Model-based assessment of unavailable hydraulic CSO data

Évaluation fondée sur un modèle des données hydrauliques manquantes sur un déversoir d'orage

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RÉSUMÉ

Les débordements d'égouts unitaires doivent être munis de capteurs de qualité et de quantité d'eau pour mesurer les charges polluantes rejetées dans les plans d'eau récepteurs ou pour étalonner et valider le logiciel de simulation utilisé. Cependant, chaque CSO est unique et l'équipement de mesure est parfois mal entretenu ou incapable de mesurer en raison de conditions hydrauliques défavorables. Le présent document propose une approche fondée sur un modèle pour estimer les variables inconnues ou non mesurables. L'étude fait référence au CSO R-05 de Graz, en Autriche. Pour cette structure d'OSC, les données de mesure sont disponibles sur une longue période. Jusqu'à présent, il n'était toutefois pas possible d'installer des appareils de mesure dans le tuyau d'étranglement et dans le collecteur principal vers lequel l'écoulement de l'étranglement s'écoule. Dans le passé, les observations ont montré que le régime d'écoulement dans le collecteur principal influence de manière significative le comportement de débordement de la structure du CSO. En supposant des débits constants dans le collecteur principal et en comparant les résultats de la simulation avec les mesures disponibles tout en appliquant différents critères d'optimisation, les débits dans le collecteur principal ainsi que dans la conduite d'étranglement peuvent être estimés rétrospectivement.

ABSTRACT

Combined Sewer Overflows (CSO) must be equipped with water quality and quantity sensors to measure the pollution loads released into receiving water bodies or to calibrate and validate the simulation software used. However, each CSO is unique and the measurement equipment is sometimes maintained poorly or unable to measure due to unfavourable hydraulic conditions. This paper proposes a model based approach to estimate unknown or unmeasurable variables. The study refers to the CSO R-05 in Graz, Austria. For this CSO structure, measurement data are available over a long period. However, so far it was not possible to install measurement devices in the throttle pipe and in the main collector to which the throttle outflow discharges. Observations in the past showed that the flow regime in the main collector is significantly influencing the overflow behaviour of the CSO structure. By assuming constant flow rates in the main collector and comparing the simulation results with the available measurements while applying different optimisation criteria, the flow rates in the main collector as well as in the throttle pipe can be estimated retrospectively.

KEYWORDS

backflow, flow reversal, optimisation, SWMM, unavailable measurements

1 INTRODUCTION

Combined sewer systems collect and drain wastewater and stormwater in the same sewer. In order to prevent hydraulic overloading of these sewers and connected wastewater treatment plants, combined sewer overflows (CSOs) release part of the combined sewage during heavy rainfalls into the environment. These overflows contain a considerable amount of pollutants. If the released pollutant loads are of interest, these structures have to be monitored with quantity and quality sensors.

Numerous high-resolution measurement data sets (water levels, flow rates, pollutant concentrations) are available from on-line measurement campaigns for the CSO R-05 in Graz, Austria starting in 2002 (Gruber et al., 2005; Gamerith, 2011). So far the throttle outflow and the subsequent main collector could not be monitored adequately. The former due to possible risks of throttle blockage induced by installed sensors and the latter due to very complicated hydraulic conditions at the confluence of the two sewers (see figure 1).

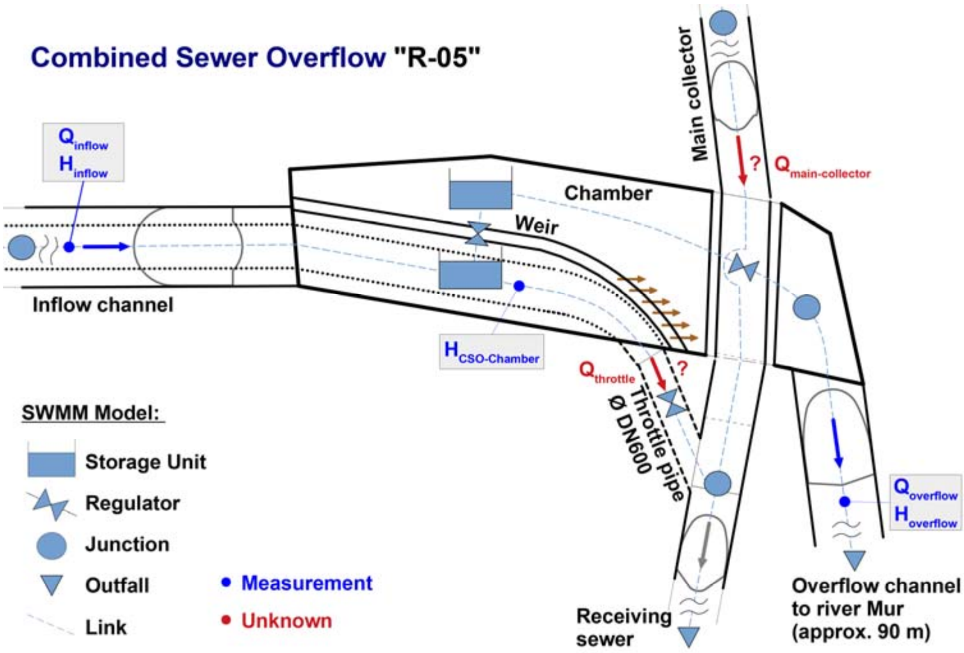

Figure 1: The structure of the CSO R-05, the observed properties at their installed measurement locations and the used SWMM model discretization

