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► **To cite this version:**

Valentin Gamerith, Miriam Monschein, Manfred S Weiss. Quantifying urban flash flood risk in a 1d-2d-model setup. Novatech 2023 : 11e Conférence internationale sur l'eau dans la ville, Jul 2023, Lyon, France. ⟨hal-04176900⟩

**HAL Id: hal-04176900**

**<https://hal.science/hal-04176900v1>**

Submitted on 3 Aug 2023

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## Quantifying urban flash flood risk in a 1d-2d-model setup

### Quantification des risques d'inondations urbaines par un modèle 1d-2d intégré

Valentin Gamerith<sup>1</sup>, Miriam Monschein<sup>2</sup>, Manfred Weiss<sup>3</sup>

<sup>1</sup>Independent researcher, Bergstraße 23a, A-8062 Kumberg, Austria  
[valentin.gamerith@yahoo.com](mailto:valentin.gamerith@yahoo.com)

<sup>2</sup>Graz University of Technology, Institute of Hydraulic Engineering and Water Resources Management, Stremayrgasse 10/II, A-8010 Graz, Austria  
[miriam.monschein@tugraz.at](mailto:miriam.monschein@tugraz.at)

<sup>3</sup>Hydroconsult GmbH, Reininghausstraße 78, A-8020 Graz, Austria  
[weiss@hydroconsult.net](mailto:weiss@hydroconsult.net)

#### RÉSUMÉ

Les inondations urbaines ont entraîné des risques et des dommages importants aux habitations et aux infrastructures dans les villes européennes au cours des dernières décennies. Dans le cadre du projet Interreg «Rainman», des modèles hydrauliques intégrés 1d-2d ont été implémentés pour évaluer des risques pour plusieurs bassins versants. Les résultats d'une étude pilote sur un bassin versant de la ville de Graz, Autriche sont présentés dans cette contribution. Un modèle intégré pour la modélisation des précipitations et du ruissèlement, utilisant un modèle hydrodynamique 2d pour l'écoulement sur la surface et un modèle hydrodynamique 1d pour l'écoulement dans le système d'assainissement ont été mis en place. Afin de créer des cartes de risques basées sur les résultats des simulations, une analyse des dommages potentiels a été réalisée et la vulnérabilité en fonction de l'objet a été définie. La classification des risques est basée sur des matrices de risques qui relient la vulnérabilité respective avec le danger de chaque objet ou zone. Des cartes de risque ont été créées pour des précipitations de différentes périodes de retour. Les résultats ont été discutés avec les différentes parties prenantes et comparés aux événements historiques et aux dommages enregistrés. La carte elle-même s'est avérée être un outil facilement compréhensible et lisible, même pour les parties prenantes qui ne sont pas familières avec les modèles ou les hypothèses sous-jacentes.

#### ABSTRACT

Urban flash floods due to heavy storm events lead to significant risks and damage to housing and infrastructure in European cities over the last decades. In scope of the Interreg project "Rainman", pilot studies for risk assessment were conducted for several catchments using an integrated model by coupling a runoff generation method, a 2d-hydrodynamic surface runoff model and a 1d-hydrodynamic sewer runoff model. This contribution discusses the results for one pilot catchment in the City of Graz, Austria. In order to create risk maps based on the simulation results, a hazard analysis for buildings and for personal injury was conducted and object-dependent vulnerability was defined. The risk classification is based on risk matrices that link the respective vulnerability with the hazard of each object or area. Risk maps were created for rainfalls of different return periods. The results were discussed with different stakeholders and compared to past events and registered flooding or damages. The map itself proved to be an easily understandable and readable tool - also by stakeholders not familiar with the underlying models or assumptions.

#### KEYWORDS

integrated 1d-2d modelling, risk analysis, risk mapping, urban flash floods

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## 1 INTRODUCTION

Over the last decades, an increase in urban flash floods can be observed (Schmitt 2011), leading to significant risks and damage of housing and infrastructure. Current climate models show a possible increase of heavy rainfall intensities in a range of 6 to 7 % per 1°C of global warming (Ban et al. 2015). In an urban context, modelling of these events recently became more frequent; Price and Vojinovic (2011) provide an exhaustive overview of possible simulation methods and model approaches.

