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Partitioning spatial and temporal rainfall variability in urban drainage modelling

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1 Introduction

The performance of urban drainage systems is typically examined using hydrological and hydrodynamic models where rainfall is uniformly distributed and derived from a single rain–gauge, thus, the response of the urban drainage system to the spatio-temporal variability of rainfall remains unexplored. High resolution stochastic rainfall generators allow studying the response and sensitivity of urban drainage networks to these spatial and temporal rainfall variabilities. The goal in this study was to understand how climate variability and spatial rainfall variability, jointly or individually considered, affect the response of a calibrated hydrodynamic urban drainage model.

2 Method Overview

A schematic illustration of the methods used in this study is presented in Fig. 1. A stochastic high resolution rainfall generator (STREAP) was used to simulate many realizations of rainfall for a period of 30 years, accounting for both climate variability and spatial rainfall variability. The generated rainfall was then used as input into a calibrated hydrodynamic model (EPA SWMM) to simulate channel flow for a small urban catchment. The variability of peak flows in response to rainfall of different return periods was evaluated and partitioned among it sources (Fig. 2).

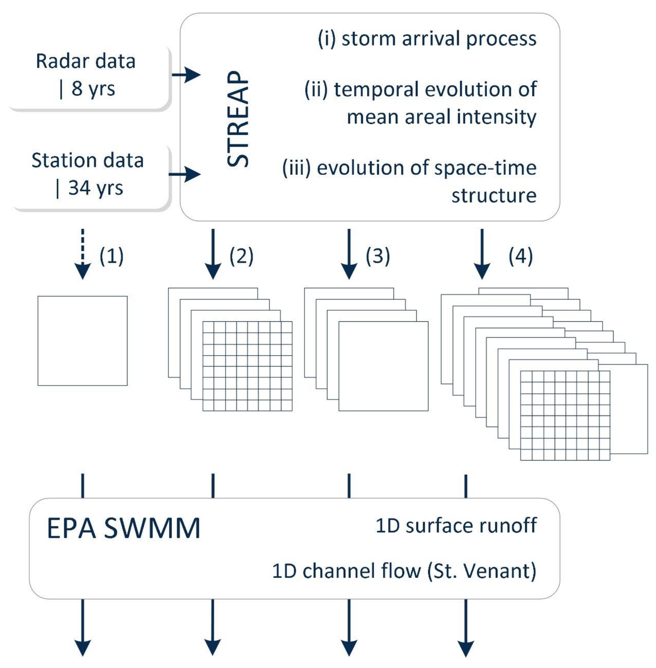

Fig 1. A schematic illustration of the methods used in this study.

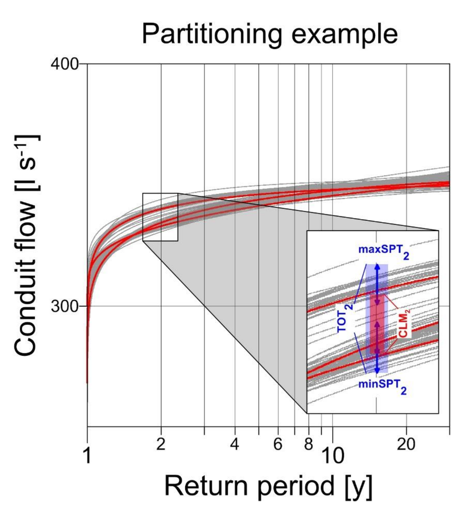

Fig 2. An example for the partition method. 3 climate trajectories are plotted (red lines) for which the 5–95 quantile range is calculated (red area). For each climate trajectory, 30 spatial realizations are plotted (grey lines). The 5–95 quantile range is then calculated for each of the 30 spatial realizations (plotted as blue arrows) and the total variability (blue area) is defined by bounding the maximum and minimum flows defined by the spatial variability. The partition of the climate variability out of the total variability is then calculated as a simple division between the two.

3 Case Study

The case study is located near the city center of Lucerne, Switzerland (Fig. 3).

