Water quality-based control evaluation by means of an integrated urban wastewater model

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INTRODUCTION

Combined sewer overflows (CSOs) are a major source of urban river pollution, causing ecological degradation (eutrophication, discharge of toxic compounds, reduction of dissolved oxygen, etc.) as well as endangering surrounding population safety by pathogen exposure. To reduce CSOs, a widespread solution is to add storage volume to the sewer networks by building combined sewer retention tanks (RTs).

In the late 90's, in an effort to regain recreational use of the St-Charles River, Québec City invested in more than 100,000 m³ of RTs, equipped with water quantity-based real-time control (Fradet *et al.*, 2011). From about fifty CSO event per summer season (from May 15th to September 15th), the RTs made that the number of CSOs could be reduced to comply with the regulations, which allow a maximum of four CSO events in the St-Charles River and a maximum of two in the St-Lawrence River, near the municipal beach. This significant reduction of CSOs is already a great achievement. However, in an objective of improving wet weather management to alleviate their environmental impact, not only the number of CSOs is important: the total loads of pollutants discharged should be the main concern. Also, although CSO reduction in sewers is an undeniable local environmental benefit, the impact of this additional load on the wastewater resource recovery facility (WRRF), which often discharges in the same receiving water, should not be neglected when quantifying the overall effect on the environment (Lindholm, 1985). This paper focuses on the particulate pollution, using an integrated urban wastewater model able to predict the total suspended solids (TSS) concentration along the system. Different wet weather control strategies are evaluated in terms of their overall environmental impact.

MATERIALS AND METHODS

Model description

The integrated urban wastewater model used in this study has been described by Maruéjouls *et al.* (2015). Some minor modifications to the grit chamber and the primary settler model were made to model the chemically enhanced primary treatment (CEPT). The model is based on Québec City's East network infrastructures and was implemented in the WEST modelling and simulation platform (mikebydhi.com). The model is able to predict TSS concentrations along the system using a particle settling velocity distribution (PSVD) approach, which discretizes the TSS in ten particle classes, each class caracterized by its settling velocity (Bachis *et al*., 2015).

Catchment and combined sewers. The sewer network has been simplified to four catchments connected to a main interceptor leading to a WRRF. Combined sewage is generated using only household and runoff characteristics and rainfall data; spatial heterogeneity of the rain was taken into account by using different rain gauges. Three of the four catchments are equipped with an off-line RT and the model used describes settling and resuspension of particulate pollutants (Maruéjouls *et al*., 2014). The combined sewer is modelled by a series of linear reservoirs, calibrated using the Kalinin-Miljukov method (Solvi, 2006). No pollutant transformations were considered in the sewer system.

Wastewater resource recovery facility. The WRRF consists of a grit chamber, a primary clarifier and three bypasses (Figure 1). Sedimentation is modelled by the PSVD approach (Bachis *et al*., 2015). In the grit chamber an upward flux has been added to account for aeration. The hydraulic behaviour of these settling units has been explored by several tracer tests, showing that they can be modelled by discretizing the water column in respectively four and eleven layers (Tik *et al.*, 2013). An appropriate hydraulics model is important to adequately represent the delay between alum addition and its actual effect on TSS removal. The possibility to perform chemically enhanced primary treatment (CEPT) is modelled by making the settling velocities depend on the alum concentration in the unit. To optimize chemical dosage, a water quality based controller using the primary clarifier outlet turbidity signal is used (Tik *et al*., 2014). Québec City's WWTP performs secondary treatment by biofiltration (not modelled at this stage). It should be noted that a major difficulty of biofilters management is the occurrence of clogging due to increased incoming TSS loads. Research to evaluate the evolution of the biofiltration capacity and its clogging rate during a rain event is ongoing.

