Managing wastewater system suspended solids emissions using integrated urban wastewater modelling

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Highlights

- A particle settling velocity distribution model was developed for simulation of TSS emissions from the Bordeaux sewer-WWTP system under different scenarios of TSS reduction measures.
- The effectiveness of the measures depends on the size of the rain events targeted.
- Control of pumping rates and retention tank operations allow 25-30% TSS emission reduction.

Introduction

Urban population is expected to increase by 2.5 billion by 2050, which will highly impact natural water bodies receiving (treated) wastewater emissions. Indeed, water pollution is a main challenge to be addressed in order to keep a natural environment that can continue providing ecological services to preserve both human and ecological health.

Sensor developments (new technologies, miniaturization, energetic autonomy, …), computing capacities (cloud, parallelization, …) bring the possibility to develop cutting edge solutions that are mixing massive data, advanced models, dashboards and efficient control of urban water systems (Therrien et al., 2021). The wastewater system of tomorrow will be totally integrated where the operator will have direct access to any data from anywhere in the system requesting for status in the past, the present but also in the future in order to understand and therefore manage the system more efficiently. This overall view will allow the operator to understand, for instance, the impact of changing a pumping rate in an upstream pumping station on the WWTP or even on the receiving water thanks to an Integrated Urban Wastewater System (IUWS) view.

The IUWS starts with the drinking water used in industries and households and ends in the natural water body. Everything in-between these two points can be included in the IUWS. Most of the time the processes included can be divided in three sub-systems: 1/ sewer system (including rainfall/runoff/and wastewater collection), 2/ wastewater treatment plant (water/sludge/gas lines), 3/ Receiving water (river/lake/marine) (Rauch et al., 2002). Research has shown that IUWS models can serve to:

1. better understand interactions between systems at the integrated scale, e.g. quantifying pollutant emissions at full urban scale (Rauch et al., 2002),
2. assess impact of various scenarios, e.g. building a retention tank, increasing primary clarifier capacity,
3. investigate the control handles to focus on (Saagi et al., 2018; Ledergerber et al., 2020)

Today real-life implementation of such systems remains quite exceptional. However, the few existing implementations have proven the substantial benefits IUWS analysis can generate (Langeveld et al., 2013, Benedetti et al., 2016). This study aims at showing a virtual implementation of IUWS on a real case illustrating the peculiarities that allow improving environmental water quality with respect to TSS in urban areas.

Material and methods

An IUWS model was developed for the urban catchment of Clos de Hilde in Bordeaux (France). The WWTP has a capacity of around 400,000 PE and a nominal flowrate of 100,000 m^3/d. The sewer is mainly combined, i.e. it collects both sewage and stormwater. The catchment includes various pumping stations and retention tanks that were designed for flood control (Figure 1). A conceptual model based on the Particle Settling Velocity Distribution (PSVD) approach (Maruéjouls et al., 2015) was developed on the WEST (westbydhi) modelling platform to predict flowrates and TSS dynamics only using rain series inputs at 5 minutes time step from the catchment, through the sewer and infrastructures down to the water line of the WWTP.

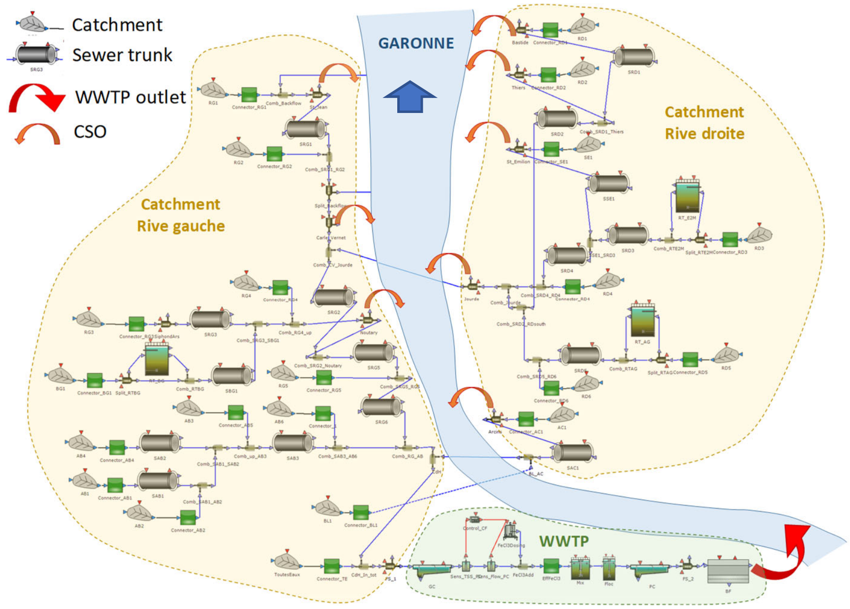

Figure 1: Screenshot of the Clos de Hilde model, catchment + sewer (incl. retention tanks) + CSO + WWTP.

The model was calibrated on a period of ten days and validated on another period of four days including both dry and wet weather conditions for flow rates and TSS that were collected using continuous measurements. Global Sensitivity Analyses (GSA) were performed using the SRC method (Ledergerber et al. 2020) to find the most impactful control handles of the system. The novel GSA approach using multiple GSAs allowed considering model uncertainty to select the control handles that would be optimal independent of system properties that could not yet be covered by the calibrated/validated model (e.g. peculiar rain events).

