Watermatex 2019

Dynamic grit chamber modelling: Dealing with particle settling velocity distributions

Queralt Plana*,*, Paul Lessard**,***, Peter A. Vanrolleghem*,*****

* modelEAU, Université Laval, 1065, Avenue de la Médecine, Québec (QC), G1V 0A6, Canada. E-mail address: queralt.plana.1@ulaval.ca
** Département de génie civil et de génie des eaux, Université Laval, 1065, Avenue de la Médecine, Québec (QC), G1V 0A6, Canada.
*** CentrEau, the Québec Water Research Center, Université Laval, 1065, Avenue de la Médecine, Québec (QC), G1V 0A6, Canada.

Abstract: Grit chambers are meant to reduce the impact of inorganic particles on equipment and processes downstream. Despite their important role, characterization and modelling studies of these process units are scarce, leading to a lack of knowledge and suboptimal operation. Thus, this study presents the first dynamic model, based on mass balances and particle settling velocity distributions for use un WRRF simulator for design and optimization of grit removal units.

Keywords: Grit particle characteristics; settling process; wastewater quality modelling

Introduction

Grit chambers can be found at the headworks of most water resource recovery facilities (WRRFs) to protect the equipment and processes downstream and maintain the performance of primary and secondary treatments (WEF, 2016). Despite their important role, characterization and modelling studies of these process units are scarce because they have always been considered to have a low influence on secondary treatment and studies often start from primary effluent. Importantly, grit removal efficiency is increasingly questioned by utilities since grit is still found to accumulate in downstream processes (McNamara et al., 2009). In addition, only a low % of particles found in wastewater are grit particles, i.e. 5-10%, which makes them difficult to measure under typical sampling and analysis situations (WEF, 2016).

The characteristics of particulate pollutants at the inlet, outlet and underflow of grit chambers are rarely documented (Rife and Botero, 2012). This lack of knowledge leads to an improper grit definition, a non-existing standard protocol for sampling and characterization, and a non-existing standard protocol to evaluate the removal performance of grit chambers (WEF, 2106). Moreover, modelling has been limited to very simple static %-removal based models or complex hydrodynamic models (i.e. computational fluid dynamic (CFD) models) (WEF, 2016).

Since a grit chamber is a sedimentation process, the particles' separation depends on the gravity force and wastewater particle settling characteristics (WEF, 2016). Thus, the goal of this study is to properly characterize the influent in view of grit chamber modelling and to propose a new dynamic model based on the particle settling velocity distribution (PSVD) approach inspired by the work of Bachis et al. (2015) on primary clarifiers.

Material and Methods

In this study, full-scale grit chambers of a combined sewage WRRF in the Québec City area (Canada) were evaluated. The WRRF has a capacity of 36,000 people equivalent and an average design flow of 18,760 m^3/d. The system studied consists in two vortex grit chambers with a diameter of 4.2 m and with a maximum capacity of 50,940 m^3/d each. With the current operational conditions, the hydraulic retention time varies between 1 and 4 minutes.

First, to characterize the particles around the grit chamber, the ViCAs protocol (Chebbo and Gromaire, 2009) was used. However, the standard 70cm-ViCAs column had to be upgraded to a 2m-column to better estimate the high settling velocities of the particles of interest (Plana et al., 2018). Several samples were collected at different flow and total suspended solids (TSS) conditions to evaluate how the PSVD varies.

To study the solids dynamics around the grit chamber, RSM-30 automated monitoring stations (Primodal, Hamilton, ON, Canada) were installed to collect long-term continuous on-line data at high frequency. The stations were equipped with several sensors to measure TSS at inlet and outlet. In addition, to assure the quality of the data series, a rigorous maintenance protocol was applied together with state-of-the-art data management and treatment (Alferes et al., 2013).

Also, to build the hydraulic model of the grit chamber, two tracer tests at different flow conditions were performed. The tests consisted in a pulse input with the Rhodamine WT fluorescent dye. This tracer was chosen because it has no influence on the hydraulics behaviour of the tank (i.e. same transport characteristics as water, no modification of the water density, no reactions with nor absorption onto solids, highly soluble and not toxic).

