USING PARTICLE SETTLING VELOCITY DISTRIBUTIONS TO BETTER MODEL THE FATE OF STORMWATER TSS THROUGHOUT THE INTEGRATED URBAN WASTEWATER SYSTEM

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Introduction

Urban stormwater composition changes a lot from the moment it hits the ground to its discharge into the receiving water, both in combined and separate sewer systems. Water pollution can be split into soluble and particulate components, the latter often being characterized by the concentration of total suspended solids (TSS). TSS is often correlated with turbidity, which can be measured online, providing then continuous information on this aspect of water quality, and allowing development of controls. This article focuses on particulate pollution of stormwater, which is a key parameter to evaluate the stormwater's impact on the environment. Indeed, particulate material not only leads to visual pollution, but also contains considerable organic matter, leading to oxygen depletion, and increasing nutrient levels, causing eutrophication. Moreover it carries adsorbed pollution (pathogens, heavy metals, micropollutants, etc.). Despite years of efforts (Ashley *et al.*, 2004), understanding the processes affecting particulate pollution in the system, especially in sewers, and predicting its fate remains a considerable challenge. This article summarizes some of the salient results of the research conducted over the last seven years at the Civil and Water Engineering Department of Université Laval.

From the perspective of improving the receiving water quality, it is essential to consider integrated urban wastewater systems (IUWS) as a whole. Indeed, interactions between the sewers, the wastewater treatment plant (WWTP) and the receiving water bodies can be significant. When dealing with such complex systems, mathematical models have been proven particularly useful. Models allow scenario elaboration to simulate management strategies and their impact, enabling the engineer to better understand the system, yielding better informed decision-making.

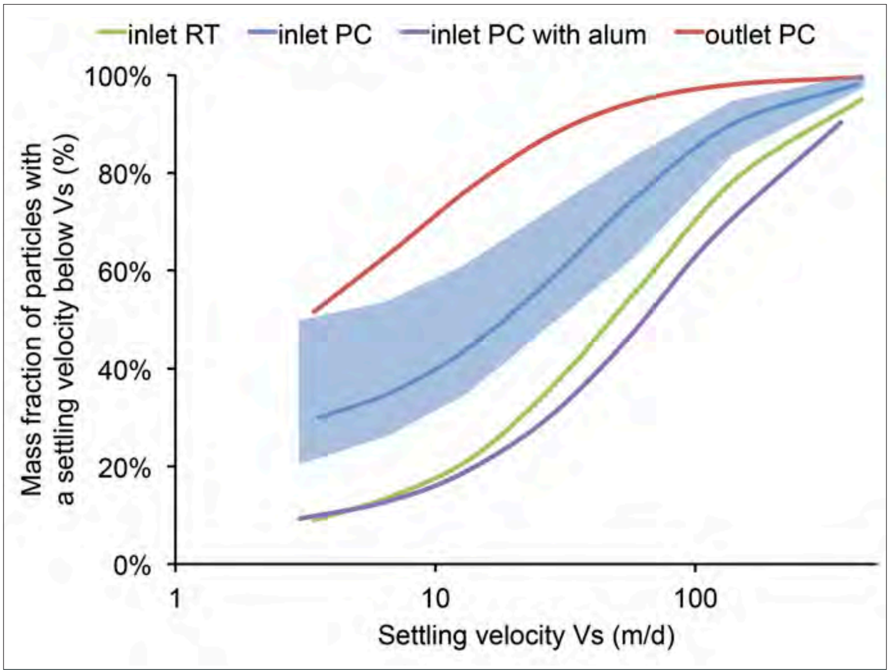

Figure 1 - Examples of particulate settling velocity distributions (PSVD) along the integrated urban wastewater systems (IUWS) and typical PSVD region observed at the inlet of the primary clarifier (PC). Alum addition 'lowers' the PSVD curve (from blue to purple). Inlet RT (retention tank) curve characterizes combined wastewater during wet weather.

