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by

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UNCERTAINTY ASSESSMENT IN URBAN STORM WATER DRAINAGE MODELLING

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Abstract: The object of this paper is to make an overall description of the author's PhD study, concerning uncertainties in urban storm water drainage models. Initially an uncertainty localization and assessment of model inputs and parameters as well as uncertainties caused by different model complexities are investigated. It is the main purpose to make an overall uncertainty estimation of the model output. This is accomplished by implementation of stochastic methods when operating the urban drainage models.

Keywords: Urban drainage modelling, sewer systems, uncertainties, stochastic methods, Monte Carlo Simulations, GLUE.

1. INTRODUCTION

Consulting engineers, municipalities, etc. frequently use drainage models to analyze urban drainage systems during rain, e.g. in order to determine flooding of critical levels and overflows from combined sewer systems to the receiving waters. The use of these models highly depends on tradition and empirical assumptions concerning the choice of models, model parameters, and also whether or not model calibration is possible. When using the models to design new sewer systems, to make sure the design criteria are kept, and partly due to a lack of knowledge concerning choice of parameter values, a great safety margin is often implemented in the model calculations. In some cases this can lead to over-dimensioned sewers. On the other hand, however, if the necessary safeties are not implemented in the models, the sewer design will result in unnecessary flooding of certain areas or a more frequent overflow from combined sewer systems to the receiving waters. Thus, from a social and an engineering point of view, there is a need for research in uncertainties, in both input and output of urban storm water drainage models. Such knowledge would help models to produce more meaningful results. During the last decades, when the use of urban drainage models has evolved, a fascination with the possibilities within these models, has to some extent neglected the fact that the results are uncertain. This is evident when looking at the number of publications within this area of research. Only few have investigated uncertainties related to modelling of urban drainage systems e.g. Lei (1996), Willems (2000) and Hansen et al. (2005)

This paper presents the outline of the current PhD study, primarily focusing on the methodologies and tools used in order to satisfy the problems mentioned above. These methodologies and tools include both field measurements to be performed and the numerical tools and probabilistic methods to be used.

The main concept of the PhD project is to use the conventional deterministic modelling approach as a starting point, and attempt to take the input and parameter uncertainties into account by using stochastic modelling. That is, instead of using one value for each input and parameter, resulting in a single output, a probability density function for each input and calculation parameter is applied, and the output yields a discrete probability density function.

The study is divided into three phases:

1. An initial registration of all contributions of uncertainties concerning input data, model parameters, calibration data, choice of model complexity, etc. This is obtained from sensitivity

analysis, field measurements, literary reviews, model testing, etc.
2. Statistical parameterization of inputs and model parameters, obtained from empirical and literary values, field measurements, etc.
3. Implementation of stochastic methods on the urban drainage models in order to transform error and uncertainty contributions of the input and model parameters to an estimation of uncertainties of the model output.

The remaining part of the paper is structured as follows: In section 2 computational, stochastic and measuring methods are described. The expected results and discussion of these are presented in section 3 and 4 respectively, and finally the conclusions are stated in section 5.

2. METHODS

Within the three phases three different ways of obtaining the overall uncertainty assessment are introduced, namely the urban drainage models, the stochastic methods, and the field measurements.

2.1 Urban drainage models

An urban drainage model consists of three sub-models: (1) A hydrological model simulating the hydrological surface processes: precipitation, evaporation, infiltration, etc, (2) a surface runoff routing model, simulating hydraulics on the catchment surface and (3) a pipe flow model simulating the hydraulics in the pipe system. In every sub-model different complexity can be applied. It will be investigated whether the overall errors can be reduced by using an advanced model contrary to a simpler model. An advanced model usually contains many parameters, thus larger possibility of parameter uncertainties, whereas a simpler model usually contains fewer parameters, thus smaller possibility of parameter uncertainties. It is preferable to handle the uncertainties stochastically, i.e. parameterization is possible. Uncertainties origination from absence of model complexity can not be handled stochastically (parameterized), which often is relevant regarding simple models.

Several commercial urban drainage models are available. The preferred model in this study is the MOUSE package from DHI Water & Environment (Lindberg & Willemoës Joergensen, 1986), as this model is most often used by consulting engineers in Europe.

2.2 Stochastic methods

A number of options are available regarding implementation of stochastic methods on urban drainage models e.g. Monte Carlo methods (Jensen, 2002; Lei, 1996; Willems, 2000):

- Plain Monte Carlo simulations
- Latin Hybercube simulations
- Generalized Likelihood Uncertainty Estimation (GLUE)

Or other reliability methods, e.g. (Jensen, 2002):

- First order reliability method (FORM)
- Second order reliability method (SORM)

Further descriptions are not presented, except a paragraph about the advantages with the GLUE-approach in section 3.

