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Uncertainties Related to Extreme Event Statistics of Sewer System Surcharge and Overflow

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ABSTRACT

Today it is common practice - in the major part of Europe - to base design of sewer systems in urban areas on recommended minimum values of flooding frequencies related to either pipe top level, basement level in buildings or level of road surfaces. Thus storm water runoff in sewer systems is only proceeding in an acceptable manner, if flooding of these levels is having an average return period bigger than a predefined value. This practice is also often used in functional analysis of existing sewer systems.
Whether a sewer system can fulfil recommended flooding frequencies or not, can only be verified by performing long term simulations - using a sewer flow simulation model - and draw up extreme event statistics from the model simulations. In this context it is important to realize that uncertainties related to the input parameters of rainfall runoff models will give rise to uncertainties related to the corresponding extreme event statistics.
This paper illustrates this problem in a case study with two different values of one input parameter - the hydrological reduction factor - in two otherwise identical operations of the MOUSE LTS model. The use of a long historical rainfall time series makes it possible to draw up extreme event statistics covering return periods of as much as 33 years. By comparing these two different extreme event statistics it is evident that these to a great extent depend on the uncertainties related to the input parameters of the rainfall runoff model.

KEYWORDS

Hydrological reduction factor; initial loss; urban runoff modelling; MOUSE LTS; extreme event statistics; combined sewer overflow; flooding.

INTRODUCTION

Today, assessment of the efficiency of urban sewer systems can be accomplished by performing long term simulations based on 1) historical rainfall time series, 2) a precise catchment description and 3) a well calibrated and well documented runoff model as e.g. the MOUSE LTS model (Jakobsen *et al.*, 2001). Thus the assessment can be performed based on extreme event statistics of combined sewer overflows together with extreme event statistics of flooding of critical levels, e.g. the basement level in buildings or road surfaces.

Concerning the flooding frequencies recommended design values for small schemes are listed in table 1, taken from European Standard for Drain and Sewer Systems Outside Buildings, European Standard no.: EN 752-4 (1997). The same standard states: *"For larger schemes,* *design should be undertaken to limit frequency of surcharge using a sewer flow simulation model, following which the design should be checked to ensure that an adequate level against flooding will be provided at specific sensitive locations".*

Table 1. Recommended design frequencies. From European Standard for Drain and Sewer Systems Outside Buildings, European Standard no.: EN 752-4 (1997).

Design storm frequency* 1 in n years	Location	Design flooding frequency 1 in n years
1 in 1	Rural areas	1 in 10
1 in 2	Residential areas	1 in 20
	City centres/industrial/commercial areas	
1 in 2	- with flooding check	1 in 30
1 in 5	- without flooding check	-
1 in 10	Underground railway/underpasses	1 in 50

* For these design storms, no surcharge shall occur

However, existing frequency requirements from any relevant authorities overrule the recommendations of EN 752-4.

On this basis it is very likely that the code of practice within design of urban sewer systems - as well as analysis of existing systems - in years to come will be characterized by long term simulations based on the MOUSE LTS model or similar urban drainage models. Only by operating such models is it possible to come up with documentation on whether or not the system in question can meet the design flooding frequencies.

In this context it becomes very important to operate the chosen urban drainage model on a well qualified description of the catchments and – if possible – to calibrate the models regarding some important model parameters. Omitting this will lead to model simulation results, which will be characterized by a considerable uncertainty in extreme event statistics. Consequently, unreliable flooding frequencies will be the result of such model simulations.

It is the object of this paper to examine to what extent extreme event statistics from such long term simulations are influenced by an uncertain estimate of catchment parameters. In order to simplify this problem only one single parameter, the hydrological reduction factor, has been chosen for this purpose. This reduction factor has been introduced in urban drainage modeling in order to fix an appropriate estimate of the impervious area of the catchment contributing to the sewer surface runoff.

THE TEST SITE

In 1997 a research and monitoring station was established as part of the intercepting sewer in Frejlev, a small town of 2000 inhabitants 7 kilometers southwest of Aalborg, Denmark (Schaarup-Jensen *et al.*, 1998) – cf. fig. 1 and fig. 2.

During dry weather conditions waste water flow from Frejlev is diverted into an intercepting pipe through a combined sewer overflow (CSO) structure located downhill approximately 500 meters north of Frejlev. During wet weather conditions CSOs are discharged into Hasseris, a stream which flows into the Limfjord about 6 kilometers north-east of Frejlev.