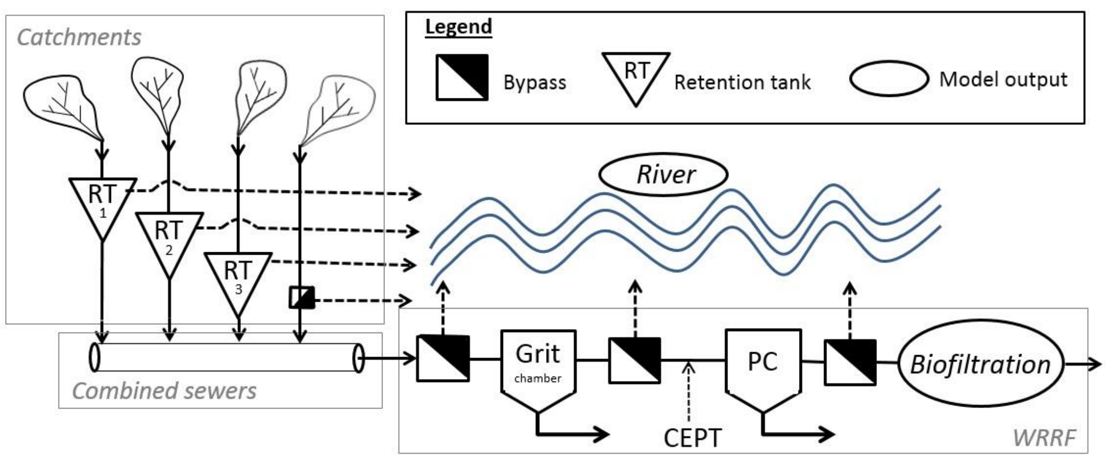

Figure 1: Schematic of the modelled integrated urban wastewater system. Four catchments, three equipped with a retention tank (RT), a WRRF (grit chamber, primary clarifier (PC), biofiltration and three possible bypasses) and the receiving water.

CONTROL STRATEGIES

Control variables

Wet weather management is generally based on water quantity variables (flow rate, water level). With the development of reliable water quality sensors, new information becomes more and more available. In this study, TSS concentration data are used to manipulate controlled variables during different phases of a rain event.

Retention tank filling. At the beginning of a rain event, the WRRF is subject to an abrupt increase of flow, which could go with an increase in TSS concentration, i.e. a first flush. By controlling the filling of the RT on the basis of on-line water quality data at its inlet, the first flush can be captured. In this study, the water quality based control strategy uses the RT inlet TSS concentration to manipulate a valve that diverts water to the RT. During a rain event, when the TSS concentration is higher than a TSS threshold concentration, the flow to the WRRF is reduced to fill the RT with the first flush flow. When the TSS concentration decreases due to dilution, a higher flow rate can be sent to the WRRF, of course limited by the sewer's maximum hydraulic capacity.

Retention tank emptying. A previous study, using a similar integrated model, showed that water quantity-based control of the RT's emptying rate can significantly reduce discharges of untreated (or partially treated) wastewater to the environment, in terms of volume of water, and to a larger extent and more importantly, in terms of load of TSS discharged to the receiving water (Tik *et al*., 2014). In this paper, RT emptying is performed sequentially; after a rain event, when the flow rate is back to dry weather flow, the RT emptying process starts by RT3, then RT2 and finally RT1. The emptying flow rates are set so that the flow rate at the inlet of the WRRF does not exceed a maximum flow rate value, set by the controller. Further study will use the predicted TSS concentration at the inlet of the WRRF to control RT emptying.

Chemically enhanced primary treatment. Inside the WRRF, application of CEPT during wet weather conditions helps to ensure proper operation of the biofiltration process, particularly subject to clogging. Alum addition could be performed either at constant concentration or could be controlled based on the primary clarifier outlet TSS concentration (Tik *et al.*, 2013).

RESULTS AND DISCUSSION

Water quality based control allows distributing the incoming pollution load over time by capturing a higher proportion of the first flush and sending it to treatment when the hydraulic loading has decreased. Indeed, Figure 2 shows (a) the flow rate and (b) TSS load reduction at the inlet of the WRRF thanks to the water quality based control for a medium intensity rain event (about 20 mm of rain over a day). For this event, the results for the RT of catchment 3 (Figure 1) are:

- With quantity-based control only, meaning that the RT is filled when the hydraulic capacity of the sewer is reached, the RT stored 930 m³ of water corresponding to 41 kg of TSS;
- When quality-based control is added (RT filling starts when the TSS concentration is higher than 50 mg/L <u>and</u> the flow rate is higher than 1.5 times the peak dry weather flow rate), the RT stored 16,630 m³ of water corresponding to 3,200 kg of TSS.

With the last control setup the RT retained 77 times more TSS and only 17 times more water than without quality control, and this retained pollution could be returned afterwards to the WRRF at a controlled emptying rate, alleviating the hydraulic stress on the WRRF and permitting full biological treatment. Of course, to reduce the risk of undesired overflow due to a longer use of the storage capacity of the sewer, a weather forecast component is advised. Control strategies will then move into different modes depending on the probability of a subsequent rain event.

For this rain event, by adding the water quality control variable, the mean storage capacity used in the RTs increased from 42% to 58%, taking about 35.5h to recover full storage capacity instead of about 32h with only water quantity-based control. However, this permits to reduce the volume of water discharged without primary treatment by about 32% and to reduce the load of TSS discharged to the environment by 40%. The longer emptying process and higher TSS concentration returned to the WRRF caused the use of an additionnal 35% of alum compared to the constant alum dosage.

The minor accumulation of TSS in the RTs, observed on the field, is also described by the model. Operationnaly, a manual cleaning of the pump chamber to remove the accumulated sludge has to be performed annually. The water quality-based control strategy seems to increase somehow the phenomenon, an impact on operational work and cost will thus have to be estimated.