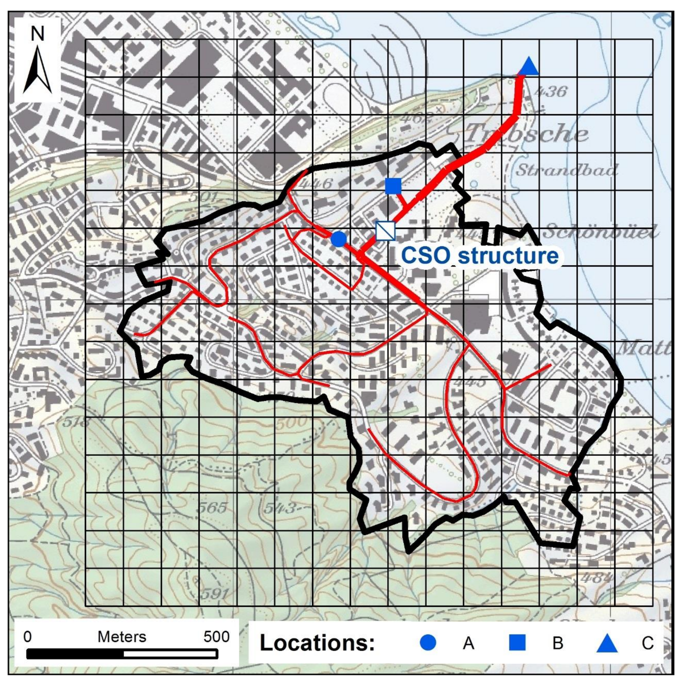

Fig 3. The black mesh represents the domain for which stochastic rainfall was generated (cells of 100 x 100 m^2). The red lines represent the drainage system (thicker lines per pipe diameter) and point A (inner network node), B (carry-on flow) and C (combined sewer overflow) represent the location for which the flow analysis was conducted.

4 Rainfall Cases Classification

Four rainfall cases were defined in order to account for climate variability and spatial rainfall variability:

Case 1: Consists of one time series of rainfall derived from a single rain–gauge, i.e. same rainfall intensity was assigned to all sub-catchments for a given time step.
Case 2: consists of 30 realizations of the same time series that was used in case 1, but spatially distributed using STREAP.
Case 3: consists of 30 realizations of uniformly distributed rainfall of 30 years generated by STREAP.
Case 4: consists of 900 realizations, each of the 30 realizations that were generated for case 3 were re-generated 30 times using STREAP.

5 Results

Computed IDF (rain) and FDF (flow) curves and the contributions of individual rainfall variabilities to the modelled sewage flow variability at location B are presented in Fig. 4. The partitioning of the flow variability was conducted for all three locations and is presented in Fig. 5.

