Real time control of sewer systems using turbidity measurements

Gestion en temps réel des réseaux d'assainissement à partir de mesures en continu de turbidité

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RÉSUMÉ

La gestion en temps réel (GTR) des réseaux d'assainissement a été reconnue comme un moyen efficace de réduire la pollution des rejets unitaires de temps de pluie. Toutefois, les questions de GTR ont été généralement traitées uniquement selon une approche quantitative. Or, devant les progrès effectués en termes de mesure de la pollution des eaux usées, l'utilisation de GTR fondée sur la qualité pourrait se révéler d'un intérêt croissant. Ainsi, des mesures de turbidité en continu issues du suivi intensif sur deux bassins-versants du réseau unitaire parisien permettent d'évaluer l'apport de l'utilisation de la qualité dans la GTR. Cet article illustre ce point en comparant des stratégies de GTR fondée sur le débit avec des stratégies de GTR fondée sur la qualité. Les résultats montrent le potentiel des stratégies fondées sur la qualité, notamment lorsque des dispositifs de mesures en continu sont disponibles.

MOTS CLÉS

Gestion en temps réel, GTR fondée sur la qualité, réseau unitaire, temps de pluie, turbidité

ABSTRACT

Real-time control (RTC) of urban drainage systems has been proven useful as a means to reduce pollution by combined sewer overflow discharges. So far, RTC has been investigated mainly with a sole focus on water quantity aspects. However, as measurement techniques for pollution of wastewater are advancing, pollution-based RTC might be of increasing interest. For example, turbidity data sets from an extensive measurement programme in two Paris catchments allow a detailed investigation of the benefits of using pollution-based data for RTC. This paper exemplifies this, comparing pollution-based RTC with flow-based RTC. Results suggest that pollution-based RTC indeed has some potential, particularly when measurements of water-quality characteristics are readily available.

KEYWORDS

Combined sewer; pollution-based RTC; real time control; storm water management; turbidity

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1 INTRODUCTION

Wet weather sewer overflows are known to be very harmful for receiving waters and aquatic ecosystems (Even *et al.*, 2004). The need of a better storm water control in sewer systems has led to an increasing interest for real time control (RTC) in sewer systems (Schütze *et al.*, 2004). However, most RTC systems are only based on hydraulic data and do not take directly into account the quality of discharges. This is mostly due to a lack of available continuous quality measurements devices and to the weak predictive effect of quality models (Kanso *et al.*, 2005). A growing number of studies focus on the possibilities to continuously monitor the quality of effluents by using optical sensors (Grüning *et al.*, 2002; Lawler, 2005). More especially, turbidity continuous measurements proved to be a very good surrogate for the monitoring of suspended solids (SS) loads in sewer systems (Fletcher & Deletic, 2007; Langeveld *et al.*, 2005; Mels *et al.*, 2004). Moreover, detailed protocols of calibration and maintenance were developed in order to guarantee reliable and accurate turbidity data series (Joannis *et al.*, 2007). For instance, in Paris, two sites have been equipped since 2005 by turbidity measurement devices and 3 years of one-minute time step turbidity data are available. A detailed analysis of these data showed the variability of SS dynamics from one event to another, without any kind of “first flush” phenomenon behaviour at this site, and highlighted the potential of using turbidity data in RTC strategies (Lacour *et al.*, 2009). Earlier literature reviews (e.g. Schütze *et al.*, 2002) include some studies on pollution-based RTC, however, only recently this type of control attracts more interest.

In this paper, we focus on turbidity-based RTC. The objective is to compare control strategies for a hypothetical system which are only based on flow rate measurements to strategies using turbidity measurements for a simple case. The simulation study will assist in establishing whether additional reduction of unwanted discharges of polluted wastewater can be achieved if water quality information is considered within RTC.

2 METHODS

2.1 Case study: system with two parallel inputs

Our work constitutes a first approach to compare RTC strategies based on turbidity measurements with solely flow-based RTC. In this framework, we choose to test a very simple case made of two distinct parallel branches, which are joining downstream. This kind of configuration was already investigated in a more complicated structure in Saint-Malo in France (Gogien *et al.*, 2004) and also in a freely available demonstration software for RTC (Messmer *et al.*, 2008). The general idea is that if a system is limited by a flow rate throttle and receives several sources of pollutants flows, it could be interesting prioritise interception of the more polluted branch (Gogien *et al.*, 2004). Figure 1 gives an overall view of the configuration to be tested.

