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Impact of urban drainage malfunctions and blue-green measures on urban flooding

Impact des dysfonctionnements du drainage urbain et des mesures de la trame verte et bleue sur les inondations urbaines

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RÉSUMÉ

Les dysfonctionnements des infrastructures de drainage urbain et les mesures de la trame verte et bleue ont été étudiés à l'aide d'un modèle intégré 1D/2D d'inondation urbaine (PCSWMM) quant à leur influence sur les inondations urbaines. Un total de 14 scénarios différents (référence, dysfonctionnements et mesures) ont été analysés avec des événements pluvieux de conception ayant des périodes de retour de 1 à 100 ans. L'étude de cas est la petite ville de Feldbach (Autriche), d'une superficie de 1,3 km², qui a récemment été touchée par des inondations urbaines. Les résultats montrent que les dysfonctionnements des infrastructures de techniques grises de drainage urbain peuvent avoir une influence significative sur la zone inondée, alors que les dysfonctionnements des infrastructures de la trame verte et bleue n'ont pas d'influence significative. Deux scénarios de référence montrent l'importance disproportionnée des caractéristiques des précipitations par rapport aux inondations urbaines qui dépassent tous les scénarios de dysfonctionnement. Toutes les mesures bleu-vert testées n'ont qu'un impact mineur sur les zones inondées et ne suffisent pas à elles seules à prévenir les événements futurs.

ABSTRACT

Malfunctions in urban drainage infrastructures and blue-green measures for stormwater management were investigated with an integrated 1D/2D urban flood model (PCSWMM) regarding their influence on urban flood risk. A total of 14 different scenarios (Reference, Malfunctions and Measures) were analysed with design rainfall events with return periods between 1 and 100 years. The case study is the small city of Feldbach (Austria), which is 1.3km² large and was recently affected by urban flooding. The results show that malfunctions in technical grey urban drainage infrastructures can have a significant influence on the flooded area, whereas malfunctions in decentralized blue-green infrastructures have no significant impact. Two reference scenarios show that changes in precipitation characteristics outweigh all malfunction scenarios. All tested blue-green measures have only a minor impact on flooded areas and are not sufficient on their own to prevent future flooding events. Consequently, results indicate that blue-green stormwater management options are robust to malfunctions, but currently are not designed in a way to prevent flooding for extreme design events.

KEYWORDS

(heavy rainfall, integrated 1D/2D modeling, urban drainage malfunctions, urban flooding)

1 INTRODUCTION

Urban drainage systems are exposed to a number of external factors that can have a negative impact on their performance and increase the risk of urban flooding. These include changing precipitation characteristics as a result of climate change (Hosseinzadehtalaei et al., 2020), an increase in the connected sealed area due to advancing urbanisation (Tscheikner-Gratl et al., 2019), but also a series of technical errors and operational failures in centralised and decentralised infrastructures (Mugume et al., 2015). With an increasing share of decentralised urban drainage systems and uncertainties regarding responsibility and their maintenance and care, as well as a progressive ageing of centralised systems that are often inspected and maintained too infrequently (Lashford et al., 2019), an increase in technical errors and operational faults can be assumed. Based on this problem, malfunctions and operational failures in centralised and decentralised urban drainage systems of a small municipality in Austria were investigated using a coupled 1D/2D urban flood model. In addition, the extent to which blue-green infrastructure is able to prevent urban flooding is investigated with 4 measure scenarios. All scenarios are calculated with design rainfall events of different return periods and compared with two reference scenarios.

2 METHOD

2.1 Case study

The case study of this research is the municipality of Feldbach (13 000 inhabitants) in Austria, which has a small urban center in the north and adjacent suburban areas in the south (Fig. 1). The investigated area is 1 km² in size, has a sealing rate of 47% and is bordered by the river Raab in the north. The following characteristics are particularly relevant for flood modeling in the study area: i) the urban area is affected by surface runoff from the adjacent slopes in the south, which are intensively used for agriculture, ii) two small streams (Aderbach, Oeder Bach), are drained into the Raab via the drainage system in the urban area, and iii) soils with poor infiltration capacity (silty loam), which prevent the infiltration of rainwater. In the study area, there are comparatively few blue-green urban drainage infrastructures, with 6 green roofs, about 3,000 m² of permeable pavement, one retention basin and 6 attenuation storage systems. The majority of the area is managed by a combination of storm and combined sewers that discharge into the three watercourses.

