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Published in:
Confernce Proceedings : 11th International Conference on Urban Drainage

Publication date:
2008

Document Version
Publisher's PDF, also known as Version of record

A low cost calibration method for urban drainage models

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ABSTRACT

The calibration of the hydrological reduction coefficient is examined for a small catchment. The objective is to determine the hydrological reduction coefficient, which is used for describing how much of the precipitation which falls on impervious areas, that actually ends up in the sewer. The reduction coefficient is found on basis of a combination of a urban drainage model (MOUSE) and a set of simple switches located in a combined sewer overflow (CSO) structure. By calibrating the model with only the duration of the CSO, it was possible to calculate a hydrological reduction coefficient close to what can be found with intensive in-sewer measurement of rain and runoff. The results also clearly indicate that there is a large variation in hydrological reduction coefficient between different rain events.

KEYWORDS
Urban Drainage modelling; calibration of models; historical rainfall series; MOUSE;

INTRODUCTION

In 1997 a research and monitoring station has been established as a part of the intercepting sewer from Frejlev, a small town of 2000 inhabitants 7 kilometres southwest of Aalborg, Denmark. Consequently, times series of dry and wet weather flow are available.

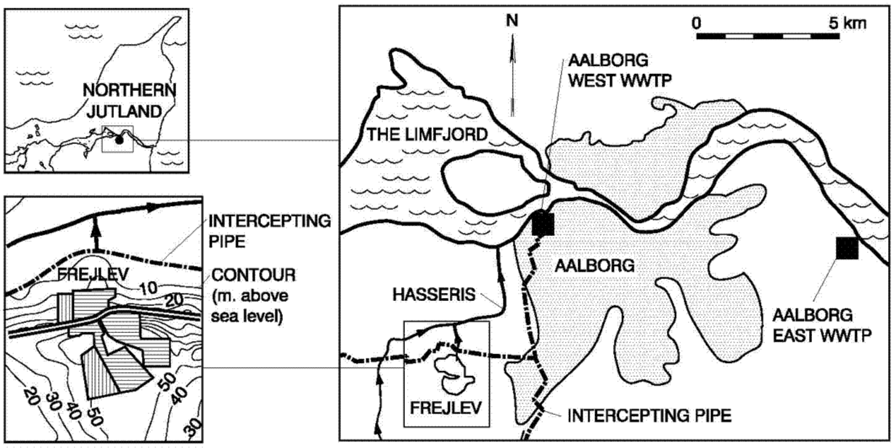

Figure 1. Aalborg, the town of Frejlev, the Hasseris stream and the Aalborg West waste water treatment plant (WWTP). Horizontal shading: combined sewer catchments; vertical shading: separate sewer catchments.

Full details of the Frejlev sewer research station and the catchment can be found in (Schaarup-Jensen et al., 1998).

Figure 2 illustrates the linear relationship between measured runoff depth (runoff volume/impervious area) and the corresponding rainfall depth in Frejlev as found based on approximately 10 years of flow measurements in the research station and a rainfall gauge. The number of events, where both rain and flow was available is approximately 300. The slope of the regression-line in this figure represents the hydrological reduction factor (ϕ) which in this case is estimated to 51%. Normally ϕ is used as the runoff coefficient which in this context is the product between hydrological reduction coefficient and the impervious fraction. The hydrological reduction coefficient describes the fraction of the rain which reaches the total impervious area and runoff into the sewer. An example of an impervious area, which does not contribute to runoff, could be the driveway to a house. Here much of the rain water will infiltrate in the surrounding grass area.

The intersection with the rain depth axis represents the initial loss – in this case 0.4 mm – which normally is considered to represent a hydrological loss due to wetting and filling of terrain depressions at the beginning of a rainfall event.

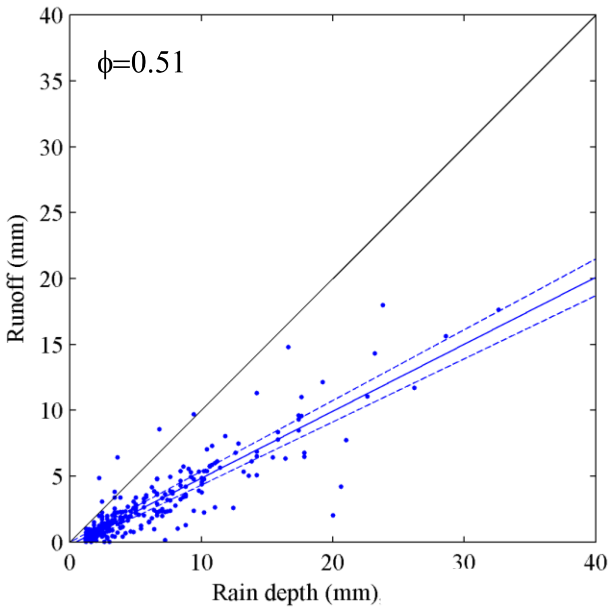

Figure 2. Corresponding values of rainfall event depths and runoff measured in Frejlev, 1998-2006, during 293 rainfall events. From Thorndahl. (2008).