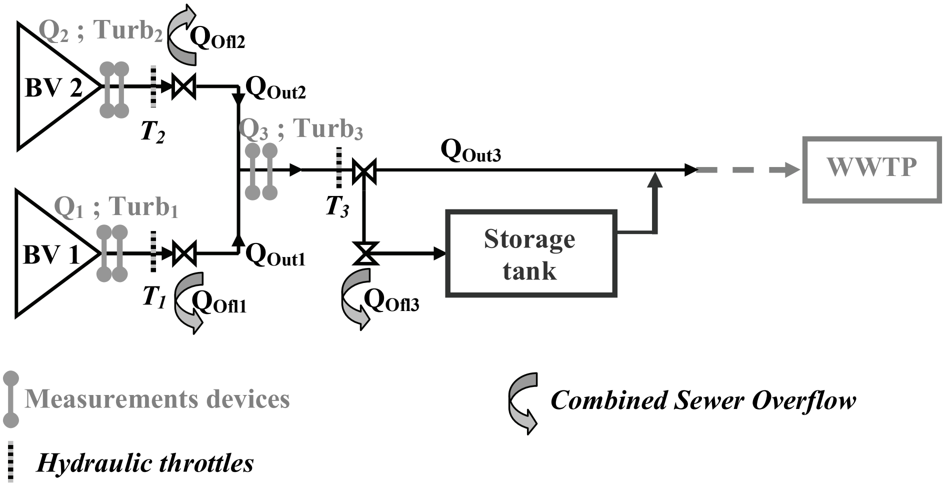


Figure 1. Case study of a system with two parallel inputs
N.B.: The notation “BV” denotes subcatchments with/without storage volume.

2.2 Modelling environment

This case was implemented in the SIMBA simulation environment (ifak, 2009). Originally developed for the dynamic simulation of waste water treatment plants (WWTP), this software also provides modules for sewer systems. SIMBA enables to build up a system by using simple blocks. Each block represents a unit element of a sewer system such as overflow structures or storage tanks which are linked together by main trunk sewers. Hence, each block contains one or several inflows, optionally some storage volume and a maximum outflow downstream, which is controlled by a throttle. In this example, hydrological modelling approaches are applied. However, it is equally possible to use the full hydrodynamic modelling features of SIMBA (if so desired, also with full consideration of water quality transformation processes). The case study with two parallel inputs shown in Figure 1 has been represented with the building blocks of SIMBA as shown in Figure 2. Our system is characterised by three throttles: T1, T2 and T3 which control all the flows of the case study (Figure 2).

- T1 regulates the flow from Branch 1 to the final branch,
- T2 regulates the flow from Branch 2 to the final branch,
- T3 regulates the final CSO structure and the inflow into the WWTP.

For this simple case, a simple hydraulic approach was chosen with a hydrologic rainfall-runoff and flow model.

