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Importance of anthropogenic climate impact, sampling error and urban development in sewer system design

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ABSTRACT

Urban drainage design relying on observed precipitation series neglects the uncertainties associated with current and indeed future climate variability. Urban drainage design is further affected by the large stochastic variability of precipitation extremes and sampling errors arising from the short observation periods of extreme precipitation. Stochastic downscaling addresses anthropogenic climate impact by allowing relevant precipitation characteristics to be derived from local observations and an ensemble of climate models. This multi-climate model approach seeks to reflect the uncertainties in the data due to structural errors of the climate models. An ensemble of outcomes from stochastic downscaling allows for addressing the sampling uncertainty. These uncertainties are clearly reflected in the precipitation-runoff predictions of three urban drainage systems. They were mostly due to the sampling uncertainty. The contribution of climate model uncertainty was found to be of minor importance. Under the applied greenhouse gas emission scenario (A1B) and within the period 2036–2065, the potential for urban flooding in our Swiss case study is slightly reduced on average compared to the reference period 1981–2010. Scenario planning was applied to consider urban development associated with future socio-economic factors affecting urban drainage. The impact of scenario uncertainty was to a large extent found to be case-specific, thus emphasizing the need for scenario planning in every individual case. The results represent a valuable basis for discussions of new drainage design standards aiming specifically to include considerations of uncertainty.

1. Introduction

1.1. Sampling uncertainty in designing urban drainage

Sewer systems are designed to remove sewage and drain stormwater in order to limit flooding. As it is not realistic to provide protection from every rainstorm, the probability that flooding will occur is limited by an acceptable level (e.g. DIN EN 752, 2008). National standards recommend maximum permissible frequencies of exceeding critical reference water levels at every manhole (e.g. DWA, 2006; IDA Spildevandskomiteen, 2005). DWA (2006) suggests using one historical high-resolution point-precipitation series

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Nomenclature

a	Unit for year
n_{max}	Acceptable maximum number of times the critical reference water level is exceeded at a manhole during the precipitation-runoff simulation period
N_i	Number of flooding events (exceeding of the critical reference water level) at manhole *i* during the precipitation-runoff simulation period.
V_i	Mean volume overloaded to the surface per flooding event at manhole *i* during the precipitation-runoff simulation period.
X	Percentage (%) of manholes of a sewer network at which $n > n_{max}$ flooding events (exceeding of the critical reference water level) occur.
Y	Total water volume discharged from the sewer network to the ground surface during the precipitation-runoff simulation period.
o	Index used for the variables *N*,*V*,*X*,*Y*. It indicates that the considered variable derives from a precipitation-runoff simulation for which an observed precipitation series was used as input.
sr	Index used for the variables *N*,*V*,*X*,*Y*. It indicates that the considered variable derives from precipitation-runoff simulations for which an ensemble of stochastic precipitation series from the reference period 1981–2010 was used as input.
sf	Index used for the variables *N*,*V*,*X*,*Y*. It indicates that the considered variable derives from precipitation-runoff simulations for which an ensemble of stochastic precipitation series from the future period 2036–2065 was used as input.

representative for the location of the sewer system as the input for precipitation-runoff simulations to predict the relevant exceeding frequencies. As opposed to design storms, historical precipitation series allow the intra-storm variability to be addressed. Today, high-resolution precipitation series are typically available with durations of 30–40 years. However, by definition, only very rare precipitation events induce critical runoff events in more or less well-designed drainage systems. We must consider these precipitation events as highly random due to the large variability of sub-daily precipitation intensities. Therefore, the available series are just single random samples of precipitation series under the climatic conditions prevailing during the observation. In consequence of this short observation periods, exceeding frequencies derived from hydraulic calculations with such short series must be considered as very uncertain estimates of the true exceeding rates even under a stationary climate. We denote the variance in the estimates of system performance which would arise from using different random samples of ‘short’ precipitation series under a stationary climate as the *sampling uncertainty*.

1.2. *Impact of climate variability*

According to IPCC (2013), “*Climate variability refers to variations in the mean state and other statistics [...] of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability)*”. Sewer system design relying on precipitation observed in the past implicitly assumes uncertainties due to climate variability to be negligible. However, the very probable anthropogenic impact on the climate system has strengthened the claim to abandon the assumption of a stationary climate (Milly et al., 2008) and to move to design specifications accounting for uncertainties associated to climate variability and its projection (Fatichi et al., 2012). Questioning current design practice is also very timely in view of the growing demand for sewer rehabilitation (Maurer and Herlyn, 2006).

1.3. *Describing precipitation under climate variability*

It is a challenge to derive relevant precipitation data from climate models. A wide range of global climate models (GCMs) predict key climate variables with fairly coarse temporal and spatial resolution. Combinations of dynamic and stochastic downscaling techniques have been used (e.g. Onof and Arnbjerg-Nielsen, 2009) to extract the fine-resolution data needed for urban drainage simulations. In a first step, dynamic downscaling is performed by feeding the output from GCMs into a regional climate model (RCM) with the capability to refine the spatial scale of the data. Various stochastic downscaling techniques have been developed (e.g. Fowler et al., 2007) for the further temporal refinement of the RCM output and transfer to the spatial point-scale. Together, these nested models allow the impact of climate variability on sewer system performance with regard to flooding to be addressed. Other downscaling techniques such as weather typing or regression-based methods were found to be inadequate for this purpose due to their inability to reproduce extreme events (Wilby et al., 2002).

1.4. *Uncertainties*

The application of these methods to generate high-resolution precipitation data reflecting climate variability implies additional uncertainties which need to be accounted for. Together, the uncertainties associated to climate variability and its prediction are diverse and can be grouped into (i) the emission scenario uncertainty, (ii) GCM uncertainties, (iii) downscaling uncertainty, and (iv) internal climate variability (Tebaldi and Knutti, 2007; Wilby and Harris, 2006). Since sewer system design relies on extreme precipitation observed within a short period, it is subject to sampling uncertainty. Sewer system design is further challenged by the uncertainty of future urban development. Thus the future runoff coefficient might change due to increased population densities. In the following we briefly discuss the relevant input uncertainties and approaches to address them in sewer system design.