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Influence of Flood Water Contribution from Multiple Sources in Extreme Event Statistics of Urban Flooding

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Abstract. For pluvial flood risk assessment in urban areas it is important to be able to calculate how often a specific area is at risk of flooding. This is especially evident in urban areas subject to contribution from multiple sources, e.g. surcharging drainage system, surface runoff, overflowing rivers, etc. In this study extreme event statistics are assessed by simulation of rainfall impact and consecutive statistics of flood response in order to estimate return periods of flooding. The model applied is an integrated hydraulic model which includes relevant hydrological processes that contribute to urban flooding. The setup is analysed based on a small urban catchment in Aalborg Denmark. Results show that it is possible to estimate return periods of flood volume, flood extent and local water levels based on simulation and that rainfall and hydrological conditions critical to flooding can be identified.

Keywords: Urban flooding · Extreme event statistics
Integrated hydrological modelling

1 Introduction

Urban areas are at risk of flooding from multiple sources e.g. surcharging sewer or drainage systems, surface water runoff (rainfall not able to infiltrate), ground water, rivers or streams, storm surges, etc. Since contribution of flooding might come from multiple sources at the same time it is difficult to determine statistically how often flooding might occur.

In this study we focus on pluvial contributions to flooding from impervious areas (drainage system), pervious areas (direct runoff on surface); and stream bank overflow, since they are the dominant sources to flooding in the case study area (see Sect. 2.1).

In management and design of urban infrastructure, it is important to be able to estimate the risk of flooding specific areas and to assess the return period of flood levels being exceeded (extreme event statistics). It is however difficult to determine the return periods accurately by simulating the flood response based on historical rainfall series.

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This is due to limited periods of observed rainfall, randomness in joint occurrences in flood contributions, e.g. high water level in stream at the same time as high saturation level in soil, and flood producing rainfall.

The objectives of the present study are: (i) to set up an integrated flood model in an urban area in Denmark that includes contributions from multiple sources; (ii) to identify rainfall and hydrological conditions critical to flooding from multiple sources; and (iii) to estimate return periods for local flooding, which can be used as a management tool in flood risk assessment.

2 Materials and Methods

2.1 Case Study Area and Urban Flood Model

The applied flood model is a semi-distributed integrated 1D-2D urban drainage model covering a residential area of 60 ha (Kærby) and an industrial area of 38 ha (håndværkerkvarteret). The catchment has a partly combined partly separated drainage system. The case study area is bounded by three branches of the stream Østerå.

The integrated flood model, which is implemented in the MIKE model environment includes: (i) the drainage system (1D) including pumps, combined sewer overflow structures, storage basins etc. which has contributions from the impervious parts of the catchment; (ii) the stream branches (1D); (iii) the surface runoff (2D) from pervious areas based on exceedance of soil infiltration capacity; and (iv) an overland flood model (2D) based on a digital terrain model.

2.2 Rainfall Data and Boundary Conditions

In order to derive extreme event statistics we need to consider historical rainfall series with long records. For this purpose we apply data from the Danish water pollution committee rain gauge network (Madsen et al. 2017). We develop a long-term (1979–2017) gridded dataset of 62 $\times$ 38 km^2 where hourly rainfall between a total of 73 gauges have been interpolated using ordinary kriging. This dataset will at a later point we applied to simulate rural catchment runoff (at a larger scale) with the HYPE model (Lindström et al. 2010) which again will be applied as an optimized boundary condition for the small scale model applied here. Since, we in this study focus on the urban hydrological processes at small scale, we need a finer temporal resolution and therefore apply rain gauge data from the dataset non-interpolated in space and in a 1 min resolution. We thus apply single rain gauges individually and neglect the spatial variability over the catchment. The rainfall is not representative of the true rainfall over the catchment, but another part of Denmark with similar climatological conditions and with long records, which makes it ideal for investigations of extreme event statistics of rainfall-flood response.

The selection of the most severe rainfall events is based on a two-step selection method explained by (Murla-Tuyls et al. 2018). First, rainfall-runoff simulations are performed over the study area for the complete historical rainfall series. The second step consists in performing a hydraulic network simulation using the obtained rainfall-runoff results as input. From this the events with the largest number of surcharged manholes are selected and the 38 most severe events are simulated with the full flood model.

Boundary conditions for stream base flow are based on a seasonally varying average obtained from a few years of observations. Initial conditions of soil saturation and boundary condition for rainfall on the pervious areas contributing to flooding is based on a continuous simulation of infiltration from Green-Ampt (Rawls et al. 1983).

3 Results and Discussion

Preliminary simulation results are presented in the following figures (further simulations are executed during spring of 2018). Figure 1 shows an estimation of return periods based on three output valuables from the model simulations: the number of flooded manholes, the max. flood area and the max. flood volume.

