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Including local rainfall dynamics and uncertain boundary conditions into a 2-D regional-local flood modelling cascade

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Flood inundation models require appropriate boundary conditions to be specified at the limits of the domain, which commonly consist of upstream flow rate and downstream water level. These data are usually acquired from gauging stations on the river network where measured water levels are converted to discharge via a rating curve. Derived streamflow estimates are therefore subject to uncertainties in this rating curve, including extrapolating beyond the maximum observed ratings magnitude. In addition, the limited number of gauges in reach-scale studies often requires flow to be routed from the nearest upstream gauge to the boundary of the model domain. This introduces additional uncertainty, derived not only from the flow routing method used, but also from the additional lateral rainfall-runoff contributions downstream of the gauging point. Although generally assumed to have a minor impact on discharge in fluvial flood modeling, this local hydrological input may become important in a sparse gauge network or in events with significant local rainfall.

In this study, a method to incorporate rating curve uncertainty and the local rainfall-runoff dynamics into the predictions of a reach-scale flood inundation model is proposed. Discharge uncertainty bounds are generated by applying a non-parametric local weighted regression approach to stage-discharge measurements for two gauging stations, while measured rainfall downstream from these locations is cascaded into a hydrological model to quantify additional inflows along the main channel. A regional simplified-physics hydraulic model is then applied to combine these inputs and generate an ensemble of discharge and water elevation time series at the boundaries of a local-scale high complexity hydraulic model. Finally, the effect of these rainfall dynamics and uncertain boundary conditions are evaluated on the local-scale model. Improvements in model performance when incorporating these processes are quantified using observed flood extent data and measured water levels from a 2007 summer flood event on the river Severn.

The area of interest is a 7 km reach in which the river passes through the city of Worcester, a low water slope, subcritical reach in which backwater effects are significant. For this domain, the catchment area between flow gauging stations extends over 540 km2. Four hydrological models from the FUSE framework (Framework for Understanding Structural Errors) were set up to simulate the rainfall-runoff process over this area. At this regional scale, a 2-dimensional hydraulic model that solves the local inertial approximation of the shallow water equations was applied to route the flow, whereas the full form of these equations was solved at the local scale to predict the urban flow field. This nested approach hence allows an examination of water fluxes from the catchment to the building scale, while requiring short setup and computational times.

An accurate prediction of the magnitude and timing of the flood peak was obtained with the proposed method, in spite of the unusual structure of the rain episode and the complexity of the River Severn system. The findings highlight the importance of estimating boundary condition uncertainty and local rainfall contribution for accurate prediction of river flows and inundation.