Sensitivity of Sustainable Urban Drainage Systems to precipitation events and malfunctions based on 60-year long-term modelling

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Highlights

- Modelling common malfunctions in SUDS with SWMM 5.1
- 60-year long-term continuous rainfall-runoff modelling with high-resolution rainfall data
- Comparing SUDS performance of real rainfall events to design events

Introduction

Based on the diverse ecological and hydrological problems caused by traditional management of urban drainage (WONG & BROWN 2009), a paradigm shift has been taking place for several years. Contrary to the concept of conveying the water away as fast as possible, the goal today is to manage rainwater on-site (store, infiltrate and evaporate) to approach the natural water balance (MATZINGER et al. 2017). For this purpose, Sustainable Urban Drainage Systems (SUDS) are used. In this work, we examine their runoff behavior for precipitation events of different return periods and duration and their behavior during different possible malfunctions. Based on a numerical model we investigate the reaction of SUDS to changed input data and parameters. The results aim at improving the selection of precipitation events for the design of the systems and to better understand how disruptions can affect the performance of these systems.

Methodology

For this purpose, 60-year continuous long-term simulations of different rainwater concepts on a daycare site in Berlin, Germany (FUNKE et al. 2019) were carried out with the rainfall-runoff model EPA SWMM 5.1 (GIRONAS et al. 2010). The location was part of the netWORKS4 research project and was redesigned in a participatory process with stakeholders concerning expanding the daycare center and integrating SUDS (TRAPP et al. 2019; NENZ et al. 2019). Figure 1 shows the layout of the stormwater management concept of

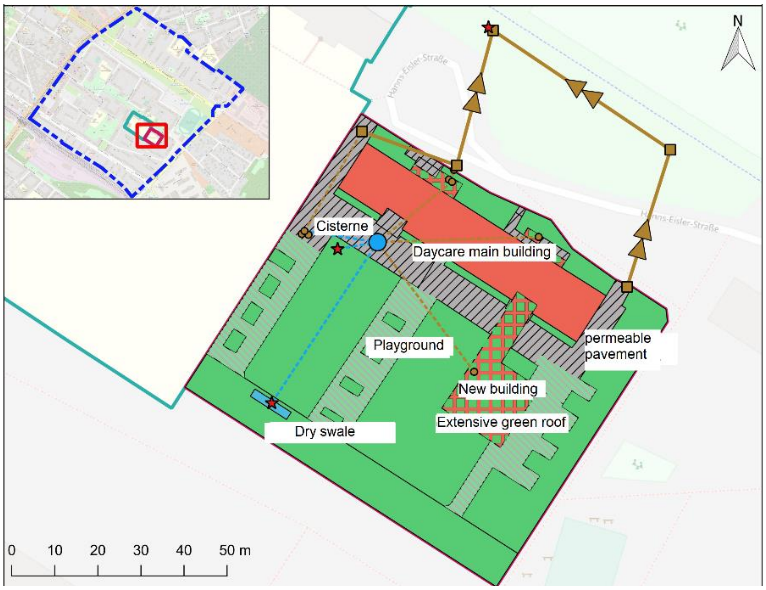

Figure 1: Map of the simulated daycare center in Berlin Germany (plan status with SUDS)

the daycare in the “plan status”, selected by the stakeholders. It combines permeable pavement, an extensive green roof, a cistern and a dry swale. Rainwater collected from the roof areas (vegetated and non-vegetated) is stored in the cistern and used as service water for sanitary use and irrigation. Cistern overflow is infiltrated to groundwater by a dry swale. In addition to the “plan status” individual and combined SUDS were simulated as scenarios. The individual systems of SUDS are mapped in the model using "Low Impact Development" (LID) controls and, in the case of the green roof, were parameterized using measured values (SCHUBERT et al. 2015). In addition, the long-term water balance of the entire property with the associated soil was parameterized using the ABIMO 3.2 water balance model validated for Berlin (GLUGA et al. 1999).
In a first step, single and combined SUDS were evaluated for a 60-year precipitation series by event return period. The precipitation signal of the simulation has a temporal resolution of 5 minutes and comes from the Berlin-Dahlem station of the FU Berlin. In addition to the measured precipitation events of the 60-year long time series, synthetic rainfall events with similar return periods and interval length were tested as single events.
In a second step, the effects of different possible malfunctions have been examined (see Table 1).

