Assessment of CSO activity using simple volume balancing

Prévision des rejets unitaire de temps de pluie par simple bilan de volume

Kroll S.[1]; Blumensaat F.[2]; Dirckx G.[1]; Thoeye C.[1]; De Gueldre, G.[1]; Van De Steene, B.[1]; Tränckner, J.[2];

[1] Aquafin NV, stefan.kroll@aquafin.be

[2] TU-Dresden, frank.blumensaat@tu-dresden.de

RESUME

Trois méthodes d'évaluation de rejets unitaire de temps de pluie sont comparées selon leur applicabilité sur un cas d'étude d'un bassin versant représentatif de Flandre (bassin versants à effet de retenue important) : une méthode de bilan de volume et deux modèles conceptuels. Cette comparaison est basée sur la prédiction du volume et de la fréquence des rejets de temps de pluie obtenus par une simulation à long terme. D'après les résultats produits, la méthode de bilan de volumes n'est pas recommandée pour des bassins versant de caractéristiques proches de celui étudié. De plus, les résultats d'un des deux modèles conceptuels (modèle qui ne calcule pas le volume des eaux retenues dans la canalisation)ne sont pas réalistes. Des modèles plus sophistiqués que ceux étudiés sont nécessaires pour prédire des rejets unitaire de temps de pluie proches de la réalité sur des bassin versants à effet de retenue important.

ABSTRACT

Three simplified methods (a static volume balancing method and two conceptual models) are compared regarding their applicability for the assessment of CSO activity on a case study of a typical Flemish catchment. This comparison is based on the evaluation of the predicted CSO volume and frequency for a long-term simulation. The application of the simple volume balancing method can not be advised for the assessment of CSO volumes in rather complex catchments like the one being subject to this case study. Also one of the conceptual models – a model not being explicitly designed to handle backwater effects – encountered problems in depicting reality in an acceptable manner. Catchments that are severely influenced by backwater effects require rather sophisticated models for a reasonable assessment of CSO activity.

KEYWORDS

Balancing method, combined sewer overflow, long time series simulation, (conceptual and deterministic) sewer modelling.

1 INTRODUCTION

Nowadays there is a popular trend to be noticed towards simplification in the field of sewer modelling in order to facilitate the implementation, calibration and computation of a sewer network under investigation. In this work, a static volume balancing method (SOBAL – Sewer Overflow BALancing method) is compared to two conceptual models and a chosen reference simulated by a hydrodynamic sewer model (InfoWorks) in order to reveal the performance and drawbacks of the three simplified approaches. The comparison is based on the results of a continuous long-term simulation for 27 years of measured rainfall data. Evaluation criterion is the CSO activity (volume, frequency) and the reliability (correlation) of the models' output. Furthermore, simulation runtime, the effort for model setup and the possibility of using the respective model as screening method are compared.

The key questions to be answered are:

- Are simple methods – and especially volume balancing – still accurate and useful enough to compete with newer approaches?
- Are the caused errors acceptable considering simpler handling and the gain in simulation runtime? Does it pay off to exchange simplification for accuracy?
- Is simple screening of rather complex catchments possible at all?

2 CASE STUDY

2.1 The investigated catchment

The considered catchment is situated in the area of the municipality of Herent in the province of Vlaams-Brabant in Flanders (Belgium). Most of the 15 700 inhabitants of the considered municipalities forming the hydrologic catchment of Herent are living concentrated in small urbanised areas that make up the contributing area: 578 ha (of which 125 ha are impervious) with an average population density of 27 IE/ha. Figure 1 provides an overview on the structure of the considered network.

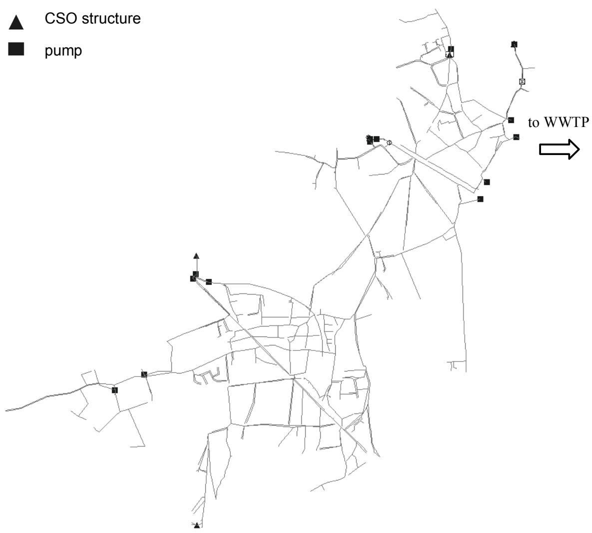

Figure 1: Overview on the sewer network of Herent

The Herent catchment has been chosen as investigation area for the evaluation and development of the balancing method for several reasons:

