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MODELING EXTREME FLOOD EVENTS AND ASSOCIATED PROCESSES IN RIVERS, ESTUARIES AND COASTAL ENVIRONMENTS

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In recent years there has been an increasing awareness of extreme flood events associated with climate change etc., particularly with regard to higher peak flows and their impact along steep river basins. Such hydrological features commonly occur across parts of the UK where many rivers flow in the trans-critical hydraulic regime during high flood events, and where river banks are also often protected by levees (e.g. through the city of Cardiff). The main difficulty in modeling levee breeches and trans/supercritical flows is that conventional numerical models do not accurately model steep water level gradients and artificial damping is generally introduced, either indirectly through the numerical scheme or through increased friction. To overcome this inaccuracy the Hydro-environmental Research Centre (HRC) has been involved in developing an efficient shock capturing TVD (Total Variation Diminishing) numerical model, specifically focused on accurately predicting flood elevations and inundation extent for such events, Liang *et al.* (2007a). The model has been tested against a number of idealized cases, including: dyke break experiments and the Toce river valley flooding experiments undertaken at ENEL (Milano). For both studies the model agreed well with the published experimental data. The model was then applied to the extreme flood event occurring at Boscastle, UK, in August 2004, where over 200mm of rainfall fell in 5hr - a 1 in 400 year event, causing extensive damage to property and infrastructure. The predicted water elevations along the centerline of the main channel were compared with observed data, with good agreement generally being obtained between both sets of results.

The model was then extended to predict supercritical flow interactions in flood events with buildings. Simulations were first undertaken, both with and without buildings, on an idealized floodplain and downstream of a levee breech. The test simulations were repeated with the building being replaced by high roughness values and treating the building as a porous media, with the porosity and permeability both being varied. It was found that when the Manning roughness coefficient was high, or when the permeability was low, then the downstream wake characteristics and the upstream and downstream water elevations were similar to those predicted by treating the building as a solid block, Liang *et al.* (2007b). This approach was then tested for flood inundation of part of Glasgow, where the three methods of representing buildings were compared. The simulations showed that the porous media method was most flexible as part of the buildings could be occupied by water. This approach offers potential opportunities for modeling a range of water quality parameters associated with flooding in buildings etc. and the model has since been extended further to study this effect in connection with flow through tidal renewable energy turbines for a barrage.

For the case of the Boscastle flood event, as referred to above, one of the main factors exacerbating the increase in flood risk was the fact that approximately 100 cars were picked up by the flood from an upstream car park and transported downstream to the open sea. However, one car blocked a small bridge on the downstream side of the town, causing considerable blockage by debris and leading to a significant increase in the water elevations and flood risk upstream. This led to the

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HRC undertaking a thorough literature review and comprehensive laboratory studies to refine the model to assess the flood hazard risk to people and vehicles during extreme flood events, as typified by this flood event and many others occurring frequently in other parts of the UK. In this model, empirical relationships between water depths and corresponding critical velocities for children and adults, developed by previous researchers, were used to assess the degree of people safety, and new incipient velocity formulae were derived to evaluate the degree of vehicle safety for unidirectional flow and for various vehicles, Shu *et al.* (2011). The developed model was then applied to two case studies, including: Glasgow and Boscastle in the UK. The analysis of model predictions showed that: (i) simulated results for the Glasgow flood showed that children would be in danger of standing in the flooded streets in a small urban area; and (ii) simulations for the Boscastle flood indicated that vehicles in the car park would be flushed away by the flow with high velocities, which confirmed the predictive accuracy of the incipient formula for vehicles, Xia *et al.* (2011),

Finally, the model was refined to simulate the hydrodynamic, sediment transport and faecal indicator organism processes in the Severn Estuary, both without and with a tidal barrage and as currently proposed to produce 5% of the UK's electricity needs from renewable resources across the estuary. The peak water levels were evaluated both in the estuary and the far-field, without and with a barrage, using three boundary scenarios. Simulated results showed that (i) without the barrage, the maximum levels along the estuary could rise by 1.0–1.2m due to sea-level rise by the end of the century, and the effect of extreme sea levels on the distribution of maximum water levels would be noticeable only in the outer estuary; (ii) with the barrage, the maximum water levels could reduce by 0.5–1.2m upstream of the barrage even if a sea-level rise of 1.0m would occur by 2100, and extreme sea levels could not influence the distribution of maximum water levels upstream of the barrage; and (iii) the future flood risk along the coastal floodplain would increase and the potential losses could reach $10M/year due to sea-level rise without the barrage, which could be avoided completely if the barrage were to be constructed as proposed. In terms of far-field effects a barrage could cause slight increases in the water levels along the north west English coastline. The model was then extended to investigate the effects of changes on bacterial levels upstream of the barrage post-impoundment, with field data for the estuary being used to provide an empirical relationship between the T_{90} value and the suspended sediment and turbidity concentration levels. The resulting dynamic decay rates and the significant reductions in the sediment concentrations post impoundment showed a corresponding reduction in the bacterial concentration levels, as a result of the increased light penetration through the water column leading to increased kinetic decay. Furthermore, the lower suspended sediment concentration levels in the water column also reduced the bacterial levels in the water column, as more of the adsorbed bacteria on the sediments now remained on the bed.

REFERENCES

Liang, D., Lin, B. and Falconer, R.A. (2007a) "Simulation of Rapidly Varying Flow Using an Efficient TVD-MacCormack Scheme", International Journal for Numerical Methods in Fluids, Vol. 53, No. 5, pp. 811-826.

Liang, D., Falconer, R.A. and Lin, B. (2007b) "Coupling Surface and Subsurface Flows in a Depth Averaged Flood Wave Model", Journal of Hydrology, Vol. 337, No. 1-2, pp. 147-158.

Shu, C., Xia, J., Falconer, R.A. and Lin, B. (2011) "Incipient Velocity for Partially Submerged Vehicles in Floodwaters", Journal of Hydraulic Research, Vol. 49, No. 6, pp. 709-717.

Xia, J., Falconer, R.A. Lin, B. and Tan, G. (2011) "Numerical Assessment of Flood Hazard Risk to People and Vehicles in Flash Floods", Environmental Modeling and Software, Vol. 26, No. 8, pp. 987-998.