Results and Discussion

A first 120 days simulation has been performed as the reference scenario using real rainfall time series. In this scenario, the whole system is operated as it currently exists. Results reported in Figure 2 show Total Suspended Solids (TSS) loads spilled into the Garonne river through CSOs, WWTP bypasses and the WWTP effluent. This approach allows to estimate all TSS mass sent from the urban wastewater system to the environment. Results show that, in terms of TSS, the CSOs contribution (125 tons) to the environment pollution is higher than that by the WWTP (55 tons). These reference scenario results were subsequently compared with results from different scenarios to assess the impact of different strategies on the pollutant loads sent to the environment.

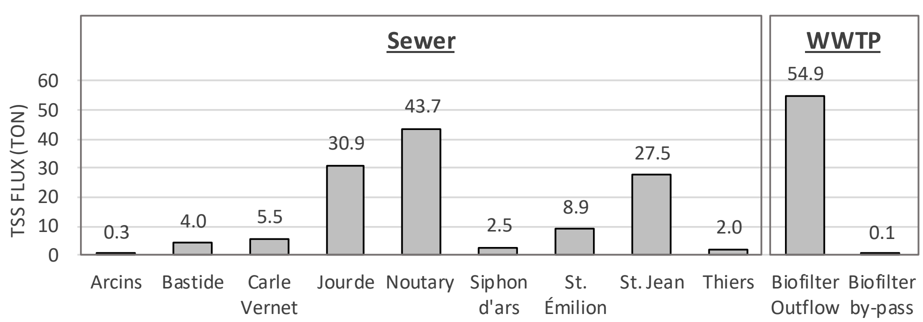

Figure 2: Reference scenario TSS flux emission results: CSO (left), WWTP (right).

Even though a single measure can already have quite an effect on a local basis, the detailed analysis of a multitude of scenarios developed around 9 management measures, showed that only a combination of different measures leads to an overall remarkable emission reduction. An example of this is the impact of an increase of the pumping capacity at Noutary. Over the evaluation of 120 days the total load is reduced locally to 60% of the reference load. The overall load to the Garonne can be reduced by 10% by this single measure. Generally, single measures reduce the overall load by approximately 5% to 10% at best, whereas scenarios with the implementation of multiple measures could reduce the overall load by 25% to 30% (Figure 3).

The combination of the modifications of the different pumping capacities (Noutary, Carle Vernet, Jourde, Siphon d'Ars) leads to a reduction of roughly 15%. However, these improvements are only possible because the WWTP is capable to handle the additional TSS load sent to the WWTP. Most of the TSS load is removed at the primary clarifier, independent of the scenario analysed.

The detailed analysis showed that the effectiveness of the measures depends on the size of the rain events. It is thus of particular importance to define whether it is desired to rather eliminate multiple overflows during smaller rain events or have a significant impact during heavier rain events.

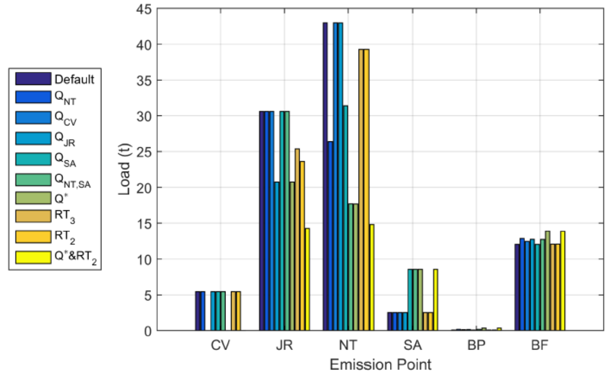

Figure 3: Individual TSS loads at the different emission points for different scenarios (individual measures: first 4 scenarios).

Simple control on the retention tanks (RTs) were also evaluated with the model allowing to draw several conclusions: First, the results generally indicate that the control has more potential on the right bank of the Garonne, which can be explained by the fact that the two RTs there cover a significant amount of the subcatchment of Jourde, which is causing one of the two main emission sources, see Figure 2.

Secondly, the earlier conclusion that the magnitude of the rain event affects the usefulness of measures is of particular importance when studying control of the RTs. By defining a threshold of 2 to 3 times the dry weather flow for the filling of the RTs rain events are targeted with a return period of 2 to 8 months. It means, however, that the large RTs constructed for flood control, are not or only very little activated for smaller rain events. For these measures it seems thus of particular interest to consider the potential of model predictive control, where the prediction of the meteorological forecast is considered. The threshold for the filling, for example, could then be based on the predicted flow and more of its capacity activated, thus further reducing TSS emissions through CSOs.

Finally, the results of this integrated modelling study allowed comparing the reductions in overall TSS emission with the results of Ledergerber et al. (2020), where the effectiveness of different control handles was evaluated. The general findings were confirmed, i.e. the top four selected control handles were indeed consistently able to reduce the TSS emissions to the receiving water for a wide range of rain events analysed.

Conclusions and future work

An integrated wastewater system model has been developed, calibrated and validated. It allowed assessing and comparing the different points of pollutant emissions. With it, the impact of optimization scenarios on the overall emission of pollutants from the IUWS to the environment was quantified. The results prove the interest and the need to tackle wastewater issues from an integrated perspective rather than through a silo-based approach as is currently still often observed in practise.

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