Estimating and minimizing both CSO and WRRF discharge impact by water quality based control

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ABSTRACT
In this study, an integrated sewer-treatment plant model has been used to evaluate different wet weather management strategies. The modelled combined sewer system is equipped with retention tanks (RTs) allowing control of the wastewater flow rate to the water resource recovery facility (WRRF), which consist in preliminary and primary treatment with possibility of chemically enhanced primary treatment. Based on a particle settling velocity distribution approach, the model is able to predict water quality in terms of total suspended solids (TSS) concentration, which can then be used as a controlled variable. Simulation results show that compared to water quantity-based control strategies only, adding water quality-based control allows an improved usage of the sewer storage capacity and a significant reduction of TSS load discharged to the receiving water.

KEYWORDS
Integrated urban wastewater system; Real-time control; Water quality modelling; Wet weather management.

INTRODUCTION
As policies are shifting from regulating only the characteristics of the discharged water to trying to ensure a good water quality in the receiving water, the need for integrated management is increasingly recognized (Corominas et al., 2013). Combined sewer overflows (CSOs) and discharges from water resource recovery facilities (WRRF) are the major source of anthropic pollution of urban rivers. Furthermore, both are tightly interconnected. For instance, enhancing the collection systems will lead to increasing the pressure on the WRRF, whereas protecting the WRRF by limiting the incoming flow will result in increased CSOs. Combined sewer retention tanks (RTs) operated by a real-time control system provide interesting options for wet weather management. This paper intends to show through a realistic simulation study that water quality based control strategies are a way to minimize the total impact of the collection systems and the WRRF on the receiving water.

CASE STUDY AND MODEL DESCRIPTION
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).

Based on large amount of data collected during extensive measurement campaigns, an integrated model representing a part of Québec City's East network infrastructures has been developed and implemented using the WEST modelling software (mikebydhi.com). Combined sewage is generated based only on rainfall data and runoff and household characteristics. The model has shown the ability to simulate dry and wet weather wastewater quality (Maruéjouls et al., 2015). Three of the four sub-catchments making up the system are equipped with an off-line RT (Maruéjouls et al., 2014), allowing control of the flow to the WRRF. The WRRF consists of a grit chamber, a primary clarifier and has three bypasses (Figure 1). In each unit process, sedimentation is modelled using a particle settling velocity distribution (PSVD) approach with ten particle classes, which showed a significant gain of performance compared to usual models (Bachis et al., 2015). The possibility to perform chemically enhanced primary treatment (CEPT) is modelled by adapting the PSVD. The CEPT is controlled by using the primary clarifier outlet turbidity signal (Tik et al., 2014). A simple model was developed to represent the decrease of biofiltration capacity due to incoming TSS.