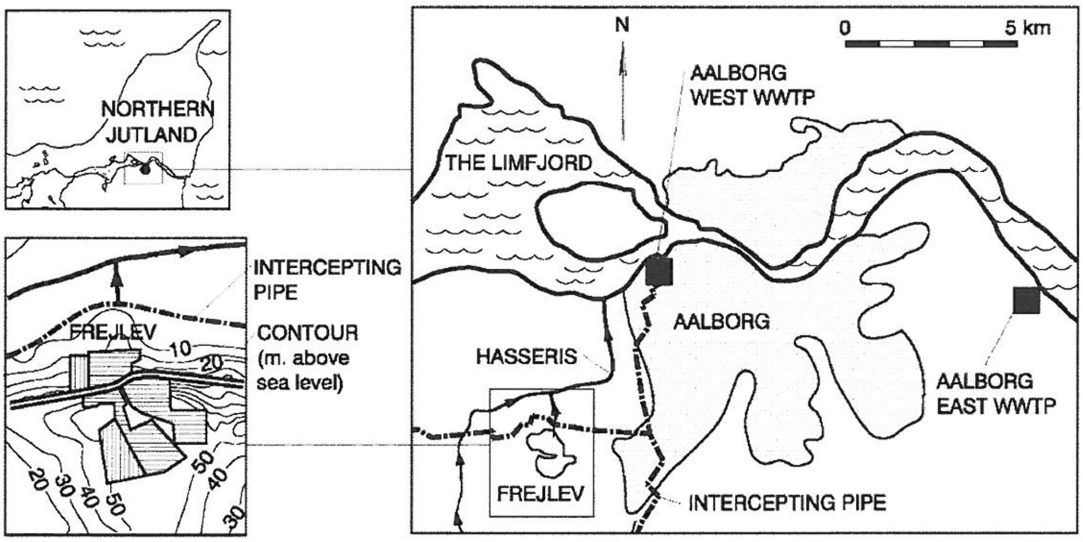

Figure 1. Aalborg, the town of Frejlev, the Hasseris stream and the Aalborg West waste water treatment plant (WWTP). Horizontal shading: combined sewered catchments; vertical shading: separate sewered catchments.

According to Thorndahl *et al.* (2005), the total Frejlev catchment covers an area of approximately 87 ha, situated on a hillside facing north from an uphill level approximately 55 m above sea level to a downhill level 15 m above sea level. 67% of the catchment, 58 ha, has combined sewers and the remaining 33%, 29 ha, are separately sewered, fig. 1 and fig. 2. The impervious part of the catchment is 40% corresponding to 35 ha.

The research and monitoring station in Frejlev is located upstream and close to the CSO structure where continuous high quality time series of both dry and wet weather flow are measured in order to gain general long term knowledge of the characteristics of both flow types. Upstream from the station, the sewer pipe system is divided into two: a 300 mm diameter "dry weather pipe" and a 1000 mm diameter "wet weather pipe". Within the station both of these pipes are equipped with high quality electromagnetic flow meters of the Parti-Mag type manufactured by ABB Automation Products GmbH, Göttingen, Germany. According to the specifications of the manufacturer, both of these flow meters function with a maximum flow rate error of 1-1.5% . The flow is measured every 20 seconds.

The flow measurements are supplemented by two automatic rain gauge stations which are included in the Danish national rain gauge system managed by the Danish Waste Water Control Committee and operated by the Danish Meteorological Institute (2004). One of the rain gauges (gauge no. 20458) is placed on top of the research station, 15 m above sea level. The second one (gauge no. 20456) is placed uphill, 55 m above sea level, in the south-western part of the town at a distance of approx. 1.2 kilometer from gauge no. 20458 – cf. fig. 2.

Until now, measurements from this station have been subject to various investigations (Schlütter and Schaarup-Jensen, 1997; Vollertsen and Hvitved-Jacobsen, 2003; Schaarup-Jensen and Rasmussen, 2004).

Measurements of precipitation and the corresponding storm water runoff flow in an urban catchment naturally results in a comparison of corresponding rainfall event volumes and storm water runoff volumes. Relating these volumes to the impervious area of the catchment, this analysis becomes a comparison of depths – cf. fig. 3.