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PART 1: MODELLING

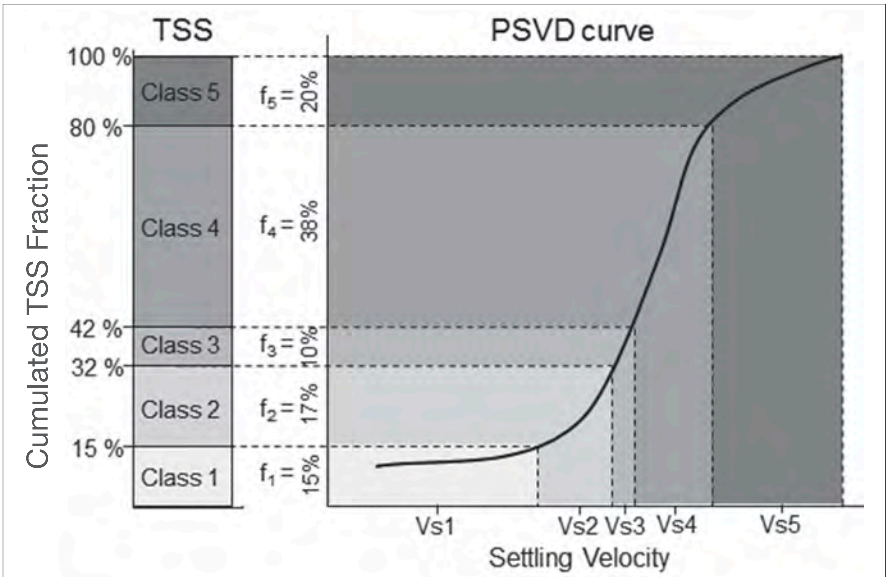

Figure 2 - An example of TSS fractionation in five particle classes (class delineation in dashed line). Each particle class, characterized by a mean settling velocity (Vs1 to Vs5) is associated with its TSS mass fraction (f_1 to f_5).

Particle Settling Velocity Distribution Characterization and Modelling Concept

Particle settling velocity distribution (PSVD)-based models, using a relatively simple wastewater characterization method, allow better prediction of water quality in terms of TSS along the system.

The ViCAs-TSS characterization protocol (Vitesse de Chute en Assainissement, Chebbo and Gromaire, 2009) originally developed to characterise stormwater particulates, was adopted in our work for characterization of particulate matter throughout the urban wastewater system. A ViCAs lab experiment consists in filling a 60-cm column with 4.5L homogeneous sample of storm- or wastewater, which is then subject to static settling. A series of cups is placed sequentially underneath the column to collect particles that settle from the column. At pre-determined time periods, a cup is withdrawn and substituted by another one. The TSS collected in each cup is quantified and the cumulative mass of settled TSS is interpreted to yield the so-called particle settling velocity distribution (PSVD) of the water sample (**Figure 1**), which enables to assign different settling velocities (Vs) to mass fractions of particles.

Over the last few years, a large number of ViCAs experiments have been performed with samples collected at different locations within the urban storm and wastewater systems in different cities in Canada and Europe. Key information extracted from this extensive experimental work is summarized below:

- the PSVD is not constant in space nor time. However, the PSVD of a sample taken under specific conditions (location, same operational conditions...) will be located in typical regions (see, for instance, **Figure 1** for the inlet primary clarifier region);
- within a specific region, the PSVD of a sample is quite well correlated with its TSS concentration (Bachis *et al.*, 2014)

Settling is the most important process to consider when dealing with particulate pollution. Hence, particle settling velocity is a key parameter to determine in view of modelling. Models that only consider a single, mean settling velocity to all particles do not incorporate the heterogeneity of particulate pollution in storm- and wastewaters. The purpose of PSVD-based models is to improve the predictive capacity of models by fractionating TSS into a limited

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"ALTHOUGH THESE STORMWATER BASINS HAVE NOT BEEN DESIGNED FOR TREATMENT, SIGNIFICANT IMPROVEMENT IN WATER QUALITY DUE TO SETTLING IN THE BASINS WAS OBSERVED."

number of particle classes, each class defined by a mean settling velocity extracted from the relatively simple and inexpensive ViCAs experiments (**Figure 2**). The models of the different systems described below use dynamic mass balances of the different particle classes to predict the evolution of their concentrations.

APPLICATIONS

Stormwater Basins

In separate sewer systems, rain water is often discharged to the receiving water without treatment, even though it is not free of pollution. In some places, stormwater basins have been built to attenuate the hydraulic impact of a sudden wet weather flow discharge to the receiving water, causing increased erosion and sometimes even flooding. Although these stormwater basins have not been designed for treatment, improvement in water quality due to settling in the basins was observed. Hence, a better understanding of the phenomenon was deemed interesting enough to explore further. Vallet *et al.* (2014) developed a multi-layer stormwater tank model based on PSVD. The model has a varying volume and is able to reproduce settling and resuspension thanks to settling fluxes between the layers and a mixing model for resuspension. The model can reproduce both the particles' concentrations at the outlet of the tank and inside the tank. Indeed, the PSVD approach coupled with a discretization of the water column in nine layers enables the model to reproduce the TSS concentration gradient over the water column (Vallet *et al*., 2014). Four particle classes was found to be the optimal number for process description.