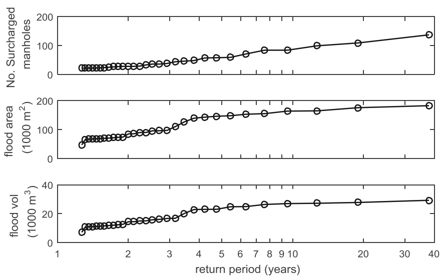

Fig. 1. Simulated no. of surcharged manholes, flood area and flood volume as function of return period.

Figure 2 (left) shows and example of a flood map for an event from June 1998. It is evident to see both flooding occurring from stream bank overflow in the eastern part of the catchment and a combination of drainage system flooding in the western part of the catchment. By ranking simulated water levels in each individual flooded cell, we can calculate the return period of flooding in a specific point. This is shown on Fig. 2 (right).

The flooding response time (Fig. 3, right), which can be considered a surrogate measure of the time of concentration, is estimated by correlating the maximum flood level in a given flood prone cell with the rainfall intensity aggregated over different durations. The flooding response time is selected for the rainfall duration with the largest correlation. (Murla-Tuyls et al. 2018). From the values of the flooding response time it is possible to identify the rainfall characteristics which are on average the most critical for flooding of a specific point in the catchment.

As an example Fig. 3 right presents correlation between rainfall intensity and flood water level in a selected point shown in the black circle of Fig. 3, left, where parts of the urban area is flooded from stream bank overflow. The best correlation between

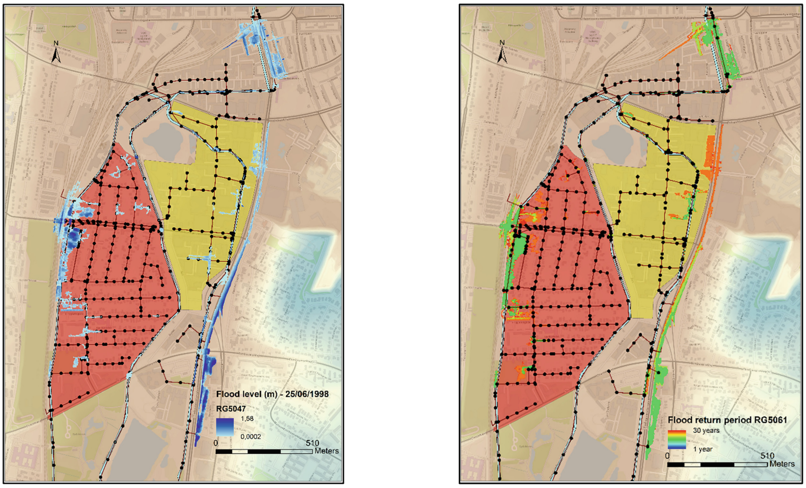

Fig. 2. Left: Example of a simulated maximum flood levels for an event on 1998.06.25; and right: estimated return period of flooding based on ranking of flood levels.

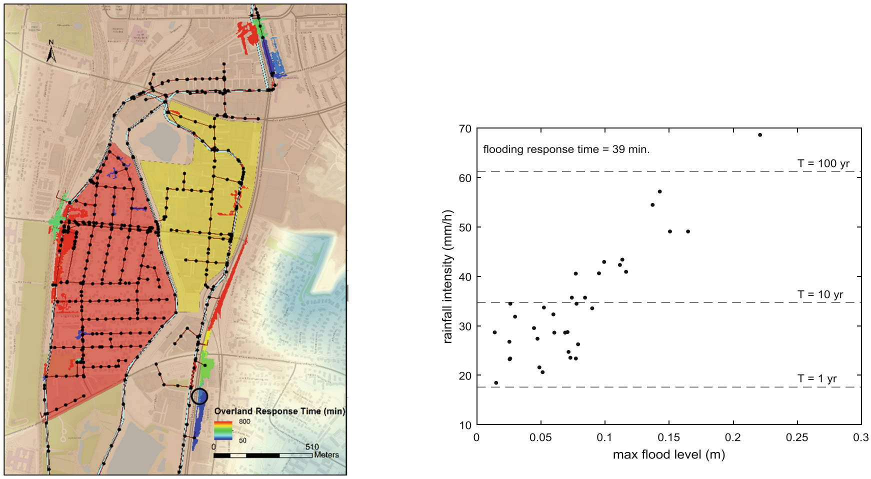

Fig. 3. Left: Estimated average flooding response time; right: rainfall intensity aggregated over 39 min. durations plotted against max simulated flood levels in a point within the black circle of the left figure.

rainfall intensity and simulated water level is found for an aggregated duration of 39 min. Moreover, return periods of rainfall corresponding to the national Danish rainfall statistics (Madsen et al. 2017) are shown. From these simulations it is evident that the point will flood with a return period of approx. 1 year.

4 Conclusions

The simulations show that it is indeed important to consider multiple sources of flood contributions in an integrated way in order to assess the return period of flooding in an urban area. In the analysis we have shown plausible ways to link rainfall statistics to flood statistics and to assess return periods of flooding locally. Further simulations and division of simulation results will show whether it is possible to assess return periods of flooding of individual cells based on their source.

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