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Conceptualizing the sewage collection system for integrated sewer-WWTP modelling and optimization

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Abstract: In this paper, a new conceptual modelling approach and calibration method is proposed for integrating sewage collection system and wastewater treatment plant (WWTP) operations. The method consists of simplifying a complex sewer network into a computationally efficient (conceptual) model able to capture the sewer dynamics, both in terms of flow rate and water quality, entering the wastewater treatment plant. Biochemical process modelling was carried out on this conceptual model and compared with a whole-network biochemical model which covered all pipes of a sewer system. The conceptual biochemical model can achieve similar results as the whole-network model in terms of water qualities, but provides fast simulation speed and easy calibration. Those advantages mean that the conceptual biochemical model of a collection system can be used in an integrated model with which sewer and WWTP can be simulated simultaneously for long-term evaluation of optimization scenarios.

Keywords: sewer biochemical processes, integrated modelling, conceptual model, corrosion, wastewater quality

1. INTRODUCTION

Driven by an increasing interest in process intensification and resource recovery, an integrated management of sewer and wastewater treatment plant (WWTP) is becoming meaningful more than ever before. Therefore, studies on sewage collection systems are extending from sewer hydraulics to sewer biochemical processes. Indeed, modelling of pollutant transport and conversion in sewers relies on two categories of models: sewer flow models (transport term) and sewer biochemical process models (reaction term), Figure 1. Thanks to decades of efforts, the study of hydraulic or hydrologic modelling has achieved great success. On the other hand, the modelling of sewer biochemical processes is catching more attentions in recent years, with models proposed by modifying or adopting similar concepts as used in the biochemical models of WWTPs (Hvitved-Jacobsen et al., 2013; Jiang et al, 2009; Sharma et al., 2008).

However, to use those sewer biochemical models in sewer networks is not as easy as in WWTPs. Modelling large-scale sewer networks asks far more computational effort than WWTPs. This drawback severely restricts the application of sewer biochemical models and their integration with WWTP models. Coding and programming is the third pillar of the modelling task (Figure 1), because it has a great impact on simulation speed and the user's experience. Unfortunately, little efforts have been put on this topic so far.

The aim of this study was to break those barriers in sewer biochemical modelling in order to achieve real integrated modelling of water quality in sewer and WWTP, which means that sewer and WWTP models can be run simultaneously on one layout for long-term evaluation. Therefore, a new method is proposed in this paper, which can simplify a complex network into a conceptual model in view of biochemical modelling. A case study was carried out on a collection system in Quebec City, Canada.

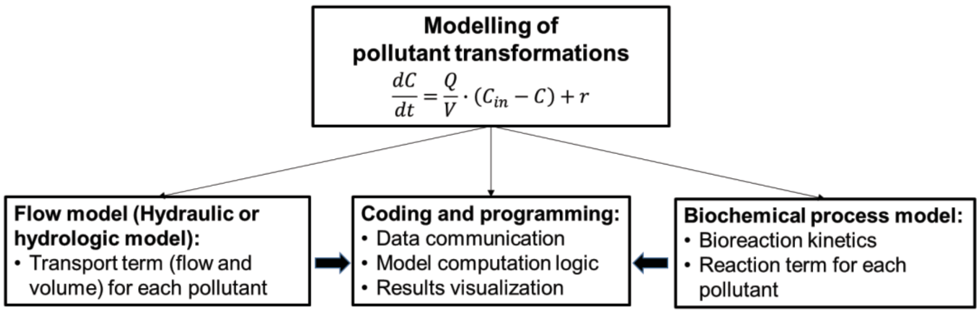

Figure 1. Scheme of pollutant transport and conversion modelling in sewers

2. METHOD

Originally, the approach of conceptual models was proposed as an alternative to traditional hydraulic models like SWMM, for its fast computation speed is an advantage in studying real-time control in stormwater management. For the modelling of sewer biochemical processes, this feature is even more advantageous, e.g. for integrated modelling and long-term simulation. However, although conceptual modelling is not a new concept, its application in sewer biochemical process modelling differs from that in sewer flow modelling.

3.1 Identifying key elements and regions

Before conceptualizing a big sewer network into a simple system, the first step is to identify which elements in the network play a crucial role and how to cut the big network into pieces. In the modelling of in-sewer biochemical processes, more interests are given to how those processes are going on under ordinary dry-weather conditions. Therefore, the storage tanks and pumping stations that are active under dry-weather conditions are picked out and included in conceptual modelling. Usually, those elements are also the accessible places where operation adjustments or chemical dosing strategies can be tested.

