain data after several floods of different magnitude, with very few cases of data after extreme flood events [5].

Where retained, wood creates and induces a variety of landforms enhancing the complexity of the physical habitat of fluvial systems [1]. Thus we still need to better understand the spatial patterns of large wood distribution and the controls on these patterns.

The aim of this contribution is to improve the knowledge about factors controlling large wood deposition in the Czarny Dunajec River in Poland, combining direct field observations, a 2D numerical modelling approach and GIS analysis. We analysed wood deposition in two different river reaches with contrasting geomorphic configuration.

II. MATERIAL AND METHODS

A. Description of the hydrodynamic modelling of large wood

Recently, a numerical model for simulating wood transport was proposed [6]. It simulates large wood transport together with the hydrodynamics by means of a Langrangian discretization. The method couples the flow variables calculated with the hydrodynamic module to update the position and velocity of tree logs at every time step. It considers incipient wood motion, performing a balance of forces (the gravitational force acting in a downstream direction; the friction force in the direction opposite to flow; and the drag force, acting in the flow direction) acting on each single piece of wood (assuming logs as cylinders). The hydrodynamics and wood transport are coupled; thus, the hydrodynamics influence the wood transport, but the presence of wood also influences the hydrodynamics. An additional term in the 2D Saint Venant equations is included in the flow model as an additional shear stress at every finite volume, resulting from the presence of logs.

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B. Inlet flow and wood scenarios

Data from the Koniówka water-gauge station was used to characterise the inlet flow. The data was used first for the calculation of flood discharges of given probability/recurrence interval (for running different inlet discharge scenarios) and next, the available rating curve was used to calibrate roughness (Manning's n). Roughness coefficients were obtained from the delineation, both in the channel and the flooding areas, of homogeneous land units in terms of their roughness (roughness homogeneous units; RHU) and using in situ measurements of sediment size in selected transects. All RHUs delimited in the field were digitized using a GIS, and afterwards a possible range of roughness values was assigned to them applying different empirical equations (Meyer-Peter and Muller, Bray and Strickler) in the transects. Different discharge ranges were run to calibrate the obtained Manning roughness values for high and low flows, and estimate the obtained error.

Assuming that wood recruitment is only occurring upstream from the studied reaches, a number of logs per minute was defined to enter the simulation. In any case, an exact number of logs is simply an approximation. To characterise each piece of wood entering the simulation, we established ranges of maximum and minimum lengths, diameters and wood density. Stochastic variations of these parameters together with log position and angle with respect to the flow were then used.

The scenarios were designed to be physically reliable and in agreement with the characteristics of the study river, the Czarny Dunajec.

