On the possibility of calibrating urban storm-water drainage models using gauge-based adjusted radar rainfall estimates

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Abstract Traditionally, urban storm water drainage models have been calibrated using only raingauge data, which may result in overly conservative models due to the lack of spatial description of rainfall. With the advent of weather radars, radar rainfall estimates with higher temporal and spatial resolution have become increasingly available and have started to be used operationally for urban storm-water model calibration and real-time operation. Nonetheless, the insufficient accuracy of radar rainfall estimates has proven problematic and has hindered its widespread practical use. This work explores the possibility of improving the applicability of radar and raingauge rainfall estimates to the calibration of urban storm-water drainage models by employing gauge-based radar rainfall adjustment techniques. Three different types of rainfall estimates were used as input to the recently verified urban storm water drainage models of the Beddington catchment in South London; these included: raingauge, radar (UK Met Office Nimrod) and the adjusted (or merged) radar rainfall estimates. The performance of the simulated flow and water depths was assessed using measurements from 78 gauges. Results suggest that a better calibration could be achieved by using the adjusted radar estimates as input, as compared to using only radar or raingauge estimates.
Keywords urban drainage; calibration, gauge-based adjustment; rain gauge; radar, Bayesian

INTRODUCTION

Urban storm water drainage models are essential tools for urban planning, real time operation of sewer systems, and urban flood forecasting. The main input for these models is rainfall; therefore, the quality of rainfall estimates dominates the overall uncertainty and reliability of urban storm-water drainage models (Golding, 2009). Raingauge and radar are two commonly-used sensors for rainfall estimation at urban scales (Cole & Moore, 2008). Raingauges provide accurate point estimates near the ground surface, but cannot capture the spatial variability of rainfall which has a significant impact on the physical processes of drainage systems (Syed *et al*., 2003). In contrast, radars can provide better spatial description of rainfall, but their accuracy is in general insufficient, particularly in the case of extreme rainfall magnitudes (Einfalt *et al*., 2005; Harrison *et al*., 2009). Until recently, urban storm water drainage models were calibrated using exclusively raingauge data, which usually results in overly conservative models due to the assumption of a uniformly-distributed rainfall field over the area in the vicinity of a given raingauge. With the advent of weather radars, radar rainfall estimates with higher temporal and spatial resolution have become increasingly available and have started to be used operationally for urban storm-water model calibration (e.g. Watt (2012)) and real-time operation (e.g. Kraemer *et al*. (2005)). Nonetheless, the insufficient accuracy of radar rainfall estimates has proven problematic and has hindered its widespread practical use (Rico-Ramirez *et al*., 2007). In fact, recent experiences have demonstrate that using only radar rainfall estimates as input for calibration of urban drainage models may result in physically infeasible model parameters (such as extremely large contributing areas to compensate for the inaccuracy of radar rainfall values) (Watt, 2012). In order to improve the accuracy of radar rainfall values while preserving the spatial structure of rainfall fields (as captured by the radar), it is possible to adjust radar estimates based on raingauge measurements; in this way, the advantages of both sensors are combined and their drawbacks are overcome. A number of studies on this subject have been conducted over the last few years (Todini, 2001; Cole & Moore, 2008; Ehret *et al*., 2008); however, most of these have focused on large scales (much larger than those of urban catchments) and, to the author's knowledge, gauge-based adjusted rainfall estimates have not yet been used for calibration of hydrological/hydraulic models. This work explores the possibility of improving the applicability of radar rainfall estimates to calibration of urban storm-water drainage models by employing gauge-based radar rainfall adjustment techniques.

EXPERIMENTAL SITE AND DATASET

The Beddington catchment stretches over the London Boroughs of Croydon and Sutton and has a drainage area of approx. 64 km^2. It is predominantly urbanised and is highly susceptible to surface water flooding. A recently verified storm water drainage (sewer) model of this catchment was obtained from the water company of the area, together with the medium term flow survey data used for verification.

The model is setup in InfoWorks CS 13.0 (Innovyze, 2012) and comprises 10,205 nodes and 10,500 pipes (total pipe length of 708 km). Rainfall is applied to the model through 5,185 subcatchments (subcathment mean size is 1.2 ha) which are connected to nodes; each subcatchment is split into different surface types and the NewUK model is used to estimate runoff at each subcatchment. The flow in the sewers is simulated based on the full Saint-Venant equations.

