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Towards 2048: the next 25 years of river studies

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On the relationship between flow-field and bank erosion in rivers: insights from large-eddy simulations

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Highlights

- A 3D large-eddy resolving hydrodynamic model setup in OpenFOAMv10
- High-resolution flow-field data for a large flume experiment with mobile bed
- Spatio-temporal evolution of bank accretion can dictate the progress of bank erosion

Overview

Bank erosion is perhaps one of the most notorious hydro-morphological processes in rivers with a complex and wide spectrum of implications – ranging from the spatio-temporal evolution of river behaviour to the impacts on riparian demography. While bank erosion is an intricate phenomenon resulting from multiple interacting process i.e. entrainment by flow and mass failure, there have been several endeavours to model the process especially in the context of river bends (Rinaldi, et al., 2008).

Studies have shown that the erosion of one river bank can be triggered by the accretion of the opposite bank (Bonilla-Porras, 2017, Vargas-Luna, et al., 2019). This bank accretion may occur naturally due to morphodynamic instability or be induced through human interventions such as the use of groynes. To gain a better understanding of the underlying processes, a computational fluid dynamics (CFD) numerical study was conducted. The study utilized data from previous experiments that were carried out in a large flume with a mobile bed, which observed bank erosion opposite to bar formation (Vargas-Luna et al., 2019). The CFD model was set up to replicate these experiments at a high-resolution (~6million cells with an average cell-size of 5mm in the region of interest), enabling a detailed investigation of the drivers behind the observed phenomenon.

The hydrodynamic model used in this study takes in boundary conditions and high-resolution bed topography data that were collected during the experiment at specific time intervals. The simulation runs until it reaches a steady state, providing the flow field for that particular bed topography configuration at that given time. This process is repeated for subsequent time instances with updated bed topography, resulting in a set of flow field data for each time instance. By correlating various flow field variables such as near-bank velocities, turbulent kinetic energy and turbulent dissipation, with the rate of bank erosion observed, we can determine the driving factors behind the erosion of the opposite bank. Additionally, the large eddy simulations allowed for the identification of coherent turbulent structures using the Q-criterion.

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Rinaldi M, Mengoni B, Luppi L, Darby SE, Mosselman E (2008) Numerical simulation of hydrodynamics and bank erosion in a river bend. Water Resources Research 44 DOI 10.1029/2008wr007008
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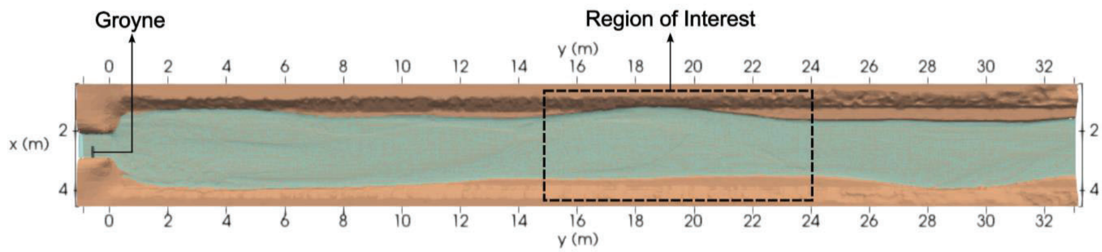

Figure 1: Model domain (shaded region indicates water)

Preliminary Results

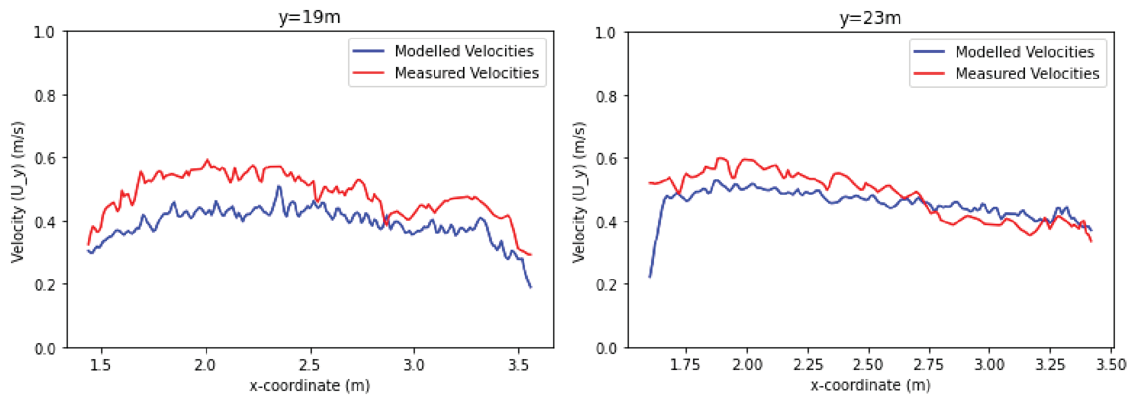

Figure 2: Modelled v/s Measured velocities

A comparison of cross-sectional velocity profiles indicates good agreement between the modelled and measured data (Vargas-Luna, et al., 2019) with the model slightly under-predicting velocities towards the upstream of the domain.

The large-eddy simulations conducted herein utilize the Wall-Adapting Local Eddy-Viscosity (WALE) sub-grid scale model. The domain is monitored so as to ensure sufficient (>80%) resolution of the turbulent kinetic energy (k).

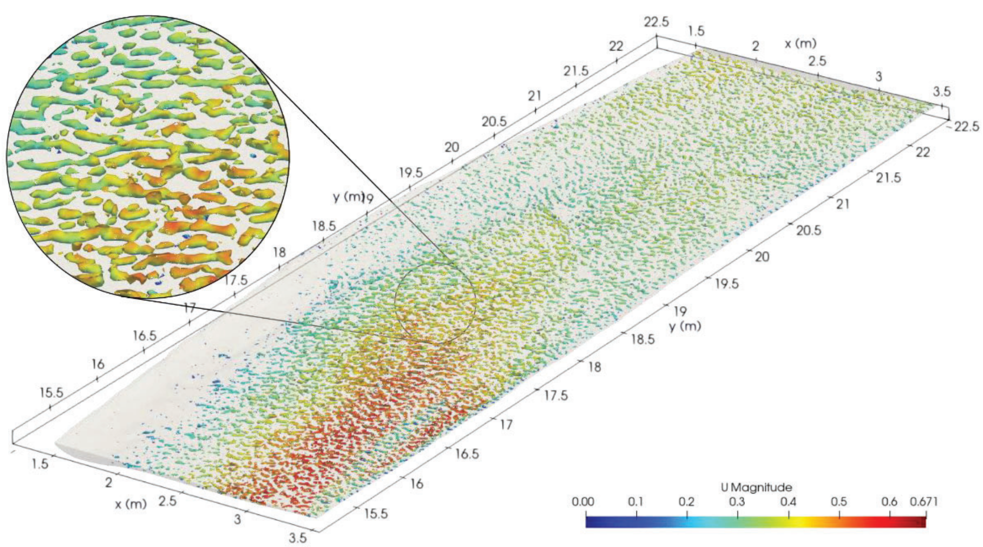

Figure 3: Contours of coherent turbulence structures identified using the Q-criterion (Coloured by velocity magnitude)

Hereafter, the rate of bank erosion is computed for all near bank points in the region of interest and Principal Component Analysis (PCA) is to be performed against a selected group of flow variables and non-dimensional quantities to identify those with highest influence on bank erosion rate.