Optimized series of rainfall events for model based assessment of combined sewer systems

Séries optimisées d'événements pluvieux pour la modélisation de systèmes d'assainissement unitaires

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RÉSUMÉ

Souvent, deux modèles différents sont fournis pour le même système d'assainissement, un modèle hydrodynamique pour la vérification hydraulique et un modèle conceptuel pour la vérification de la conformité par rapport aux normes en matière de rejets unitaires en temps de pluie. Cependant, une vérification combinée utilisant un seul modèle présente de nombreux avantages. Pour le calcul nécessaire du niveau de l'eau, pour les besoins de la vérification hydraulique, seuls les modèles hydrodynamiques sont applicables. Par conséquent, un modèle hydrodynamique doit être utilisé pour effectuer une vérification combinée, si un seul modèle doit être utilisé pour les deux vérifications.
Souvent, la vérification et l'évaluation des rejets unitaires en temps de pluie nécessitent une simulation à long terme. L'utilisation de modèles hydrodynamiques en combinaison avec une simulation continue allant de deux ans jusqu'à plusieurs décennies entraîne régulièrement des temps de calcul excessivement élevés. Une autre solution consiste à utiliser une série de chutes de pluie pour les simulations au lieu du continuum des précipitations, ce qui réduit considérablement le temps de calcul.
Cet article présente une méthode permettant de générer une telle série de chutes de pluie. Cette série est optimisée pour correspondre aux volumes de surverse de la simulation continue et pour réduire le temps global de calcul sur la simulation à partir d'une série.

ABSTRACT

Often, two different models are provided for the same sewer system, namely a hydrodynamic model for the hydraulic verification and a conceptual model for the verification of compliance with standards for combined sewer overflows (CSO). However, a combined verification using only one model has many advantages. For the necessary calculation of water levels for the hydraulic verification, only hydrodynamic models are applicable. Consequently, a hydrodynamic model has to be used for a combined verification if the same model should be used for both applications.
Often, the verification and assessment of CSOs asks for long-term simulation. The use of hydrodynamic models in combination with continuous simulation of a couple of years up to several decades regularly leads to unacceptable high computation times. As an alternative, a series of rainfall events can be used for the simulations instead of the precipitation continuum leading to dramatically reduced computational times.
This paper introduces a method to generate such a series of rainfall events. This series is optimized to match the overflow volumes of the continuous simulation and to reduce the overall computation time of the series simulation.

KEYWORDS

Combined sewer overflow, Genetic Algorithms, Sensitivity Analysis, Urban drainage modeling

1 INTRODUCTION

Generally, combined sewer systems have to be verified (i) hydraulically and (ii) in terms of their compliance with standards for combined sewer overflows (CSOs). These verifications are implemented in various country-specific guidelines.

Both the German DWA-A 118 (DWA, 2006) and the Austrian ÖWAV-Guideline 11 (OEWAV, 2009) suggest the "overflow frequency" - how often the head is above ground level at single manholes - as the objective for the hydraulic verification. Simulation techniques using 1D hydrodynamic models (solving the de Saint Venant equation) have to be used for this purpose for calculating the required water levels at each junction of interest.

For conducting such a hydraulic verification, two different methods are widely accepted:

- Principle of loading cases (using design storms of different return periods)
- Long-term simulations (using long-term rainfall time series or series of storm events that could cause surcharged conditions in the sewer)

In order to verify the compliance with standards for CSO emissions (in Austria regulated by the ÖWAV-Guideline 19 (OEWAV, 2007b)), the discharge volume at CSOs as well as the surface runoff volume have to be estimated to calculate the CSO efficiency (for a detailed description see (Kleidorfer and Rauch, 2011)). For this purpose, a long-term simulation using the precipitation continuum of at least 10 years - is required. In contrast to detailed hydrodynamic models used for the hydraulic verification, conceptual lumped models are normally used due to their reasonable computation times.

In consequence, two different models are often provided for the same sewer system, namely a hydrodynamic model for the hydraulic verification and a conceptual lumped model for the verification of compliance with standards for CSOs.

This paper aims at analysing the possibility of a combined verification using hydrodynamic models only. A combined verification has the advantage that only one model – the hydrodynamic model – is required for two different tasks. Consequently, double model-building as well as double model-maintenance would not be necessary anymore.