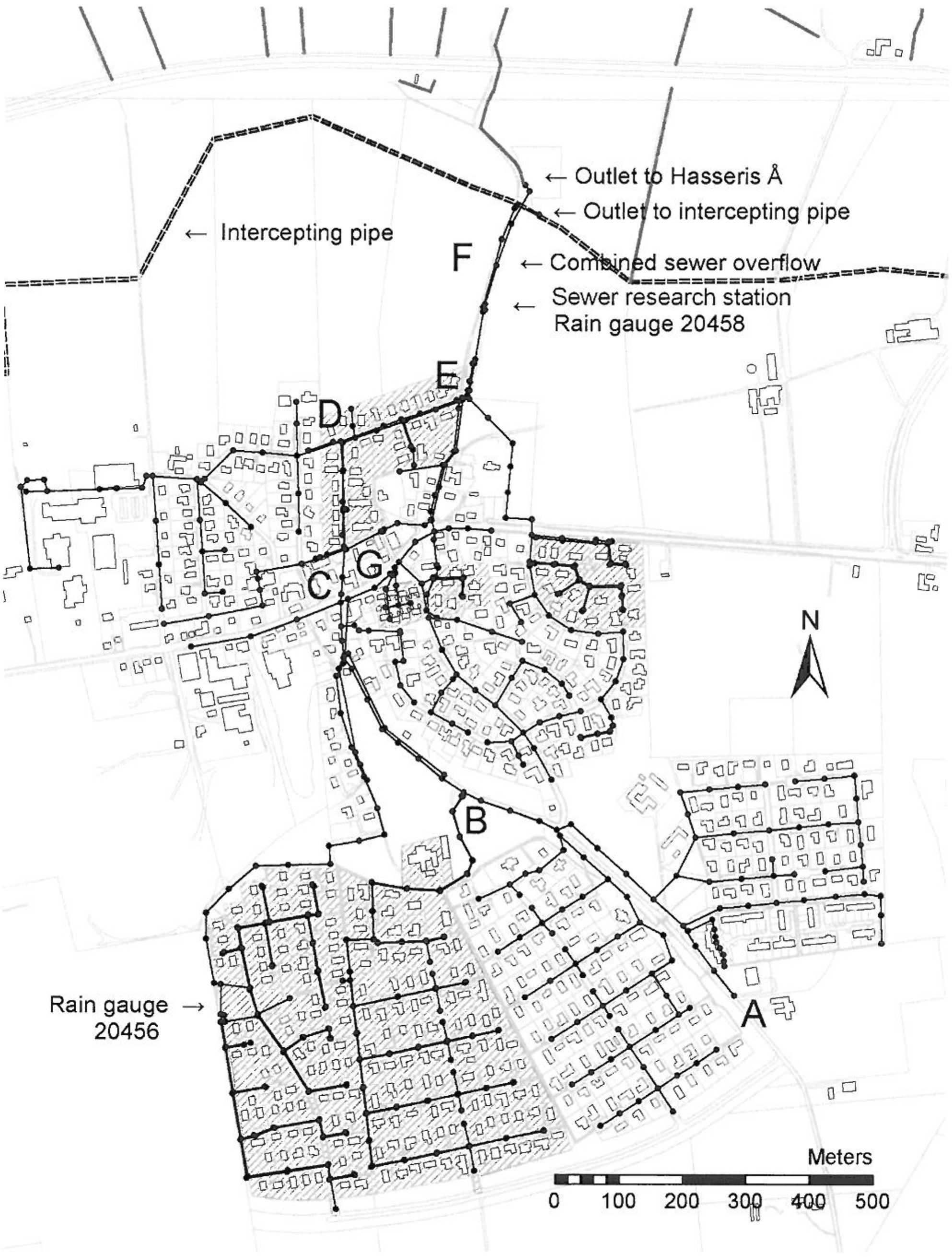

Figure 2. The town of Frejlev, the rain gauges, the sewer system, the research station, the CSO structure and the outlets to the intercepting pipe and the Hasseris stream. Areas without shading: combined sewered catchments; areas with shading: separate sewered catchments.

From figure 3 it is evident that the classical linear relationship between these two parameters seems to be present. The slope of the regression-line in fig. 3 represents the hydrological reduction factor and the intersection of the same line with the rain depth axis represents the initial loss. The initial loss – in this case 0.4 mm – is normally considered to represent a hydrological loss due to wetting and filling of terrain depressions at the beginning of a rainfall event. Likewise, the hydrological reduction factor – or more accurately 100% minus this factor - is considered to represent a hydrological loss from impervious areas during a rainfall event. Normally this loss is explained as the percentage of the impervious catchment area from which storm water runoff is not discharged into the inlets – gullies – of the sewer system, e.g. due to local slope conditions. In the Frejlev case this loss seems to be in the order of 58%. Accordingly, the hydrological reduction factor is estimated to 42%.