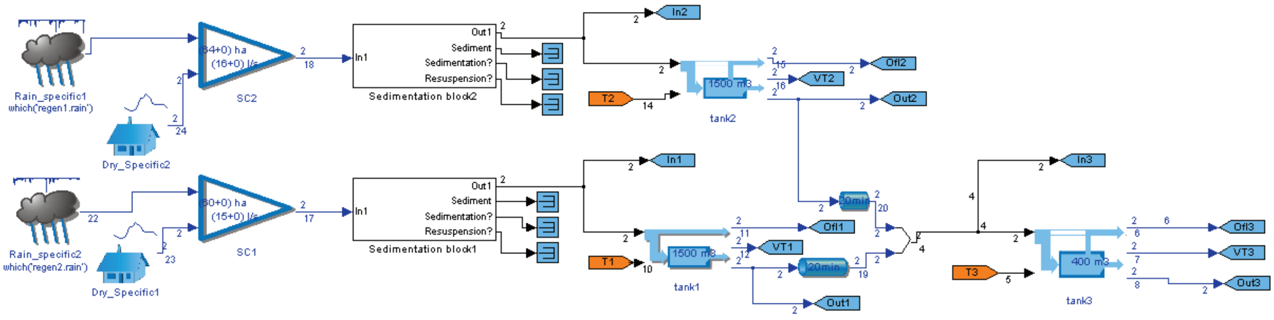


Figure 2. Hydrologic model of the system with two parallel inputs

2.3 Setting up the simulated system

Dry weather parameters

For the purposes of this study, the hydraulic characteristics of the two parallel catchments are kept similar, so that comparisons between common RTC and turbidity-RTC are not biased by particular hydraulic features. Catchment 1 was then parameterized with a 60 ha area and a dry weather average flow of 15 l/s whereas Catchment 2 covers an area of 64 ha for a dry weather average flow of 16 l/s. In the same way, a mean dry weather turbidity value can be chosen for each catchment and adjusted to 250 Formazine Attenuation Units (FAU).

During dry weather, flow and turbidity signals follow a regular daily pattern (Lacour *et al.*, 2009). These cycles have been implemented in Simba using the results obtained from the two experimental catchments in Paris equipped with flow and turbidity sensors.

Hydraulic constraints

Traditionally, the maximum inflow to the waste water treatment plant (WWTP) is about 3 times the average dry weather flow. Here, T3 was fixed at 2.5 times the total dry weather flow i.e. 2.5*(15+16) = 77.5 l/s.

As a base case of static control (fixed maximum throttle flows), the throttle T1 was fixed at 4 times the dry weather flow of Subcatchment 1 (4*15=60 l/s) and T2 was fixed at 4 times the dry weather flow of Subcatchment 2 (4*16=64 l/s). A storage tank volume of 400 m3 was chosen. With these default settings of the maximum throttle flows, almost no overflow is observed downstream (Qofl3) for the given rainfall input. As a consequence, the overflows upstream in each branch (Qofl1 and Qofl2) can really be compared depending on the strategies with no interaction with downstream overflows. Control rules have been implemented using the internationally standardised IEC61131 Structured Text notation as is available in SIMBA.

Turbidity signal modelling
In order to consider the turbidity in the modelling exercise, an appropriate module has been added to the SIMBA model. At this stage, our aim is not to find a model for turbidity signal but to generate a "realistic" turbidity signal in the inflow time series, including effects of sedimentation at low flows and resuspension at higher flows. Turbidity data inputs are taken from real turbidity measurements at two French case study sites. A simple function dealing with sedimentation and re-suspension phenomenon was implemented as well. This function is characterised by 5 parameters:

- Qsed: Flow threshold: If Qin < Qsed: sedimentation takes place
- Qres: Flow threshold: If Qin ≥ Qres: resuspension takes place (naturally, Qres > Qsed),
- Vsed is the size of the (conceptual) sediment storage
- α is a dimensionless coefficient describing sedimentation efficiency
- β defines the speed of the resuspension process ($1/\beta$ denotes the time required for emptying the sediment storage; thus, large values of β allow to model "first flush" effects)..