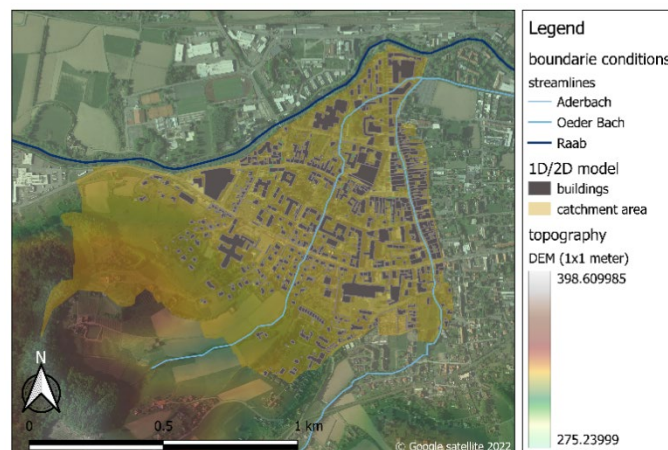


Figure 1: Overview map of the urban study site Feldbach (Austria), including the relevant streams (Raab, Aderbach and Oeder Bach) and the digital elevation model (DEM) used for the integrated 1D/2D model (resolution 1x1 meter).

2.2 Model approach

The coupled 1D/2D urban flood model was created using the software PCSWMM2D and enables to reproduce water levels and flow velocities on the surface and in the drainage system (Abdelrahman et al., 2018). The model represents the hydraulic and hydrological processes on three levels: i) the hydrological model, which calculates the runoff hydrograph from precipitation as input to the 1D and 2D hydraulic models with considering the Low Impact Development (LID) approach of SWMM 5.1 (Rossman, 2015), ii) the 2D hydraulic model, which represents the flow processes at the surface, and iii) the 1D hydraulic model, which simulates the runoff in the drainage system. The model, inundation areas and flow velocities were validated with a heavy rain event in summer 2020

(56-79mm/1h), using information on affected buildings and observed water levels based on photos and videos from a flood documentation and fire brigade protocols.

2.3 Scenarios

A total of 14 different scenarios were created for the case study: i) the base scenario, which represents the current situation, ii) two reference scenarios with modified precipitation characteristics, iii) 7 malfunction scenarios in urban drainage systems and iv) 4 blue-green infrastructure measure scenarios which represent a large-scale implementation of blue-green infrastructure (Tab. 1). Each scenario was run with design rainfall events with a Euler-II distribution and an interval length of one hour as well as return periods between 1 and 100 years. The effects of the scenarios are examined on the basis of 5 flood hazard classes which take into account water depths and flow velocities (Smith et al., 2014).

Table 1: Description of the Reference, Malfunction and Measures Scenarios

Scenario type	Scenario name	Description
Reference Scenarios	Climate Change	Increased rainfall depth of the design rainfall event
	Wet Precondition	6-hour continuous rain before a design rainfall event
Malfunctions in technical grey infrastructures	River flood	CSO blockage due to river flood
	Blocked Inlets	Blocked street inlets due to leaves, rubbish or snow
	Log jam	Log jam of the stream inlets into the drainage system
	Conduit blockage	Conduit blockage due to drought, root intrusion or lack of maintenance
Malfunctions in SUDS and green infrastructures	Green roof substrate erosion	Erosion of green roof substrate due to storms, lack of maintenance or drought
	Permeable pavement clogging	Clogging of permeable pavements due to sediment accumulation
	Sedimentation retention pond	The storage volume of the retention pond is reduced by erosion of embankments and deposition of foreign material
	Misuse attenuation storage tank	The storage volume of the attenuation storage tank is reduced by misuse or design faults
Blue-green infrastructure measure scenarios	Attenuation storage system	Runoff from all buildings is treated by a storage system with a throttle back to the main sewer
	Green roof (all roofs)	All roofs in the study area are equipped with an extensive green roof
	Green roof (flat roofs)	All flat roofs (< 5°) in the study area are equipped with an extensive green roof
	Permeable pavement	All sealed surfaces in the study area which are not streets or roofs are converted to permeable pavement (e.g. pavements, parking spaces, squares etc.)

3 RESULTS AND DISCUSSION

For the actual state (base scenario) of the case study Feldbach and the other scenarios investigated, clearly increasing inundation areas are shown with increasing return period of the design rainfall event. For a 100-year design rainfall, the base scenario shows a flooded area of 19.5ha (24% of the total area) (Fig. 2). Compared to the base scenario, both reference scenarios, climate change and wet preconditions, show a significant increase in flooded areas over all return periods.

