A water quality-based control strategy to reduce CSO pollutant loads

Une stratégie fondée sur la qualité des eaux pour réduire les rejets polluants des déversoirs d'orage

Duy Khiem Ly[1], Jean-Luc Bertrand-Krajewski[1], Guillaume Binet[2], Thibaud Maruéjouls[2],
[1]University of Lyon, INSA Lyon, DEEP, EA 7429, F-69621 Villeurbanne cedex, France
[2]Suez Eau France, LyRE, 43 rue Pierre Noailles, 33400 Talence, France
Email of corresponding author: duy-khiem.ly@insa-lyon.fr

RÉSUMÉ

La gestion en temps réel est de plus en plus proposée pour optimiser la capacité de stockage dans les réseaux d'assainissement par temps de pluie. Cette étude propose une nouvelle stratégie de gestion en temps réel fondée sur la qualité de l'eau (QBR) mettant en œuvre la prévision des courbes masse-volume événementielles. Cette nouvelle stratégie est évaluée pour un cas test de bassin versant urbain pour quatre événements de déversement. Les éléments de régulation comprennent trois bassins de rétention de 8000, 6000 et 1500 m^3 et un intercepteur aval comportant quatre déversoirs d'orage. La performance de la stratégie QBR est comparée à celle d'une gestion basée sur l'hydraulique (HBR) utilisée comme référence. Les résultats sont positifs et montrent que la stratégie QBR peut apporter un bénéfice significatif par rapport à la stratégie HBR. La réduction des charges de polluantes déversées est estimée à 9.7 %. De plus, la stratégie QBR est capable d'améliorer les flux polluants interceptés par les bassins de retenue : le gain est par exemple de +16 % pour les quatre déversements dans le bassin de Carmaux pour cette étude. Cette nouvelle stratégie mérite donc d'être évaluée plus en détail, par exemple en travaillant à l'échelle d'une chronique annuelle pour mieux caractériser la méthode proposée et en avoir une compréhension plus approfondie.

ABSTRACT

Real time control (RTC) has been widely considered to optimize the storage capacity of sewer networks during wet weather conditions. This study proposes a new water quality-based real time control (QBR) strategy using the prevision of event mass-volume curves. The new strategy is evaluated on a catchment test case for four combined sewer overflows (CSOs) events. Its control elements include three retention tanks of 8000, 6000, and 1500 m^3 volumes and a downstream interceptor connected with four CSO structures. The performance of the QBR is compared with the one of a hydraulic-based RTC (HBR) reference strategy. The results are positive and show that the QBR can bring a valuable benefit over the HBR. The total CSO load reduction is estimated to be 9.7 %. Furthermore, the QBR is able to improve load interceptions by the tanks, e.g. +16 % for the four CSO events at Carmaux tank in this study. This new strategy is therefore worth investigating further, e.g. applying it over one year long to better characterise the method and develop a complete understanding.

KEYWORDS

Combined sewer overflow, mass-volume curve, pollutant load, real time control

1 INTRODUCTION

In most applications, real time control (RTC) aims maximising the storage capacity of combined sewer networks under wet weather conditions. Several past studies have demonstrated its advantages towards minimizing the negative effects of CSOs and avoiding substantial costs of upgrading storage facilities. Recent examples of RTC implementation can be found e.g. in Mollerup *et al.* (2017). RTC strategies for sewer networks can be classified into two major types. HBR is based on hydraulic measurements (e.g. flow, depth) to propose control decisions that are meant to lower the amount of CSO volumes. QBR uses hydraulics together with water quality measurements (e.g. concentration, load) to propose control decisions, taking into account the objective function of improving CSO load reduction. Literature on QBR is more limited, e.g. Vezzaro *et al.* (2014). This study introduces a new simple and robust QBR strategy and assesses its benefits compared with a typical HBR strategy.

