LIMITATIONS AND PITFALLS OF CLIMATE CHANGE IMPACT ANALYSIS ON URBAN RAINFALL EXTREMES

by

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ABSTRACT
Under the umbrella of the IWA/IAHR Joint Committee on Urban Drainage, the International Working Group on Urban Rainfall (IGUR) has reviewed existing methodologies for the analysis of long-term historical and future trends in urban rainfall extremes and their effects on urban drainage systems, due to anthropogenic climate change. Current practices have several limitations and pitfalls, which are important to be considered by trend or climate change impact modellers and users of trend/impact results. Climate change may well be the driver that ensures that changes in urban drainage paradigms are identified and suitable solutions implemented. Design and optimization of urban drainage infrastructure considering climate change impacts and co-optimizing with other objectives will become ever more important to keep our cities liveable into the future.

Keywords: extreme rainfall, review, climate change adaptation, urban drainage

1 INTRODUCTION
During the last 150 years sewer systems have become an increasingly important part of cities, securing human health and enabling more dense development. The key has been an increase in our knowledge of precipitation extremes and improved understanding of the hydrological and hydraulic transport phenomena in cities. This knowledge has been used to design urban drainage infrastructure to meet prescribed service levels. Hence a substantial part of urban drainage research has focused on understanding and describing precipitation extremes. This is also why the IWA/IAHR Joint Committee on Urban Drainage has established the International Working Group on Urban Rainfall. Members of this group have initiated an extensive review of current methods for assessing long-term historical and future trends in urban rainfall extremes and their effects on urban drainage systems, due to anthropogenic climate change (Willems et al., 2012). While this book contains more than 600 references to recent work on these topics and hence documents many state-of-the-art methods, the purpose of this paper is to point out that in spite of these significant advances and much activity within the field there are still many limitations in our understanding of processes as well as in our understanding of how changes in precipitation patterns will influence how we should design urban drainage infrastructure.
Figure 1 shows the different aspects to be considered when studying the impacts of climate change on rainfall extremes and urban drainage systems (Willems et al., 2012). This paper will focus on shortcomings within three domains of the figure:

1) Whether historical rainfall series contain trends, and why,
2) How to analyse and quantify long-term future trends,
3) What the implications could there be for urban drainage infrastructure design and operation.

Each of these domains is discussed in the following sections of the paper.

Figure 1 – Different aspects involved in urban hydrological impact analysis of climate change.

2 ANALYSIS OF HISTORICAL TRENDS IN PRECIPITATION

Trends in historical observations are often difficult to quantify and verify because of limited data, instrument or environmental changes, interannual variations and longer term climate oscillations. The signal-to-noise ratio in a trend analysis depends on the record length, the trend magnitude, the ‘noise’ level (e.g. the magnitude of the variations in the values), and the frequency of events under consideration. In general it is recommended to use averaging over 30 years to account for interannual variations in seasonal and annual means. When studying extremes, the uncertainty is inherently larger than when studying mean values and hence the demand for long records is often even greater than 30 years. The requirements for good quality observations are therefore very high.

Adjustments to rainfall measurements might be required to account for site relocation, changes in measurement programs, known instrument changes, measurement program deficiencies or changes in the microclimate (e.g. changes in sheltering effects or urban heat island effects). These changes take the form of bias correction because they aim to remove changes in observations that are occurring due to external factors rather than real changes in the precipitation extremes.

In the trend analysis of rainfall processes and extremes, the effect of clustering in time of the frequency and amplitude of the rainfall extremes has to be taken into account. This requires an analysis to be carried out to describe the short- and long-term time dependence induced by annual, decadal and multidecadal climate oscillations. Several authors have also detected such oscillations in series of extreme rainfall observations (e.g.
Ntegeka and Willems, 2008) and in some cases also found co-variates that explain the variations (e.g. Grimm and Tedeschi, 2009; Kamruzzaman et al., 2011). When such oscillations or short- and long-term persistence are present in the series, classical trend testing techniques such as the linear regression, Mann-Kendall, Spearman’s rank and other tests cannot be directly applied. They assume independence in the data, which may not be valid when short- and/or long-term persistence is present in the rainfall series. One solution is to remove autocorrelation in the series by careful pre-whitening or de-oscillating the series before application of a trend test. If the persistence is not taken into account in a proper way, differences in trend testing results might be found when the tests are applied to different periods, or to subperiods of the full available series.