The focus of the following investigations is on the overflow volume of CSOs. Calculating it with hydrodynamic models (according to a combined verification) can lead to high computation times. A series of rainfall events can be used instead of the precipitation continuum to reduce the computation time. An approach in order to optimize such a series of rainfall events is described below.

2 METHODOLOGY

In order to obtain reasonable computation times, it is necessary to only use a series of significant rainfall events for the simulation of the total overflow volume of CSOs. Therefore, a series of rainfall events has to be created, which leads to the same overflow characteristics in terms of volume and frequency as using the continuous series. To generate such a series of rainfall events, we present a method working with three (four) input parameters:

- Threshold-time [min]
- Treshold-value [mm]
- Event gap [min]
- (Time extension [min])

First, the method calculates the amount of precipitation for a certain time segment (threshold-time). Only if the obtained value is higher than the selected threshold-value, this time segment is considered for the final series of rainfall events. Second, the "event gap" determines the minimum time interval between two separate rainfall periods and ensures that the runoffs of two consecutive rainfall events do not influence each other. Therefore, the event gap should also include the "run dry-time" of the system particularly with regard to existing storage tanks, retention volume, etc.. Finally, an overflow event must not stop immediately after the rainfall event. For this reason the created events have to be extended (time extension).

The obtained series of rainfall events are used as input for a test model. To investigate the effects of different parameter sets, the results of all individual rainfall events are added up (in this case the overflow volumes) and compared with the result of the continuum simulation.

For a first assessment of the model behaviour using different parameter sets, a global sensitivity analysis (GSA) is conducted by using the “Morris Screening” (Campolongo et al., 2007).

To analyze possible reductions of computation time, the following steps are considered:

- Step 0: Hydrodynamic simulation with precipitation continuum (reference case)
- Step 1: Exclusion of “real” dry periods (steady state periods are skipped)
- Step 2: Exclusion of “fictitious” dry periods (using the method described above) – small events contributing to the surface runoff volume but not leading to overflow events are not simulated anymore (but are still required for calculating the CSO efficiency). Possible solutions for this problem are investigated (e.g. separate continuous simulation of the surface runoff only).
- Step 3: Optimization of the parameters of step 2 considering the following two targets:
    - Minimize computation time (instead of the computation time itself the time sum of the generated rainfall events is used to be independent of CPU-power and possibly occurring background processes during the simulations. The lower the event time sum is, the lower the computation time for the simulation of the rainfall event series will be.)
    - keep unchanged total overflow volume of the reference case
- Step 4: Parallelization of the event simulations – using a series of rainfall events instead of the precipitation continuum has the big advantage that the simulations of the single events can be parallelized on a multi-core CPU. This results in further reductions of the computation time.

In particular, Step 3 is the central aspect of this paper. The applied optimization tool uses multi-objective genetic algorithms. Figure 1 shows the general procedure of the tool.

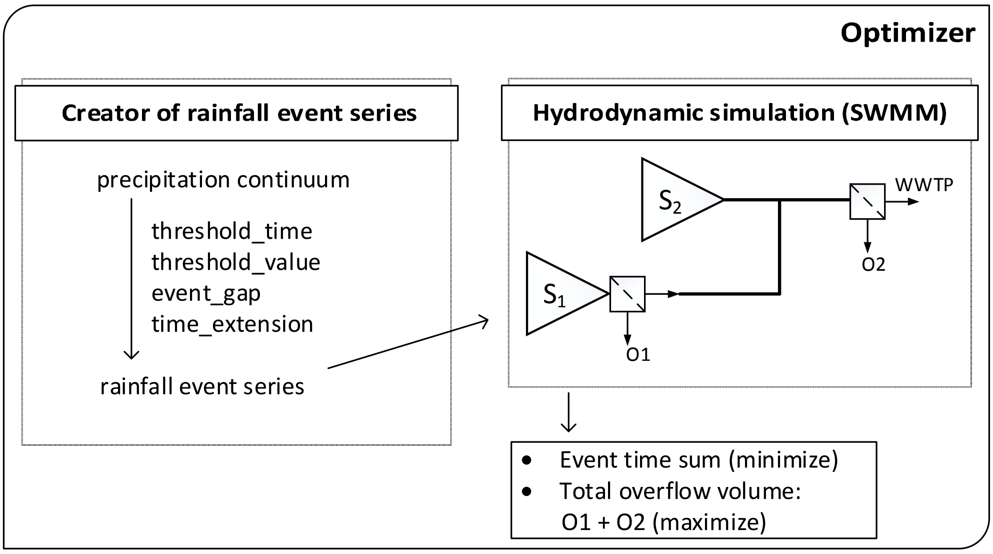

Figure 1: Procedure of the optimization tool

The optimization tool is applied to 5 virtual case studies with varying system properties, which are generated using the case study generator described by (Möderl et al., 2009). Additionally, two different precipitation time series with a length of 3 and 5 years provided by OEWAV (2007a) are used for the optimization runs.

