An idealized model study into the effects of patchy vegetation on mean river flow

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Introduction

A paradigm shift in Dutch river management has lead to a focus on restoring natural rivers as a means of flood defence. This was initiated by a combination of changing European Union environmental policy and the realization that Dutch water management was subjected to a technological lock-in (Wesselink, 2007). The changes in river management have led to larger floodplain dimensions and more frequent inundations. As a result, more research focuses on the flow processes over these floodplains, and how these influence discharge capacity. Herein the modelling of hydraulic roughness, specifically as caused by vegetation rather than bedforms, is of key importance for changing water levels due to resistance. Recent research has shown that a change of 50% in roughness can lead to a 40% change in peak water level (Ballesteros et al., 2011).

Hydraulic model calculations cannot account for roughness variations on a small spatial scale due to limitations imposed by computer power. As a result, aggregate roughness formulations are sought that incorporate these roughness variations in an aggregated roughness parameter value. Several methods, based on fitting WAQUA simulation results, have been developed for this purpose (Van Velzen and Klaassen, 1999; Van Velzen et al., 2003; Ter Haar, 2010).

Research Objective

The objective of this study is to gain a better understanding of the physical processes and the influence of roughness patch characteristics on aggregate roughness through the use of an idealized model.

Method

A new approach, based on an analytical rather than a numerical approach, was developed to investigate how spatial scales and various system parameters affect aggregate roughness as induced by vegetation patches. It is based on steady nonlinear depth-averaged shallow water equations while

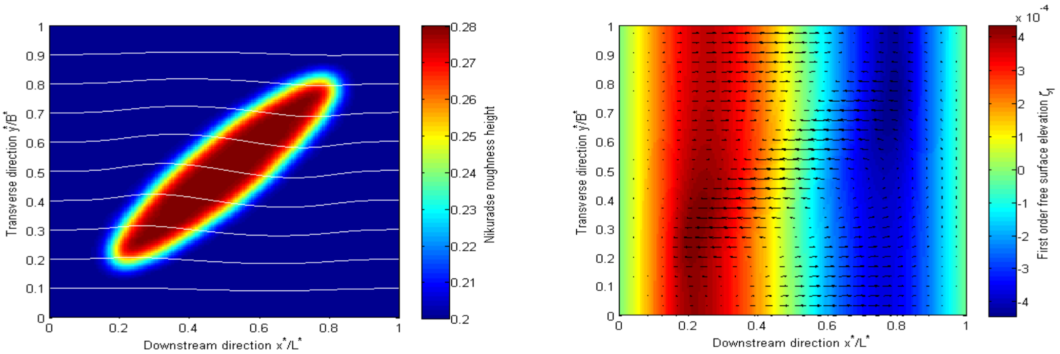

Figure 6 *(Left) shows the roughness patch at a 45° counter clockwise rotation on a floodplain along with exaggerated resulting streamlines of the flow; (right) shows the first order response to this patch. The first order response leads to a spatially invariant response in the second order.*

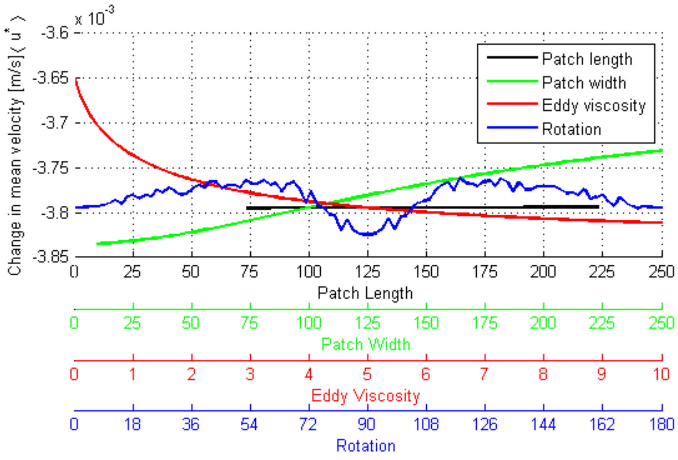

Figure 7 *Influence of patch length, channel width, eddy viscosity and counter clockwise rotation on the mean flow velocity in the channel of a roughness patch as visualized in Fig. 1.*

closing turbulence using a spatially constant horizontal eddy viscosity and allowing spatial variations in bed resistance. A weakly non-linear analysis was performed where small changes in resistance and the corresponding response in the flow were approximated up to the second order in a small parameter quantifying these variations. At second order, a spatially invariant contribution to the downstream flow velocity is obtained. Fig. 1 shows a modelled vegetation patch and the accompanying first order solution, which leads to a spatially invariant contribution in the second order. This second order spatially invariant contribution is used to calculate the aggregate resistance over a floodplain.

Results

Model simulations show that increased water depths and a larger energy slope decrease aggregate roughness the most. The influence of four remaining model input parameters can be seen in Fig. 2. Increasing the width of the channel in which the roughness patch is positioned reduces the overall velocity reduction. Increasing the eddy viscosity leads to higher energy losses to turbulent eddies reducing the mean flow velocity in the river section. Finally it was also found that, using this solution method, a skewed and nearly diagonal orientation of elliptical patches leads to a lower overall resistance than patches that are oriented perpendicular or parallel to the flow.

Conclusions

The idealized approach allows a quick assessment of the influence of various system parameters on the mean river flow velocity as caused by spatially varying resistance. It also provides insight into the physical mechanisms that lead to a difference between the aggregate resistance and the average resistance of a river section. No explanation has been found yet regarding the unexpected influence of patch orientation on aggregate resistance and this will require further investigation.

References

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