Recent investigations (Thorndahl et al., 2006) indicate that 50% seems to be a “reasonable” value of ϕ 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 ϕ regardless of the type of catchment. (Miljoestyrelsen, 1990).

The choice of hydrological reduction coefficient is of great importance for planning and design of sewer system, as it is directly proportional to the amount of water entering the sewer. Designing sewer system requires a realistic hydrological reduction coefficient in order apply the correct safety level. In the analysis of sewer systems after an extreme flooding event, it is also important to know the hydrological reduction coefficient precisely for that event or the modelling can lead to erroneous conclusions. Figure 3 illustrates how the water level depends on the choice of hydrological reduction coefficient. When the standard value of 0.9 is compared with the experimental determined value of 0.45 it is clear that one will lead to the possibility of flooding, while the other will result in acceptable conditions.

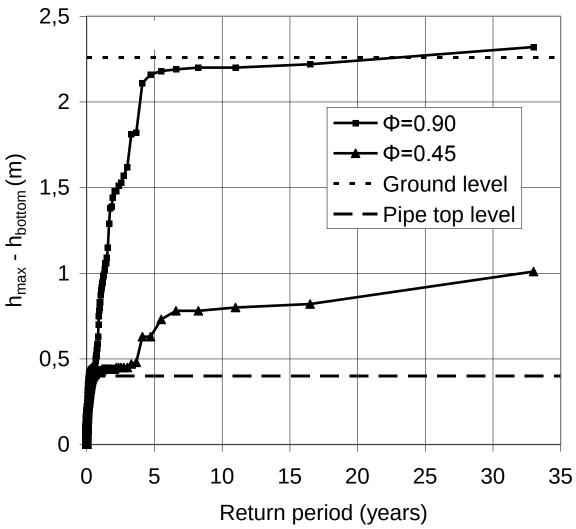

Figure 3. Flooding frequencies in an arbitrarily chosen manhole in the Frejlev sewer system From Schaarup-Jensen et al. (2005).

It is important to realize that variations in hydrological runoff coefficients can be significant between catchments and within the same catchment. Becciu and Paoletti (2000) found the runoff coefficient to be normal distributed over a wide range of catchment types and climatic conditions. Thorndahl (2008) found that the variation in hydrological reduction coefficient to some extent can be explained by spatial variations in rain.

Analysis of urban rainfall – runoff relationships requires extensive measurements of both rainfall and runoff. While measurement of rainfall is reasonable simple and affordable, flow measurements in sewer systems are often complicated and costly to perform. For instance, accurate – and thus very expensive – pipe flow measurements are a necessity in order to estimate the hydrological reduction factor illustrated in figure 2. The Frejlev sewer research station is estimated to cost around 125.000 Euro to establish and run during the period (1997-2008). This is of course not feasible for most practical applications. Other in-sewer measurement techniques, such as weirs, ultrasonic are only practical with a significant amount of maintenance.

An alternative to direct measurement of the hydrological reduction factor is to model the runoff with a numerical model. The result of the model (e.g. MOUSE) (Lindberg and Joergensen., 1986) is compared with observations in the sewer system. This opens for other data types than precipitation and flow, when determining relevant hydrological parameters.

This is the key for the low cost calibration method examined here. By measuring the beginning and end of CSO, it is assumed that it is possible to determine the hydrological reduction coefficient without expensive in-sewer flow measurements.

METHODS

The method is to calibrate urban drainage model MOUSE to measurements of the CSO measured by switches in overflow structure. The switches are simple contact type switches, figure 4. The only variable registered is the time, the CSO is in operation. The resolution is 4 minutes.

Figure 4. Water level switch for overflow indication

The overflow is registered as a binary indication (on/off) and a timestamp. The MOUSE model is set up using the digitised geometry of the sewer system and with program default values. The only parameter adjusted in this work is the hydrological reduction coefficient. All other constants (manning number, head loss in manholes, surfaces models ect.) are kept at default values. Description of the sewer system, hydrological properties and application of MOUSE can be found in Thorndahl et al. (2006)

The principle of the method is to only calibrate the hydrological reduction coefficient to match the modelled duration of the CSO to the measured duration. It was found that trying to exactly fit the overflow hydrograph to the measurement of the start and stop of the CSO lead to unrealistic reduction coefficients. In order to get the kinematics correct, friction losses and surface model constants has to be calibrated extensively. The purpose of this calibration is to get the overall mass balance to be as correct as possible. The activation time is in this case a more realistic measure of the overflow.

RESULTS AND DISCUSSION

The model was calibrated against 4 rain events, which were chosen to guarantee significant overflow from the CSO. Figure 5 illustrates the modelling result for one of the simulations. The red line indicates the default value of ϕ=0.9, often used for analysis of drainage systems. The blue line is when the hydrological reduction coefficient is calibrated to give the same activation duration. In this case, the hydrological reduction coefficient has to be halved in order to fit the measurement. It is also clear that the CSO is also halved as a consequence of the lower reduction coefficient.