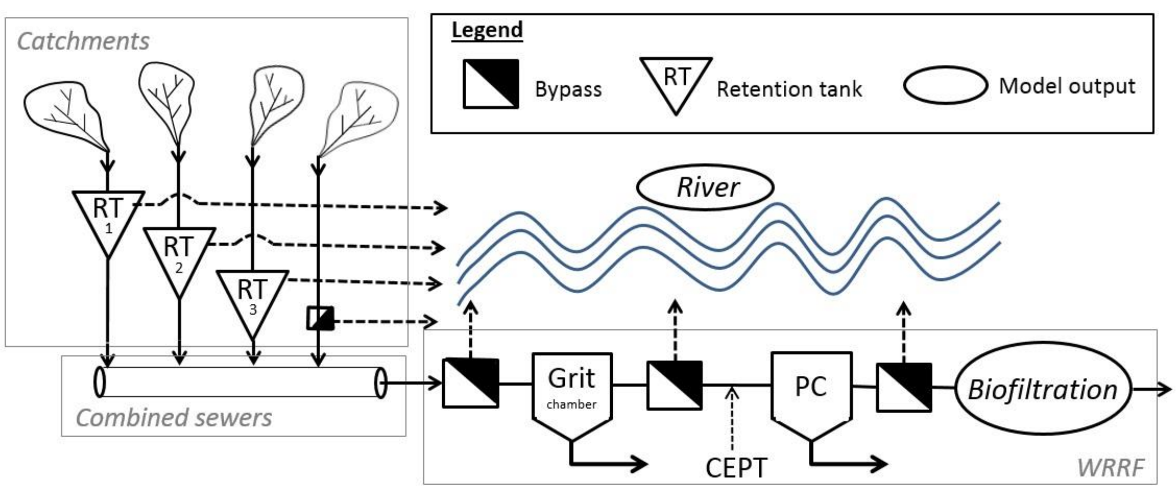

Figure 1: Schematic of the modelled integrated urban wastewater system. Four catchments, three with a retention tank (RT), a WRRF (grit chamber, primary clarifier (PC), biofiltration and three possible bypasses) and the receiving water.

CONTROL STRATEGIES

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, even if full hydraulic capacity of the sewer system has not been reached. 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, illustrated for the RT of catchment 3 (Figure 1):

- With quantity-based control only meaning that the RT is filled when the hydraulic capacity of the sewer is reach, 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 and the flow rate is higher than 1.5 times the peak dry weather flow rate), the RT stored 16630 m³ of water corresponding to 3200 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 additional 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.

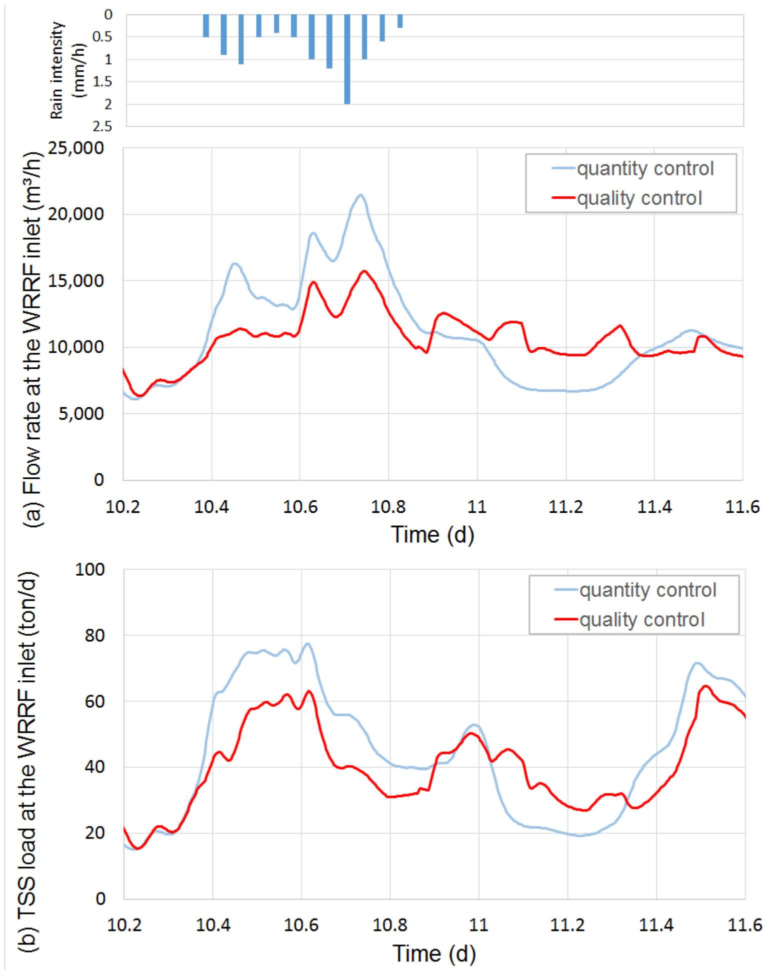

Figure 2. (a) Flow rate and **(b)** TSS load at the WRRF inlet with only water quantity-based control (dash line) and with water quantity- and quality-based control of RT filling (solid line). $Q_{max}PC$ = 15,000 m³/h and $Q_{max}bio$ = 13,000 m³/h are the maximum flow rates respectively to the primary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

CONCLUSIONS

An integrated urban wastewater system model allowing control strategy development for optimal management of wet weather conditions has been presented. Water quantity based control was shown worth the investment. With the availability of efficient sensors, water quality based control is the next step to be explored. As the simulations show, better use of the infrastructures can be pursued, delaying the need to build new facilities to meet environmental protection needs.

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