Optimal operation of CSO tanks based on highly resolved online data

Gestion optimale des bassins d'orage avec déversoir basée sur des mesures en continu (haute résolution)

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RÉSUMÉ

Le volume de stockage dans les réseaux unitaires d’assainissement est souvent réparti sur l'ensemble du réseau. La performance globale par temps de pluie est déterminée par le réglage du débit de sortie de chaque unité de stockage.

Cet article présente une méthode d'optimisation basée sur les données pour un réglage optimal des débits statiques contrôlés de sortie de bassins d’orage. Contrairement à l'optimisation conventionnelle des systèmes d’assainissement basée sur les résultats de la modélisation pluie-débit, les données de ruissellement mesurées sont directement utilisées pour l'optimisation du système. Cette méthode exclut les incertitudes de la modélisation hydrologique qui peuvent influencer les résultats des approches d'optimisation classiques.

Les débits de sortie dans un bassin versant conceptuel idéal comprenant deux bassins d’orage avec surverse ont été optimisés sur la base de mesures de débit et de qualité en continu. Différents objectifs d'optimisation (réduction du volume, de la charge et de la durée de déversement) ont été évalués. La méthodologie proposée s'est révélée appropriée. Tous les objectifs testés permettent d'obtenir presque le même réglage optimal. Une série de mesures en continu de quatre mois incluant au moins 10 épisodes pluvieux semble suffisante pour obtenir des résultats d'optimisation fiables.

ABSTRACT

Storage volume in combined sewer systems (CSS) is often distributed over the entire drainage system. The overall performance during rain events is determined by the setting of the outflow of each storage unit.

The paper presents a data based optimization method for optimal setting of static controlled outflows from combined sewer overflow (CSO) tanks. In contrast to conventional system optimization based on rainfall-runoff modelling results, measured runoff data is used directly for system optimization. This method excludes uncertainties from hydrological modelling that may influence results from conventional optimization approaches.

Controlled outflows in a conceptual ideal catchment comprising two CSO tanks were optimized based on high resolution online flow and quality data. Different optimization objectives (reduction of overflow volume, load and duration) were assessed. The proposed methodology showed good applicability. All tested objectives lead to almost the same optimal setting. A measured time series of four months including at least 10 rain events seems sufficient for reliable optimization results.

KEYWORDS

Combined sewer overflow, optimization, online monitoring, urban drainage systems, measurements

1 INTRODUCTION

The effectivity of storage units within the sewer system depends on the available storage volume and their controlled outflows. Optimizing the setting of these outflows is therefore an important contribution to reduce emissions from CSOs without constructing additional tanks. Especially in complex systems with many distributed storage units this is a challenging task.

In practice as well as in research optimization is almost exclusively done based on sewer system models (e.g. Fiorelli et al., 2013; Lacour and Schütze, 2011). A major source of uncertainty of such models is the representation of the subcatchments in the hydrological model part (runoff generation and overland flow). Previous studies have identified the effective impervious area as particularly sensitive for stormwater runoff simulations (e.g. Bachmann-Machnik et al., 2018; Kleidorfer et al., 2009). The often observed high level of uncertainty in stormwater modelling (Dotto et al., 2010; Kanso et al., 2005) may lead to biased results and - as a consequence - to non-optimal decisions in design and operation.

Uncertainty can be reduced by calibrating models to measured data. However, this process is costly and challenging and considerable uncertainties inevitably remain due to model structure. A particular problem is the representation of unevenly distributed rainfall. Furthermore, urban catchments are developing continually. In practice the existing sewer system model usually does not reflect the actual stage of catchment development. This causes additional uncertainties in hydrologic models. As several types of sensors have reached a mature stage and are well applicable in urban drainage systems (Campisano et al., 2013) there is nowadays a general trend towards more and continuous monitoring of combined sewer overflow structures. Thus an ever growing data base is available to improve design and operation.

We propose a methodology to optimize operation of sewer systems based on measured runoff time series. Instead of using the data to calibrate a hydrologic model, we replace the model by measured time series. These data serve as direct input to a sewer transport model that is used for optimization of sewer system operation (see Figure 2). This approach aims at excluding all uncertainties from hydrological modelling and reducing bias and misleading results. In reality measured data are only available for limited periods of time and their predictive capacity is restricted because they only reflect the current status. By decoupling the hydrological modelling blocks from transport the methodology still allows to model and evaluate different scenarios.

2 MATERIAL AND METHODS

2.1 Measured data

Measured data from two real CSO tanks in a combined sewer system in Southern Germany were used. The tanks were equipped with online flow, water level and quality measurements. Inflow from the subcatchments was balanced over controlled outflow measurements and water level changes within the tanks. Equivalent concentrations for total suspended solids (TSS) were monitored in the flow-dividing structure of the CSO tanks by online UV/Vis spectrometer probes (s::can spectro::lyser) in 5 min intervals. Flow and water level data were measured in 1 min intervals. Quality and flow time series from the inflow of both tanks were available for 680 days from August 2014 until June 2016.