3 ANALYSIS OF LONG-TERM FUTURE TRENDS DUE TO ANTHROPOGENIC CLIMATE CHANGE

3.1 Climate models

Future trends in rainfall extremes are assessed by complementing empirical historical data with the results from physically-based climate models, e.g. regional climate models (RCMs) nested in general circulation models (GCMs). In this way, the drivers of the change and the temporal projections on these drivers can be accounted for. The role of the GCM is to simulate the response of the global circulation to large scale forcing (i.e. greenhouse gas concentrations). RCMs account for finer scale forcing, like topographic features, in a physical manner, and they enhance the simulation of the climatic variables at these finer spatial scales. Although GCM boundaries in general have a very strong influence on the RCM results (including the effect of changes in GHG forcing on the global climate), RCMs may have a significant role during periods of convective precipitation due to local convection effects. For example, cumulus formation, which is an important cloud process that leads to rain storms, occurs at around 0.1km – 10km horizontal scales. With Limited Area Models (LAMs), e.g. city scale LAMs or fine-scale RCMs, with spatial scales finer than perhaps 3km, it is possible to represent the cumulus process explicitly by the model physics (Lo et al., 2008; Pathirana et al., 2012). However, computational times do not allow LAM simulations to be conducted for long periods (30 years or more) for a set of models and simulations. Therefore, for urban drainage impact investigations we currently often rely on the synoptic-scale RCM simulations. These models do not explicitly model small-scale cloud processes, but use cumulus parameterization to represent the collective influence of clouds (e.g. rainfall, radiation budget) within a larger area (single grid). This enables the models to simulate convective rainfall. However, the primary purpose of cumulus parameterization is not to produce accurate rainfall, but to release model instabilities. Synoptic-scale RCMs therefore have poor accuracy in simulating precipitation extremes. This strongly complicates the urban impact analysis.

3.2 Climate model validation

Validation of RCM/GCM results for local conditions is required before these models are used as inputs for local climate change impact studies. This is commonly done by comparison with statistics obtained from long-term historical rainfall series. Statistical tests can be applied to the initial set of available climate model runs and after testing, rejected runs can be removed. These are generally the ones that are inconsistent with the current or past climate observations. However, one has to be careful with such rejections for several reasons, including natural variability, the limited length of the available time series, differences in spatial scales, and the influence of climate oscillations. Hence removal of simulations is likely to lead to an underestimation of the overall uncertainty of climate change projections because it is only the outlying simulations that are removed.

3.3 Statistical downscaling to fine-scale rainfall extremes

When considering rainfall extremes of short duration, including convective storms, deviations from historical values might be systematic for most if not all climate models and bias correction is needed to avoid rejection of the majority of models. There is a need to adapt the results of RCM/GCM simulations so that they can be meaningfully used at the more detailed scales (spatial scales of a few kilometres and temporal scales as low as 5 or 10 minutes) that are needed for urban drainage models. This can be done using statistical methods, which also offer a potential way to tackle the uncertainties and biases in RCM/GCM urban rainfall extremes (Maraun et al., 2008).
Several methods for statistical downscaling exist, each with their own assumptions and all based on the combined use of historical data and climate model results (see Willems et al., 2012, for an overview including several recent developments). However, there is generally limited possibility to validate the statistical downscaling assumptions and of cause they all have a key assumption that some statistical properties remain constant even when assuming that the climate is changing. Good practice therefore involves assessment of the uncertainties associated with the downscaling method being applied. More importantly the different downscaling methods differ substantially; some focus primarily on the model outputs (time series or extremes), while others focus on linking more generic properties of current and future weather such as (changes in) circulation patterns, thus inferring changes in precipitation extremes from a different perspective.

Application of several downscaling methods can often be recommended, but these should be limited to the methods for which assumptions are found to be valid for the specific study area and perhaps also weighted with the suitability to study the type of problem in question. Statistical bias correction and temporal and spatial downscaling can be performed separately, or together. Due to the lack of accurate long-term spatial rainfall statistics, spatial downscaling and bias correction of rainfall intensities at given temporal scales are difficult to separate, and hence they are commonly combined.

