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Quantifying the effects of boundary condition uncertainty in nested flood modelling of complex hydraulic systems

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Flood inundation models require appropriate boundary conditions to be specified at the limits of the domain, which commonly include upstream flow rate and water stage at the downstream boundary of the reach being modelled. These data are usually acquired from gauging stations of the river network, where measured water levels are converted to discharge by means of a rating curve. Although generally treated as deterministic relationships, rating curves are subject to uncertainties which can limit their accuracy and applicability to any particular event, particularly for low-frequency events, where the rating curve relationship is sparsely sampled and needs to be extrapolated. Consequently, derived streamflow records can be particularly uncertain and/or problematic for high-return period estimates. Moreover, the limited number of gauges in reach-scale studies usually requires flow to be routed from upstream gauge stations to the boundary of the model domain, which introduces additional uncertainty. This is more likely to be the case with complex modelling approaches, in which only limited areas can be simulated due to computational cost and model setup requirements.

In this study, a method to incorporate the rating curve uncertainty into the predictions of a reach-scale flood inundation model is proposed. Firstly, the uncertainty in the rating curves is quantified using a non-parametric local weighted regression approach and uncertainty bounds for discharge and water elevations at gauging locations are generated. A regional simplified-physics hydraulic model is then applied to combine these uncertainties and generate an ensemble of discharge and water elevation time series at the boundaries of a local-scale high complexity hydraulic model. Finally, the impact of this uncertainty on the local model performance is evaluated using flood extent data and measured water levels within the local model area.

The local-scale model is applied to 7 km of the river Severn passing through the city of Worcester (West Midlands, England), a flat subcritical reach in which backwater effects are significant. The flood event selected as a case study took place on the 20th July 2007 and is part of a series of destructive floods that occurred in the United Kingdom during that summer season. A full two-dimensional hydraulic model with a high resolution grid is adopted at the local scale to resolve the complex urban flow field within Worcester, whereas a simpler representation of the flow processes that ignores convective acceleration has been selected for the regional model. This nested modelling approach hence allows a continuous examination of the water fluxes from the catchment scale down to the reach and building scale, while still requiring reduced setup time and computational demand.

Differences with measured water levels at benchmark stations and with flood extent from SAR images are used to evaluate the resulting prediction uncertainties. The results quantify how external forcing uncertainty propagates through flood inundation models and affects model predictions. This allows us to compare the relative importance of this uncertainty, often neglected in flood modelling, with that of model parameters.