A validated conceptual sewer water quality model based on the particle settling velocity distribution

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Abstract
Historically water quality models have been developed for water resource recovery facilites, but recent developments in urban drainge legislation ask to consider not only water quantity but also water quality when evaluating the performance of a sewer system. This research work proposes a new sewer water quality model for total suspended solids based on the particles' settling velocity distribution that affects the settling and resuspension of particulate matter. The model allows assessing concentration and fluxes at crucial points in the sewer system, such as combined sewer overflows. It has been successfully validated for two case studies.

Keywords
Linear reservoirs in series; Total suspended solids; Settling and Resuspension; Sewer sediment modelling

INTRODUCTION

The development of water quality models has historically been driven by the needs of water resource recovery facilities (WRRF). Recent developments in urban drainage, however, show increased interest in water quality as well. A driver for this development is the changing legislation that is no longer asking for compliance of frequencies and volumes for combined sewer overflows (CSO) only, but is asking for water quality standards as well, as for instance in France (JORF, 2015). Water quality-based real time control (RTC) is a potential solution to reduce emissions over CSOs (Bachmann et al., 2016). If multiple model evaluations are necessary, as in the context of RTC or if multiple models have to be evaluated in parallel, as in integrated modelling, calculation speed is important (Rauch et al., 2002, Achleitner et al., 2007). Conceptual models provide this as they use linear reservoirs in series and therefore ordinary differential equations to model flow. This research work proposes and validates a conceptual sewer water quality model for total suspended solids (TSS). The approach is based on the particle settling velocity distribution (PSVD), that was already successfully implemented in other parts of the integrated urban wastewater system, for example in retention tanks (Maruéjouls et al., 2012) or the primary clarifier (Bachis et al., 2015, Tik and Vanrolleghem, 2017). TSS is split into ten classes according to its measured settling velocity, which allows settling and resuspension for each identified class. These processes are important to consider as a share of 47% to 69% of TSS originate from resuspension of deposits in the sewer (Gromaire et al., 2008).

MATERIAL AND METHODS

Case Studies

The case studies, Québec City, QC, Canada and Bordeaux, France have a number of similarities: the main environmental concern is TSS, both have a combined sewer and a similar size (300 000 PE). Measurement campaigns provided the necessary water quality data, including ViCAs experiments for the PSVDs (Chebbo and Gromaire, 2009).

Models

Sewer Water Quantity. Series of linear reservoirs are implemented to represent flow in a sewer stretch. The Kalinin-Miljukov method adapted by Euler (1983) is used to determine the number of reservoirs and the residence time. Approaches exist to approximate backwater conditions (Vanrolleghem et al., 2009).

Catchment. The catchment model is based on the KOSIM-WEST model (Meirlaen, 2002), coupling a module for wet weather flow (WWF) and a module for dry weather flow (DWF). Daily profiles generate dry weather flow and pollution. For WWF pollution, the event-mean concentration is implemented. In comparison to the original model, WWF routing can now be split in a fast and a slow component (Pieper, 2017).

RESULTS

Sewer Water Quality Model

The proposed PSVD sewer model (schema Figure 1) incorporates settling and resuspension for TSS in each linear reservoir. The TSS generated in the catchment is split into ten particle classes i before entering the sewer system. Each class has a specific settling velocity $v_{s,i}$ according to the measured ViCAs. The settling flux $F_{sett,i}$ for each particle class is calculated with equation (1), where M_i represents the particle mass in the sewer compartment, A the surface area, and V the water volume.

$$(1) \qquad F_{sett,i}(t) = M_i(t)\frac{A}{V(t)}v_{s,i}$$

The resuspension flux $F_{resusp,i}$ is calculated with equation (2), which depends on the particle mass settled in the sediment compartment $M_{sed,i}$ and the resuspension rate r_{resusp} that is defined in equation (3). The resuspension is calculated using the flow rate into the linear reservoir Q_{In} and depends on the maximum resuspension rate $r_{resusp,max}$, the flow at which half of the maximum resuspension rate is reached Q_{half} and the exponent n, an indication for the steepness of the change. Note that the resuspension rate is independent of the particle class i.

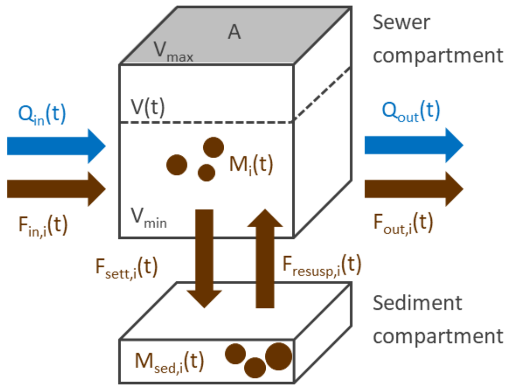

Figure 1: Schema of PSVD water quality model

$$(2) \qquad F_{resusp,i}(t) = M_{sed,i}(t)\, r_{resusp}(t)$$

$$(3) \qquad r_{resusp}(t) = r_{resusp,max}\frac{Q_{In}^n(t)}{Q_{In}^n(t)+Q_{half}^n}$$

Model Validation

The model was successfully validated under both dry and wet weather. Data for the Bordeaux case are shown in Figure 2. The RMSE for flow is 0.064 m^3/s (10-15%) and 58 mg/l for TSS (25-30%).

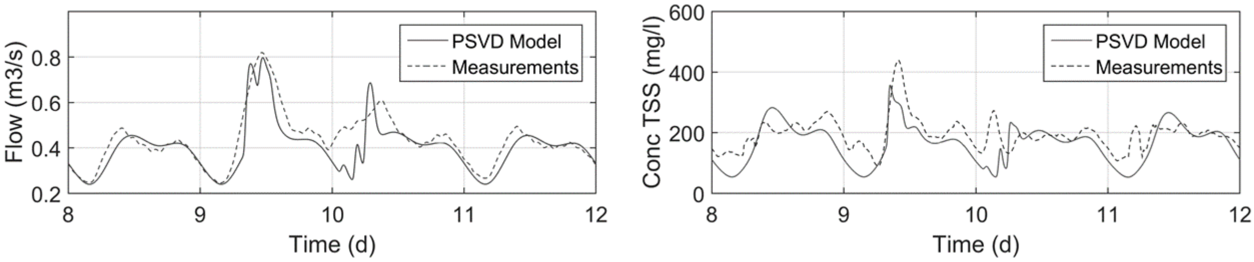

Figure 2: Validation results for water quantity (left-hand side) and water quality (right-hand side)

DISCUSSION

The validation of the conceptual PSVD sewer model shows that TSS dynamics can appropriately be modelled. Considering both settling and resuspension in the sewer pipes, allows implementing a relatively simple approach for the catchment. Indeed, TSS discretized in PSVD-classes allows differentiated settling of TSS fractions. This leads to a representative sediment composition in terms of TSS-classes that have passed by. It was found that the resuspension function can remain simple, i.e. independent of the classes, because the differential behaviour is integrated in the sediment's composition.

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