Table 1: Overview over the modelled SUDS malfunctions and their corresponding SWMM LID Parameters

SUDS	Malfunction	SWMM LID Parameter	Initial Value	Adapted Value	% of Initial Value
Extensive green roof	substrate erosion	Soil thickness	109 mm	54.5 mm	50
Permeable pavement	clogging	Soil conductivity	18 mm/h	9 mm/h	50
Cistern	pump failure	Pump curve	1500 l/day	500 l/day	33
	debris build-up	Storage Max. Depth	3 m	2.25 m	75
Dry swale	clogging	Soil conductivity	178 mm/h	44.5 mm/h	25
	sediment and debris build-up	Surface berm height	300 mm	200 mm	66
		Soil conductivity	178 mm/h	89 mm/h	50
	soil compaction	Soil thickness	100 mm	50 mm	50
		Soil conductivity	178 mm/h	26.7 mm/h	15
		Soil Porosity	0.44 Vol.%	0.35 Vol.%	80

Results and discussion

The 60-year long time series consists of over 9000 precipitation events, for which the intensity-duration-frequency curve (IDF curve) was evaluated. In addition to the runoff, information on seasonality and pre-event conditions (e.g. soil moisture) are available for each event. The first results show that the runoff characteristics of the SUDS can only be partially explained by the characteristics of the precipitation events and that other influencing factors such as pre-moisture and seasonality play an important role. In comparison to cisterns and green roofs, dry swales show an overall higher correlation between the total runoff and the return period of different durations (see Figures 2a & 2b). This is especially true for the short and medium duration intervals between 20 minutes and 1 hour. Shorter or longer events show a poorer correlation, either because they are insufficient in quantity to cause an overflow or because the intensities are too low compared to the infiltration capacity. In the case of green roofs, pre-weathering and seasonality are more dominant (see Figure 2b).
Both synthetic rainfall types are commonly used in Germany and Austria as design events and consist of a) an even rainfall distribution (block rain) or b) a Euler II shaped distribution. For both synthetic rainfall types total runoff for the same return periods is much lower than for measured rain events for return periods > 2 years (see Figure 2a & 2b). Partially due to missing pre-weathering which can decrease available storage before the event and also because the analyzed IDF curve interval is normally part of a bigger rain event.
Regarding malfunctions, single-measure systems are more sensitive than the plan state which combines different SUDS. Among the single SUDS, green roof, swale and cistern malfunctions show the greatest effect on overall performance.