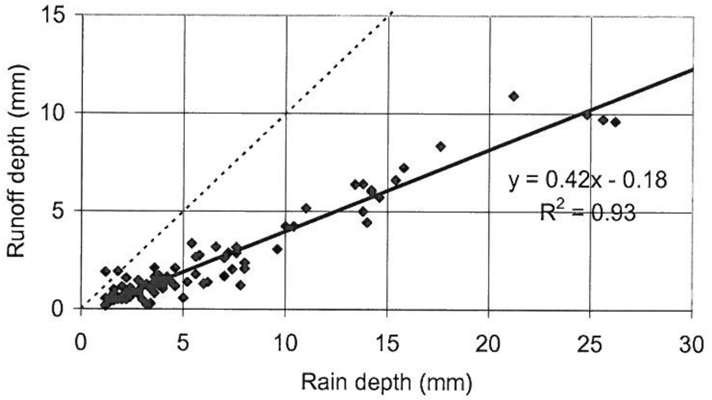

Figure 3. Corresponding values of rainfall event depths and runoff measured in Frejlev, 1998-2001, during 96 rainfall events. From Thorndahl *et al.* (2005).

Recent investigations (Thorndahl *et al.*, 2005) indicate that 50% seems to be a "normal" value of the hydrological reduction factor for Danish catchments in residential areas – when all possible contributions to the impervious area are included in the assessment of this area, i.e. road surfaces including pavements, car entrances and roof surfaces including garages, tool sheds, covered or uncovered terraces, etc.

However, during a number of years the code of practice in Denmark in rainfall-runoff modelling has been based on Danish literature values of 70-90% of this reduction factor regardless of the type of catchment. (Miljoestyrelsen, 1990)

MOUSE LTS SIMULATIONS

In order to describe the influence of this single catchment parameter value on the results of a long term rainfall runoff simulation on the Frejlev catchment, two MOUSE LTS simulations have been executed – one with a 45% value, the other with a 90% value of the reduction factor. Indirectly this means a choice of the time-area surface flow model (Model A) in MOUSE.

Actually, quite a lot of rainfall runoff parameters could have been taken in as stochastic parameters defined by a specific distribution having a certain mean value and standard deviation. For reasons of clarity only the hydrological reduction factor has been chosen by the authors in order to describe how the variability of one single input parameter related to a long term rainfall runoff simulation by MOUSE LTS influences the result of such a model operation.

In years to come, Aalborg University will accomplish a research effort in this field in order to 1) point out the most significant input parameters to this problem 2) implement uncertainties to the extreme event statistics based on the results of such long term simulations.

The Frejlev catchment description was adapted from recent investigations performed by Thorndahl *et al.* (2005). Furthermore, an elderly historical rainfall time series – measured about the middle of the previous century in Odense, Denmark – was chosen for these simulations, simply due to the length (33 years) of this specific time series.

RESULTS FROM SIMULATIONS

One important result from the MOUSE LTS simulations appears from figure 4 illustrating the extreme event statistics on simulated CSO volumes – see fig. 2, structure F. As expected, the difference between a simulation based on hydraulic reduction factors (ϕ) of 0.90 and 0.45 respectively is evident.

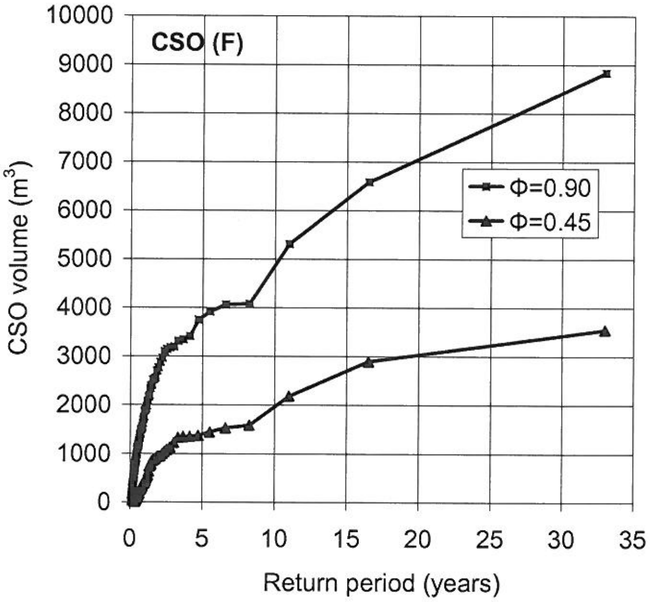

Figure 4. CSO volumes as a function of (average) return period.

