Impact of model structure on analysing malfunctions in urban drainage systems

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Highlights

- Analysing common malfunctions in a small scale virtual urban drainage system
- Comparison of 1D and coupled 1D-2D rainfall runoff models
- 1D-2D coupled model shows better performance in assessing the vulnerability of critical infrastructure

Introduction

Urban drainage systems are complex structures consisting of a wide range of different assets and subsystems. As such they are vulnerable to a lot of different possible malfunctions, making it difficult to predict the entire system's response to the different disruptions (Mugume et al., 2015). With the increasing integration of sustainable urban drainage systems (SUDS) and the expected increase of extreme precipitation events (Hosseinzadehtalaei et al., 2020), there is a growing demand for a better understanding. Modelling this system to assess sewer capacity and the effects of pluvial flooding is a difficult task, especially due to the lack of input data and limited computational time (Kleidorfer et al., 2019). Therefore, conventional modelling approaches of urban drainage (1D urban drainage model) are simulating only the sewer in a one-dimensional hydrodynamic way. More advanced approaches (1D-2D) consist of a coupled one-dimensional sewer system and a two-dimensional surface system, therefore able to represent inundation depths and flooding extent on the surface (Leandro et al., 2009). In this work, we are comparing these two modelling approaches with the software PCSWMM2D (Abdelrahman et al., 2018) in a virtual urban study site. The goal is to highlight differences between both model structures in simulating failures and malfunctions in both grey and blue-green infrastructures for different scenarios.

Method

Virtual urban study site

The base of the work is a small virtual urban study site (1.5ha), which represents a small part of an urban catchment. It includes the following sub-structures and assets: i) combined sewer system, ii) urban stream, iii) urban structures including buildings, marketplaces, streets, bridges, pathways, and underbridges. The surface contour is represented by a DEM dataset including small structures like curbs, embankments and swales, with a moderate slope from southeast to northwest. Connected to the combined sewer system are three catchments (30ha, 10ha, 10ha) representing the surrounding area to generate the inflow from outside. Each asset of the urban drainage system was designed based on a design rainfall (Euler Typ II) with a 5-year return period and 1-hour event duration (peak rainfall 12.3 mm/5 min, total rainfall 38 mm).

Three different scenarios were designed for the virtual urban study site a) the 0-scenario which represents the base case, b) the SUDS-scenario which includes four different green infrastructure assets, a green roof, bio-retention cell, permeable pavement and swales (Figure 1), and c) the malfunction-scenario which is the SUDS-scenario with blocked gully inlets. Each scenario was run with a measured extreme rainfall event (100mm in 1h, peak 14.67 mm/5min, return period>100a) and an Euler II design rainfall event which is used to design the assets. (38mm in 1h, peak 12.3 mm/5min , return period=5a).

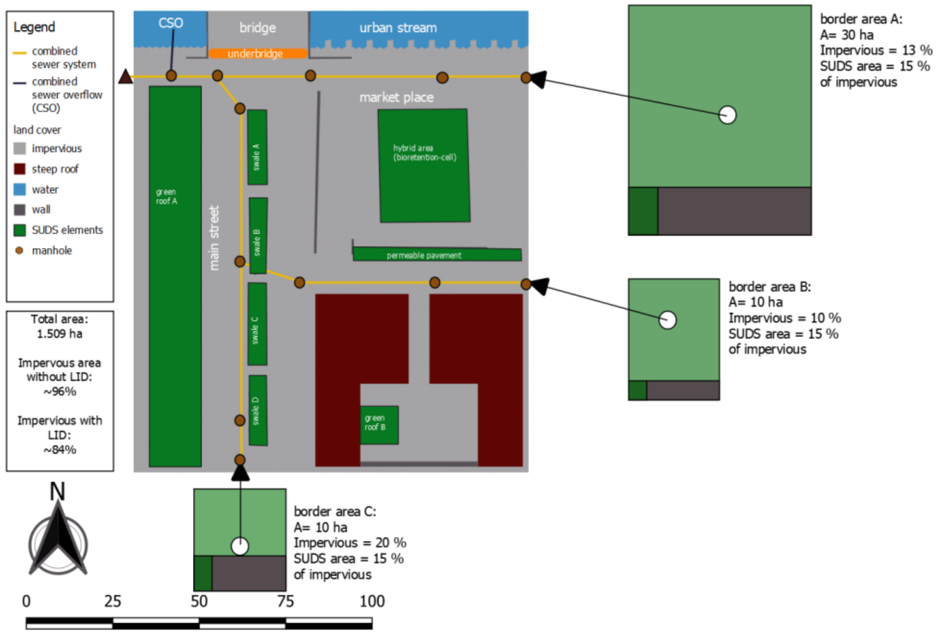

Figure 1: The Character of the virtual urban catchment area (A = 1.509 ha) with three border areas (border area A: 30 ha, border area B and C: 10 ha) including the places of the SUDS assets (green roof, bio-retention cell, permeable pavement and swales)