3.4 Uncertainties in fine-scale climate change projections

Due to the difficulties and uncertainties in climate change impact modelling and analysis at urban scales, caution must be exercised when interpreting climate change scenarios. Consideration of an ensemble approach where several climate forcing scenarios, climate models, initial states and statistical downscaling techniques are considered, allows the order of magnitude of the uncertainty associated with each aspect to be assessed. At the same time, it must be recognised that the total uncertainty of climate projections is likely to be larger than that exhibited by an ensemble of models, because the models share the same level of process understanding and sometimes even the same parameterization schemes and code. Whatever methods are adopted, the resulting change should not be interpreted as an exact number but only as being indicative of the expected magnitude of future change.

4 IMPLICATIONS FOR URBAN DRAINAGE INFRASTRUCTURE DESIGN AND MANAGEMENT

4.1 Study of urban runoff impacts

When the impact on urban runoff is studied (e.g. through runoff peak flows, floods, surcharge frequencies, and combined sewer overflow frequencies and volumes), the projected impacts are uncertain, not only due to the uncertainties in the climate projections, but also due to uncertainties in the impact models. Care is required when predicting the impacts of more extreme conditions. Impact models are often calibrated and validated based on historical series of limited lengths, which may have included only a few extreme events. Extension of the model simulations to future conditions should therefore be made with caution, especially when considering system performance under extreme events that might become more common under future climate change.

The uncertainty in the extreme rainfall changes, after propagation to impact changes, may also amplify because floods and overflows are due to exceedance of runoff or urban drainage flow thresholds and they react to rainfall and changes in rainfall in a highly non-linear way. When the exceedance probabilities are lower or the threshold is higher (e.g. for systems with a higher safety level), the relative change often becomes higher. The impact ranges can be even wider when studying environmental or socio-economic impacts.

4.2 Flexible and sustainable adaptation

Urban planners and designers of urban drainage infrastructure can use the projected changes in extreme rainfall and other key inputs to start accounting for the effects of future climate change. Sections of the urban drainage system with insufficient capacity to convey future design flows can be upgraded over the next few decades as part of a program of routine and scheduled replacement and renewal of aging infrastructure. The large uncertainties that currently exist should not be an argument for delaying climate change impact investigations or adaptation actions. Instead, uncertainties should be accounted for and flexible and sustainable solutions should be sought. An adaptive approach has to be established that both provides inherent flexibility.
and reversibility and also avoids closing off options. This is different from the traditional engineering approach, which is rather static and is often based on design rules set by engineering communities without much public debate. This adaptive approach involves active learning, hence recognizing that flexibility is required as understanding increases. Essentially two paradigms are being questioned: First of all the last two to three decades of research has focussed on optimization of the infrastructure to more and more advanced levels. This has led to much cheaper investment and operational costs, but also in general to an aging and deteriorating infrastructure with lower service levels. Secondly, the concept of urban drainage as a well-defined and static scientific discipline is being challenged. The implications of urban drainage design decisions are intricately connected to other decisions about the wellbeing of the city in the same way that decisions about the wellbeing of the city have a major influence on the ability of the urban drainage to deliver the essential services in an affordable and efficient way.

5 CONCLUSIONS
Even though more than 600 references are cited in a recent review of impacts of climate change on precipitation extremes and urban drainage systems there are still large gaps in our understanding. We point out some of the limitations in our current understanding and highlight some of the pitfalls that we have observed are occurring in practice in urban applications. The scientific level of understanding of how climate change will impact on urban drainage remains limited for two reasons. The first is because of our lack of understanding of how to quantify the impacts given our understanding of climate change. The second reason, which is of equal importance, is because of our lack of understanding of how the urban drainage sector should react to the challenges that large changes in precipitation extremes will generate. Together with other drivers indicate the need for rapid action and for increased flexibility, robustness and resilience in our cities. Climate change may well be the driver that ensures that changes in urban drainage paradigms are identified and suitable solutions implemented. Design and optimization of urban drainage infrastructure that considers climate change impacts and co-optimizes this with other objectives for a liveable city will become increasingly important in the future.

6 REFERENCES