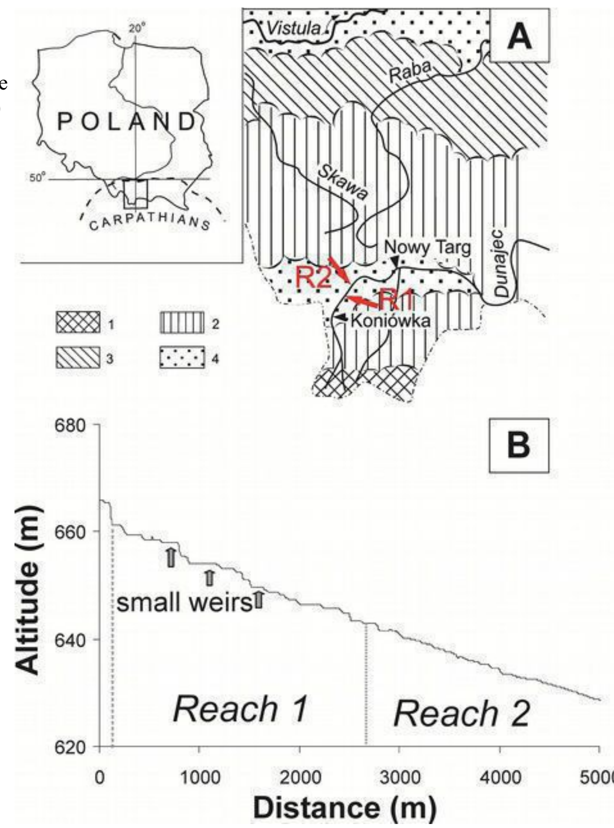
C. GIS analysis of the model results

For each model run, sites with wood deposition were projected on channel centerline, the boundary of low-flow channel and channel banks. The intersection of the projection line with the channel centerline indicated the position of each deposition site along the length of the investigated reaches. The altitude of deposition sites was read from digital elevation model (DEM) and compared with that of the intersection points of the projection lines with low-flow channel boundary, hence providing information about the relative elevation of each wood deposit above low-flow water surface in the reaches. The height of both channel banks in the channel cross-sections with wood deposits was determined and the lower one of two channel banks was considered in further analysis. Finally, the elevation of each deposition site in relation to the lower channel bank was established by comparing their altitudes read from the DEM.

III. STUDY SITE

The Czarny Dunajec River (Figure 1) drains the Inner Western Carpathians in southern Poland. It rises at about 1500 m above sea level (a.s.l.) in the high-mountain Tatra massif, with the highest peak in the catchment at 2176 m a.s.l. In the Tatra Mountains foreland, the river formed a non-cohesive alluvial plain consisting of resistant granitic and quartzitic particles transported from the Tatras and sandstone gravel delivered to the Czarny Dunajec in the upper part of the foreland reach. The studied reach falls from an altitude of 670 to 626 m and is 5 km long.

Figure (A)



Location of the study area in the Polish Carpathians and location of the Czarny Dunajec River and studied reaches (R1 and R2). Physiogeographic regions of southern Poland: 1 – high mountains; 2 – mountains of intermediate and low height; 3 – foothills; 4 – intramontane and submontane depressions; (B) Longitudinal profile of the Czarny Dunajec in the studied reaches.

Characteristic features of the hydrological regime of the river are low winter flows and floods occurring between May and August due to heavy rains, sometimes superimposed on snow-melt runoff. Mean annual discharge of the river amounts to 4.4 $m^3 s^{-1}$ at Koniówka, where the catchment area is 134 km^2 and where the model was calibrated. This gauging station is situated a few kilometres upstream of the study reaches, but catchment area and river discharges increase little between the station and these reaches.

The riparian forest is composed of alder and willow species with predominating young, shrubby forms of *Alnus incana, Salix eleagnos, S. purpurea and S. fragilis,* less frequent stands of older *A. incana* trees and occasional *S. alba* trees.

An interesting feature of the selected part of the river course is the high variability of the river width and morphology. This enabled us to distinguish two different reaches representing single-thread (R1) and multi-thread (R2) channel morphologies. The single-thread reach is partially channelized with one or both channel banks lined with gabions or rip-rap, and a few drop structures reduce the slope locally. Both studied reaches may be considered large channels with respect to in-stream wood.

The high width variation in the study reaches must be reflected in differences in the availability of large wood retention sites. As already observed [5], the largest quantities of wood (up to 33 t ha^{-1} according to some field inventories after floods) were stored in wide, multi-thread sections where transporting ability of the river was low. In contrast, very low amounts of wood were retained in narrow single-thread sections of regulated or bedrock channels where unit stream power of flood flows was higher. These observations were made after a 7-year flood in 2001 (peak discharge of 94 m^3 s^{-1}) during an intensive post-event field campaign when wood storage was analysed.

IV. PRELIMINARY RESULTS AND DISCUSSION

Preliminary results gave information about sites of preferential wood deposition, wood retention capacity and relationships with the river morphology. We observed that wood retention capacity differs significantly between both reaches (p-value = 0.001). It is higher in the multi-thread channel than in the single-thread one for all the flood scenarios and log types considered. We also identified the preferential sites for deposition (Figure 2), and combining all the scenarios will allow to estimate wood deposition probability.