Observations indicate that flow characteristics in the main collector highly affects the overflow behaviour of the CSO structure. Therefore, the aim of this paper is to develop a modelling approach to assess this influence. A quantification of this influence is crucial for the hydraulic simulation of such structures and subsequent estimation of released pollutant loads into the aquatic environment.

2 MATERIAL AND METHODS

In order to estimate an unknown variable, it is treated as a parameter. Then its sensitivity is assessed, by simulating the model with the assumption that this variable is constant. Finally, the variable is calibrated with the known measurements variably over time.

For that approach, all remaining input variables as well as at least one output variable influenced by the unknown variable have to be known. The assessment of the resulting deviations within the observed time window are evaluated using various objective functions reported in Hauduc et al. (2015).

In the case of the CSO R-05 study, the influence of the unknown flow of the main collector on the overflow quantity was investigated. The known variables are the measured water level in the CSO chamber and the measured flow in the overflow channel. The impact of the unknown flow in the main collector was estimated for a range from 0-6000 L/s in increments of 10 L/s. The SWMM 5 simulation engine (U.S. Environmental Protection Agency, 2018) was used for the simulation approach.

Every two minutes (simulation interval), the simulated and the measured data were compared for a rolling time window of 6 minutes (resulting in three value pairs in each rolling time window) according to the following three assessment criteria:

- Nash-Sutcliffe Efficiency (NSE),
- Mean Absolute Error Relative (MAER) and
- Peak Error (PE) criteria.

As a result, for each used criterion above and each output measurement, the occurring flow in the main collector (Q_{mc}) were estimated. In a second step, the estimated Q_{mc} was applied to the used model to check the resulting accuracy of the simulation results against observed data.

3 RESULTS AND DISCUSSION

Although the throttle flow could not be measured, it can be recalculated via the measured inflow and overflow. Looking at the years 2009-2011, this throttle flow also becomes negative, which means a backwater or backflow of the main collector trough the throttle to the CSO chamber (see figure 2).

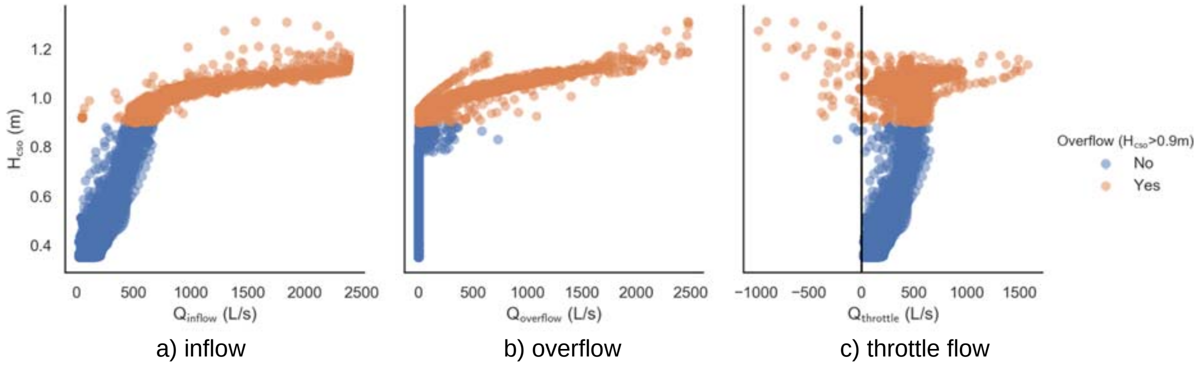

Figure 2: Comparison of the flows of the CSO R-05 against the water level of the CSO chamber for a period of 30 months (2009-2011) The data was subdivided into data points occurring during overflow events (orange) and periods without overflow (blue) for better visualization. The weir crest height in the overflow chamber determines the occurrence of an overflow and corresponds to a water level Hcso of 0.9 m.

The methodology was applied for the same period of time. As an example the results of a smaller event will be discussed. The inflow measurement (see figure 3) was used as an input for the simulation. The flow reached a maximum peak flow of approx. 800 L/s, which caused an overflow even.

