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Modelling river flow through in-stream natural vegetation for a gravel-bed river reach

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ABSTRACT

Key to a nuanced appreciation of river flood mechanisms is understanding the role of macrophytes (aquatic vegetation) as flow modifiers. Previous research has identified macrophyte-flow dynamics resulting in increased turbulence generation and reduced flow velocities, causing an increased local flow depth. Turbulence structures and heterogeneity within the velocity flow field are three dimensional (3D) phenomena, however research has often used 2D modelling approaches or has investigated macrophyte-flow dynamics within simplified laboratory conditions. As such, uncertainty exists when considering how macrophytes alter local flow dynamics in natural channels and how this may influence flood risk. This study attempts to better characterise the impact of macrophytes within a natural open-channel flow environment by using finite-element modelling techniques to simulate changes to the 3D flow field. Two methods of parameterising vegetation using the drag-force approach were explored for a single reach of a gravel-bed river. Their suitability is discussed within this paper.

Fig.1 The River Blackwater: Winter and Spring

This modelling study was carried out on a 140 m reach of the River Blackwater, near Farnborough in Hampshire, UK (Fig. 1). In this highly eutrophic river, emergent and submerged macrophytes generally grow as distinct patches within the channel. TELEMAC 3D, a finite-element modelling suite for free surface flows, was used to simulate flow using RANS equations and a k - ε turbulence closure model. Gravel-bed roughness was parameterized using a spatial-averaging method and calibrated using a bulk roughness coefficient with a drag equation. The drag term was added to the momentum equations and represented the average vertical spacing of the gravel-bed by applying head losses at four bottom layers spaced 0.01m in height apart. To determine the best approach to represent vegetation drag two methods were investigated, and both methods were calibrated through the incremental adjustment of the vegetation drag coefficient. Calibration was achieved by running the model until convergence was reached and discrepancies between the observed and modelled free surface were minimized.

A simulation of the reach with no vegetation calibrated within an acceptable range, with the gravel-bed bulk drag coefficient calibrating within the same order of magnitude as similar studies. The simulated flow profiles for streamwise velocity and turbulent kinetic energy (TKE) matched the observed profiles reasonably well. Cross-sectional flow profiles revealed rotational patterns in the secondary flow due to the meandering nature of the reach. Flow profiles for simulated streamwise velocity and TKE were approximated reasonably well for both methods with differences small between the two, however for method one turbulence notably deviated from the observed data at bank locations.

Both methods were found to perform reasonably well and produced the heterogenetic, 3D flow field that generally matched the observed data. Vegetation patches were shown to clearly alter flow conveyance, with clear influences on streamwise velocity evident within the patch and immediately downstream indicating wake production. Higher velocities occur in the vegetation-free zones at patch boundaries due to flow bifurcation. TKE is increased at patch boundaries due to greater shearing induced by the higher velocities (Fig. 2).

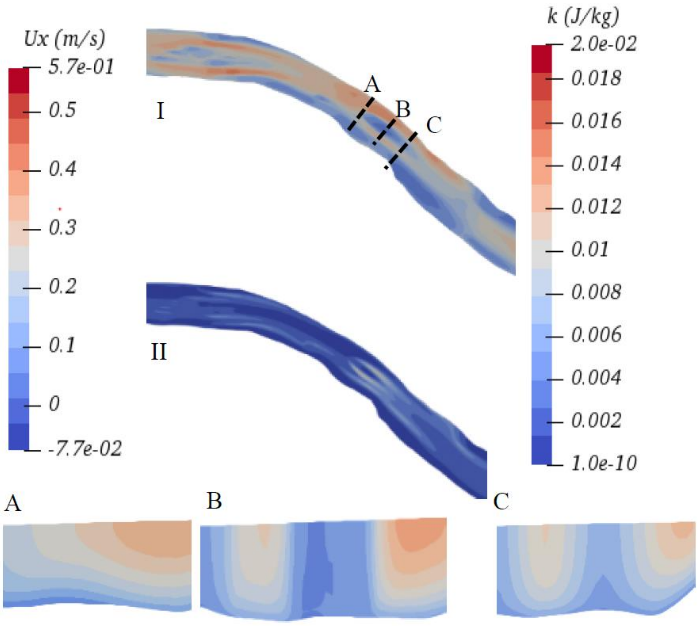

Fig. 2. Spatial distribution of streamwise velocity (I) and TKE (II) including cross-sections showing velocity changes within an individual patch.

This study provides insight into modelling work investigating the influence of river flow and patch size variation under climate change. The goal of this project is to elucidate the impact changing vegetation-flow dynamics on flood risk with which to better inform river management strategies.