In scope of the Interreg project “Rainman”, tools were developed to assess and reduce the risk of urban flooding. A guideline for model based urban flood prevention (Leitner et al. 2020) was proposed and evaluated in several pilot studies. This contribution details on the methods and results obtained for one pilot catchment in the city of Graz, Austria with coupled 1d-2d-hydraulic model where flooding occurred regularly over the last years resulting from both surface runoff and sewer surcharge.

## 2 MATERIALS AND METHODS

### 2.1 Catchment and data

The pilot catchment „Schloss Eggenberg“ (Figure 1) is situated in the city of Graz, Austria. The western part of the 1.3 km<sup>2</sup> catchment is hilly terrain (mainly woodland), flattening out to the east. The flat areas are urbanized with a heterogeneous structure of detached houses to apartment buildings. The urbanized part is drained by a combined sewer system.

Data on topography was available as digital elevation data. Polygons of buildings, aerial view photos, land use data and information on documented flooding were provided. Terrestrial survey of hydraulic relevant structures was conducted based on i) a GIS analysis of the major flow paths and ii) a field visit. Data on the sewer system was provided by the municipality of Graz. No measurement data on rainfall or runoff was available for the catchment or in the sewer system.

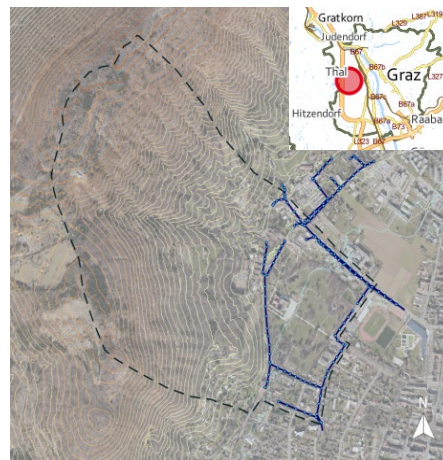


Figure 1: Overview of pilot catchment with boundaries (dashed black) and sewers (blue). Top right: Location of the catchment in Graz (marked in red). (Aerial view photo and base map: [basemap.at](https://www.basemap.at))

### 2.2 Integrated 1d-2d model

An integrated model for runoff generation, 2d-hydrodynamic surface runoff and 1d-hydrodynamic sewer runoff was set up for this study. In a first step, a triangulated mesh was generated for the catchment based on airborne laserscan data. Terrestrial survey data for hydraulic relevant structures was implemented and a material class was defined for each element based on land use and aerial view photos.

**Runoff generation** was calculated by the SCS-CN method (US-SCS, 1972). A curve number (CN) value was assigned to each mesh element, based on the material classes. The values were chosen a-priori based on literature values and experience from similar catchments. Hyetographs for effective rainfall were calculated for each CN value. For simulation of the return periods of interest (10, 30 and 100 years), synthetic rainfall events for different durations were derived from local intensity–duration–frequency rainfall curves.

**Simulations of runoff concentration** on the surface were conducted with a 2d-hydrodynamic model based on the shallow water equations (Hydro\_As-2D 4.2.0). An input hydrograph was calculated based the effective rainfall and the surrounding area in each model node. As surfaces act rougher for sheet flows (USDA, 1986), the Strickler roughness values were define as water depth dependent.

**Runoff in the sewer system** was calculated with a 1d-hydrodynamic sewer model in EPA SWMM 5.1. Only the existing roof areas were connected directly to the sewer model.

For **Model coupling** an interface was coded in R Project using the swmmr package (Leutnant et al. 2019). The coupling was done sequentially in an iterative simulation. Mesh nodes were defined at the

manhole positions of the sewer system. In each of these nodes in the 2d-surface runoff model an inflow (surface flooding from sewer system model) or outflow (surface runoff drains into the sewer system where sewer system not overloaded) was defined. In the sewer network model, inflows were implemented if there is i) no surface flooding from the sewer system and ii) a surface runoff in the respective 2d-mesh node. A **local sensitivity analysis** was conducted for the parameters CN-value and roughness coefficient (Strickler value) and for the rainfall distribution of the synthetic rainfall events. The results are presented in Monschein and Gamerith, 2020.