3.2 Conceptualizing sewer network

One vital question in conceptual modelling is calibration. In sewer system modelling, calibration is more focused on sewer flow. However, in order to model pollutant concentration changes, flow and volume are equally important (Figure 1). Therefore, two calibration targets are set: the total volume (V_{Target}) and the final outflow (Q_{Target}) of the target sewer network. Therefore, the calibration question can be stated as (Figure 2): knowing all inflows coming into the target network ($Q_{In,Total}$) and assuming volume (V) and flow (Q) of each conceptual tank expressed in a relationship of: $Q_i = k \cdot V_i^m$, find parameters: n (number of tanks), k and m of a tank-in-series system to meet V_{Target} and Q_{Target}.

In most parameter optimization methods, the algorithm searches the best parameter set in a pre-defined parameter space. However, this kind of methods usually requires a good guess of the parameter ranges. The search can take a long time, and sometimes, it may end up only in a local optimum. For these reasons, a simple calibration procedure is proposed. First, one should compare $Q_{In,Total}$ and Q_{Target}. If the curves present a completely mixed flow, then the network can be simplified as one tank. Otherwise, one must shift Q_{Target} forwards by a time step (ts) to get a new data series, $Q_{Target,ts}$, until finding the best match between ln(V_{Target}) and ln($Q_{Target,ts}$): ln(V_{Target}) = a · ln($Q_{Target,ts}$) + b. k and m can be calculated as:

$$m = 1/a \quad \text{Eq. 1}$$

$$k = n^{(1/a)} / \exp(b/a) \quad \text{Eq. 2}$$

n depends on the flow type. For a clear plug flow, it is suggested to try n ≥ 10.

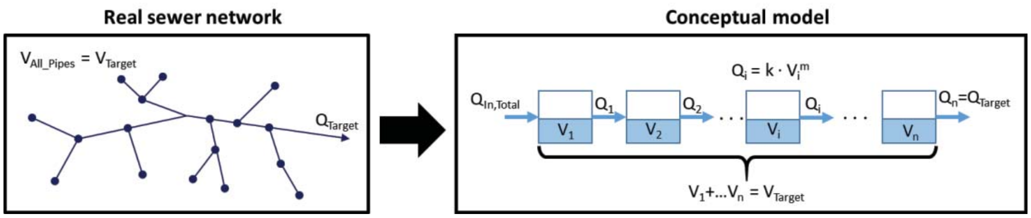

Figure 2 Scheme of Conceptual modelling

3.3 Conceptualizing storage tanks

The storage tanks controlled by pumping stations were modelled by applying pumping rules; otherwise, they were modelled as a non-linear tank using the equation $Q_{st} = k \cdot V_{st}^{m}$.

3.4 In-sewer biochemical process modeling

As shown in Figure 1, the modelling of sewer pollutant variations consists of choosing a combination among a set of sewer flow models and a set of biochemical process models. Therefore, a new modelling tool was developed, which couples sewer flow models, i.e. hydraulic models and conceptual models, with different biochemical models. The tool can easily handle large-scale networks and quickly deliver results. The tool offers a basis in which different biochemical models can be embedded. Currently, it incorporates two biochemical models: the SeweX model (Sharma et al., 2008) and a modified version of a simple biofilm model (Rauch et al., 1999). In this study, the SeweX model was selected, which is suitable for simulating conventional sewer processes including sulfide production, fermentation, and so on.

3. RESULTS

The studied sewage collection system is located in Quebec City, Quebec, Canada. The SWMM model of the sewer network (Wipliez, 2011) was calibrated based on real flow sensor data (Figure 3). The WWTP receives wastewater from two big regions. In this case, the collection system from the central region was investigated.

As explained above, the first step is to identify key elements and regions. As a result, the blue zone in Figure 3, which covers about 400 sewer pipes, is the region retained after excluding the key storage tanks and pumping stations. Clearly, this blue zone is the main target of the conceptual modelling in this case, because it covers almost the whole network.

The wastewater inflow to this blue zone can be categorized as two types based on their sources. First, the blue zone has a plenty of local inflow nodes. All those local inflow nodes are summed up into one input to the blue zone. Second, there are several small pieces of network consisting of storage tanks, pumping stations and pipes running short distance, which transport wastewater downstream to the blue zone. Since they only account for a small fraction of the whole network, at the first stage of the study the focus was given to the blue zone, and the

SWMM information of those small network pieces was directly used as an input. As a result, the sewer network covered by the blue zone was conceptualized and calibrated into a system of 20 tanks-in-series (Figure 4).

