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Integrated urban wastewater systems: Prediction of particle settling velocity distributions along the sewer - retention tank - primary clarifier system

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Abstract An integrated urban wastewater system model is presented to describe the evolution of the particle settling velocity distribution along the system. The simulations show that it is possible with this approach to describe that the concentration of rapidly settling particles in the outputs of the system is increased under rain conditions. It is shown that proper scheduling of emptying leads to improved primary clarification performance.

Keywords: Real-time control; sedimentation; wet weather management; integrated modelling.

INTRODUCTION

Many efforts are made to reduce wet weather impacts, mainly by building retention tanks (RT) along the sewer system. However, operation of these tanks, and in the context of this study their emptying, has an impact on the behaviour of the whole wastewater system. Emptying the whole tank in a short time produces important disturbances at the wastewater treatment plant (WWTP) such as hydraulic shocks at primary clarifiers, loss of the sludge blanket in activated sludge systems, or an increase of the clogging rate in biofilter, while emptying over a long period could lead to more overflows in receiving waters as tanks will not be emptied in time before the next rain comes. It is then of importance to study the complex interactions between retention tanks and WWTP in order to improve the operation of retention tanks and the water quality of the receiving body.

The present study proposes an integrated urban wastewater model inspired by an actual system. To model water quality, it describes the total suspended solids (TSS) dynamics, and particularly, the particle settling velocity distribution (PSVD) of the solids as this allows better describing TSS dynamics. Objectives of this work are 1) building a realistic integrated model, 2) comparing simulated and observed data in terms of PSVD, and 3) testing two emptying strategies that differ in terms of the instant at which tank emptying is started (e.g. with or without a delay over each RT emptying).

MATERIAL AND METHODS

Integrated model description

The integrated model is implemented in WEST® (www.mikebydhi.com) allowing short calculation times thanks to the use of a model only consisting of ordinary differential equations. The system consists in three identical catchments, each equipped at the outlet with off-line RTs that are emptied by pumping (Figure 1). Water is then transported to a primary clarifier by means of a combined sewer. PSVD calibration (using PSVD measurements) allowed setting the settling velocities for each class: TSS_1=0.004 m/h; TSS_2=0.21 m/h; TSS_3=0.6 m/h; TSS_4=1.5 m/h; and TSS_5=9.75 m/h. The concepts of each unit are further detailed below.

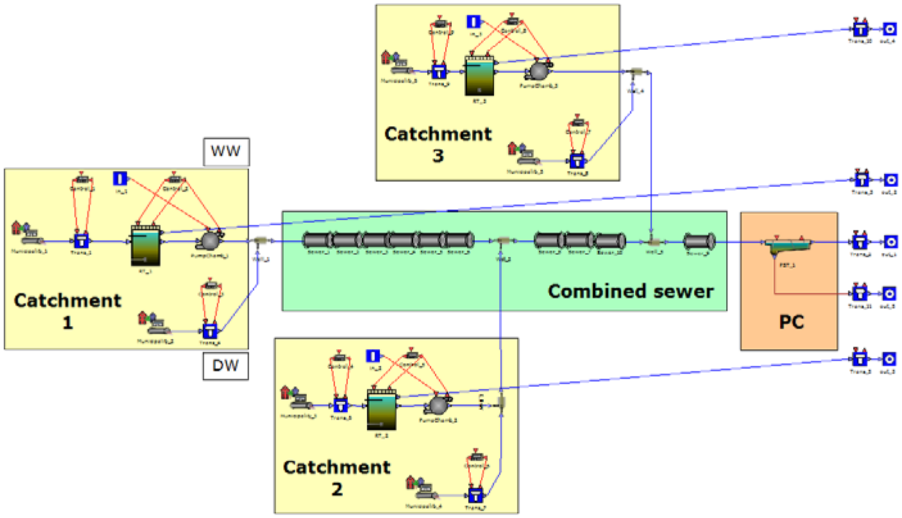

Figure 1: *WEST® configuration of the integrated urban wastewater system.*

Catchment: Two flows feed the catchment model. The dry weather (DW) is mixed with the RT effluent that is fed by a wet weather input file. Each RT is 7,580 m^3 with a depth of 5.5 m. They are equipped with a pumping chamber of 37 m^3 which is of significant interest due to settling and resuspension processes that highly influence the wastewater TSS concentrations returned to WWTP.