## 2.3 Risk classification

In order to create risk maps based on the simulation results, a hazard analysis was conducted and object-dependent vulnerability was defined.

The **hazard analysis** was carried out i) for possible damage to buildings and structures based on the calculated water depth and ii) for the personal injury hazard, based on the calculated water depth and the flow velocity. Hazard maps for buildings were created from overlay of simulated water levels and the building layer in the software QGIS 3.8.3. Each building was assigned one of four hazard classes (low, average, high and very high) based on the adjacent water depth as defined in the DWA-M 119 guideline (DWA, 2016). A similar approach was chosen for the area definition of personal injury hazard based on CHLwater (2019), where both water depth and flow velocity define the hazard classes.

**Vulnerability** was defined for each building and area based on building/area type according to the classification given in the DWA-M 119 guideline (DWA, 2016) and in Leitner et al. (2020). The corresponding building type and area classification were determined by aerial view photos and on-site visits and assigned to each building/area in QGIS.

The **risk classification** is based on risk matrices that link the respective vulnerability with the hazard of each object or area. The matrices also take the probability of occurrence of the precipitation events (return period) into account. Table 3 shows an exemplary risk matrix for a return period of 30 years. The risk class of each building and area was calculated based on the underlying risk matrices using a specially developed Python script in QGIS. Risk maps were created for each investigated return period with color-coded result of the risk for buildings and personal injury.

Table 1 : Risk matrix for 30-year return period

		Vulnerability (buildings)			
		low	average	high	very high
Hazard	low	low	average	high	high
	average	average	average	high	very high
	high	average	high	high	very high
	very high	average	high	very high	very high

## 3 RESULTS AND DISCUSSION

### 3.1 Simulation results

The simulation results showed that a sensible choice of model parameter values for both the hydrological and the hydraulic models is crucial. Even relatively small changes in parameter values within reasonable boundaries (+/- 10 %) showed significant impact on the results (e.g. + 42 / - 24 % change in the resulting peak discharge) and risk classification. The same was valid for the chosen synthetic rainfall distribution.

It can be expected, that – as for this study – high-resolution calibration data is rarely available for similar catchments. A sensitivity analysis and a plausibility check (e.g. with empirical runoff values, expert knowledge from prior events) is therefore advocated. Additionally, existing structures can have significant impact on the flow behaviour and need to be charted and incorporated in the models.

Regarding the coupling of the 1d-sewer system and the 2d-surface runoff model, results of the pilot study showed that runoff in the sewer system – resulting from both the connected roof surfaces and the inflow via the manholes – is significantly lower than the total surface runoff. This was to be expected for the catchment structure with a large proportion of the contributing area from the steeper woodland areas.

However, in the flatter, urbanized areas, coupling of the 2d-surface runoff and the 1d-sewer model locally showed significant impacts. At several points in the system, a relevant flooding from the sewer

system occurs, leading to significantly higher water depths and therefore higher hazard classification at certain locations compared to modelling the system separately.

### 3.2 Risk mapping

Risk maps were created for all four examined return periods for both the i) risk classification for buildings and structures and ii) areas with risks of personal injuries. All risk maps included a color-coded classification of the risk. Risk maps for risk classification of buildings also included the calculated water depth (maximum depth in each mesh node for the simulation period). For the pilot study catchment, highest risk classes were obtained for the 30-year return period event. Figure 1 shows an exemplary outtake of the risk map (buildings) for the return periods 10 and 30 years.



Figure 2: Outtake of risk map for return period 10 years (left) and 30 years (right) (Aerial view photo: [basemap.at](https://basemap.at))

The results were discussed with different stakeholders and compared to past events and registered flooding or damage. The map itself proved to be an easily understandable and readable tool - also by stakeholders not familiar with the underlying models or assumptions. Overall classification of hazards, vulnerability and risk based on the automated evaluation of the simulation results and the available data via scripts and GIS-tools worked satisfactorily. However, as for all automated routines, a plausibility check based on site knowledge proved to be indispensable.

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