Then, the PSVD model, based on mass balances and particle settling velocity distributions, has been developed to reproduce the TSS dynamics at the outlet and underflow of the grit chamber. It consists of the fractionation of the TSS in a determined number of particle classes, each class being characterized by a mean settling velocity extracted from the experimental PSVD curves. The 1D layered model was implemented in WEST (mikebydhi.com), dividing the tank in a limited number of homogeneous layers. For each layer, a dynamic mass balance is calculated for the different particle classes to predict the evolution of their concentration (Bachis et al., 2015). In contrast to the PSVD model proposed for primary clarifiers by Bachis et al. (2015), a mixing flow between layers was added to better represent the induced vortex forces in the grit chamber. The approach was inspired by the work of Vallet et al. (2014).

Results and Discussion

Characterization of PSVD

First, at the inlet of the grit chamber, the settling characteristics were determined using 20 samples collected under different flow and weather conditions. The PSVD curves obtained with the 2m-ViCAs column were described by ten particle classes. Each particle class is characterized by a mean settling velocity (Figure 1). The boundaries of the 10 classes were chosen considering ten equal fractions of the average PSVD curve. In addition, when analysing the ensemble of the 20 measured PSVD curves, it was observed that they depend on the inlet TSS concentration of the sample, i.e. at higher concentration, the PSVD curve is located in the lower region as indicated in Figure 1 (this was also found in the studies of Bachis et al., 2015 and Maruéjouls et al., 2011). This variation is explained by the fact that, at higher flows, more particles are transported into the WRRF (higher TSS), and that generally these particles are characterized by higher settling velocities because these higher flows have more energy, allowing to resuspend these faster settling particles.

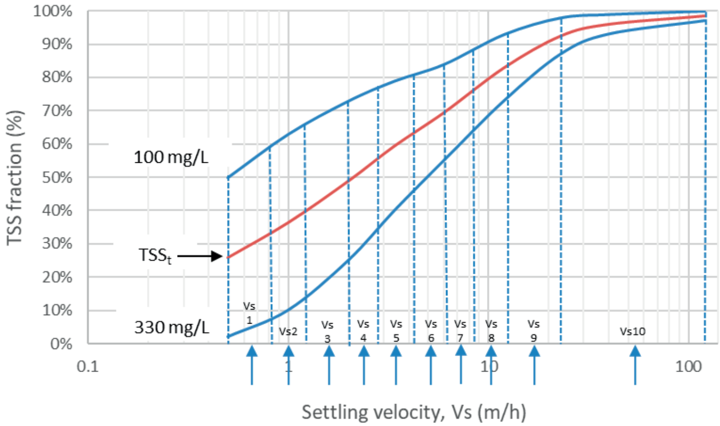

Figure 1 Inlet PSVD settling velocity class boundaries for a particle classes fractionation into 10 classes. The arrows indicate the settling velocity that characterizes each class, calculated as the geometrical mean of the boundaries of each class.

Inlet and outlet TSS dynamics

Monitoring the inlet and the outlet of the grit chamber, the solids dynamics were tracked. Figure 2 shows an example of how the TSS concentrations vary at the inlet and the outlet of the grit chamber with the flow under dry weather conditions. Remarkably, the sudden inlet flow variations, due to pumping sequences, have a direct impact on the TSS concentrations, both at the inlet and outlet. They also affect the retention time of the grit chamber (varying between 1 and 4 min, in this case study) and, thus, the removal efficiency. Despite the fact that the flow and the pumping sequences are important for the grit chamber performance, only hourly flow rate data were available from the facility. Hence, the actual high frequency flow rate data used ($\Delta t = 10$ sec.) was obtained with a physical model, only considering the data available (i.e. hourly inlet flow, high frequency on-line temperature data, 2 days of detailed inlet flow at $\Delta t = 10$ sec., and physical characteristics of the pump station) (Plana, 2019).

Hydraulic model

From the two tracer tests, a hydraulic model of the grit chamber was built. The tracer dynamics suggested that 30% of the flow short-circuited very quickly through the grit chamber, not allowing significant sedimentation. The other 70% was considered passing through a settler section, and the tracer curve suggested three (vertical) layers. The detailed hydraulic model and its development are presented in Plana (2019). Importantly, this hydraulic model agrees with the behaviour observed in CFD studies performed by the industrial partner, Veolia Water Technologies Canada, on a vortex grit chamber with the same configuration as the studied unit (Couture et al., 2009).

Calibration of PSVD model

The removal performance of the ten particle classes could now be evaluated through comparing the proposed model with a one-day on-line TSS data set so as to calibrate the model (Figure 2). First, the physical model parameters (surface area and height of the grit chamber, and the underflow) were set to the physical characteristics and operation of the unit. Only using the ViCAs-derived settling velocity parameters (see above), a promising fit to the data was obtained, albeit with a too good removal performance. The mixing flow between the layers, leading to a resuspension of particles, was therefore augmented to make a better fit between measured and simulated TSS data.