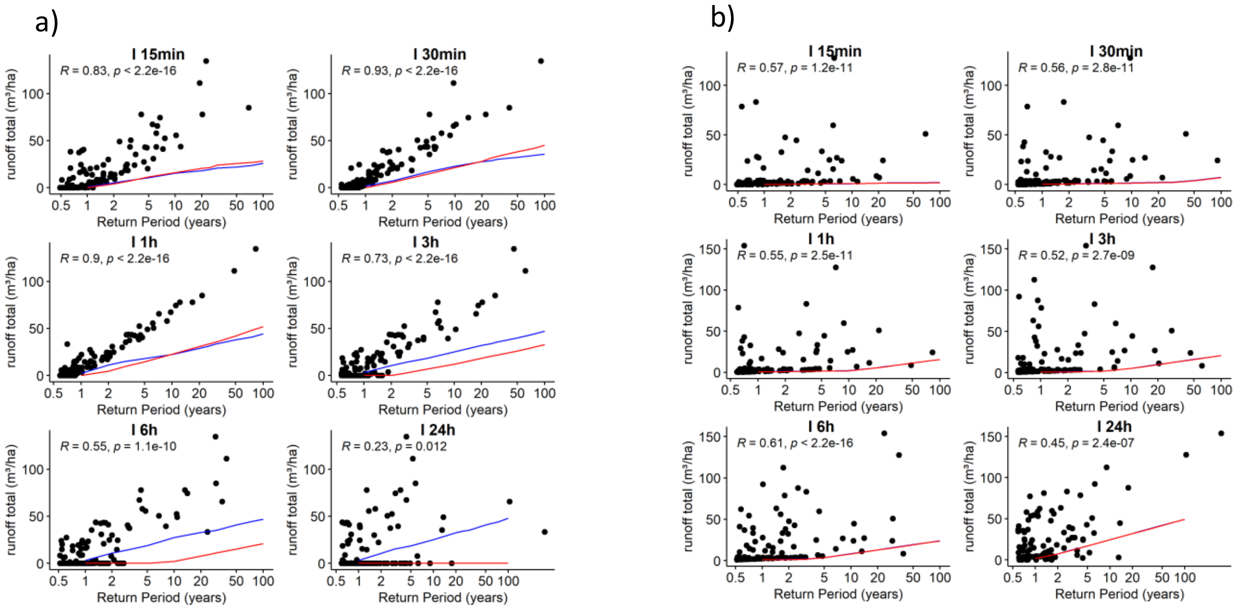

Figure 2a & b: Correlation between the return period of the IDF curve intervals of > 9000 precipitation events with the total runoff from the daycare center when stormwater is managed by a dry swale (2a) and a green roof (2b). The coloured lines show total runoff for single synthetic rain events of same interval length and return period, with an even rainfall distribution (red) and a Euler II distribution (blue). Note that most of 9000 precipitation events do not lead to any runoff.

Conclusions and future work

The preliminary work shows that runoff characteristics of SUDS are only partly dependent on rainfall characteristics and that other factors like conditions at the beginning of the event are relevant. Therefore, the design of SUDS with single synthetic rainfall events can be misleading.

A systematic analysis of possible malfunctions (potentially in relation to maintenance) can further complement the planning of stormwater management.

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References

Funke, F., Matzinger, A., Gunkel, M., Nenz, D., Schulte, P. A., Reichmann, B., & Rouault, P. (2019). Partizipative Regenwasserkonzepte als wirksames Element zur Gestaltung klimaresilienter Städte. Wwt Modernisierungsreport 2019/20, 6–10.

Gironás, J., Roesner, L. A., Rossman, L. A., & Davis, J. (2010). A new applications manual for the Storm Water Management Model (SWMM). Environmental Modelling and Software, 25(6), 813–814. https://doi.org/10.1016/j.envsoft.2009.11.009

Glugla, G., Goedecke, M., Wessolek, G. and Fürtig, G. (1999) Long-term runoff and water balance calculation in urban Berlin (in German). Wasserwirtschaft 89, 34-42.

Matzinger, A., Schmidt, M., Strehl, C., Nickel, D., Pallasch, M., Kaiser, D., Möller, C., Lessmann, D., Tils, R.v., Säumel, I., Winkler, A., Heinzmann, B., Reichmann, B., Sonnenberg, H., Rehfeld-Klein, M. and Rouault, P. (2017) Integrated planning of urban stormwater management - Introduction to the KURAS-approach from Berlin, Germany. ICUD, 1881-1887.

Nenz, D., Trapp, J., Matzinger, A., Funke, F. and Rouault, P. (2019). Potenziale grau-grün-blau gekoppelter Wasserinfrastrukturen für die Gestaltung zukunftsfähiger und klimagerechter Städte - Ergebnisse eines strategischen Planungsprozesses in einem Pilotquartier, Aqua Urbanica. HSR Hochschule für Technik Rapperswil, Rigi Kaltbad, Schweiz. 165-170.

Schubert, R.-L., Sperling, K., Cardot, N., Kaiser, D., Köhler, M., Schmidt, M., Riechel, M. and Matzinger, A. (2015). Monitoring of runoff water quality from green and gravel roofs with bitumen membranes., 17th IWA International Conference on Diffuse Pollution and Eutrophication (DIPCON), Berlin.

Trapp, J. H., Nenz, D., Matzinger, A., Rouault, P., Gunkel, M., & Reichmann, B. (2019). Planungsprozesse in der wasser sensiblen und klimagerechten Stadt. Blau-grün-grau gekoppelte Infrastrukturen in der Planungspraxis am Beispiel Berlin. Korrespondenz Abwasser, Abfall, 66(11), 929–934.

Wong, T. H. F., & Brown, R. R. (2009). The water sensitive city: principles for practice. Water Science & Technology 60(3), 673–682.