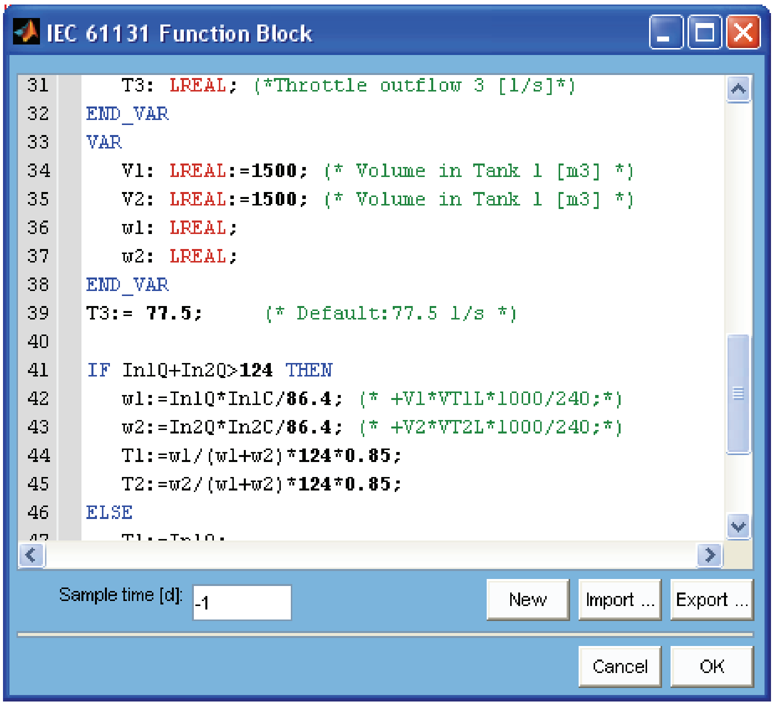
First flush effects can be considered by appropriate parameter settings (e.g. $\alpha = 0.8$; $\beta = 100$). In the sequel, simulations have been carried out using two distinct 3-days rain series for the catchments, thus considering also spatial distribution of rainfall and of pollution.

2.4 Real time control strategies tested

Default and flow-based strategies

In order to establish whether the use of turbidity information in control can lead to (further) reduction of discharges of wastewater pollution, a number of different strategies have been set up and tested against each other. T3, which limits the maximum flow to the WWTP, has been set to 77.5 l/s (corresponding to 2.5 dry weather flow) for all scenarios.

- Default case: Fixed maximum permissible flows (static throttle) values for T1 and T2.
- Simple flow-based control (Simple QBRTC): The throttles T1 and T2 are set in a proportion according to the proportion of the incoming flows Q1 and Q2, whilst respecting the maximum capacities of the branches (T1 ≤ 60 l/s and T2 ≤ 66 l/s in any case).
- Simple pollution-based control (Simple PBRTC): Again, the throttles T1 and T2 are set according to the incoming pollution. However, in this strategy, inflows from the branches are prioritised according to the "turbidity masses" of the branches. As "turbidity mass" in this context, we denote the product of turbidity and flow (as no relation between turbidity and SS has been set up, turbidity was used here directly). Figure 3 illustrates the implementation of this algorithm as IEC61131 Structured Text within the SIMBA simulation environment.



```
    T3: LREAL; (*Throttle outflow 3 [l/s]*)
END_VAR
VAR
    V1: LREAL:=1500; (* Volume in Tank 1 [m3] *)
    V2: LREAL:=1500; (* Volume in Tank 1 [m3] *)
    w1: LREAL;
    w2: LREAL;
END_VAR
T3:= 77.5;      (* Default:77.5 l/s *)

IF In1Q+In2Q>124 THEN
    w1:=In1Q*In1C/86.4; (* +V1*VT1L*1000/240;*)
    w2:=In2Q*In2C/86.4; (* +V2*VT2L*1000/240;*)
    T1:=w1/(w1+w2)*124*0.85;
    T2:=w2/(w1+w2)*124*0.85;
ELSE
```

Sample time [d]: -1

Figure 3. Extract of simple pollution-based RTC strategy

The following two control scenarios are shown just as reference cases:

- Global-flow-based RTC algorithm (global QRTC): Here, the algorithm as described by Alex *et al.* (2008) and Schütze *et al.* (2005) is applied. This algorithm aims at equalised utilisation of storage volume. Pollutant concentrations are not considered in the algorithm.
- Theoretical optimum for flow-based control (Central Basin Approach): This value of overflow volume calculated according to the Central Basin Approach (Einfalt and Stölting, 2002) indicates the theoretical optimum of overflow reduction by RTC. No RTC strategy can yield a lower overflow volume. However, the value given for overflow load is given only for indicative purposes, as the Central Basin Approach does not allow any statement about this to be made.

Each of these RTC algorithms has been applied to four different configurations of the sewer network:

- With/without storage volume (1500 m^3, corresponding to about 25 m^3/ha specific storage volume) in each of the branches
- With/without “first flush” effects in the branches.

3 RESULTS AND DISCUSSION

Figure 4 illustrates the results for the system configuration with storage volume and taking into account first flush effects in the branches.