- Size: With about 1300 nodes, slightly more than 1000 sewer reaches, a total sewer length of 87 km and 12 CSO structures the Herent catchment is rather small and manageable in terms of measurements and supervision in comparison to other catchments available for this investigation. This is also crucial for modelling since long-term simulations were carried out with a hydrodynamic model.
- Established operational model: A detailed validated and updated hydrodynamic model was already available on the platform InfoWorks at the beginning of this case study.
- Catchment characteristics: Herent is considered to show the typical properties of a Flemish sewer system: fairly small slopes, considerable influence of backwater effects on the routing process, in-sewer storage, throttle pipes instead of dedicated throttle devices, several backwards working overflows (weir separated from throttle).

The latter of these aspects may be seen controversial since the catchment is representative for Flemish circumstances but not necessarily for other European regions. However, it has been decided to base further developments of SOBAL on the evaluation of the results that were obtained for this case, since the catchment provides a range of different CSO catchments and thus a thorough basis for the evaluation of the here considered modelling approaches.

2.2 Applied models

Four different approaches of determining CSO volumes were evaluated and compared to each other in the frame of this work: a rather simple and pragmatic volume balancing method (SOBAL), two conceptual modelling packages (Cosimat++ and CityDrain2) and a hydrodynamic modelling environment (InfoWorks). The hydrodynamic model served as reference for the comparison of all four models since it represents reality in an exact manner. In concordance with conclusions drawn by Illgen and Schmitt (2004) from a comparable study, all catchment and rain data used to set up the simplified models are based on data coming from the detailed model.

2.2.1 Balancing method – SOBAL

SOBAL was developed during a research project (CD4WC, 2003) for the estimation of CSO volumes in a catchment with few overflow data available (Benedetti et al, 2005). It was intended to develop a simple volume balancing method that should be straightforward to use and easy to understand. The resulting method is comparable to the method of Kuipers (formerly tested by e.g. Vaes & Berlamont (1995)), also known as “Entlastungsgrenzlinie” (Butz, 2005; Xantholpoulos, 1990) a long-term established method in German and Dutch speaking regions. Both methods try to estimate the overflow volume of a catchment by carrying out a volume balance over the whole duration of a rain event. The basic algorithm of SOBAL is illustrated in Figure 2:

After subtraction of a constant amount of wetting losses from the block rain, some water is temporarily stored (dynamic storage) in the sewers during the runoff process. The in this way reduced flow in the sewer is joined by additional inflow introduced to the system by an upstream connected throttle. If this total flow exceeds the capacity of throttle device, static offline storage may be activated if available. When the maximum of this storage is reached, the remaining water is spilled through the overflow. The result of SOBAL is thus a sequence of overflow volumes for a given sequence of block rain events. Dynamic effects during one event (maximum overflow, overflow duration etc.) cannot be considered.

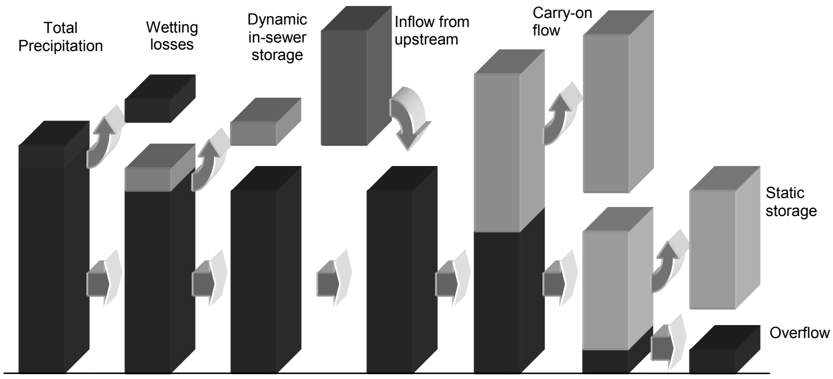

Figure 2: Scheme of the algorithm applied in SOBAL

During this case study several amendments (explicit consideration of variable rain duration, antecedent events and in-sewer storage) were made in order to adapt the method SOBAL to the requirements of the catchment characteristics under consideration. However, the nature of the method – static volume balancing – still entails drawbacks:

- Many details (dynamics) of the rainfall characteristics are lost. All rains are reshaped to block rains. The more a rain does not resemble a block rain event, the higher the caused error regarding the overflow volume.
- The consideration of detailed processes like attenuation of the runoff wave that passes the sewer system and backwater effects as well as the importance of storage aside from dedicated storage facilities are not accounted for or may only be assumed. This will especially lead to errors in catchments with long concentration times and small conduit slopes.