For the single reach 1, and for low magnitude (high frequency) floods, the preferential sites for wood deposition are the main channel, bars and the forested areas very close to the main channel. For reach 2 and frequent floods, bars, vegetated islands and forested islands are the preferential sites for wood deposition.

We hypothesized that one of the main controls on wood deposition is the relative elevation of the depositional sites. For each reach, this relative elevation of deposition sites (above low-flow water surface and above lower channel bank) was compared between particular discharges using Kruskal-Wallis Anova. Results confirmed that the deposition elevation changes significantly with changing flood magnitude. However, no statistically significant differences in the bank height at the river cross-sections with wood deposits were found in either of the reaches. It seems important because allows to consider differences in the relative elevation of deposition sites as resulting from differences in the hydraulic characteristics of different flows rather than from different bank heights.

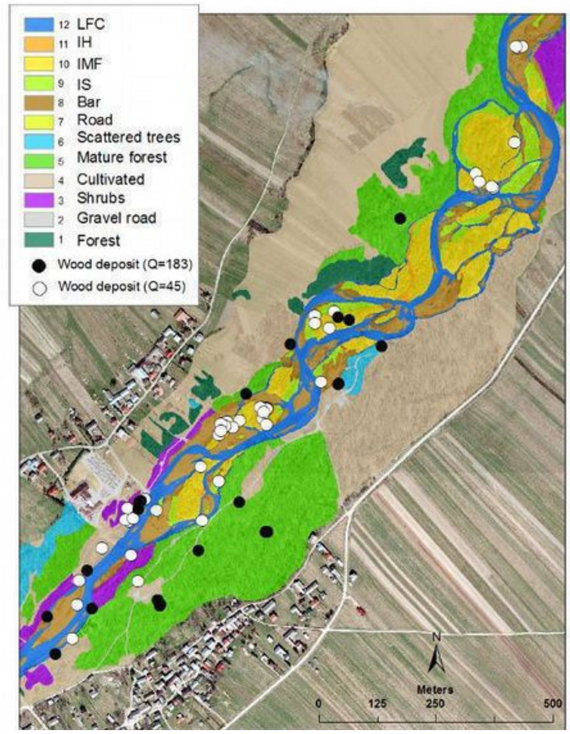


Figure 2. Example of the spatial distribution of wood deposits in the multi-thread reach for two flood scenarios considered.

The two reaches differ significantly in relative elevation of wood deposition above low-flow surface for all flood magnitudes. However, when the relative elevation of wood deposition above lower river bank is considered, significant differences were found only for the higher flood magnitudes (Figure 3).

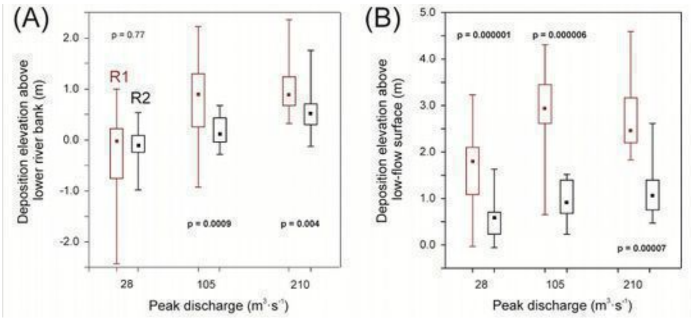


Figure 3. Comparison of the elevation of wood deposition in relation to the lower river bank (A) and the low-flow water surface (B) between reach 1 and reach 2. Statistical significance of the differences between the reaches at different peak discharges, determined by Mann-Whitney test, is indicated. p-values <0.05 are shown in bold.

Differences in the relative elevation of wood deposition between the two reaches apparently increase with increasing flood magnitude, but they become statistically significant once a certain flood magnitude is attained.

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