The virtual conference of AQUA≈360: Water for All - Emerging Issues and Innovations
31st August 2021 – 2nd September 2021, University of Exeter, United Kingdom

Validation of a 2D flow model using high-resolution experimental data sets for sub/surface flow interactions.

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Keywords: *dual drainage; flow exchange; model validation; surface flow*

EXTENDED ABSTRACT

Introduction

Flood risk in urban environments has undoubtedly increased over the past decade due to accelerated urbanisation and land use changes [1] and more frequent extreme rainfall, induced by climate change, have exacerbated this convoluted issue [2]. Effective contemporary urban flood risk analysis requires detailed computational modelling techniques which, to date, have been widely adopted to investigate behaviours of urban floods and their impacts (e.g. microbial risk assessments [3], flood risk zoning [4], property damage [5], in order to develop countermeasures in flood mitigation decision making [6]). Two systems are always considered for modelling purposes: the minor system refers to subterranean pipes and manholes and the major system represents flow pathways over a surface (e.g., street). The minor system is often simulated via one-dimensional (1D) sewer network models, while the major system can be modelled via either 1D channel networks or two-dimensional (2D) overland flow models. The interactions between subsurface and surface systems are analysed via 1D-1D or 1D-2D modelling approaches [7], where the coefficients for linking the two models require careful calibration to accurately reflect the flow dynamics between them. In this study, experimental datasets collected within a facility that replicates urban flooding scenarios are used to calibrate a 1D sewer and 2D overflow hydraulic model such that it can increase its accuracy and therefore be applied with more confidence to analyse a wider range of flooding conditions.

Methods and Materials

The collection of the experimental hydraulic parameters such as flow rates (Qe, Q4 and Q2), water depths (P0-P5) and velocity fields, was completed using a physical scale model (1:6) of a sewer pipe system linked to a hypothetical urban surface via a single manhole. This unique experimental facility was constructed at the University of Sheffield and has been used for multiple studies [8]–[10] to calibrate and validate a variety of numerical models. The numerical model considered for this study was constructed in MIKE URBAN + to the exact experimental geometries. More in detail, two dissimilar street configuration were selected for the calibration and validation of the numerical model: a simple rectangular profile, and one with parking spaces incorporated, so that the model's performance could be assessed for a more complex scenario. Within the experimental facility, flow rates (pipe inflow and outflow, manhole exchange and 2D surface inflow and outflow) were measured using calibrated electro-magnetic flow meters, depths around the manhole were recorded using transducers and velocity fields were obtained via adopting Particle Image Velocimetry techniques, processing the frames that were gathered with GoPro cameras fitted within the model. Three hydraulic conditions were tested experimentally and run numerically with MIKE URBAN+: i) lid on top of the manhole, no sewer pipe surcharge and flow exchange from the hypothetical urban surface into the below sewer system (S1); ii) no lid on the top of the manhole, no sewer pipe surcharge and flow exchange from the hypothetical urban surface into the below sewer system (S2); iii) no lid on the top of the manhole, sewer pipe surcharge and overflow into the hypothetical urban surface (S3). Results were then compared to evaluate the performance of the numerical modelling using R^2 values of linear regression, normalised root mean square errors (NRMSE**)** and statistical significance.

Results and Discussion

The numerical model was successfully calibrated against measured flows and depths around the manhole. This meant that the validated data set replicated water depths within 1.423mm and flows within 0.138l/s. R^2 values for both these parameters were above 0.90, and similarly, NRMSE were within 0.079; all tests were statistically significant <.05. According to Pogson and Smith, [11], %NRMSE < 10% is considered highly accurate. The results of the numerical model revealed that during S1 and S2 the model slightly over calculated flow exchange into the minor system (ranges were 0.124 - 0.150 l/s), whereas during S3 the model slightly over calculated pipe surcharge (ranges were 0.125 - 0.148 l/s). This meant that depths around the manhole were underestimated for S1 and S2 (ranges were 0.813 - 1.756 mm) and overestimated for S3 (ranges were 1.120 - 1.55 mm). The results suggest that errors linked to the estimation of flow rates and depths could be attributable to inflow 2D boundary conditions. S1 and S2 were related to floodplain inflow and S3 was related to pipe inflow. Figure 1 illustrates the validated model results for the rectangular configuration (depths around the manhole and flows are plotted along a 45-degree line).