Gaborit *et al.* (2013) also demonstrated that the forecast of the TSS at the stormwater tank inlet could be improved by adopting the PSVD approach for build-up of wash-off phenomena. They observed that consecutive rain peaks were not resulting in the same TSS concentration in wash-off as observed at the pond inlet. By implementing various build-up and wash-off rates depending on particle classes (and thus particle settling velocity), they could reproduce TSS wash-off peaks of consecutive rain events.

Combined Sewer Retention Tanks (RT)

When combined sewage is prevented from overflowing by storage in retention tanks (RT), it is not surprising that PSVD has proven a key parameter to consider when trying to model the fate of TSS as the water resides in the RT. Very few studies have been carried out characterizing the settling process in a RT. Métadier *et al.* (2013) and Maruéjouls *et al.* (2013) both highlight the interest in observing particulate pollutant behaviour in RT in order to better understand and predict effective TSS removal in these tanks.

The calibration/validation work of the RT model of Maruéjouls et al. (2014) has proven the superiority of a model considering three settling velocity classes rather than a single average settling velocity for all the particles. An important characteristic of the model is that it can accommodate for the fact that the PSVD of the TSS is not constant, but depends on a number of factors such as the time of the day (low TSS waters have a different PSVD than high TSS waters), dry or wet weather conditions, etc. This highly enhanced the model's adaptability to different case studies all the while keeping the calibration work limited, since the PSVD model's parameter values are the direct result of ViCAs measurements. The model performance was compared with a former existing RT model by Lessard and Beck (1991) and found to be improved using the PSVD approach.

Primary clarifier and CEPT

The PSVD-based primary clarifier model is similar to the above RT model, with the exception that the volume of water in the tank is now constant. It was shown that the vertical gradient of the concentration of each of the particle classes in the settler can be simulated. To describe the vertical gradient, the settler is again divided into a number of layers and a mass balance is calculated around each layer for each of the classes. Five particle classes with different (constant) settling velocities make up the core of the model (Bachis *et al.*, 2014). Again, ViCAs experiments allow simple calibration of the PSVD-based primary clarifier model.

Primary clarification is the first wastewater treatment process to suffer from sudden changes in WWTP influent characteristics due to stormwater. To attenuate the negative impact of wet weather conditions, chemically-enhanced primary treatment (CEPT) can be applied. Chemicals (usually alum as coagulant) are added to the primary clarifier influent, changing the TSS settling characteristics. By performing a ViCAs experiment on samples with and without alum addition, the impact of CEPT on the PSVD has been determined (**Figure 1**). CEPT tends to 'lower' the PSVD curve implying that the fractions of particles with higher settling velocity are increased at the expense of classes with lower settling velocity. CEPT can thus be modelled by making the TSS fractionation dependent on the chemical concentration. The layer structure of the model enables reproducing the mixing conditions in the clarifier, which is essential to describe the observed delay between

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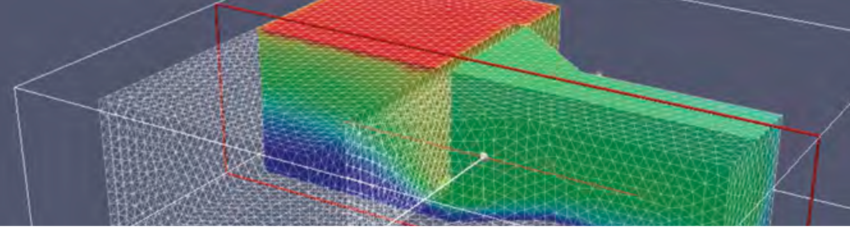