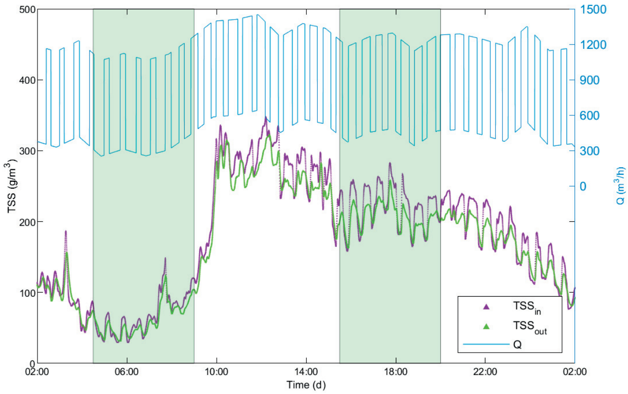

Figure 2 On-line TSS measurements for calibration at the inlet and outlet of the studied system, together with the simulated inlet flow. The two zones depict two different periods that are studied in detail: low flow period (from 04:30 to 09:00) and high flow period (from 15:30 to 20:00).

Results of the calibrated model show a good approximation of the outlet TSS and their dynamics (see Figure 3). The goodness-of-fit of the model was statistically estimated with the root mean squared error (RMSE) criterion. The simulated removal efficiency of 12% was similar to the measured removal of 9%. The estimated RMSE was 10 mg/L, which is in the same order of magnitude of the measurement errors of the TSS sensors.

The removal efficiency of the grit chamber obviously varies with flow conditions: At low flow, due to the higher retention time, the removal is higher and particles with low settling velocities can be removed to a reasonable extent. Conversely, at high flow conditions, the retention time is reduced, leading to a lower removal and most of the particles that are removed, are the ones that settle fast.

However, while a fixed Q_{mix} was used, it was found that the removal efficiency was overpredicted at low flow conditions and underpredicted at high flow. To accommodate for this, the Q_{mix} was made dependent on the inflow. In fact, dispersion is higher at low flow conditions ("there is more time for dispersion"), as for instance, expressed in the model of Chambers and Jones (1988). A turbulent dispersion mixing flow (Q_{mix}), inversely proportional to the inlet flow (Q_{in}), was estimated from equation (1). The parameters related to this mixing flow (dispersion factor, α_D and mixing behaviour, β_D) between the model layers, were determined by fitting the model to the selected data set for calibration.

$$Q_{mix} = \frac{\alpha_D}{Q_{in}^{\beta_D}} \tag{1}$$

In Table 1 the overall impact of the inlet flow on the percentage removal can be observed for each particle class at low and high flow conditions. A key feature of the model is, of course, that it is capable to describe the more efficient removal of the particles with higher settling velocities (i.e. classes 8-10).

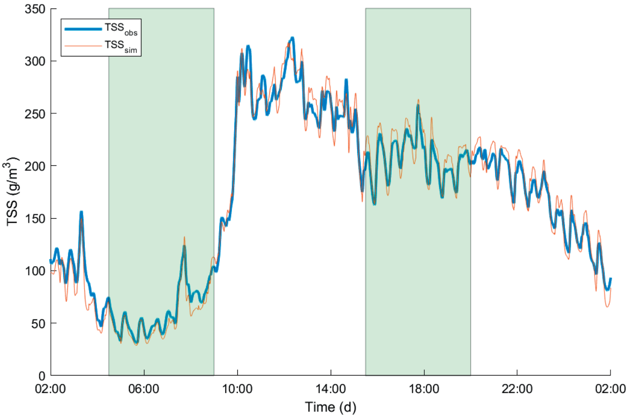

Figure 3 Calibration model fit for outlet TSS concentrations for a 1day-simulation under dry weather flows: during the low flow period (left patch) with high backmixing conditions and during the high flow period (right patch) with low backmixing conditions. The removal efficiencies under these conditions are 17% and 12% respectively (See Table 1).

Table 1 Summary of removal efficiency for each particle class for a whole 1-day period and at low and high flow conditions separately.

