Qualitative techniques to evaluate urban flood models

Stefan Reinstaller[1*] and Dirk Muschalla[1]

[1]Institute of urban water management and landscape engineering, Graz University of Technology, Austria
**Corresponding author email: stefan.reinstaller@tugraz.at*

Highlights

- An alternative way to evaluate an urban flood model based on operation protocols of the fire department is demonstrated
- The combination of water depth and velocity as threshold value yielded robust results
- The chosen parameters for threshold values have a large impact on the qualitative evaluation of model performance

Introduction

Integrated 1D/2D urban flood models are well-known tools to manage and assess the increasing risk of urban flooding (Chen et al., 2017). Traditionally, model calibration for urban drainage models is done by comparing model results and flow measurement data based on a pre-defined cross-section under the surface (Moy de Vitry et al., 2017). For calibration in the context of urban flooding, the relevant objective function is the flooding area on the surface, which is spatially distributed. Therefore, more than one data point in a catchment is required to evaluate an urban flood model. Such data are often not available in accurate quality. Consequently, other data sources and evaluation methods are required to evaluate these models. The qualitative evaluation method based on damage data to determine the contingency table is one such alternative (Bennett et al., 2013). This method uses recorded damages as an objective function for model calibration. Its applicability has been demonstrated by numerous studies (Chang et al., 2015; Zischg et al., 2017; Wang et al., 2018). However, it is rarely discussed what threshold value and what model variable (water depth, flow velocity) should be used to classify simulated flooding areas as "damaged". This study discusses the impact of the model variable and the used threshold value for the qualitative evaluation method of three different heavy rainfall events in a small study site in Graz Austria.

Method

The study site is located in the border area of the city Graz in Austria and is characterized by a mixture of urban and semi-urban land use with a total catchment area of 132 hectares. The catchment includes two hillside subcatchments in the northeast and southwest. A small stream is located in the catchment which is surrounded by buildings. For this reason, the study site can be described as a valley with urban character (Figure 1). A fully distributed hydrological model is used to estimate the runoff volume that is used as input for the 2D hydrodynamic model. Consequently, the catchment area is divided into individual 2D cells with a pre-defined resolution. The hydrological parameters are depending on the land use within each created 2D cell. The flow in the sewer system is calculated hydrodynamically and coupled with the surface in a bidirectional way it. This approach resulted in a fully distributed and hydrodynamic 1D/2D urban flood model with surface water-levels and flow-velocities as outputs.

After the model build-up, three real heavy rainfall events with more or less the same return period of 30 years were simulated (2005, 2009, 2013). These events were selected for their good availability of data on the spatial distribution of damages.

From the 1D/2D urban flood model, damages are estimated by comparing model parameters to a threshold parameter and value. The suitability of different threshold parameters and values was evaluated using a contingency table that compares simulated with recorded damages (true positive (TP), false negative (FN), false positive (FP), true negative (TN)) (Casati et al., 2008; Bennett et al., 2013). Three objective values were selected to evaluate the threshold values suitability: i) model accuracy, ii) bias score and iii) success index.
Different threshold values and parameters (water depth [m], flow velocity [m/s] and combination of both [m²/s]) were tested within realistic ranges that were taken from existing hazard curves (Ball et al., 2019).

A)

B)

contingency table		observation		
		positiv	negative	total
simulation	positiv	TP (true positiv)	FN (false negative)	yes
	negative	FP (false positive)	TN (true negative)	no
	total	yes	no	total

Figure 1. Study site Annabach including the land-cover distribution (A) which is differentiated in hillside and flatland area to define the hydrological parameters (roughness, losses and infiltration parameter) and the basic form of the contingency table (B) for the qualitative evaluation approach