2.3 Field measurements

In order to get a precise output from the urban drainage model in question, a consistent set of observation data for calibration is essential. Therefore, flow measurements from Aalborg University's research and Monitoring station in Frejlev (Schaarup-Jensen et al., 1998) will be used. The Frejlev Research and Monitoring Station provides high temporal resolution runoff data from a combined sewer system of approx. 80 hectares. Owing to these unique flow measurements a large part of the study will be conducted with the Frejlev catchment as a case study. As a supplement to the flow measurements water level gauges will be installed in a few selected manholes and in a combined sewer overflow with the intention of generating comprehensive local observation data.

In addition to observation data such as flow and water level measurements, a large part of the uncertainties in urban drainage models are related to the model input. Therefore, detailed rainfall measurements will be performed by placing a number of rain gauges around the Frejlev catchment in order to investigate the geographical distribution of rainfall.

3. EXPECTED RESULTS

In the initial registration of uncertainties (phase 1), a profound investigation of the most important and largest uncertainty sources must be conducted in order to target the further research. It is expected that this will show that the main uncertainties exist within the hydrological modelling: (1) in the input of rainfall time series (whether or not rainfall data from a single rain gauge or the use of geographical distributed rainfall is preferable), (2) in the assessment of catchment areas, and (3) in the hydrological reduction of the precipitation on the surface, due to infiltration and evaporation.

Calibration of urban drainage models is very important in order to obtain valid results. Thorndahl et al. (2005) has shown up to a 100 % difference in water volumes using calibrated and uncalibrated models respectively. Using extreme statistics on long term simulations Schaarup-Jensen et al. (2005) has shown considerable flooding using an uncalibrated model and no flooding using a calibrated model,.

Therefore whether or not the model is calibrated can be decisive for reconstruction of a sewer system.
It is evident that it is most important to simulate the water volumes correctly and this can only be achieved by calibration. It is the author's conviction that e.g. the choice of surface routing model, and the majority of model parameters, is negligible when the model is uncalibrated. Unfortunately calibration data are seldom available. A feasible way of handling this problem is to implement a stochastic contribution to the models. Thus it is possible to present the probability of certain results instead of just one single value. Figure 1 shows an example of a simulated water level as a function of the return period (black line). The grey lines represent the 95 % confidence level. Instead of concluding that flooding (exceeding of ground level) occurs with at return period of 5 years, the conclusion yields, that there is a probability of 95 % that flooding occurs with a return period of 2 – 13 years. Related to design of sewer systems, a result like this is very important to keep in mind.

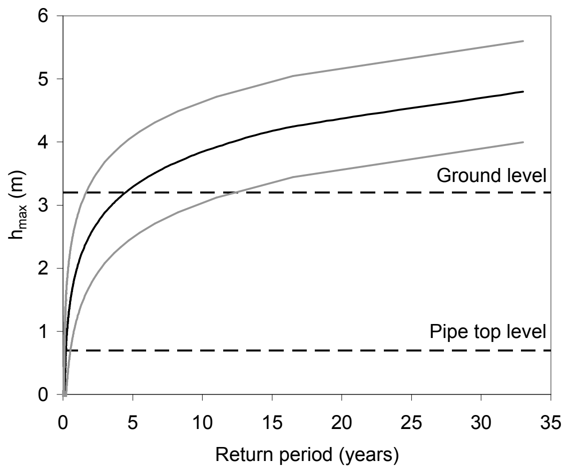

Fig. 1. An example of a long term simulation of a water level as a function of the return period with confidence intervals. The black line can be interpreted as a conventional deterministic model result and the grey lines as the uncertainty.

Traditionally it is difficult to join calibration and stochastic modelling, due to a wide range of input and model parameters are used. Ideally there is only one correct set of parameters. In the GLUE-approach a large number of Monte Carlo simulations are executed and for each execution the result is weighted (by its likelihood measure) proportional to how well the model output fits the observation data. Accordingly it is possible to create discrete probability density function of the model output.

4. DISCUSSION

A serious problem doing stochastic long term simulations, and probably the reason why very few have done it, is that it is computationally demanding - especially when long term simulations are used. Consequently there is a need for optimizing or sophistication of the stochastic methods so the number of simulation executions can be reduced.

5. CONCLUSION

As stated in the introduction model inputs and parameters are generally assessed with a certain safety in order to make sure design criteria are kept. By implementing stochastic long term simulations it is possible to confront to the model output uncertainties. Subsequently it can be decided in what way this must effect the decision-making process regarding the overall design of the sewer system in question. By doing this the chances of construction of over- or under-dimensioned sewer systems will be reduced.

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