Particle class	**Settling velocity (m/h)**	**Conc. (mg/L)**	**% removal**	**Conc. – low flow (mg/L)**	**% removal – low flow**	**Conc. – high flow (mg/L)**	**% removal – high flow**
Class 1	0.67	126.6	9%	52.0	13%	153.5	9%
Class 2	1.04	5.8	9%	4.3	9%	6.2	9%
Class 3	1.63	8.9	9%	6.5	9%	9.6	10%
Class 4	2.35	6.8	10%	4.9	10%	7.4	10%
Class 5	3.44	10.6	10%	7.6	11%	11.3	11%
Class 6	5.21	9.9	11%	7.2	13%	10.6	12%
Class 7	7.50	7.4	13%	5.5	16%	8.0	13%
Class 8	10.63	6.7	15%	5.1	19%	7.1	15%
Class 9	17.71	8.3	19%	6.4	25%	8.8	19%
Class 10	71.46	10.9	47%	9.0	58%	11.2	44%
Total		*202.0*	*12%*	*108.5*	*17%*	*233.6*	*12%*

Validation of the PSVD model

The model was validated with other data sets collected under different weather conditions (see Figure 4). The results obtained confirmed the good performance of the model, reproducing the outlet TSS concentrations and their dynamics (see Figure 5). This time, the % removal simulated was 11% which is the same as the 11% observed. The RMSE was 15 mg/L. By comparing this RMSE with the calibration RMSE, the Janus coefficient could be estimated, and it was equal to 1.5 (Rieger et al., 2012). Thus, validation was successful (Janus coefficient <2).

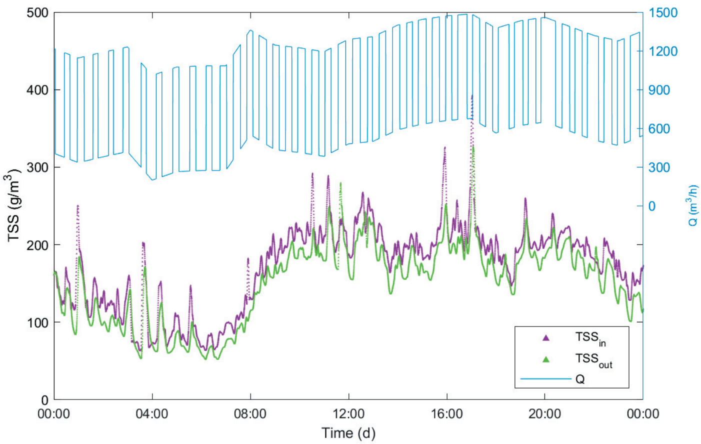

Figure 4 One-day on-line TSS measurements used for the validation test at the inlet and outlet of the studied system, together with the simulated inlet flow.

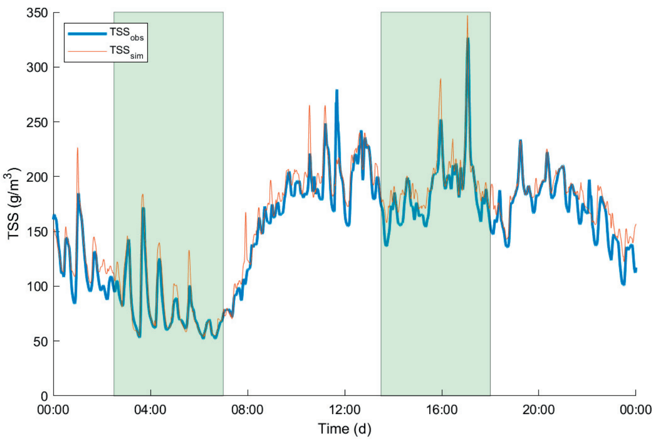

Figure 5 Observed and simulated outlet TSS concentrations for the model validation step for a 1day-simulation. During low flow period (left patch) and during the high flow period (right patch) are detailed in Figure 7.

Conclusions

Grit chambers need to be properly characterized in view of whole WRRF modelling, settling characteristics and hydraulic dynamics being the key characteristics. A new experimental characterization and modelling approach based on PSVD has been proposed and the new model was successfully calibrated and validated. Compared to the existing (static) grit chamber models, the proposed dynamic model allows remarkably good dynamic predictions of effluent TSS and overall removal performance.

Acknowledgements

The authors thank the financial support by a Collaborative Research & Development grant of the Natural Sciences and Engineering Research Council (NSERC) and Veolia Water Technologies Canada. Peter Vanrolleghem holds the Canada Research Chair in Water Quality Modelling.

References

Alferes, J., S. Tik, J. Copp and P. A. Vanrolleghem (2013). Advanced monitoring of water systems using in situ measurement stations: Data validation and fault detection. *Water Science and Technology* **68**(5), 1022–1030.