Combined sewer: The combined sewer is 4 km long. Catchment 1 is located at the beginning of the sewer, catchment 2 is located 2.2 km downstream and catchment 3 is located 3 km downstream.

PC: The volume of the tank is equal to 1,000 m^3. The presence of lamellas in the clarifier highly increases the tank surface for settling and reduces its relevant depth.

Model inputs

Dry (around 15,000 m^3/d) and wet (around 27,000 m^3/d during 1h) weather inlet flows and wastewater quality at each catchment were based on intensive measurement campaigns carried out on full-scale infrastructures. Two days are simulated: 1) the first one represents the training run to set all state variables during DW conditions, and 2) a second day when a rain event occurs during the morning with tanks' emptying started at 11h00 a.m. Four PSVD fractionations of the TSS are used depending on the simulated TSS concentrations: 1) for DW, a lighter PSVD is used when TSS is lower than 250 g/m^3 and a heavier one when TSS is over this threshold. For WW, the same principle is applied, with a threshold fixed at 100 g/m^3. Indeed, particles settle faster during WW since heavy particles are resuspended as a result of the higher flow rates.

A realistic model

RT: Maruéjouls et al., (2012b) successfully calibrated and validated the proposed model with three particle classes. Following the same methodology, another calibration was performed after extension of the model to include five particle classes.

Sewer: The trunk sewer is modelled as a Nash cascade of ten reservoirs for hydraulics and ten continuously stirred tank reactors for quality. No pollutant transformation is modelled. The model is inspired by a real case trunk. For the conceptual hydrological model calibration, a calibrated SWMM model of the Quebec City sewer system using dynamic wave equations (Wipliez, 2011) was fed with the same DW input file. Parameters were adjusted so as to give satisfying approximation of the travel time (1 hour) and the dispersion process.

PC: The PC model is a succession of ten layers in which TSS is fractionated in five particle settling velocity (Vs). Calibration and validation were done using four different datasets from two full-scale systems in UK and Canada.

RESULTS

The first result is a comparison of observed and simulated data of the PSVD at the inlet and outlet of the PC. The ability of the model to represent the PSVD after settling and resuspension of particles in pumping wells, after mixing of DW and WW flows in the sewer and after sedimentation in the PC is demonstrated with these simulations. The second result is a comparison of the mass fluxes at the outlet of the PC between two emptying strategies of the RT (with or without a 2 hour delay between each RTs' emptying).

PSVD: Figure 2 shows simulated PSVD's at different times during the second day (WW). Continuous lines are inlet data and dash lines are the simulations at the outlet of the PC. One can observe that the PSVD are "lighter" at the outlet, i.e. particles with high Vs are removed by the PC. When comparing with the range of PSVD's observed at full-scale (red zone for inlet and blue zone for outlet), PC inlet PSVDs seems properly simulated. At PC outlet, it is obvious that the simulation tends to slightly overestimate the PSVDs.

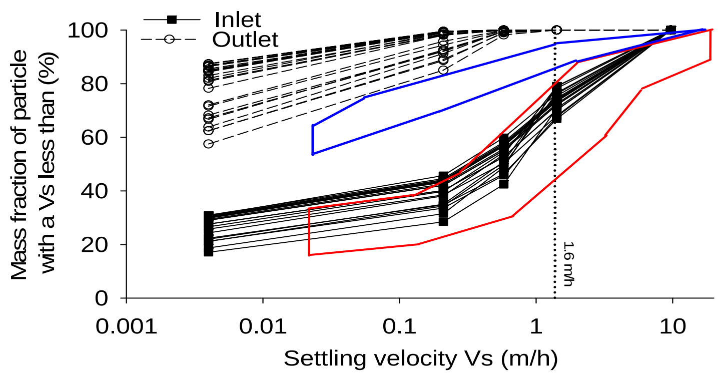

Figure 2: *Comparison between observed and simulated PSVD. The red zone corresponds to the PSVD observed at the inlet and the blue zone to the outlet of the Eastern Quebec WWTP PC. The red and blue zone data come from Maruéjouls et al., 2011.*