2 MATERIALS AND METHODS

2.1 Study area, modelling tool, and CSO events

The catchment modelled in this study is the Louis Fargue urban catchment located in Bordeaux, France. Multiple retention tanks were built within the catchment over decades to protect the downstream urban areas against flooding. For this study, three tanks, Carmaux, Abria, and Alhambra (blue cylinder symbols in Figure 1), with volumes of 8000 m^3, 6000 m^3 and 1500 m^3 respectively, are selected for implementing the control strategies. The above volumes are lower than the volumes in reality because in order to keep the primary functionality of the above tanks, designed for flooding control, only a fraction of them is used for pollution control. Major CSO discharges into the receiving water come from five CSO points (red triangle symbols in Figure 1). There is a main interceptor which receives and transfers upstream water to the wastewater treatment plant (WWTP). The topmost CSO point (i.e. Lauzun) receives flows from a separate part of the network, which is under static control and does not have any connection with the interceptor or other CSO points. Lauzun is thus not included in the calculation of this study to allow proper assessment of the efficiency of the demonstrated strategy.

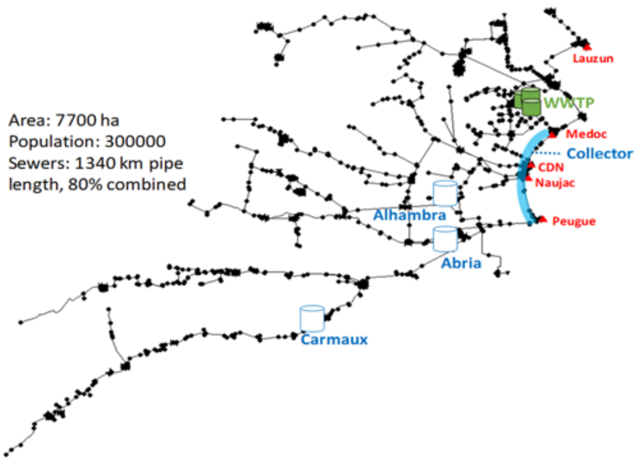

Figure 1. The sewer network with important locations for control.

Four CSO events (Table 1) are used for the assessment of the control strategies. A CSO event is considered as starting from the first droplet of the rain event. It ends when the three retention tanks are fully emptied and there are no more overflows through CSO structures or the WWTP bypass. Total suspended solids (TSS) concentration is used as the quality state variable for control. Main hydraulics and water quality processes are simulated using the SWMM-TSS model, which contains a user-defined improved library of the SWMM5.1.11. The model was previously calibrated and verified using long-term measurement data of turbidity, flow, and water level at the catchment outlets (Montserrat *et al.*, 2017 and Maruéjouls *et al.*, 2018).

Table 1. Rainfall characteristics of the four CSO events used in the study

	Rainfall depth (mm)	Rainfall duration (hours)
Event 1	18.8	9.8
Event 2	7	4.2
Event 3	15.2	5.6
Event 4	8.6	22.3

2.2 Control rules

The retention tanks are controlled using hydraulic thresholds in the case of the HBR. For instance, the tank is filled when the flow in an upstream pipe exceeds certain values. The QBR is based on the receding horizon control algorithm presented in Figure 2a which utilizes a computer-based controller. Online measurements from the network and rainfall forecast are used by the controller to predict quantity and quality processes and to propose optimized actions for the actuators. Figure 2b shows the predicted flow and TSS flux in a pipe right upstream of a retention tank. With HBR, the tank is completely filled right after the first peak of the flow. QBR only fills the tank during the highest peak of the TSS flux (i.e. the second peak of the flow in this example). Both strategies thus intercept different TSS loads despite using the same retention tank volume.

To capture the most appropriate peaks of TSS flux, the QBR controller needs to derive a mass-volume (MV) curve using information from the predicted flow and TSS flux above. This curve represents the evolution of the pollutant load versus the water volume during a CSO event, as presented in Figure 2c. From the MV curve, the controller can identify the time window when there is the highest increase of load over volume, corresponding to the sharpest gradient of the MV curve. This time window is then prioritized for filling the tank. More details about the method can be found in Ly *et al.* (2018).