Bachis, G., T. Maruéjouls, S. Tik, Y. Amerlinck, H. Melcer, I. Nopens, P. Lessard and P. A. Vanrolleghem (2015). Modelling and characterization of primary settlers in view of whole plant and resource recovery modelling. *Water Science and Technology,* **72**(12), 2251–2261.

Chambers, B. and Jones, G. L. (1988). Optimization and uprating of activated sludge plants by efficient process design. *Water Science and Technology*, **20**(4-5), 121-132.

Chebbo, G. and M.-C. Gromaire (2009). ViCAs – An operating protocol to measure the distributions of suspended solid settling velocities within urban drainage samples. *Journal of Environmental Engineering*, **135**(9), 768–775.

Couture, M., A. Steele, M. Bruneau, A. Gadbois and B. Hohman (2009). Achieving greater efficiency for 360 rotational grit removal technology using empirical data and CFD analysis. In Proceedings *82nd Water Environment Federation Technical Exhibition and Conference; WEFTEC2009*; 10-14 October, Orlando, FL, USA

Maruéjouls, T., P. Lessard, B. Wipliez, G. Pelletier and P.A. Vanrolleghem (2011). Characterization of the potential impact of retention tank emptying on wastewater primary treatment: A new element for CSO management. *Water Science and Technology,* **64**(9), 1898–1905.

McNamara, B. F., J. Griffiths and D. Book (2009). True Grit. A grit removal efficiency investigation at five wastewater treatment plants. In Proceedings *82nd Water Environment Federation Technical Exhibition and Conference; WEFTEC2009*; 10-14 October, Orlando, FL, USA.

Plana, Q. (2019). *Characterization and modelling of grit chambers based on particle settling velocity distributions*. PhD thesis, Université Laval, Québec, QC, Canada. In preparation.

Plana, Q., J. Carpentier, L. Gagnon, A. Pauléat, A. Gadbois, P. Lessard and P.A. Vanrolleghem (2018). Grit particle characterization: Study of the settleability. In Proceedings *91st Water Environment Federation Technical Exhibition and Conference; WEFTEC2018*; 29 September - 3 October, New Orleans, LA, USA.

Rieger, L., S. Gillot, G. Langergraber, T. Ohtsuki, A. Shaw, I. Takacs and S. Winkler (2012). *Guidelines for using activated sludge models*. IWA Publishing. London, UK.

Rife, J. C. and L. Botero (2012). Last of the neglected treatment processes: Rewriting the Manual of Practice no. 8 section on grit removal. In Proceedings *85th Water Environment Federation Technical Exhibition and Conference; WEFTEC2012*; 29 September - 3 October, New Orleans, LA, USA.

Vallet, B., D. Muschalla, P. Lessard and P.A. Vanrolleghem (2014). A new dynamic water quality model for stormwater basins as a tool for urban runoff management: Concept and validation. *Urban Water Journal*, **11**(3), 211-220.

WEF (2016). *Guidelines of Grit Sampling and Characterization*. Water Environment Federation. Alexandria, VA, USA.

Dynamic grit chamber modelling: Dealing with particle settling velocity distributions

Queralt Plana[1,2], Paul Lessard[2,3] and Peter A. Vanrolleghem[1,2]

[1] model*EAU*, Département de génie civil et de génie des eaux, Université Laval, 1605 Avenue de la Médecine, Québec (QC) G1V 0A6, Canada

[2] CentrEau, Québec Water Research Center, Université Laval, 1065 avenue de la Médecine, Québec (QC) G1V 0A6, Canada

[3] Département de génie civil et de génie des eaux, Université Laval, 1065, Avenue de la Médecine, Québec (QC) G1V 0A6, Canada

Problem: There is a lack of knowledge on the characteristics of particulate pollutants around a grit chamber. Current grit chamber models are simple static %-removal based models or complex hydrodynamic models (i.e. CFD).

Objectives:

1. Properly characterize the influent and effluent of a grit chamber.
2. Propose a new dynamic grit chamber model based on particle settling velocity distributions (PSVD).