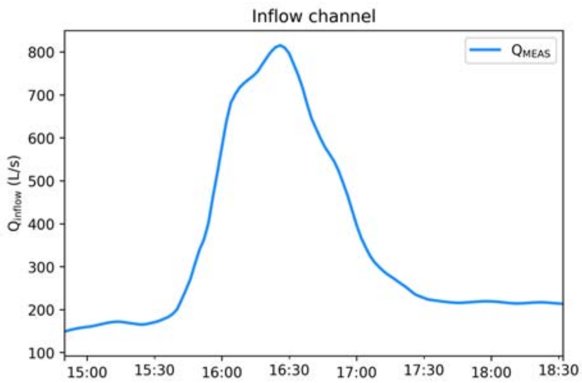

Figure 3: Inflow of the CSO R-05 for a smaller overflow event from 2010-02-26.

For each simulation of a constant main collector flow a curve for the water level in the chamber (see figure 4a) and a curve for the overflow results (see figure 4b). After comparing the simulation results with the measured values, a optimized main collector flow can be estimated (see figure 4c). The criteria used to compare the values was the Nash-Sutcliffe Efficiency.

To validate the method, the estimated Q_{mc} was used in the final simulation (see figures 4a, b and d) and compared with the measurements.

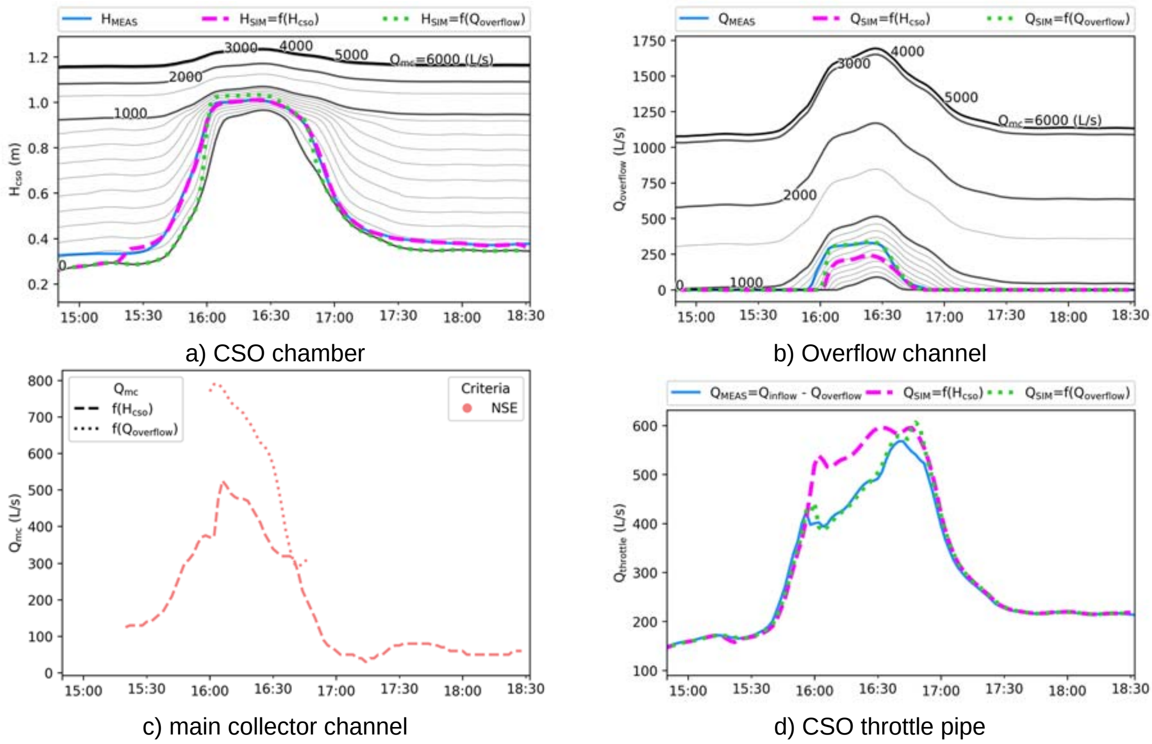

Figure 4: Comparison of the measured data (blue) with the simulation results based on constant main collector flows (steps of 1000 L/s (thick black lines) and of 500 and 100 L/s (thin black lines) and on the estimated main collector flow (magenta: optimized for H_{cso}, green: optimized for $Q_{overflow}$)

The estimated Q_{mc} hydrographs based on the measured $Q_{overflow}$ can only be estimated for the time after the overflow starts, whereas the estimated Q_{mc} hydrographs based on the measured H_{cso} can be estimated by the introduced method for the whole event. However only a water level of more than 0.35 m was used, due to a plate, which dams the water to a minimum level of approx. 0.2 m.

4 CONCLUSION AND OUTLOOK

The introduced method in this paper to assess unknown hydraulic CSO data by modelling approaches shows reasonable results. It is to be noted that a sufficient amount of data concerning the remaining hydraulic properties (boundary conditions, variables, and parameters) is required. Due to a hydraulic jump in the CSO chamber downstream the installed water level sensor H_{cso}, no estimation for Q_{mc} could be done for dry weather conditions. A water level sensor has recently been installed in the main collector. Additional measurement information will be use to conduct a further validation of the introduced method in the future.

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