Model structure

The virtual urban study site was set up with PCSWMM2D in two different model structures, a conventional 1D urban drainage model and a coupled 1D-2D model In the 1D model subcatchments are conceptualized by nonlinear reservoirs and connected to a hydrodynamic 1D pipe model (sewer system). All urban structures like buildings, streets, rivers, marketplace and pathways are implemented as single semi-distributed subcatchments. Flooding occurs only in the sewer system and is stored on top of the respective network nodes. In the coupled 1D-2D model the hydrodynamic 1D pipe model (sewer system) is combined with a 2D hydrodynamic surface runoff model. Both models are coupled in each timestep with an orifice as a coupling element. The bidirectional exchange between both models is described by the orifice equation in each timestep. In contrast to the 1D model, this modelling approach can evaluate the spatial and temporal distribution of the flooding area on the surface. The benefit of the 1D-2D model is a better system understanding because it allows not only to analyse individual elements of the urban drainage network directly (e.g. sewer system overload) but also the impact of urban drainage networks on its environment (e.g. sewer overload resulting in flooding of underbridges).

Results and discussion

The simulations results of all model scenarios and both rainfall events are evaluated based on four performance indicators (total flooding volume of the sewer system, the discharge volume of the combined sewer overflow, water depth in the underbridge, total surface runoff volume in the system) (Table 1). The results show a significant difference in maximum water depth for the real storm event in the underbridge (0.01 m for the 1D model and 1.86 m in the 1D-2D model) and a smaller difference in the CSO volume (4257 – 5319 m^3 in the 1D model and 2810 – 3286 m^3 in the 1D-2D model) between the two model structures. This is related to the missing overland flow in the 1D model, where only the closest subcatchments contribute to the flooding volume of the underbridge. In the 1D-2D model overland flow from all subcatchments and surcharging nodes can add to the flooding volume. For the design rainfall event, only the 1D/2D model identifies a clear difference between the SUDS- and malfunction-scenario for the maximum water depth in the underbridge (0.01 m in the 0-scenario and 0.64 m in the malfunction scenario). The total flooding volume and the total surface runoff show very similar results between the two model structures for the design rainfall event. In summary, the results show the limitations of the 1D model in representing urban water fluxes and malfunctions and the importance of a coupled 1D/2D rainfall-runoff model to assess the vulnerability of urban infrastructures.

Table 1. Results of all different model scenarios and both rainfall scenarios including the four performance indicators to compare and analyse the two model structures (1D model and 1D-2D model)

event	**model scenarios**	**model structure**	**objective values**			
			flooding volume [m³]	**CSO volume [m³]**	**water depth critical infrastructure [m]**	**total surface runoff [m³]**
Measured extreme rainfall event (100mm/h; T>100a)	0-scenario	1D/2D model	3466	3286	1.86	18360
		1D model	3578	5319	0.01	18290
	SUDS-scenario	1D/2D model	2558	2830	1.86	14280
		1D model	2685	4407	0.01	14170
	malfunction-scenario	1D/2D model	2485	2810	1.86	14280
		1D model	2432	4257	0.22	14170
Euler II design event (38mm/h; T=5a)	0-scenario	1D/2D model	0	33	0.01	2940
		1D model	0	52	0.01	2880
	SUDS-scenario	1D/2D model	0	0	0.01	480
		1D model	0	0	0.01	420
	malfunction-scenario	1D/2D model	0	0	0.64	480
		1D model	0	0	0.01	420

Conclusions and future work

The first results show some significant differences in the analyzed objective values between both model structures, with the 1D/2D model providing more plausible results. However, the higher effort in model setup, data requirements and simulation time has to be considered. Subsequently, it is planned to investigate further malfunctions and combinations of malfunctions in both grey and green-blue infrastructures to complete the initial picture.

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