Characterization of PSVD

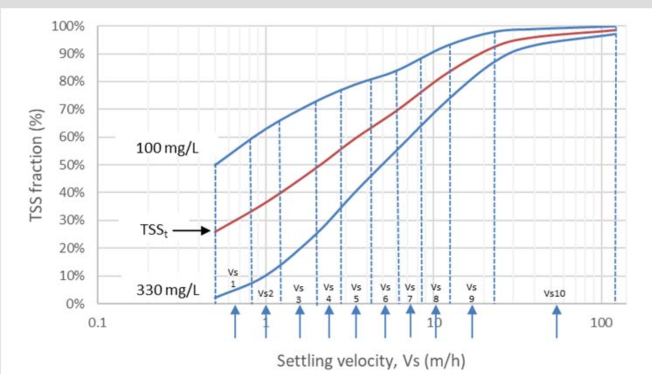

Figure 1. Region of Inlet PSVDs obtained from 2m-ViCAs tests. Particle classes fractionation into 10 classes characterized by settling velocities.

Inlet and outlet TSS dynamics after a rain event

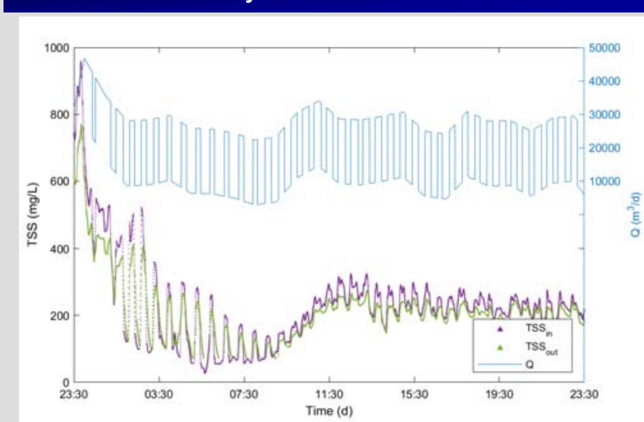

Figure 2. On-line TSS measurements at the inlet and outlet of the studied vortex grit chamber, with the simulated inlet flow under wet weather conditions. The observed TSS removal is 12.7%.

Hydraulic model

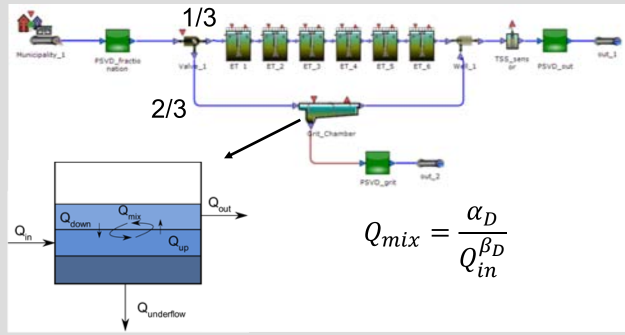

Figure 3. Hydraulic model built from two tracer tests with rhodamine WT.

Validation of the PSVD model – wet weather conditions

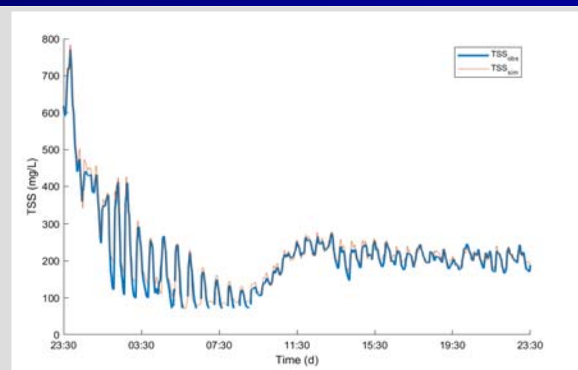

Figure 4. Validation model fit for the outlet TSS concentration for a 1-day simulation under wet weather conditions.

Table 1. Summary of the simulated removal efficiency for each particle class for a whole 1-day period.

Particle class	Vs (m/h)	Inlet conc. (mg/L)	% mass	% removal
Class 1	0.67	67.1	28%	1%
Class 2	1.04	13.8	6%	1%
Class 3	1.63	20.9	9%	2%
Class 4	2.35	15.9	7%	2%
Class 5	3.44	24.6	10%	4%
Class 6	5.21	23.3	10%	6%
Class 7	7.50	18.0	8%	9%
Class 8	10.63	15.1	6%	12%
Class 9	17.71	18.7	8%	21%
Class 10	71.46	18.2	8%	56%
Total		*235.5*		*9.8%*

TAKE HOME MESSAGE

- Grit chambers need to be properly characterized.
- A new experimental characterization and modelling approach based on PSVD has been proposed.
- The new model was successfully calibrated and validated.

http://modelEAU.fsg.ulaval.ca
queralt.plana.1@ulaval.ca