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Flume Investigation of Hydraulics of Nature-like Patchy Vegetation

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Abstract

Spatial distribution of riparian vegetation is a critical factor altering flow hydrodynamics and transport processes in rivers. Distribution of riparian vegetation in the form of distinct patches is typical for riverbanks and floodplains, but scarcely investigated from the viewpoint of its hydraulic impacts. The present study aims to investigate reconfiguration of the riparian vegetation patches in relation to the mean flow conditions. Experiments were conducted over a range of mean flow velocities (0.1 to 0.6 m/s) and under low relative submergences ($h/h_d \approx$ 1 and 2). The results showed a substantial increase in the patch reconfiguration and flow resistance with the increase in velocities. The extent of these phenomena depends on the patch density and shape.

1. INTRODUCTION

The significance of vegetation growing on riverbed, banks, and on floodplains is widely recognized by river managers (Jakubínský et al. 2021). The application of this vegetation to manage the quantity and quality of flow is considered as a vital tool for sustainable river management (Rowiński et al. 2018).

Riparian vegetation typically forms in patchy distributions (Bae et al. 2024), which contribute to spatial variations in hydraulic resistance. These variations are influenced by the arrangement, size, and shape of the patches (Luhar and Nepf 2013). Beyond its natural distribution, the management of vegetation in patchy patterns offers a cost-effective, sustainable, and aesthetically beneficial approach to manage the flood risk in streams and rivers (Bae et al. 2024). Therefore, accurate quantification of flow resistance in areas with patchy vegetation is essential for optimizing the conservation of riparian habitats.

The present study reports the ongoing development, as part of a larger research project focused on the investigation of influence of patchy riparian vegetation on hydraulic resistance. The patchiness was characterized using leaf area index (LAI) and blockage factors. Laboratory experiments were carried out with six different patch setups to study the relative significance of static and dynamic reconfiguration of the woody patches in explaining the hydraulic resistance.

2. FLUME EXPERIMENTS

The experiments were conducted at the Aalto Environmental Hydraulics Lab in the 16 m long flow channel having width and depth of 60 and 80 cm, respectively. A vegetated reach of about 7 m was constructed, consisting of 14 patches, each made using 22 cm tall flexible wo-ody plants. Two reach scale plant densities (LAI = leaf area/ground area ≈ 1 and 2.4) and three different patch shapes were formed to obtain the six different patch setups (L3W4, L4W4, L9W2, L9W3, L5W2, and L6W2). For each setup, the number of plants varied between the patch setups, but per patch was constant across the reach. The vegetated reach also had 35 mm tall understory grasses.

Twelve hydraulic conditions were investigated with flow rates varying between 11–140 l/s. The hydraulic conditions were varied by testing two different submergences ($h/h_d \approx 1$ and 2) and six flow velocities for each patch setup, ranging from 0.1 to 0.6 m/s. The water depths were adjusted with the weir located at the end of the channel. The flume bed was tilted to establish steady quasi-uniform flow conditions. The water depths were measured at six different locations along the reach using the high accuracy pressure sensors (0.1% of full-scale value, corresponding to 1 mm accuracy at full scale) to obtain bulk friction factors f.

The friction factors of the foliated woody patches were derived by subtracting f' of the grasses from the bulk friction ($f'' = f - f'$), assuming the linear superposition principle (Västilä and Järvelä 2014). The f' of the grasses was derived separately by running experiments with only grasses.

Patch blockage parameters were determined using the patch areas at two different planes. Planform (i.e. bird's eye view) ($A_{b,p}$) and cross-sectional (B_A) areas were measured at static and dynamic conditions through image analysis using open-source software imageJ. Here, static and dynamic refer to no-flow in dry conditions and velocity-dependent reconfigured areas, respectively.

3. RESULTS

Figure 1 shows the static and dynamic measurement of vegetation patch areas with relation to measured vegetative friction factors f''. The results are further categorized as per two investigated submergence levels. The markers for data points are varied for different patch shapes as shown in the legend. Here, the cross-section projection areas (B_A) of the vegetation patches represent the vegetation blockage within the representative cross-section but not the number of vegetation patches occupied at the reach scale. The dynamic planform projection areas ($A_{b,p}$) changed by 23% on average, as compared to static values for various patch setups. On the other hand, the cross-sectional projection areas (B_A) changed on an average by 37%, with higher changes observed at higher velocities and comparatively lower deflections at high sub-mergence levels. This can be attributed to the fact that, at $h/h_d = 1$ all the flow bypasses within the vegetation column, and there is no free flow on top of the patches.