Particle class fluxes: On Figure 3, the particle classes simulated at the PC outlet are compared for two emptying scenarios and a DW scenario (Figure 3a). Flow rates are plotted as the grey areas: the dark area represents the DW flow contribution while the light grey represents the WW flow contribution. Figure 3b is the result of the scenario where the emptying of the three RTs starts at the same time while Figure 3c presents a scenario in which 2 hours of delay were set between the start of emptying at each RT (the first one to start is catchment 3, then 2, then 1). For both WW scenarios, one can see that the concentrations of particles with low Vs decrease while concentrations of particles with high Vs increase. This can be explained by the hydraulic shock resulting in an increase of the overflow rate. The same is observed when looking at Figure 2: the three lower curves simulated during the rain are the "heaviest" PSVD.

For DW, the TSS mass simulated at the PC outlet is 31 tons (TSS_1=84% and TSS_2=26%). The two simple scenarios show that over the "emptying period with impact on the PC" 65 tons of TSS (TSS_1=65%, TSS_2=23%, TSS_3=10% and TSS_4=2%) are found at the PC outlet for simultaneous emptying while 61 tons (TSS_1=68%, TSS_2=24%, TSS_3=7% and TSS_4=1%) are sent to the subsequent treatment step for the scenario with delay.

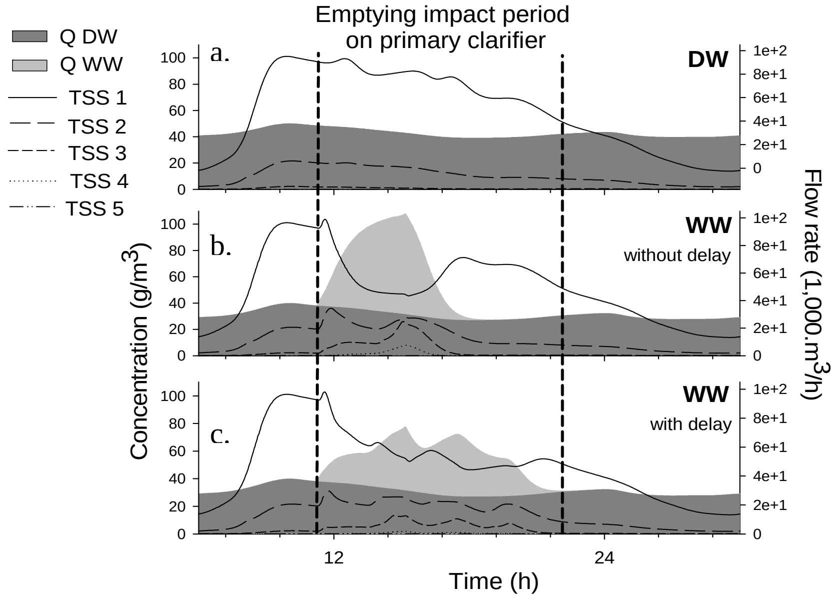

Figure 3: *Simulated TSS class concentrations at the PC outlet for three simple scenarios: a) under DW conditions (reference); b) under WW with simultaneous start of each RT emptying; and c) under WW with a 2 hour delay between the start of the emptying of each tank.*

CONCLUSIONS

Results of the integrated simulations presented in this paper show that it is possible to achieve good predictions of the PSVD in a sewer-retention tank-primary clarifier system. This PSVD model prediction is the result of simulating several phenomena occurring throughout the urban wastewater system such as settling and resuspension in pumping wells, mixing and dispersion in sewers and settling in primary clarifiers. Furthermore, this preliminary work shows that an efficiency gain of primary clarification can be pursued by adding a delay between the initiation of retention tanks emptying. Other scenarios can be imagined that focus on tuning the rate of emptying of such tanks or adding scrappers in retention tanks to convey the settled solids to the WWTP or testing different real-time control strategies on PSVD in order to optimize secondary treatment.

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