The most extreme CSO volumes increase by a factor close to 3, from 1.500-3000 m^3 to 4.000-8.500 m^3 corresponding to average return periods between 5 and 33 years. The average volume of CSO events only increases slightly from 410 m^3 to 558 m^3 but the average number of CSO events per year increases conspicuously from 3.5 to 13.3. This difference in both extreme and average CSO numbers was expected owing to the fact that the effective drainage areas in the two MOUSE LTS simulations differ from each other by a factor of 2.

Regarding damming-up frequencies, these are illustrated in figures 5 and 6 below. Figure 5 illustrates the maximum water level, h_{max}, during a rainfall event in two arbitrarily chosen manholes, E and G, see fig. 2. Actually the figure illustrates the distance between h_{max} and the bottom level, h_{bottom}, of the manholes.

For manhole E it is evident that damming-up to ground level does not occur in any case. If basements can be found in the vicinity of this manhole and basement levels are defined as ground level minus 1.5-2 m, the possibility of basement flooding is very high in case of ϕ = 0.90 and almost negligible in case of ϕ = 0.45. Furthermore, the top level of the outgoing pipe (an 1100 mm diameter pipe) from the manhole is exceeded with an average return period of less than 1 year for ϕ = 0.90 and approx. every 4 years for ϕ = 0.45. According to table 1 this could lead to two contradictory conclusions concerning observation of the design criteria.

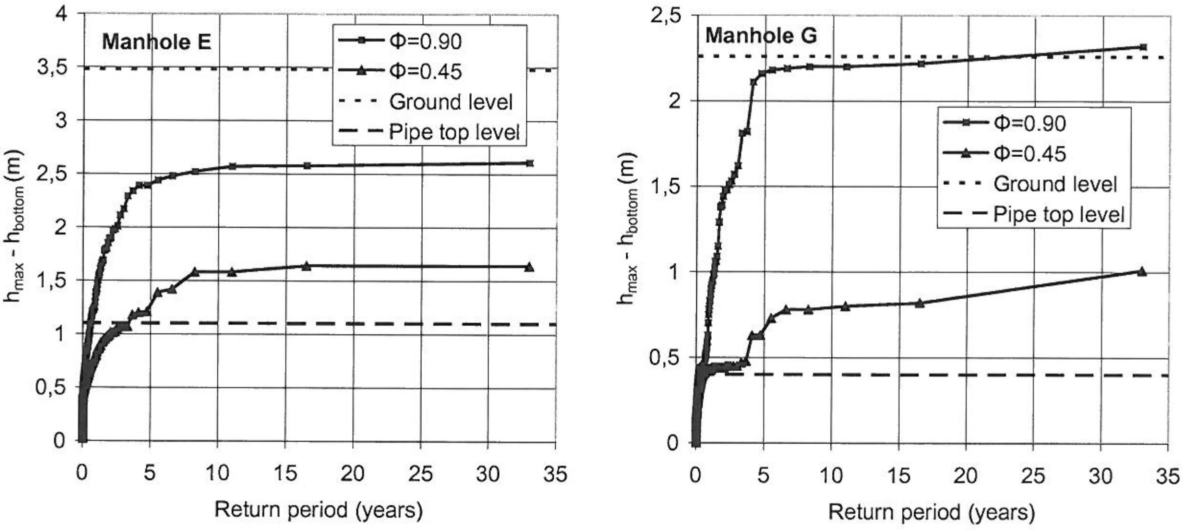

Figure 5. Flooding frequencies in the Frejlev sewer system, manhole E and G, see fig. 2.

In the case of manhole G, ground level is exceeded on average every 20 years in case of $\phi = 0.90$ while this exceeding level never occurs in case of $\phi = 0.45$. The top level of the outgoing pipe (a 400 mm diameter pipe) is exceeded in both cases with return periods below 1 year.