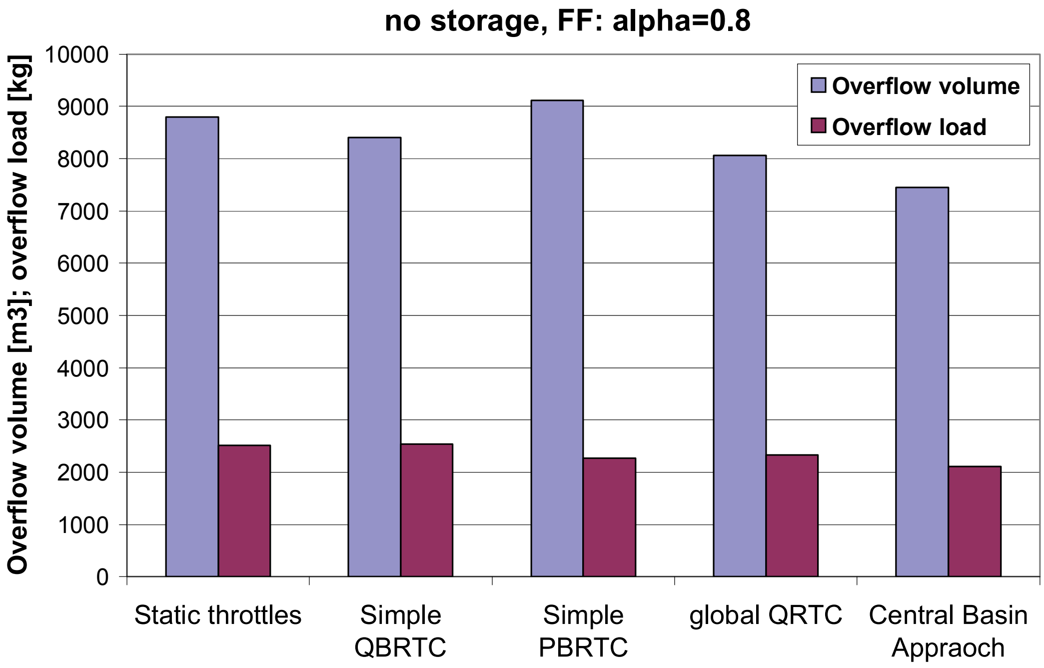


Figure 4. Performance of the RTC scenarios defined above (system with storage and first flush)

It can be seen that RTC can reduce overflow volumes and, to a lesser extent, pollutant loads. Reduction of pollutant loads is better achieved with a pollution-based RTC algorithm, resulting in an additional 10.8 % reduction of load discharged. In comparison, also the global QRTC seems to be promising; yet needs to be extended to consider pollutant information as well.

Table 1 summarises the gains of pollutant reduction achievable by pollutant-based RTC for the various system configurations simulated:

	with first flush	no first flush
with storage in branches	17,3	19,8
without storage in branches	10,8	13,3

Table 1. Additional reduction of loads by application of pollution-based RTC [%]

It is remarkable to note that the reduction seems to be larger when no first-flush effects are considered. This may be due to the fact that pollution information gathered at the moment of the first-flush effect influences control decisions at other locations and time instants when there is no such or a less pronounced effect. This, obviously, should be analysed further in an in-depth study; this also might contribute to the on-going discussion about the relevance of first-flush effects. Furthermore, the observation that the results indicate higher pollution removal potential when there are storage tanks in the system, is also in-line with the procedures set up by DWA (2005) for establishing a system's RTC potential.

4 CONCLUSIONS

The results indicate that RTC has potential not only to reduce overflow volumes, but also to minimise pollutant loads discharged into the receiving water body. This holds true in particular when use of pollutant information (illustrated here for turbidity as an easy-to-measure parameter) can be made for consideration in the control algorithm. Of course, further studies are required to validate the findings also for larger systems. It is obvious that the RTC algorithm should be further developed, with particular emphasis on the pollution considerations. It is expected that a fine-tuned RTC algorithm will further contribute to minimise discharges. For an overall assessment of discharges into the receiving water body, the urban wastewater system should be considered in its entirety, also considering the WWTP, using integrated modelling.

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