Results and discussion

Each simulated heavy rainfall event has similar return periods and event durations. Therefore, the optimum threshold values for each event are expected to not vary strongly. BIAS values, model accuracy and success index were highly sensitive to threshold values when only one model variable was used. While a water depth of 0.05 m or a flow velocity of 0.1 m/s as threshold value resulted in a BIAS of 100, a value of 1.2 m or 2 m/s results in a BIAS of 4. The combined index, using both model variables reacted less sensitive. The fitness parameters resulting from different threshold parameters and values can be seen in Figure 3.
Since the combined threshold value showed the least sensitivity to varying values, it was decided to use the combined threshold value for further analysis. The optimal threshold values for all three events were identified: i) 0,43 m^2/s (2005 event); ii) 0,36 m^2/s (2009 event); iii) 0,3 m^2/s (2013 event) (Figure 2). The objective values in each event demonstrate an accurate model performance, although the model tends to overestimate the damages (Bias between 4 and 10). The threshold values are within the realistic range of hazard curves proving the combined threshold parameter suitable to evaluate an urban flooding model qualitatively. The initial assumption that the optimum threshold values for the selected events should be in the same order of magnitude was thus confirmed.

f-c	Event 2005				Event 2009				Event 2013			
	Ø X_{opt}	accuracy	bias	success index	Ø X_{opt}	accuracy	bias	success index	Ø X_{opt}	accuracy	bias	success index
d[m]	0,76	0,94	13,2	0,48	0,76	0,98	1,65	0,65	0,76	0,97	2,82	0,61
v[m/s]	2	0,98	4	0,48	1,67	0,95	4,21	0,66	0,93	0,88	10	0,54
d*v[m²/s]	0,43	0,98	3,67	0,49	0,36	0,97	2,44	0,65	0,3	0,96	3	0,59
evaluation												

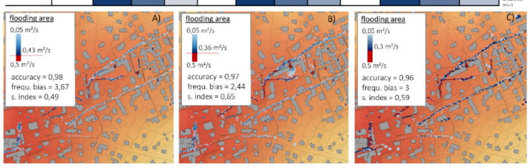

Figure 2: The ideal threshold values of the objective values depending on the mean Xopt value including an evaluation scale (blue: satisfying results, grey: unsatisfied result) and the corresponding flooding maps with the combined model variable (d*v) as the best model variable to detect the flooding damages of each event (A) event 2005, B) event 2009, C) event 2013)

Conclusions and future work

The main output of the presented study is the sensitivity of the parameter chosen as a threshold value to evaluate an urban flood model qualitatively. Especially when using only the single model variables water depth or flow velocity as threshold values to assess damages, large differences to the qualitative objective functions are observed. In contrast, the combination of both model variables into an index value provides more robust results and is consequently more useful for qualitative model evaluation. In summary, the qualitative evaluation approach is a suitable alternative for evaluating the highly distributed processes of urban flooding if no measurement data are available. However, the quality of the results depends on a careful selection of the threshold value according to the contingency table.

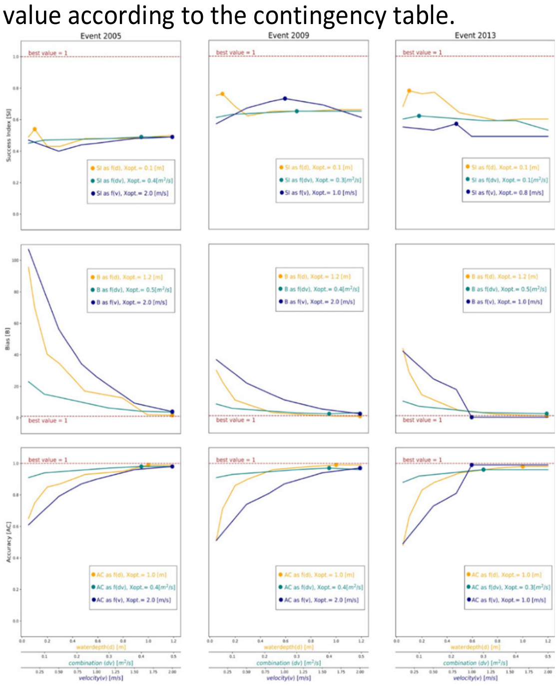

Figure 3: Impact of different threshold values and model variables (water depth, flow velocity and combination of both) to evaluate an urban flood model for three real heavy storm events (2005, 2009, 2013) based on three qualitative objective functions (Accuracy, Bias, Success Index) including the optimum threshold value.

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