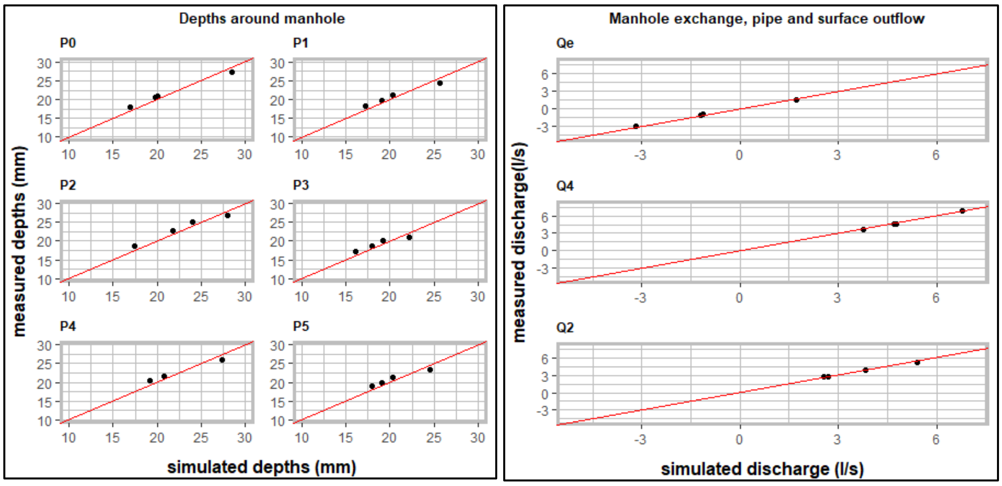

Figure 1: Validated depths (mm) around the manhole (left) and manhole exchange, pipe, and surface outflows (l/s) on right. Both graphs show simulated and measured results plotted along a 45-degree line.

The numerical model was able to replicate surface flow dynamics to a high accuracy for both high-resolution data sets involving longitudinal and transversal velocity fields. Longitudinal velocities had smaller errors (NRMSE ranges were 0.058 – 0.130) than transversal velocities (NRMSE ranges were 0.069 – 0.173); in addition, errors decreased with increasing distance from the manhole. Similarly, velocity field errors were smaller 2m away from the manhole than those recorded at the manhole. The accuracy of surface flow dynamics was more consistent with the lower resolution experimental data, as the error in the lower resolution grid was averaged out more, with a smoothing effect in the observations by aggregating the information. This meant that there was slightly more error for longitudinal velocities (NRMSE ranges were 0.068 – 0.141) and transversal error (NRMSE range was 0.076 – 0.192) in the higher resolution grid, in line with what is available in literature [12]. The next part of this study will investigate the second hypothetic street profile with parking spaces. It is expected that the flows and depths will be consistent to the rectangular configuration, however velocity fields are expected to be less consistent, as the second street configuration is more complex.

Conclusions

The numerical model was able to replicate highly accurate flows, depths, and surface flow dynamics recorded within the experimental facility. The model seemed to respond well to increasing complexity of each parameter under three different hydraulic scenarios. Future work will be conducted on the second street profile. This data set is intended to be used to further validate the selected numerical model. It is expected that the model will respond well to the new configuration, albeit with slightly more error in the velocity field calculations.

Acknowledgement

The work presented above was supported by the EPSRC Centre for Doctoral Training in Water Informatics Science and Engineering (WISE CDT; EP/L016214/1). Furthermore, the experimental part of this research has been supported by the UK Engineering and Physical Sciences Research Council (grants ID: EP/K040405/1)

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