PART 1: MODELLING

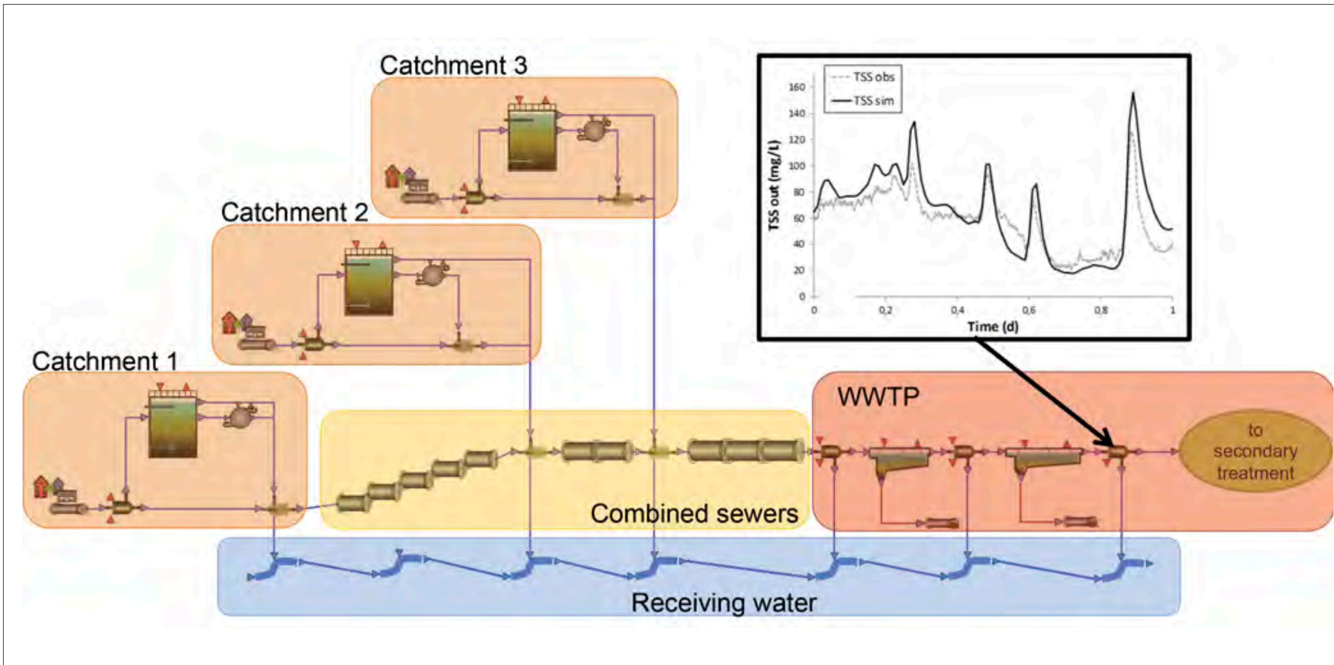

Figure 3 - Integrated model configuration in WEST® (mikebydhi.com).
Insert shows results of a validation of the primary clarifier PSVD-model (Bachis et al.*, 2014).*

chemical addition and its effect on the outlet TSS concentration. Properly dealing with this delay is essential for the development of a chemical dosing controller which aims at reducing chemical addition without jeopardizing settling performance (Tik *et al.*, 2013).

Integrated Model and Control Possibilities

All models presented above have been developed using the modelling and simulation platform WEST® (*mikebydhi.com*), facilitating their combination in an integrated model. Based on data collected in the field, the system represented in **Figure 3** has been modelled. It includes three catchment areas, each equipped with an off-line RT. These three catchments are connected to a main interceptor bringing combined sewage to the WWTP. The plant is modelled by a grit chamber, a primary clarifier with possibility of CEPT and three bypasses. Data have been collected at multiple locations of this system and the model performance is remarkable given the complexity of the processes affecting TSS (Tik *et al.*, 2014).

Using the integrated model, different control strategies have been evaluated. Scenarios were designed around the following control actions that only use water height, flow rate and turbidity data:

- retention tanks emptying flow rate
- activation of CEPT and chemical dosing flow rate
- flow rate sent to secondary treatment

The impact of each scenario, in terms of water volume and TSS load discharged in the receiving water vs. time to empty the RTs, has then been computed (Tik *et al.*, 2014). The results showed a significant reduction in volume of untreated or partially-treated wastewater discharged into the receiving water, but more importantly from an environmental protection perspective, a greater reduction of mass of suspended solids discharged. However, this indisputable benefit for the environment comes at the expense of an increase in RT emptying times. Weather predictions should therefore be used to prevent such slower emptying in case the retention capacity is needed for an upcoming rain event.

Conclusion

This article presented PSVD-based models of the major units involved in stormwater treatment. The PSVD approach allows significantly better prediction of water quality, in terms of TSS concentration, compared to the standard approach of assigning a mean settling velocity to all particles. By combining these models in an integrated model, the potential of improving system management has been evaluated. Preliminary results of relatively simple control strategies show that there is room for considerable reduction of environmental impact of discharged particles. Further real-time control ideas are currently being examined.

Acknowledgements

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