The goal of the optimization runs is to find a generally applicable parameter set. The general validity of this parameter set is verified by applying it to 5 real case studies.

3 RESULTS AND DISCUSSION

Figure 2 shows a result of the proposed method. The green-colored series of rainfall events was created by using the blue-colored precipitation continuum of 1992 measured in Graz and the following parameters: threshold-time=400 min, threshold-value=15 mm, event gap=720 min.

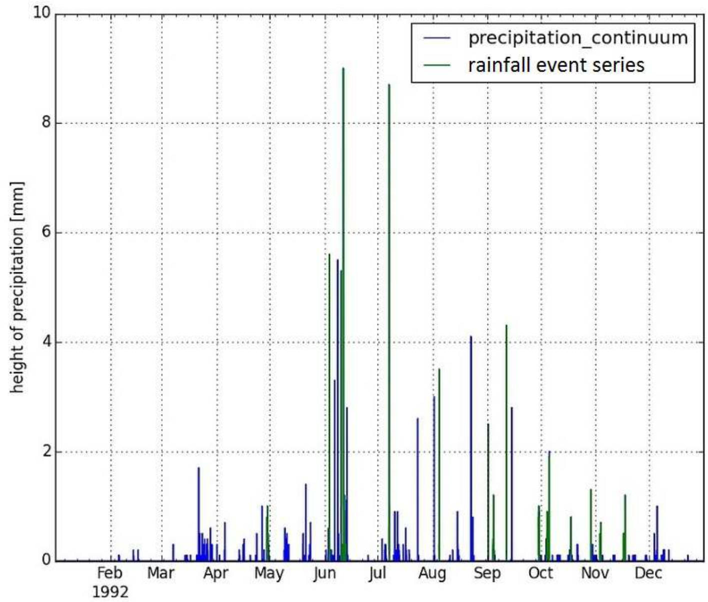

Figure 2: Precipitation continuum and rainfall event series

Figure 3 shows a first result of the GSA using the total overflow volume as investigated model output variable. All parameters are sensitive (based on μ*) and the result suggests a non-linearity and/or interactions with other parameters (based on σ) as well.

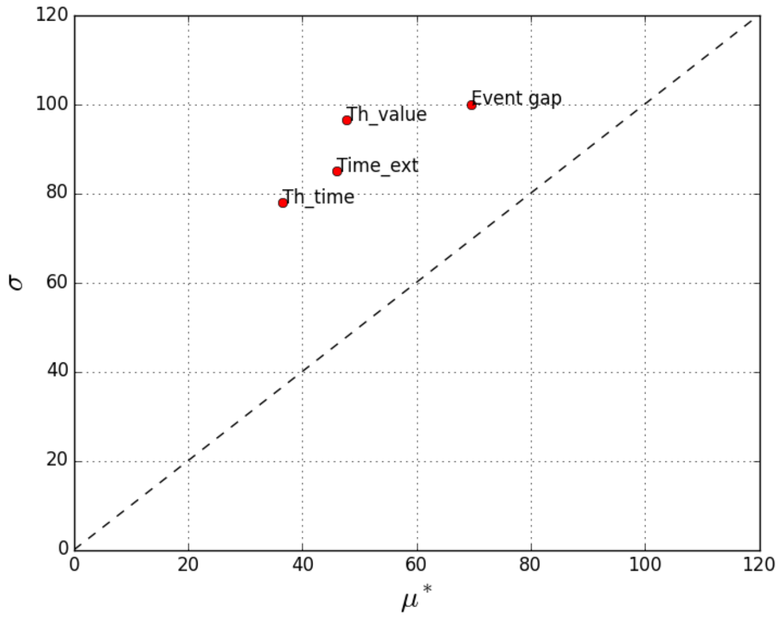

Figure 3: Morris Screening result for total overflow volume

An exemplary result of the optimization tool is presented in Figure 4. The optimal results can be found at the bottom right of the scatter-plot, because here the maximal total overflow volume and the minimal event time sums are reached. In this case a precipitation time series of 5 years (1825 days) was used. As the figure shows, the simulation of only 427 days (event time sum) is necessary to get the same overflow volume as with the precipitation continuum. Accepting a minimum degree of imprecision in the result of the overflow volume leads to further reductions of the event time sum. In the investigated case of Figure 4, the reduction of the overflow volume of 1% resulted in a reduction of the event time sum of 65%. Thus, the rainfall event series reduced by 65% in its length results in an overflow volume reduced by only 1% (always compared to the rainfall event series leading to the maximal overflow volume).