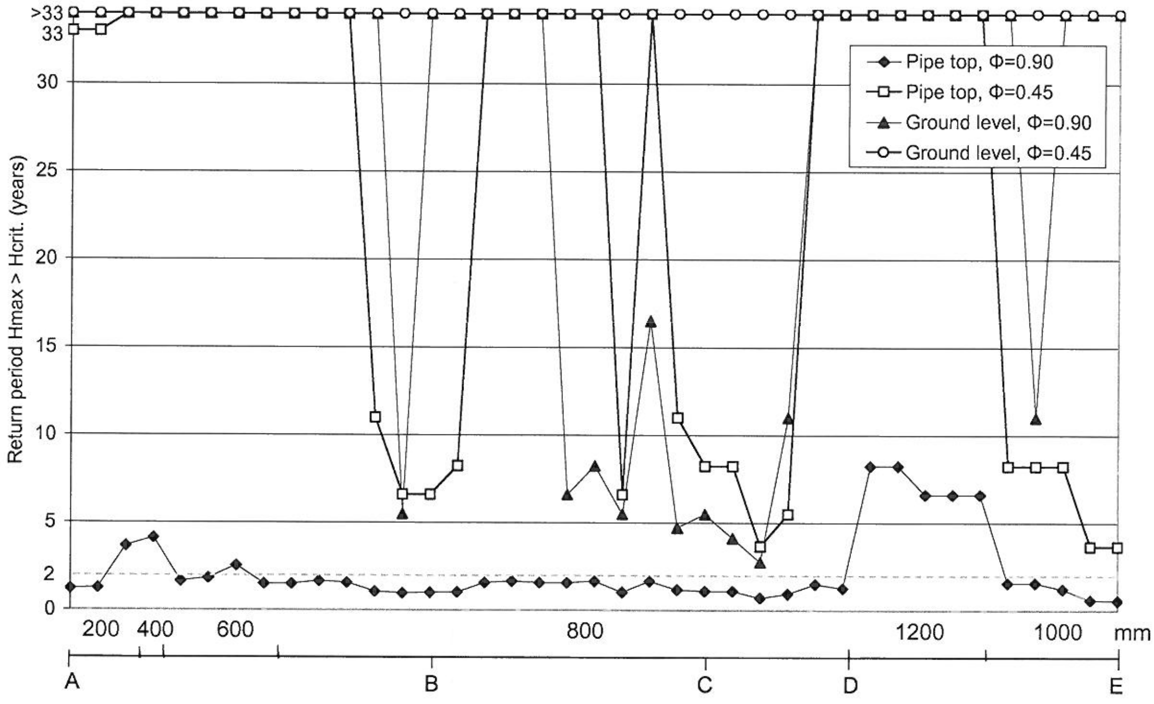

Figure 6. Flooding frequencies in the Frejlev sewer system. Longitudinal profile for the stretch, A-B-C-D-E (combined sewer), see fig .2.

Along the most significant pipe stretch in the Frejlev sewer, A-B-C-D-E (see fig. 2), the return periods of water level exceeding the pipe top level and eventually the ground level is illustrated in figure 6.

This stretch is a part of the combined sewer in Frejlev. Consequently – see table 1 – the design storm frequency was 1 in 2 years corresponding to a demand of an average return period greater than or equal to 2 years for flooding of pipe top level.

In case of $\phi = 0.90$ the return period of flooding of pipe top level is less than 1 for a big part of this stretch. This frequency – in case of $\phi = 0.45$ (corresponding to reality) – never becomes less than approx. 4 years. For some manholes along this stretch flooding of ground level is as frequent as every third or fourth year in case of $\phi = 0.90$ while this in case of $\phi = 0.45$ (in reality) happens with a frequency greater than 33 years.

CONCLUSIONS

In this paper a plausible difference between a recommended (0.90) and a realistic value (0.45) of the hydrological reduction factor ϕ for residential catchments has been presented in order to illustrate the corresponding variability in results from long term simulations.

Otherwise identical MOUSE LTS simulations based on these two different values of ϕ clearly indicate, that uncertainties related to central input parameters of rainfall runoff models to a high degree are influencing extreme event statistics on results from long term simulations, e.g. CSO volumes and flooding of critical levels in the catchment such as basements and road surfaces.

Variability in estimation and/or assessment of other input variables to this type of models may have a similar influence to such extreme event statistics. Concurrently with an increasing use of long term simulations within the field of urban drainage a well organized research effort becomes a necessity in order to reveal the uncertainties related to extreme event statistics on the results from such model operations.

ACKNOWLEDGEMENT

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