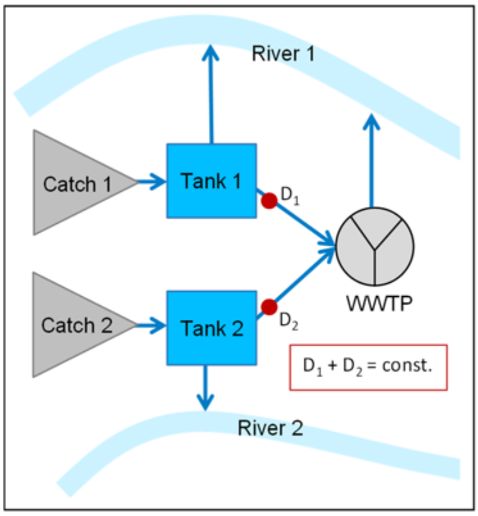

Figure 1 : Conceptual idealized catchment for data based system optimization; Catch = catchment, D = controlled outflow, WWTP = wastewater treatment plant

2.2 Data based optimization

Data based optimization was performed on a conceptual idealized catchment (see Figure 1). Tank sizes and geometries were adapted to the two CSO tanks the measured time series were obtained from. The CSO tanks have storage volumes of 804 m^3 and 1949 m^3, corresponding to a specific storage volume of 23 m^3/ha and 26 m^3/ha respectively.

The system was set up in the Storm Water Management Model SWMM without implementation of subcatchments and rain gauges. Measured inflow and concentration time series were inserted directly into the model as inflow at the nodes. The controlled outflows of each tank were optimized with MATLAB using simulated annealing algorithm under the constraint of a fixed constant combined controlled outflow from both tanks (D_1+D_2 = const.). The following optimization objectives were assessed:

- Minimization of total overflow volume from both tanks
- Minimization of total TSS overflow load from both tanks
- Minimization of total overflow duration from both tanks

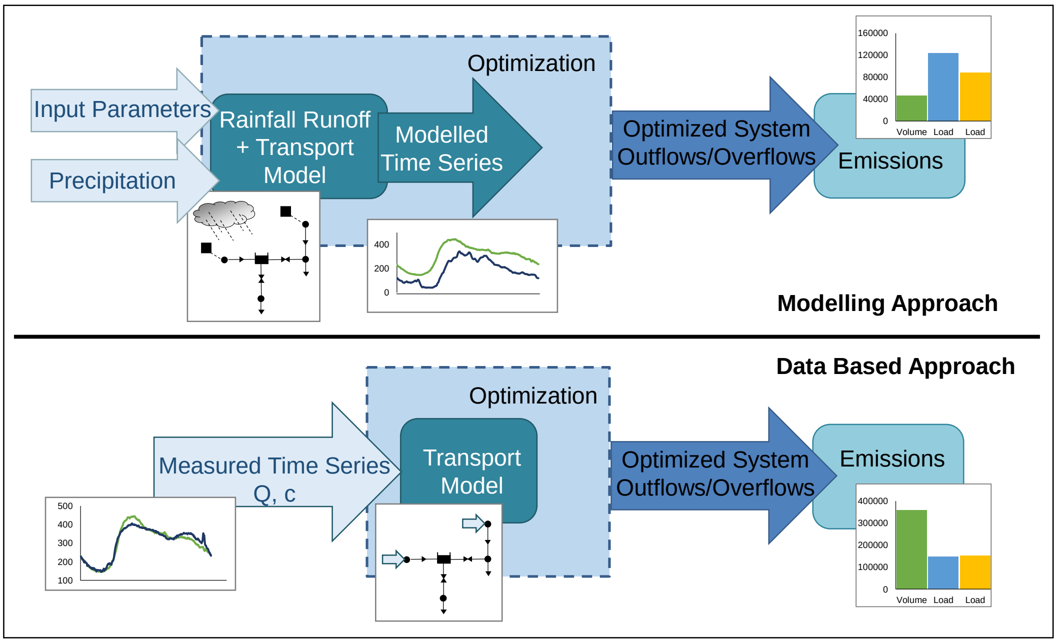

Figure 2: Conventional modelling approach for optimizing combined sewer systems and data based methodology in comparison; Q = flow time series; c = concentration time series

3 RESULTS AND DISCUSSION

A time series input of four months with average rainfall characteristics (approx. 10 rain events within this time period) seems sufficient for sewer system optimization in this case. Using this database robust optimal controlled outflows for both CSO tanks could be obtained (see Figure 3, left).