It is believed, that these drawbacks may not be overcome in the frame of static volume balancing. Thus, it was tried to minimise the errors emanating from these drawbacks by calibration instead of trying to abolish their sources. This calibration however, prevents SOBAL from being a straight-forward applicable screening method, since it then requires either detailed reference data or rather specific experience for the estimation of required parameters.

2.2.2 Conceptual models – Cosimat++ and CityDrain2

Developed on a case study of the sewer network of Brussels (deSmedt, 1997) and considerably modified and improved during a case study for the same catchment as presented here by Cuppens (2006), Cosimat++ can be considered state-of-the-art in conceptual sewer modelling. Within the modelling environment of Cosimat++ special attention is paid to detailed consideration of backwater effects and numerous control structures such as pumps, weirs and storage facilities. The model is principally based on the application of a reservoir cascade and therefore requires detailed calibration and high understanding of the simulated processes.

Set up by Achleitner (2006) for rather specific catchment properties (steep conduit slopes, low storage in sewers, dedicated reservoirs), CityDrain2 uses a derivative of the in river modelling well-established Muskingum method for the calculation of a CSO catchment runoff. However, the applicability of CityDrain2 to the investigated catchment showed to be limited, since severe problems are encountered in depicting backwater and backflow effects at throttle devices.

2.2.3 Deterministic model – InfoWorks

The evaluation and modification of SOBAL and the two conceptual models were carried out using results of a deterministic model. This operational model, built on the well-established platform of InfoWorks, was readily available for this study and is seen as reference for all other here tested approaches. It is an exact, constantly updated reproduction of the real sewer network.

2.3 Calibration

An ideal screening tool should not require any calibration at all. However, no such tool or methodology depicting overflow volumes in sufficient detail could be found during an extensive literature review. Even simple tools like SOBAL require the estimation or calibration of a number of parameters (see (Kroll, 2006) for details):

- The surface wetting losses,
- two parameters for the definition of block rain events from continuous rain data: minimum dry weather period specifies the minimum time-lag between two rain events and a threshold of the registered rain height that serves neglecting marginal rain contributions and
- A parameter for the influence of dynamic in-sewer storage (filling degree).

While the short runtime of SOBAL allowed using the whole period of 27 years of rainfall for calibration, the more time consuming conceptual models required a rough pre-estimation of parameters by evaluating the results based on composite (i.e. synthetic) storms that are usually used for design purposes in Flanders.

Detailed information on the calibration of Cosimat++ can be found in literature (Cuppens, 2006). CityDrain2 was calibrated following the methodology suggested by its developer (Achleitner, 2006). However, some problems could not be overcome during the calibration of CityDrain2. The most important drawback that was encountered is the fact that backflow and pressurisation of throttle pipes can not be modelled accurately. Since this process is crucial for the exact determination of CSO activity in the investigated catchment, considerable errors can be expected. The literature review also revealed that apart from Cosimat++ none of the found conceptual models so far considers pressurised throttle flow sufficiently detailed to depict typical “flat land” catchments like Herent. Consequently, CityDrain2 might be seen rather as a typical representative than as an exception among the numerous existing conceptual models. Calibration of throttle capacities – as e.g. suggested by Solvi (2005) – did improve the total error of CSO volume and frequency but since it could not be combined with any backflow-consideration this single measure was not sufficient to lead to accurate results.

3 MODEL COMPARISON

The considered **temporal scope** of a simulation showed to be of high importance when comparing the results of the conceptual models and SOBAL to the reference data generated by the hydrodynamic model. As can be seen in Figure 3, SOBAL performs fairly well. Concerning total CSO volumes for whole Herent on an annual basis it even outflanks the two other modelling approaches. For this fact the following reasons can be identified:

- The model on the platform of Cosimat++ has not been calibrated concerning overflow volumes but purely on runoff considerations since it is intended to be used as a generally applicable sewer model – not being focused on overflow activity.

- Given that CityDrain2 does not provide detailed considerations of processes that play an important role in the investigated catchment, this model's outcome is still afflicted by severe errors despite of the fact that also overflow volumes were consulted for calibration of this model.
- The latest version of SOBAL was developed and calibrated for the system of Herent. Rather good compliance with the reference used during development was thus expected.