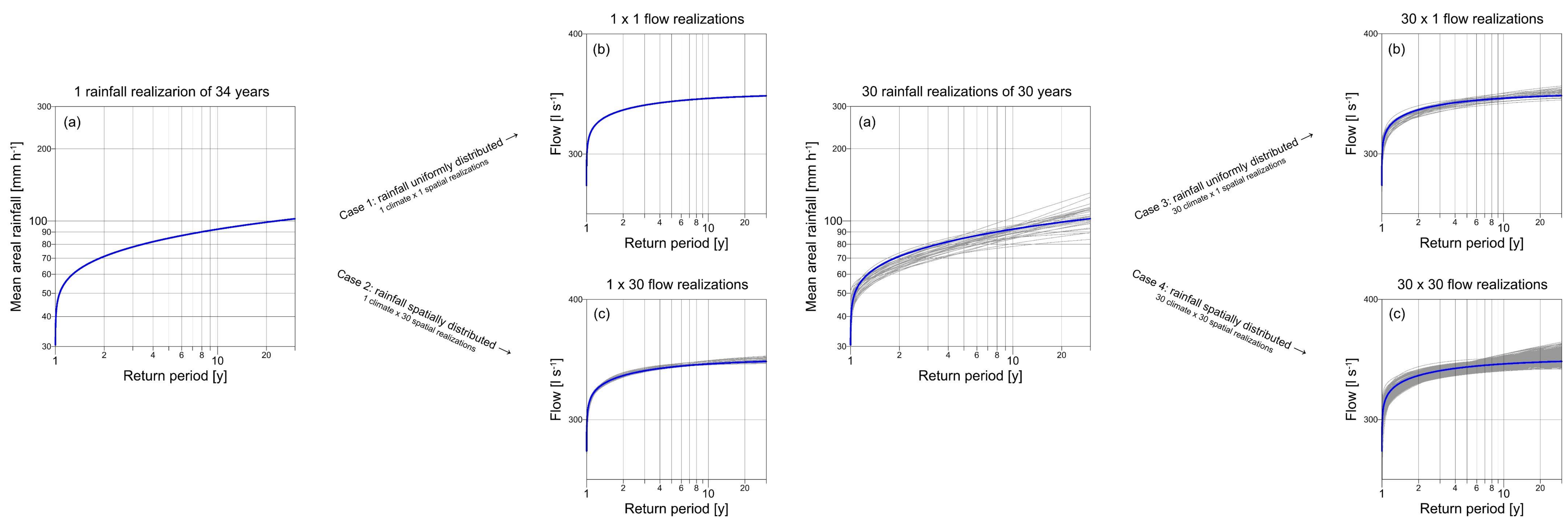

Fig 4. Left panel: rainfall and flow results for cases 1 and 2. (A), the IDF curve computed for the mean areal rainfall over the catchment. (B) and (C), FDF curves. Blue line represents the IDF curve and the FDF curves computed from the observed uniformly distributed rainfall. Gray lines represent the FDF curves computed for the realizations with spatial rainfall variability. Right panel: same as left panel, but for cases 3 and 4.

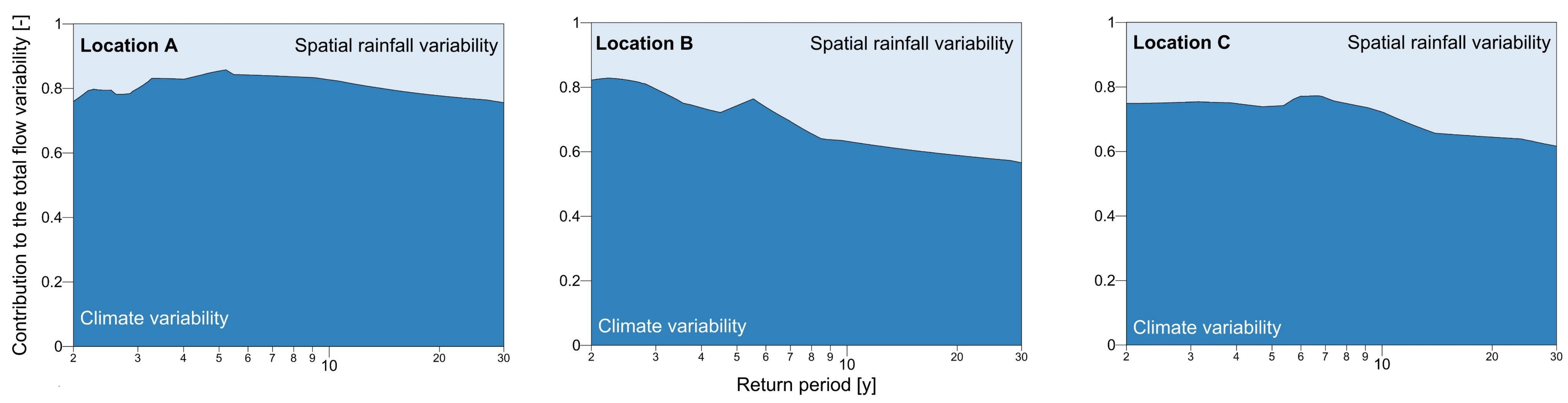

Fig 5. The contribution of the spatial rainfall variability (light blue area) and climate variability (dark blue area) to the total flow variability for a given return period and for different locations within the urban drainage system.

6 Summary

We found that the main contribution to the total flow variability originates from the natural climate variability (on average over 74%). In addition, the contribution of spatial rainfall variability to the total flow variability was found to increase with longer return periods. This implies that while the use of spatially distributed rainfall data can supply valuable information for sewer network design (based on rainfall with return periods from 5 to 15 years), there is a more pronounced relevance when conducting flood risk assessments for larger return periods.