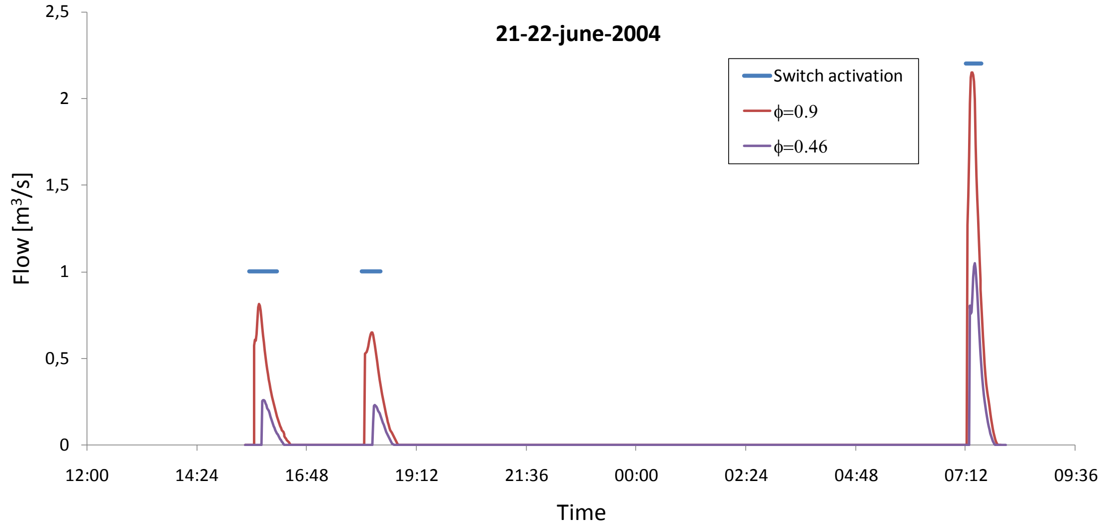

Figure 5. overflow from CSO with two different hydrological reduction coefficients.

Repeating this procedure for the rest of the 4 events yields individual hydrological reduction coefficients. As can be seen from table 1, the measured and calibrated duration of the CSO match well. As a result of the calibration an average hydrological reduction coefficient of 0.56 is found. This is fairly close to the value of 0.51 found by Thorndahl (2008) using 293 rain event, figure 2. The ϕ−value is also measured with a combination of flow meter and rain gauge. In this comparison there is a near perfect match.

Table 1. Result of calibration with CSO duration.

Date	Duration for ϕ=0.9 (min)	Measured duration(min)	Calibrated duration (min)	Calibrated ϕ	Measured ϕ
21-22/6 2004	131	88	89	0.46	0.47
23/6 2004	108	56	55	0.65	0.65
17/10 2004	201	20	17	0.70	0.71
22-23/6 2004	356	200	198	0.50	0.50

As a small test of the calibration, two events were selected for validation of the results, table 2. The average value of ϕ=0.56 is used as a default value. These two events illustrates that in the first simulation, the average hydrological reduction coefficient is too large, while in the second event the coefficient is very close to the average. Comparing to the actual value underlines the importance of using local hydrological reduction coefficients.

Table 2. Result of validation with CSO duration.

Date	Measured duration (Min)	Simulated duration (min)	ϕ	Measured ϕ
22/5 2006	20	75	0.56	0.33
26/9 2006	68	69	0.56	0,49

The drainage system in Frejlev is relatively simple, compared to large systems with many basins and pumps. There is only one basin and CSO in the system before the intercepting sewer line. For this reason it can be speculated that the method is most suited for simpler systems with basins. The CSO duration can in this situation clearly be linked to mass balance of the system. It is however realistic to expect that the method also can be used for larger systems further down in the system, as long as the urban drainage model is able to capture the more complex interactions between basins, pumps and other regulation. It is however clear, that the calibration will involve much more work, than indicated in this example. The results also state that there is a large variation in the hydrological processes from one rain event to another. Figure 2 illustrates that a significant number of events is outside the 95 % significance level of the best fit. This leads to the conclusion that the actual hydrological reduction coefficient has to be used when - for example - studying flooding. Thorndahl (2008) has in the Frejlev catchment not found a correlation between rain intensity and the hydrological reduction coefficient. Nor has the dry weather period before the event any influence. In the case of design of new system, a more probabilistic approach is necessary.

An important aspect of this method is how simple and cost effective it is to establish such simple switches at CSO's. A typical system will cast less than 1.000 Euro pr CSO structure. As a consequence, the municipality of Aalborg has installed switches on all their CSO structures

CONCLUSION

It was found that calibration the MOUSE model to fit the duration of the CSO was sufficient to get an estimate on the hydrological reduction coefficient, which was close to what was measured during 293 rain events with a sophisticated sewer monitoring system. The validation indicates that not one single hydrological reduction coefficient can be used for all events.

ACKNOWLEDGEMENT

The authors wish to acknowledge Aalborg municipality for providing data for the study and M.Sc. student Jesper Ellerbæk Nielsen, Jesper Christensen and Henrik Skytte for doing a lot of laborious work with the simulations.

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