Simulation of heavy precipitation in urban areas: a multi-level approach

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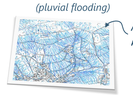
A Introduction

- While long and continual rainfall events lead to riverine flooding (fluvial floods), heavy rainfall events are able to cause flooding in any urban area (pluvial floods).
- For this reason, there are essentially two types of hazard maps in Germany:

Flood hazard maps *(fluvial flooding)*

Legal requirement

Heavy rainfall hazard maps *(pluvial flooding)*



No legal requirement

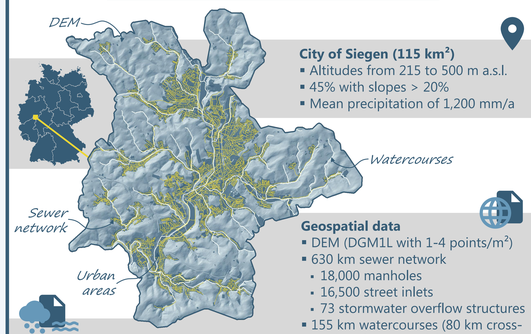
- These maps, however, just consider the effects of either pluvial or fluvial events, i.e. only represent a part of the entire hydraulic system.

- **The project SiSSi aims at developing a methodology to consider physical as well as statistical dependencies of pluvial and fluvial flooding processes.**

- In this context, the following questions shall be answered:
  - ***Which regions of the study area are at risk due to either pluvial or fluvial flooding?***
  - ***What kind of influence does the river discharge have on the surface water runoff and the efficiency of the sewer network? How does the surface flow influence the discharge in the watercourses?***
  - ***Can the simultaneous occurrence of two less extreme fluvial and pluvial events with a certain joint probability of occurrence cause greater flooding than a single extreme fluvial or pluvial event of equal probability?***

- **To answer these questions, bidirectionally coupled hydrodynamic-numerical models will be set up and multivariate statistical analyses carried out. Here we present the current status of the work.**

B Study area and data



City of Siegen (115 km²)
- Altitudes from 215 to 500 m a.s.l.
- 45% with slopes > 20%
- Mean precipitation of 1,200 mm/a

Geospatial data
- DEM (DGM1L with 1-4 points/m²)
- 630 km sewer network
  - 18,000 manholes
  - 16,500 street inlets
  - 73 stormwater overflow structures
- 155 km watercourses (80 km cross-sections by terrestrial survey)
- Landuse data (Basis DLM)
- Building data (ALKIS® NRW)

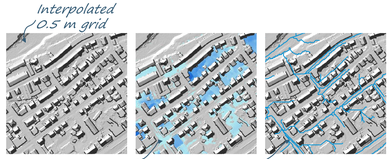
Hydrometeorological data
- 29 precipitation gauges with an average time series length of 18 yrs
- 10 hydrographs with an average time series length of 42 yrs
- Rainfall intensity tables (KOSTRA-DWD 2010R)
- 5-min radar data (RADKLIM-YW)

C Main steps

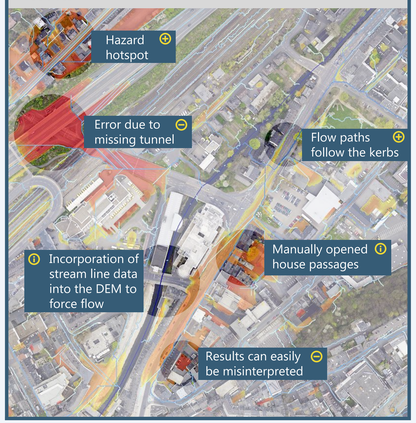
1. Data collection and preparation
2. GIS-based DEM analyses
3. 1D sewer network model
4. 2D surface and stream model
5. Coupling of the 1D/2D models
6. Statistical analyses

D GIS-based DEM analyses

- In order to assess the data basis and to obtain initial information on the flood hazard (e.g. potential hazard hotspots), sinks and the flow accumulation were calculated.
- The analyses were carried out using the MATLAB®-based TopoToolbox 2 (*Schwanghart & Scherler, 2014*) with a single flow direction approach.



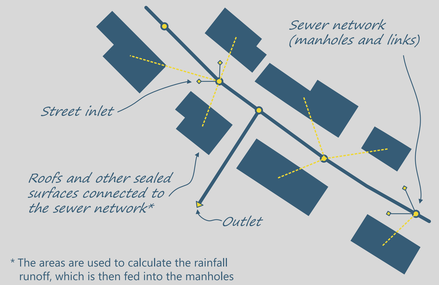
Results



E Hydrodynamic-numerical model approach

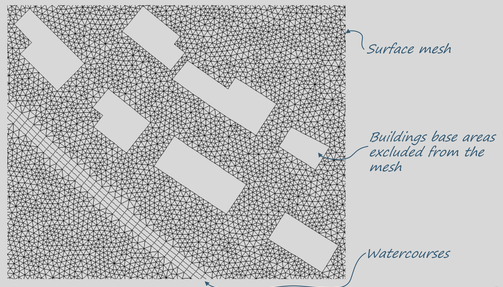
Models

1D sewer network model *(MIKE URBAN)*



* The areas are used to calculate the rainfall runoff, which is then fed into the manholes