Focusing on single events in an increased temporal resolution, it is interesting to note that Cosimat++, CityDrain and SOBAL react very different on the same rain events. While Cosimat++ also for this temporal resolution constantly tends to overestimations, CityDrain2 and SOBAL show less steady behaviour on daily resolution. Both models' results alternate around the outcomes of InfoWorks. For SOBAL, it is these alternations between over- and underestimation that finally lead to the apparent good result over long periods. Mainly as a result of too coarse considerations for flow splitting at the CSO device, CityDrain2 shows more over- than underestimations whereas the 'offset' cannot easily be eliminated by calibration.

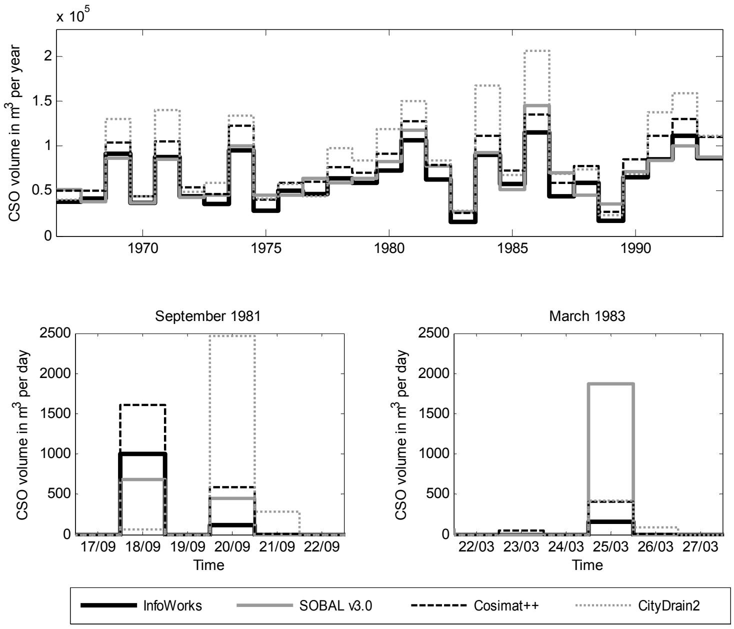

Figure 3: CSO volumes for different temporal scopes: per year (upper) and per day for SOBAL, InfoWorks, Cosimat++ and CityDrain2

The ability of correct description of **spatial variability** of results plays a major role in the application of screening methods. Such methods should be able to reliably predict results for all overflow devices they are applied to.

Figure 4 reveals that rather complex systems like the one being subject to the here presented case study cannot be described correctly by the balancing method: While the importance of some overflow structures is almost neglected (CSO 5, 6 and 11), the volume of others is distinctively overestimated (CSO 8). However, it can be stated that also the two conceptual models face difficulties in depicting the overflow volumes in a correct manner.

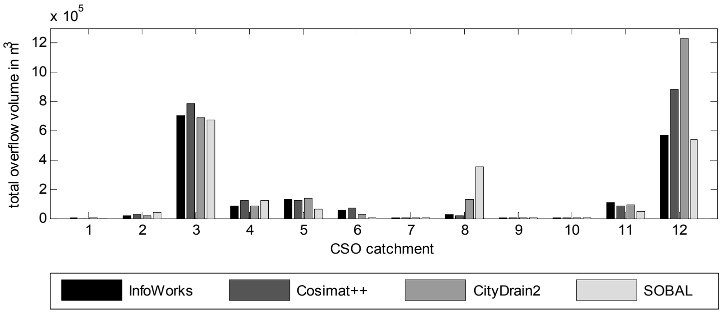

Figure 4: Total overflow volume per CSO catchment over 27 years modelling vs. SOBAL

Two main reasons could be identified for this:

- Cosimat++ ( ) has not been calibrated with regard to the overflow volumes; the calibration was mainly based on the carry-on flow in the throttle device of each CSO-catchment (Cuppens, 2006).
- CityDrain2 ( ) is – due to its development background – focused on accurate description of the runoff process in the catchments but applies rather simple estimations for the considerations of flow splitting at the throttle device. Even the assumption of a virtual maximum capacity of a CSO's throttle does not lead to acceptable results for the highly varying flows to be observed in the here considered catchment.

The following table summarises the performance of each modelling approach showing simulation runtime along with total over- and underestimations of CSO activity under consideration of temporal and spatial scope.