The medium term flow survey used for verification of the model was carried out between 28/01/11 and 13/07/11 and comprises data from 78 flow gauges and 18 raingauges (with 2 min resolution). In addition, high spatial (1 km) and temporal (5 min) resolution radar rainfall estimates covering the entire catchment were obtained for the same period (the radar estimates correspond to the Nimrod quality-controlled multi-radar composite product of the UK Met Office - see Harrison *et al*., 2009). During the monitoring period, 3 relatively large storms were recorded and were used for verification of the model (Table 1), thus complying with UK Wastewater Planning Users Group standards (WAPUG, 2002). The sewer model provided to us was verified by a consultant using predominantly radar data and then checked against rain gauge data (Watt, 2012). This was founded upon recent recommendations of the water company of the area, according to which all London models should be verified using both raingauge and rain radar data. Nonetheless, when verifying the Beddington model, it was found that raingauges were generally recording higher peak intensities than the coincidental radar pixels and applying these higher intensities across the whole Thiessen polygon associated to each raingauge would lead to unrealistically high flows (which would need to be compensated by decreasing contributing areas). For this reason, the consultant decided to verify the model using predominantly radar data, as it can capture the spatial variability of rainfall; however, this proved problematic (e.g. at some points radar appears to underestimate and miss peaks, making it difficult to match the model with the measurements). At particularly problematic sites, the consultant applied his/her best judgment and tried to find a balance between the results obtained with raingauge and radar inputs (Watt, 2012).

Table 1. Characteristics of the rainfall events used for verification of the urban drainage model (RG = raingauge; RD = radar).

Event	Period (length in hr)	RG Total (mm) Areal/Max/min	RG Peak (mm/hr) Areal/Max/min	RD (mm) Areal	RD (mm/hr) Areal
E1	05-07/05/11 (72 hrs)	34.5/43.8/23.8	4.8/10.8/3.6	36	3.8
E2	17-18/06/11 (48 hrs)	14.9/21.0/7.8	9.2/26.4/4.2	18.7	6.6
E3	05-07/07/11 (57 hrs)	7.4/10.8/4.8	4.4/16.8/2.9	8.6	3.9

METHODOLOGY

In order to explore the possibility of calibrating storm water urban drainage model using gauge-based adjusted radar rainfall estimates, three different types of rainfall estimates, corresponding to the 3 verification storms described above, were used as input to the recently verified model of the Beddington catchment. These were: raingauge (applied through Thiessen polygons), radar (UK Met Office Nimrod), and gauge-based adjusted (or merged) radar rainfall estimates obtained with a Bayesian merging method which proved to be suitable for urban hydrological applications (see Wang et al. 2013). The simulated flow depths and flow rates were compared against the measurements from the 78 gauging sites described above. It is important to note that the model was not re-calibrated for each of the three rainfall inputs: given the problems reported by the modeller when verifying the model using predominantly radar rainfall estimates (as described above), it was expected that a better goodness of fit could be achieved by simply inputting merged rainfall inputs into the recently verified model of Beddington. The work presented herein aims at proving this hypothesis.

RESULTS, CONCLUSIONS AND OUTLOOK

The performance of the model for the different rainfall inputs was evaluated in terms of the relative error (*RE*) in peak flows and depths, and in terms of the coefficient of determination (R^2) between the simulated and the observed flow and depth time series (see Table 2).

Table 2. Performance of the Beddington model for different rainfall inputs for the three storm events under consideration.

	E1	**E2**	**E3**	**E1**	**E2**	**E3**
	MEAN *RE*† – PEAK FLOW RATE			**MEAN *RE*† – PEAK FLOW DEPTH**		
RG	30.57%	40.56%	40.40%	90.96%	76.29%	20.79%
NIMROD	28.27%	36.96%	53.59%	46.21%	24.76%	26.34%
MERGED	24.91%	29.75%	37.51%	32.34%	21.12%	18.93%
	MEAN R^2 – FLOW RATE			**MEAN R^2 – FLOW DEPTH**		
RG	0.694	0.697	0.641	0.705	0.702	0.691
NIMROD	0.666	0.667	0.575	0.703	0.656	0.664
MERGED	0.701	0.703	0.633	0.748	0.713	0.718

† $MEAN\ RE(\%) = \langle |O_{Peak} - S_{peak}| / O_{Peak} \rangle$, where O_{peak} and S_{peak} represent the maximum observed and simulated flows

It can be seen that the best overall performance, both in terms of quantity (i.e. lowest *RE*) and ’pattern’ (i.e. highest R^2), is achieved with merged raingauge-radar rainfall inputs. This can be explained by the fact that these inputs can better preserve the accuracy, spatial and temporal structure of rainfall fields. These results suggests that a better calibration of sewer models could be achieved by using these ’improved’ rainfall inputs, as compared to using only radar or raingauge estimates. Further investigation is needed to confirm these initial findings, including uncertainty-based calibration of the model using different rainfall inputs and explicitely considering the uncertainty associated to them. Work in this direction is currently underway.

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