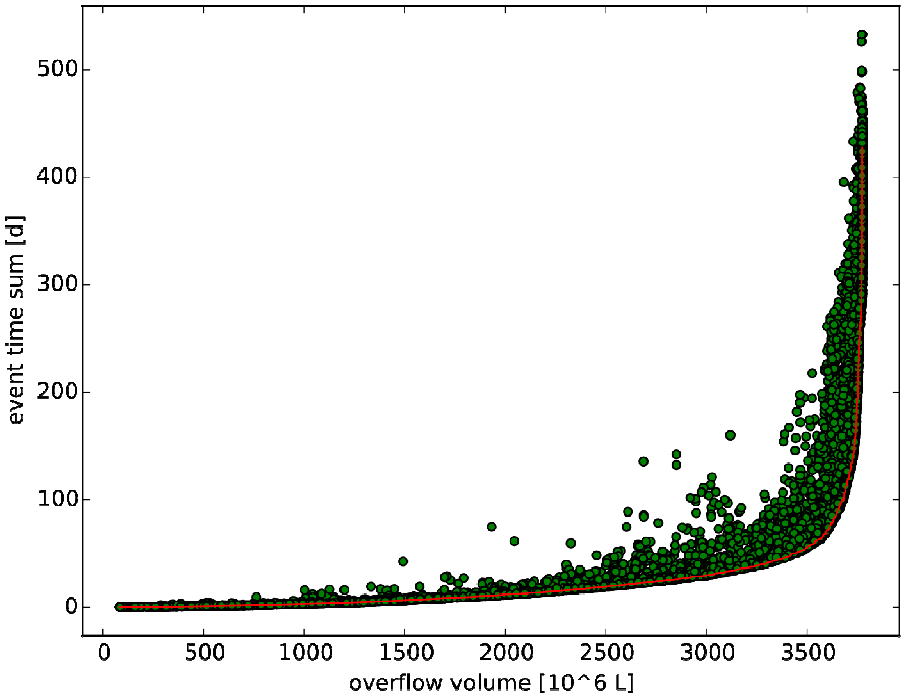

Figure 4: Result of the optimization tool

Using an obtained “optimal” rainfall event series for the simulations of the 5 virtual case studies leads to a speedup of computation time ranging from 4 to 9 times compared to the simulation with the precipitation continuum. A parallelization of the event simulations (using an eight-way hyperthreaded quad core CPU), can be used for a further reduction of the computation time, resulting in a speedup of approximately 18 to 40 times.

The analysis of the optimization runs shows a generally applicable parameter set, which is not the absolute optimal one for every particular case study, but it leads to considerable reductions of the computation time and to an overflow volume which deviates max. 1% from to the result of the reference case. The values of the parameter set are:

- Threshold-time: 480 min
- Threshold-value: 2 mm
- Event gap: 1400 min
- Time extension: 100 min

The application of the parameter set to the 5 real case studies showed its general validity due to the results for the overflow volumes (max. 1 % deviation from results of reference case) as well as due to the considerable reductions of the computation times.

4 CONCLUSION

A combined verification of the combined sewer system (hydraulic verification and verification of compliance with standards for CSOs) with only one hydrodynamic model has many advantages, e.g. the avoided double model-building as well as the avoided double model- and data-maintenance.

To get reasonable computation times in the course of a combined verification, it is necessary to only use a series of rainfall events instead of the precipitation continuum for the calculation of the overflow volume of CSOs. Therefore, a simple method was developed to generate this series of rainfall events. The parameters of the method were optimized in order to get the same overflow volume as using the precipitation continuum and in order to reduce the computation time of the series simulation as much as possible. By using a series of rainfall events instead of the precipitation continuum, a speedup of up to 40 times is possible. As a result of the optimization runs a generally applicable parameter set was identified, an important outcome for the general application of this method.

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