The extent of reconfiguration reflected in the changes in $A_{b,p}$ and B_A varied across different density and shapes of patches. The longer patches with low density (L9W3 and L9W2) showed the highest decrease in areas, results in minimal resistance, allowing the flow to move freely while causing the patches to flex or bend in response. Overall, both areas explaining the blockage properties of patches are dependent on velocity-induced reconfiguration, and this "dynamic" velocity-dependency of areas explains variability of f''.

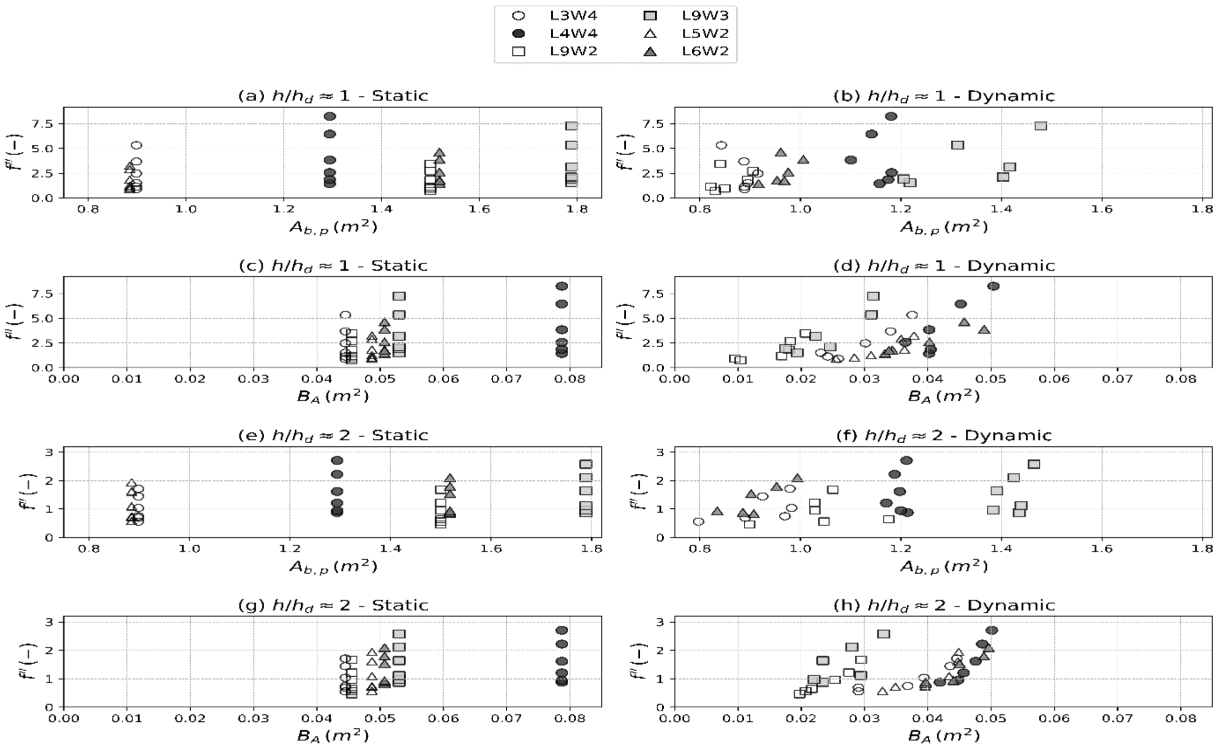

Fig. 1. Vegetated resistance *f''* caused by woody vegetation patches as a function of static and dynamic planform $A_{b,p}$ and cross-sectional B_A areas categorized by the two investigated hydraulic submergences h/h_d = 1 and 2. Patch designs for reach scale LAI 1.0: L3W4, L9W2, and L5W2. Patch designs with reach scale LAI 2.4: L4W4, L9W3, and L6W2. Name of the layouts are given with reference to number of rows and columns of plants in one patch.

4. CONCLUDING REMARKS

The observed patch reconfiguration explained through patch projection areas was found to be sensitive to the flow velocities, patch shape, while its sensitivity to submergence level is comparatively lower. These areas will further be converted to the non-dimensional analyses using blockage factors to incorporate the patch characteristics in hydraulic modelling.

Further investigations are under way, including relative analyses of static and dynamic blockage factors and patch shapes in determination of hydraulic resistance of patchy vegetation.

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