For the malfunction scenarios in technical grey infrastructures, all investigated scenarios show an increase of the flood area compared to the base scenario. The conduit blockages show the strongest impact with a significant increase in the higher risk classes (high, very high and extreme risk). Malfunctions in blue-green infrastructures show little to no changes in the flood area. Three of the four measure scenarios, the attenuation storage system and both green roof scenarios, show very little reduction in flood area for the 100-year rainfall event. Only the widespread implementation of permeable pavement results in a significant reduction in flood area compared to the base scenario, but is also not sufficient to prevent widespread urban flooding during an extreme event.

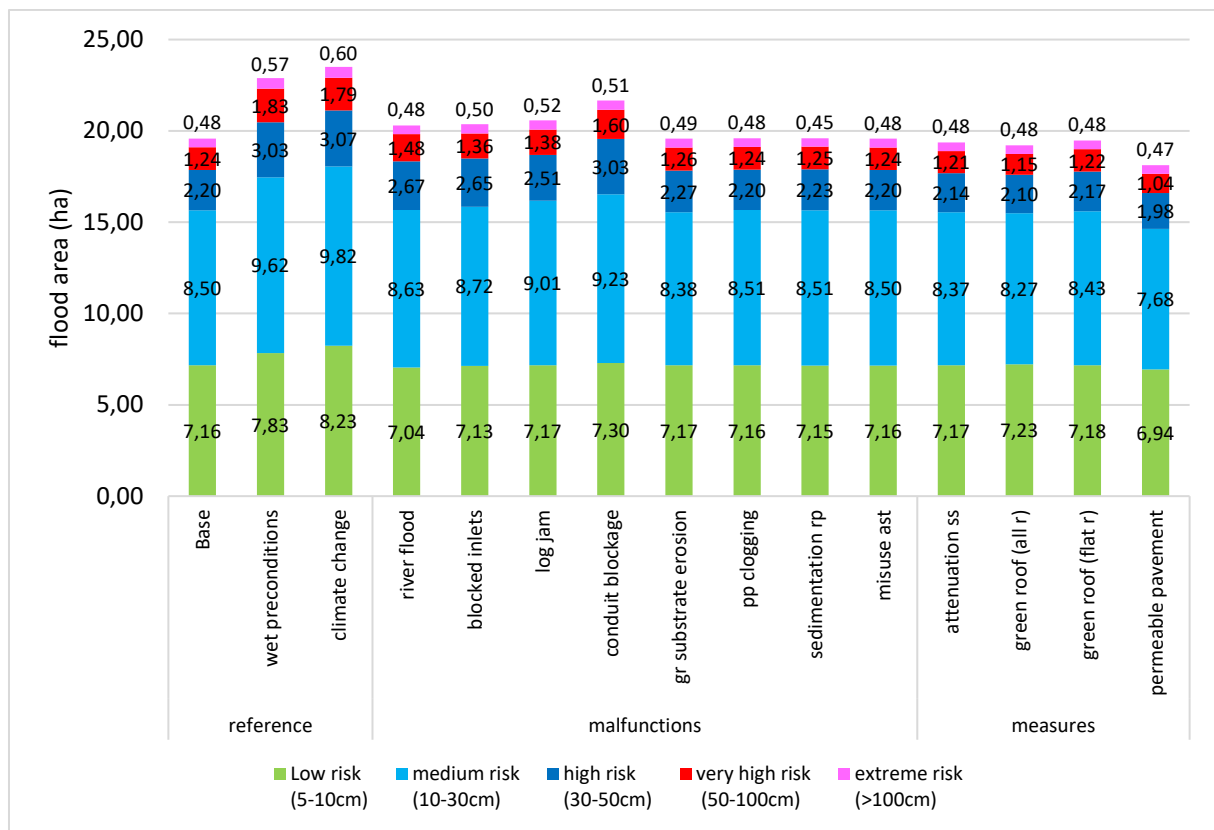


Figure 2: The figure shows the flood area for a 1h 100-year design rainfall event for the reference, malfunction and measure scenarios in the case study Feldbach. The flood area is divided into 5 risk classes based on maximum water depth and flow velocities.

Preliminary results only show scenarios where all infrastructures are affected (e.g. conduit blockage in all pipes or attenuation storage systems for all buildings), while in a next step we want to capture the uncertainty of malfunctions and measures by varying the number of affected infrastructures. This will give a better picture of the potential effect of malfunctions and measures in regard to urban flooding.

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