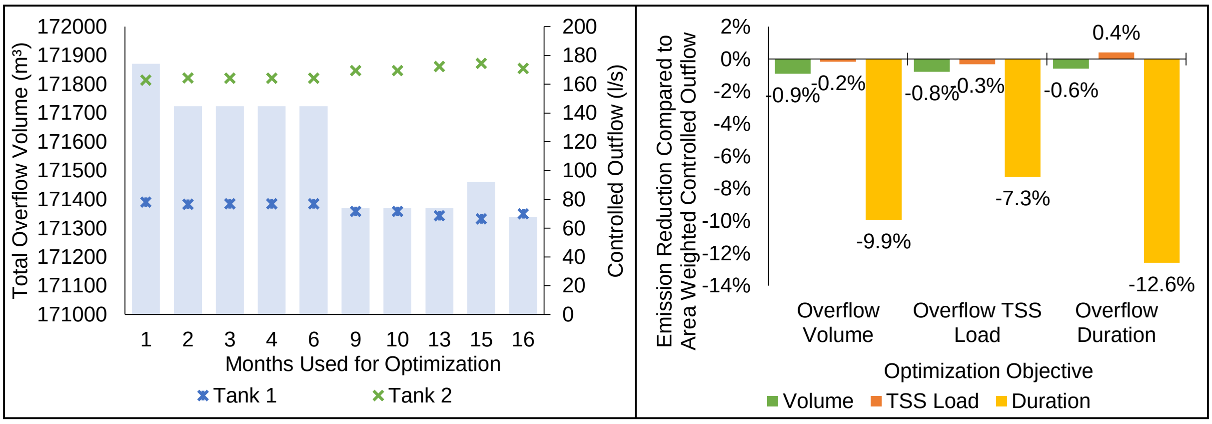

Figure 3 : Influence of length of measured input time series on optimized controlled outflow and total overflow volume (left) and influence of optimization objective on reduction of overflow volume, load and duration (right)

Using the reduction of total overflow volume, load or duration as optimization objective gave similar results for optimal controlled outflows. The emitted loads and volumes differed only between +0.4% and -0.9% in comparison to the emissions from the system with area weighted controlled outflows (see Figure 3, right). Each optimization objective gave good results. This confirms previous findings that no major variations in first flush characteristics have been observed within this system (Bachmann et al., 2016). The optimization potential in the system compared to area weighted controlled outflows seems low. However, in this example the effective impervious area was determined by evaluating rainfall-runoff balances. In practice, an accurate value of the connected impervious area is often not known and therefore area weighted controlled outflows may not give optimal results. The potential for practical application therefore is probably much higher than the presented values suggest. Furthermore, a simple test system has less optimization potential than larger urban drainage systems since smaller systems additionally reduce the optimization effectivity.

4 CONCLUSIONS

Optimization of controlled outflows from CSO tanks based on measured data was well applicable to a conceptual idealized catchment and produced promising results. Using this method optimal settings for controlled outflows from storage units can be determined. The methodology is especially beneficial in catchments where the actual degree of development is unknown and therefore sensitive and hard to determine parameters required for hydrologic modelling such as connected impervious area are highly uncertain. However, the data used as input for the transport model has to be reliable and of good quality so regular maintenance of online measurement devices and careful data processing is necessary.

Different optimization objectives as minimization of overflow duration, load and volume gave similar results. A time series of four months containing at least 10 rain events seems sufficient for a robust determination of controlled outflows. The proposed methodology cannot account for future catchment developments. However, being independent from hydrologic simulations all uncertainties considering rainfall-runoff modelling can be excluded and replaced by uncertainty of measurements. Scenario evaluation can still be performed because the transport and the storage volumes within the sewer system can still be modified and assessed. Reliable optimal controlled outflow settings under constant conditions can be obtained.

Most studies focus on dynamic real time control (RTC) for reducing emissions from CSOs (e.g. Dirckx et al., 2011). Although dynamically operated systems probably perform more efficiently, static optimization of controlled outflows as shown here can avoid extra costs and additional energy consumptions (Pleau et al., 2004) and therefore improve system performance. Real time control strategies will also be assessed using this methodology in future research. Further evaluations will assess the impact of measurement uncertainties and errors on the optimization results and the robustness of this approach using data of lower quality. In a next step, the methodology will be applied to test its applicability on a more complex case.

ACKNOWLEDGEMENTS

The work was funded by the German Federal Environmental Foundation (DBU). The database used for this study was collected within the joint research project SAMUWA (Steps towards an Adaptive Management of the Urban Water Cycle) within the funding measure "Smart and Multifunctional Infrastructural Systems for Sustainable Water Supply, Sanitation and Stormwater Management" (BMBF INIS).

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