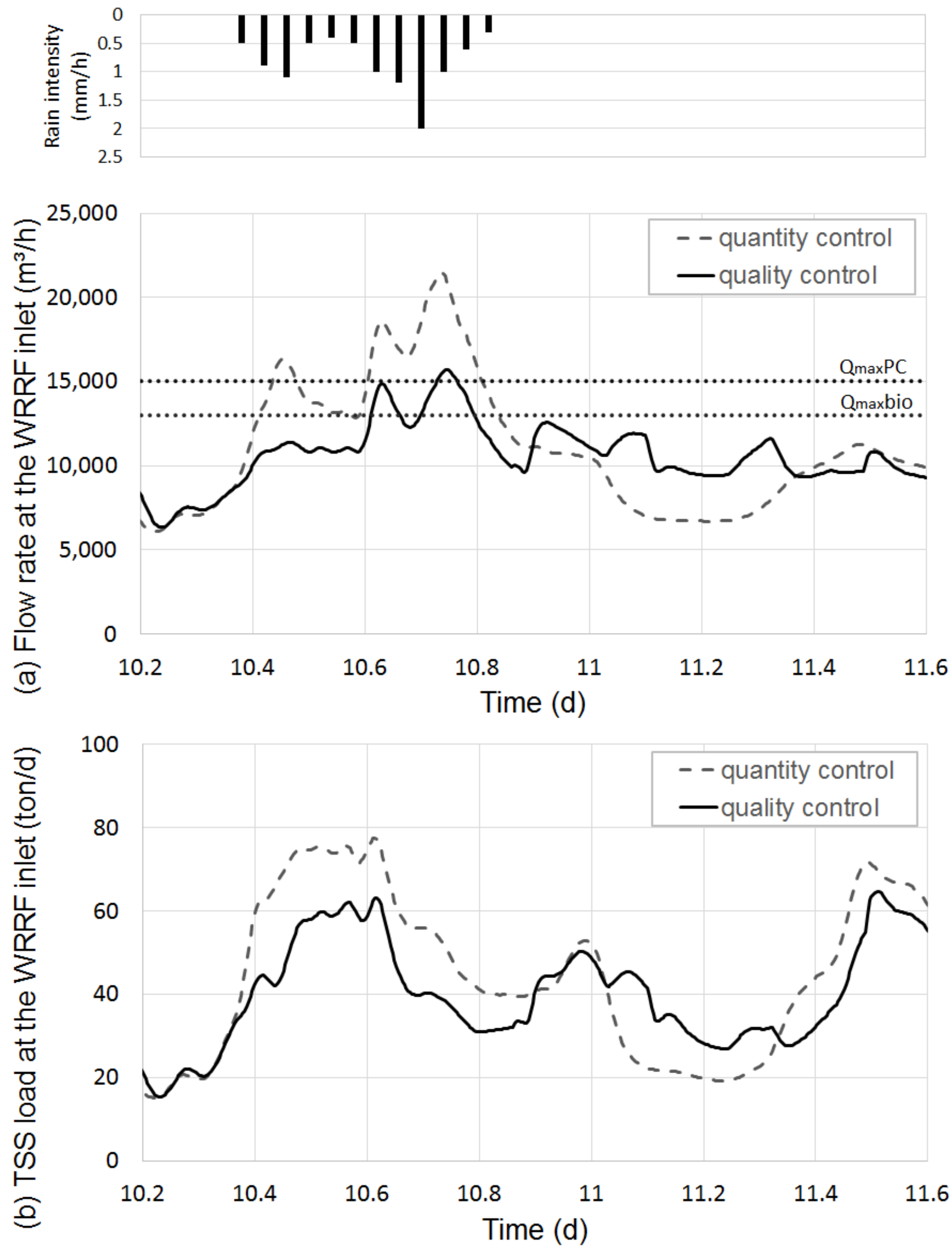

Figure 2: **(a)** Flow rate and **(b)** TSS load at the WRRF inlet with only water quantity-based control (dash line) and with water quantity- and quality-based control of RT filling (solid line). $Q_{max}PC$ = 15,000 m³/h and $Q_{max}bio$ = 13,000 m³/h are the maximum flow rates respectively to the primary clarifier and the maximum flow rate to the biofiltration. On top, the rainfall intensity.

CONCLUSION

An integrated urban wastewater system model has been presented and used to develop a control strategy for optimal management under wet weather conditions. In several studies, water quantity-based control was shown to be worth the investment. However, with the development of reliable water quality sensors, water quality-based control is the next step that is being explored. As the simulations show, a better use of the infrastructures can be achieved, delaying the need to build additional facilities to meet the environmental requirements.

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