Model	cumulated under- / overestimation in %				simulation time[1]	time factor
	temporal scope		spatial scope			
	CSO volume	CSO frequency	CSO volume	CSO frequency		
InfoWorks	(0)	(0)	(0)	(0)	13.5 d	(1)
Cosimat++	-0,1 / 24,7	-3,0 / 27,9	-2,2 / 26,7	-3,4 / 28,3	20 h	1/16
CityDrain2	-15,5 / 57,6	-46,2 / 13,1	-3,2 / 45,3	-35,6 / 2,4	7 h	1/46
SOBAL	-42,8 / 51,5	-36,4 / 49,8	-14,2 / 22,9	-24,3 / 37,8	< 1 min	≈ 1/25 000

[1]: time indicated for 3.2 GHz Intel Pentium IV HT, 512 MB RAM desktop computer

Table 1: Comparison of performance of the different modelling approaches for the catchment of Herent, 27 years of continuous rainfall

While SOBAL yields rather accurate results for rough local and temporal considerations by counterbalancing positive and negative errors, Cosimat++ shows high accuracy as a result of exact consideration of all processes being important for the catchment of Herent. The application of CityDrain2 seems rather disproportionate for the given case study since calibration effort and result accuracy are in no relation given that the program is not designed to handle backwater effects that are of high importance for the catchment of this study.

4 CONCLUSION

Rather complex catchments require more sophisticated algorithms to gain accurate and reliable results. This is not only true for the simple screening method that made up the focus of this work but also for the more detailed conceptual models that were used for comparison. The catchment being used for the here presented case study required a special conceptual modelling approach.

The application of CityDrain2, a typical unspecific conceptual model, showed to be disproportionate. In contrast Cosimat++, the more detailed conceptual model, depicts all in the considered system relevant processes with rather high accuracy and hence yields very good results. The static balancing method yields moderate results but this effect is achieved by counterbalancing errors emanating from the different modelled processes. Its outcomes are thus less accurate and reliable. In CityDrain2, some considerations like the rain-runoff process are depicted sufficiently detailed, while others as for example the outflow conditions in a pressurised throttle pipe caused severe errors in the presented case study. Consequently there is no possibility of counterbalancing errors; the results here are thus as poor as the ones obtained by the simple balancing method.

As suggested by other authors, the application of methods comparable to Kuipers should – where still used – be replaced by more accurate but still simplified modelling concepts. The findings derived from this case clearly underline this demand. However, also these models should be tailored to the systems they are applied to.

The investigations show that the selection of the modelling concept strongly depends on the modelling requirements arising from the present system characteristics and on the objective of the modelling study.

In any case SOBAL should be applied to further investigations; an application under less stringent conditions may give more reliable results. The need for calibration should be overcome; otherwise there will always be models that will yield better results when being calibrated accurately. Still, the limiting process in SOBAL is seen in its main feature itself: the restriction of simple static volume balancing. Complex systems cannot be described by arbitrarily simple methods.

LIST OF REFERENCES

Achleitner, S. (2006), Modular conceptual modelling in urban drainage development and application of CityDrain, Leopold Franzens Universität Innsbruck, Innsbruck.

Benedetti, L., F. Blumensaat, G. Bönisch, G. Dirckx, N. Jardin, P. Krebs, and P. A. Vanrolleghem (2005), Systems analysis of urban wastewater systems – two systematic approaches to analyse a complex system, Water Science & Technology, Vol 52, pp 171–179.

Butz, J. (2005), Stoffstrombilanzen für Phosphor und sechs Schwermetalle am Beispiel des oberen Kraichbachs, Universität Fridericiana zu Karlsruhe (TH), Karlsruhe.

CD4WC (2003), Cost-effective development of Urban Wastewater Systems for Water Framework Directive compliance, www.cd4wc.org

Cuppens, A. (2006), Implementation of a conceptual sewer modelling software on the Matlab-Simulink platform for the catchment of Herent, Vrije universiteit Brussel / Katholieke universiteit Leuven, Leuven, Brussels.

deSmedt, D. (1997), Development of a continuous simulation model for sewer systems using Matlab, Vrije Universiteit Brussel, Brussels.

Illgen, M., and T. G. Schmitt (2004), Different model applications, different results? An approach to achieve consistency in urban drainage modelling, paper presented at Urban Drainage Modelling 2004, Dresden.

Kroll, S. (2006), Quantification of overflow volumes – balancing methods vs. hydrodynamic modelling, Technische Universität Dresden, Dresden.

Solvi, A.-M. (2005), Integrated urban catchment modelling for a sewer-treatment-river system, paper presented at 10th International Conference on Urban Drainage, Copenhagen/Denmark, 21-26 August 2005.

Vaes, G., and J. Berlamont (1995), Methodologieën voor de bepaling van de overstortfrequentie met behulp van beperkte neerslaginvoer, Leuven.

Xanthopoulos, C. (1990), Methode für die Entwicklung von Modellregenspektren für die Schmutzfrachtberechnung, Universtät Karlsruhe, Karlsruhe.