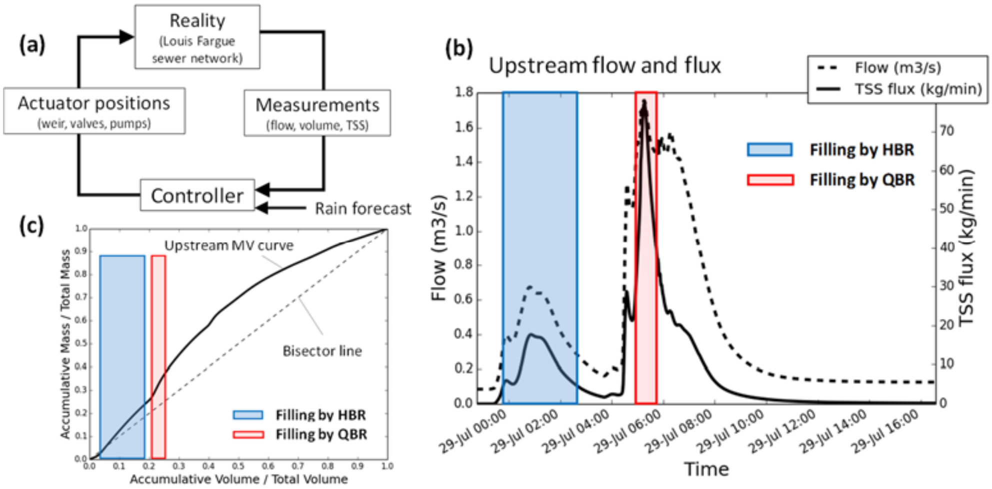

Figure 2. a) Summary of RTC workflow; b) Illustration of filling periods by two strategies over flow and TSS flux plots (upstream of the tank); c) Same illustration over the MV curve plot (upstream of the tank).

In addition, QBR is implemented at the interceptor by controlling valve N and pump C (Figure 3a). Valve N and pump C are always turned on and not controlled with HBR. Valve N allows CSOs at Naujac during periods of high flows coming from the upstream part of the interceptor. Pump C transfers part of water from CDN's contributory sub-catchments to the WWTP.

The TSS concentration at Naujac is overall higher than at CDN (Figure 3b). Doing optimization using i) the MV curve, ii) the predicted flow through valve N, and iii) the predicted flows through pump C, the QBR controller can make CSO discharges lower at Naujac and higher at CDN during periods of peak TSS flux, while maintaining the same flow rate directed downstream of the interceptor. Besides, there is a large pipe connected to CDN, acting as an inline storage (4000 m^3 volume) that slows down overflows at CDN. Application of QBR thus can exploit more this advantage.

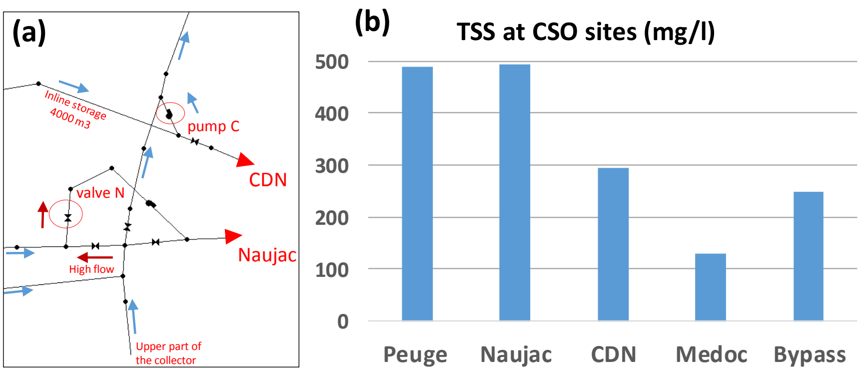

Figure 3. a: Actuators at the interceptor controlled by QBR; b: Mean TSS values from four CSO events with HBR.