2D surface and stream model *(MIKE 21)*



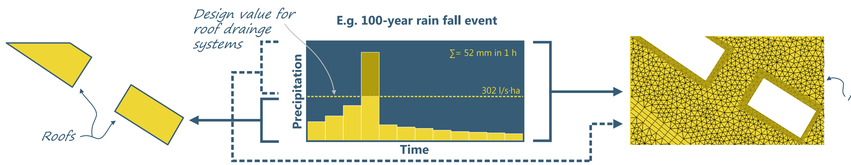
Manholes (○)
Strees inlets (□)
Outlets (▽)

Coupling of the 1D/2D models *(MIKE FLOOD)*

Corresponding mesh elements

ⓘ The **computation** of both models takes place **simultaneously and bidirectional**, i.e. **water exchange** between both models and **in both directions** is possible.

Hydrological input



The rain height difference is distributed in a buffer zone around the buildings base areas.

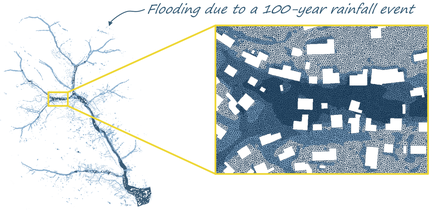
Calibration

1. To calibrate and validate the coupled 1D/2D model specific rainfall events (5-min rainfall radar data) will be used as model input.
2. The simulated discharges in the sewer network will be compared to continously measured discharges at certain stormwater overflow structures.
3. Possible calibration parameters are for instance the imperviousness and roughness of the surfaces, time of concentration (roof runoff) and the coupling parameters of the street inlets (e.g. calculation method, inlet area, max. inflow).

Simulation

According to MUNLV (2018) at least three heavy rain scenarios should be simulated:
- 1. Rare event, more frequently than a 100-year event but still significantly exceeding the dimensioning of the sewer network, e.g. 50-year event
- 2. Extraordinary event, i.e. 100-year event
- 3. Extreme event, i.e. 90 mm in 1 h

ⓘ In order to consider the interactions with the watercourses, first a mean annual discharge is assumed. In a second step, the effects of higher discharges are also taken into account.



F Discussion and outlook

- The data required for the analyses are partly available in high quality and free of charge (e.g. DEM, landuse data, building data; https://open.nrw/).
- The results of the DEM analysis (preliminary study) show numerous hazard hotspots in the urban area. However, due to various methodological uncertainties, these simplified analyses cannot replace hydrodynamic-numerical models.
- In order to reduce the modelling uncertainties, a detailed modelling approach is used for the 1D and 2D model that comes close to the real conditions (e.g. runoff generation and coupling).
- However, detailed analyses also require precise data. For instance height deviations between the manhole covers and the DEM lead to coupling problems.
- Due to height inaccuracies of the DEM in the area of water bodies (up to 1.5 m) and bridges, extensive surveying work is currently being carried out for roughly 80 km watercourses.
- Currently the 2D surface and stream model is being built. In the next step it will be coupled with the sewer network to perform the simulations.
- Based on the simulation results, extensive sensitivity analyses and statistical analyses will be carried out.

References

MUNLV (2018): Arbeitshilfe kommunales Starkregenrisikomanagement Hochwasserrisikomanagementplanung in NRW. Ministerium für Umwelt, Landwirtschaft, Natur- und Verbraucherschutz des Landes Nordrhein-Westfalen, Düsseldorf.

HSB (2017): Ermittlung von Überflutungsgefahren mit vereinfachten und detaillierten hydrodynamischen Modellen. Praxisleitfaden, erstellt im Rahmen des DBU-Forschungsprojekts "KLASIL". Lehrgebiet Siedlungswasserwirtschaft, Hochschule Bremen, Oktober 2017.

Schwanghart, W.; Scherler, D. (2014): TopoToolbox 2 - MATLAB-based software for topographic analysis and modeling in Earth surface sciences. In: Earth Surface Dynamics. 2, 1-7, doi: 10.5194/esurf-2-1-2014

Data sources

DGM1L, Basis DLM, ALKIS® NRW: Land NRW (2019) Datenlizenz Deutschland - Namensnennung - Version 2.0 (www.govdata.de/dl-de/by-2-0)

GSK3c: LANUV NRW (2019) Datenlizenz Deutschland - Namensnennung - Version 2.0 (www.govdata.de/dl-de/by-2-0)

Aerial photos, Sewer network: Entsorgungsbetrieb der Stadt Siegen

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