Conference Paper, Published Version

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VEGETATED FLOWS: CHARACTERIZATION OF FLOODPLAIN PLANTS IN HYDRAULIC ANALYSES

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Estimation of flow resistance due to complex natural vegetation such as foliated bushes and trees is a critical task in the analysis of floodplain hydraulics. Most of the available approaches rely on theory and experiments carried out under idealized conditions using cylindrical roughness elements, regular element spacing, etc. Natural vegetation, however, differs substantially from such artificial arrangements, and for the reliable assessment of flow resistance the consideration of various plant specific parameters is required. Although this fact has been acknowledged, there exists only a limited number of approaches in which plant specific properties are directly considered. The purpose of this work is to investigate relevant parameters and methods for the estimation of flow resistance due to foliated floodplain vegetation.

The basis for many resistance equations is the momentum balance, in which the weight component of water is balanced against the resistance from the boundary and vegetation. Consequently, the vegetative component is often quantified using the classical drag force definition of $F_D = \frac{1}{2}\rho C_D A_c u_c^2$. Some of the methods based on this approach can be considered more physically based than others depending on how the bulk drag coefficient C_D, characteristic area A_c, and approach velocity u_c are defined. The obvious problem is that none of these properties is easy to determine in case of complex-shaped flexible plants that interact with the flow (Fig. 1).

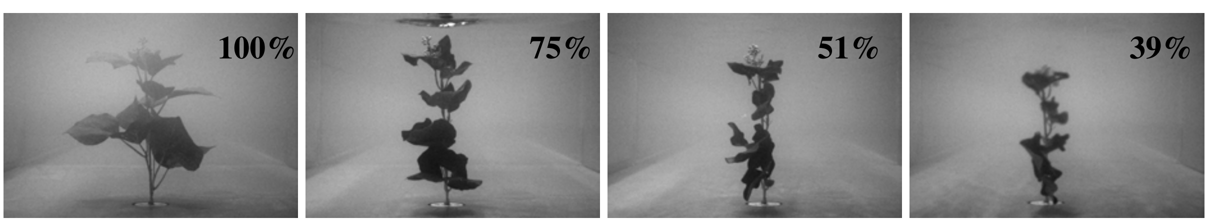

Figure 1 An artificial vegetation element normal to flow direction at velocities 0, 0.30, 0.50, and 0.89 m/s. The percentages indicate the corresponding projected area compared to the no-flow case.

The density of vegetation and its reconfiguration in a flow are critical processes in formulating a reliable resistance equation. Recent investigations have shown that the leaf area index (LAI, defined as the one-sided leaf area per unit of ground area) represents a physically based parameter which can be used to characterize the combined effect of vegetation density and foliage on flow resistance. LAI is commonly used in hydrological modeling in determining evapotranspiration, in agriculture predicting crop growth, and in forest studies for estimating primary production. A benefit of this parameter for hydraulic applications is that methods such as laser scanning together with image analysis allow for efficient estimation of LAI for large floodplain areas at a high resolution.

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For leafy woody vegetation, Järvelä (2004) suggested characterization based on three parameters: 1) leaf area index (LAI); 2) a species-specific drag coefficient $C_{D\chi}$; and 3) a vegetation parameter χ, which accounts for the effects of plant deformation in a flow and is unique for a particular species. A computational approach was formulated to determine the vegetative friction factor f'' for flexible vegetation under emergent conditions as

$$f'' = 4C_{D\chi}\text{LAI}\left(\frac{u_m}{u_\chi}\right)^{\chi} \quad (1)$$

where the mean velocity u_m is normalized with u_χ that denotes the lowest velocity used in determining χ. Using recent data from the authors' investigations, Fig. 2a shows the friction factor f'' as a function of the mean velocity for different roughness types (natural willows and artificial poplars with rigid cylinders shown for comparison) investigated in flume conditions. Fig. 2a reveals that the friction factor for the willows and poplars decreased non-linearly with increasing velocity due to the reconfiguration. The dependency from the density (LAI) was clearly observable. Fig. 2b presents the f''–u_m relationship normalized by LAI using eq. 1 with calibrated parameter values.

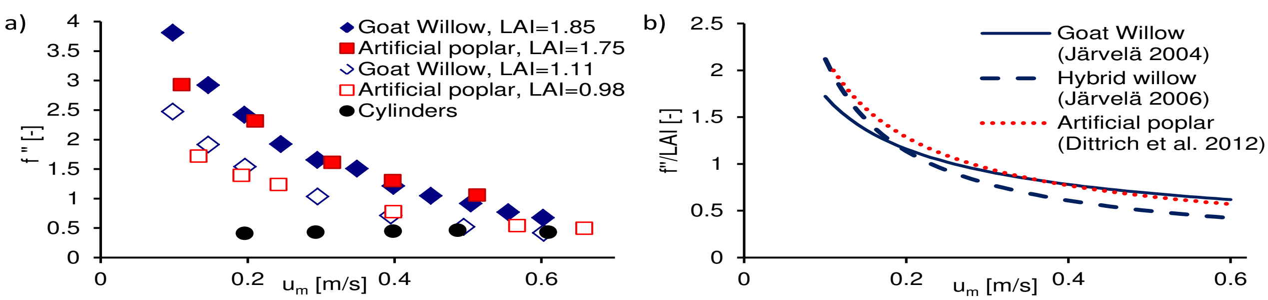

Figure 2 a) f'' vs. u_m measured for natural willows and artificial poplars; b) f''/LAI vs. u_m predicted using eq. 1 with parameter values derived from the investigations indicated in the legend.

In conclusion, the leaf area index (LAI) was found to be a suitable independent parameter to quantify the effect of vegetation density for estimating flow resistance. LAI is a widely used property that can be measured with conventional field methods as well as novel and efficient remote sensing methods such as laser scanning. It is postulated that a major advantage of eq. 1 over many other methods is its ability to estimate the flow resistance of complex vegetation using sound hydraulic principles while incorporating adjustments based on knowledge of the reconfiguration of foliage in a flow. The method is simple enough to be used as a practical tool in estimating the relationship between objectively measurable plant characteristics and flow resistance for flows through emergent vegetation.

REFERENCES

Dittrich, A., Aberle, J., Schoneboom, T. (2012). "Drag forces and flow resistance of flexible riparian vegetation." Environmental Fluid Mechanics: Memorial Colloquium on Environmental Fluid Mechanics in honour of Professor Gerhard H. Jirka, June 3 and 4, 2011, Karlsruhe, Germany.

Järvelä, J. (2004). "Determination of flow resistance caused by non-submerged woody vegetation." Int. J. River Basin Manag., 2(1), 61-70.

Järvelä, J. (2006). "Vegetative flow resistance: characterization of woody plants for modeling applications." In: R. Graham (ed), Proceedings of the World Water and Environmental Resources Congress 2006. 21-25 May 2006, Omaha, USA. 10 pp.