3 RESULTS AND CONCLUSIONS

The comparison given in Table 2 shows that QBR can bring a valuable benefit over HBR, with load reduction percentage per event varying between 6.4 and 18.7 %. The CSO events #2 and #4 with smaller rainfall depths show larger percentages of CSO load differences. It is also interesting to note that compared to HBR, QBR also reduces the CSO volumes, i.e. total reduction of -3.9 %.

Figure 4 shows that the total CSO loads and volumes at Peugue and Naujac are lower with QBR, because the two tanks Carmaux and Abria are located wholly within the contributory sub-catchments of Peugue. The reduction at Naujac is due to the control of both the three tanks and the interceptor. QBR transfers more volumes and TSS loads to the WWTP. Furthermore, the total TSS loads stored by the tanks are generally higher for QBR, in particular +16 % in Carmaux and +5 % in Abria. The numbers deem directly proportional with the tank volumes. Higher interception for QBR additionally confirms the objective of QBR controller to intercept peak TSS fluxes during the CSO events.

In conclusion, the results obtained by the new QBR strategy using MV curve prediction are positive. They indicate the potential of the control method. It is thus worth investigating further to characterise and develop a more complete understanding. As a next step, the authors are expanding the number of CSO events to be tested and are planning to implement QBR over a full year time series of events.

Table 2. Performances of QBR and HBR control strategies in terms of CSO volumes and loads.

	HBR		QBR		Difference (QBR vs HBR)	
	CSO Volume m^3	CSO Load *tons*	CSO Volume m^3	CSO Load *tons*	CSO Volume %	CSO Load %
Event 1	126.0	42.1	125.3	39.4	-0.6	-6.4
Event 2	39.2	19.3	34.0	15.7	-13.3	-18.7
Event 3	112.2	44.6	112.7	41.0	0.4	-8.1
Event 4	103.2	29.5	93.7	26.3	-9.2	-10.8
Total	380.6	135.5	365.7	122.4	-3.9	-9.7

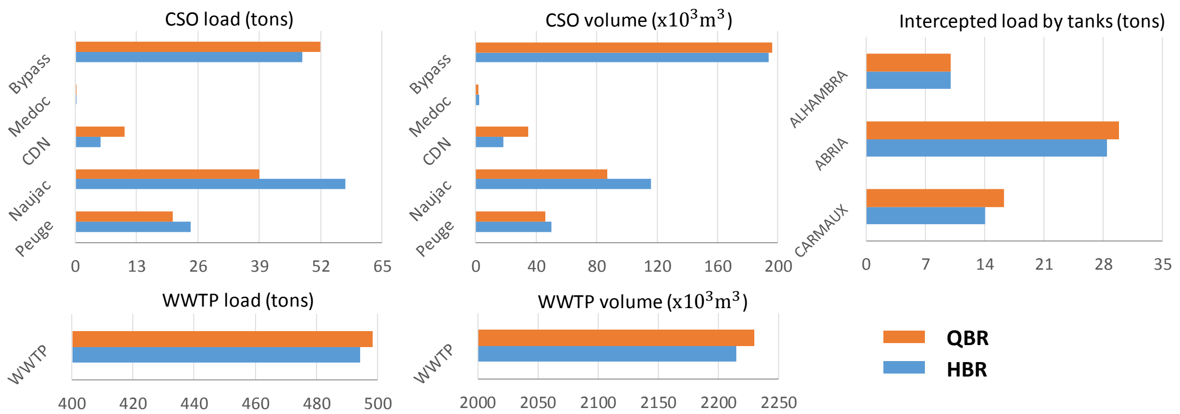

Figure 4. Total TSS loads and water volumes at different outlets together with intercepted loads by all the tanks from four CSO events.

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