a. SWMM model b. SWMM calibration results

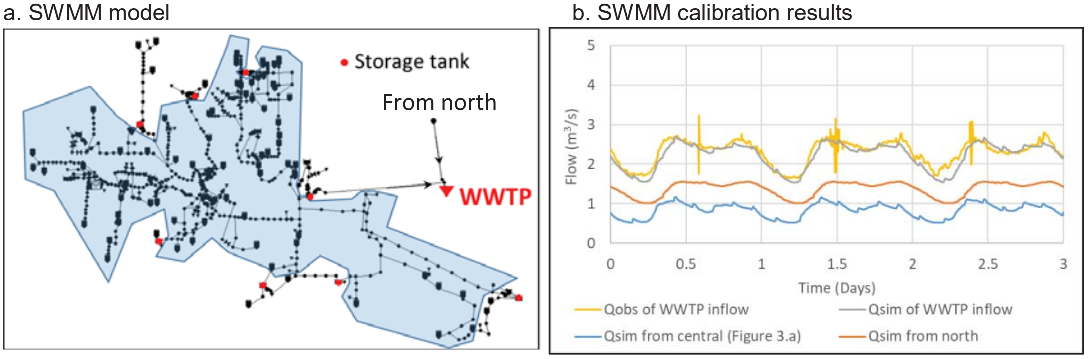

Figure 3. SWMM model of the studied case in Quebec City, Quebec, Canada

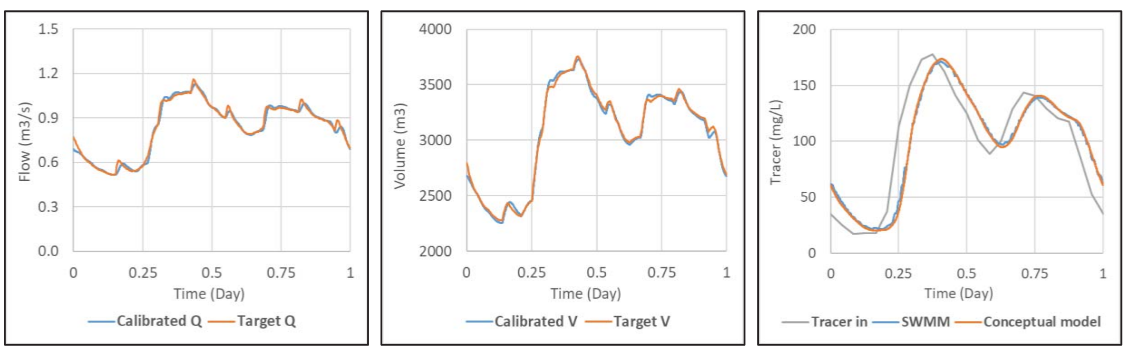

Figure 4 Calibration results of conceptual model (n=20, k=30.0919, m=1.5449)

After that, conceptual modelling of the collection system was further extended to storage tanks, pumping stations and small network pieces by using the method as described above. For the sewer network of those small pieces, most of them can be simplified as one conceptual sewer tank. In the end, the entire network of Figure 3.a was conceptualized as Figure 5. Sewer4 is the conceptual sewer of the blue zone in Figure 3.a. It consists of 20 tanks, receiving wastewater from two small branches (Sewer1 and Sewer 3) and local inflows (Inflow4).

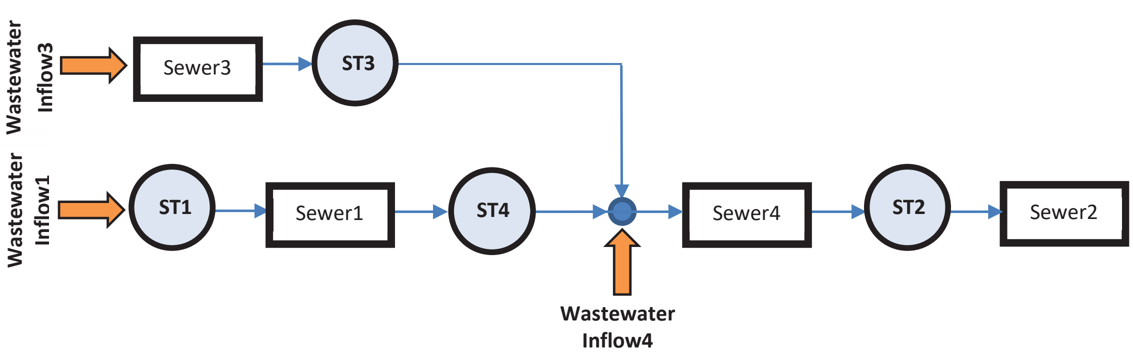

Figure 5 The schematic map of the conceptual collection system (Note: ST means storage tank)

Then, by using the new modelling tool presented above the SWMM model and the conceptual model were coupled with the SeweX biochemical model, i.e. SWMM-SeweX set and Conceptual-SeweX set. As shown in Figure 6, the two show very similar results. Noticeably, the simulation with the conceptual model is significantly faster than with the SWMM (hours vs. minutes). The simulation speed of the sewer conceptual model is competitive with that of a full-scale WWTP model. Therefore, the sewer conceptual model can be connected to a WWTP model like the Benchmark Model No.2 (BSM2) to form a real integrated model, which means that sewer and WWTP can be run simultaneously on the same layout for long-term simulation. Also, the conceptual biochemical model is easier to be calibrated than the SWMM biochemical model because the system is simpler with fewer objects to be considered and the simulation is faster for quick result evaluation.

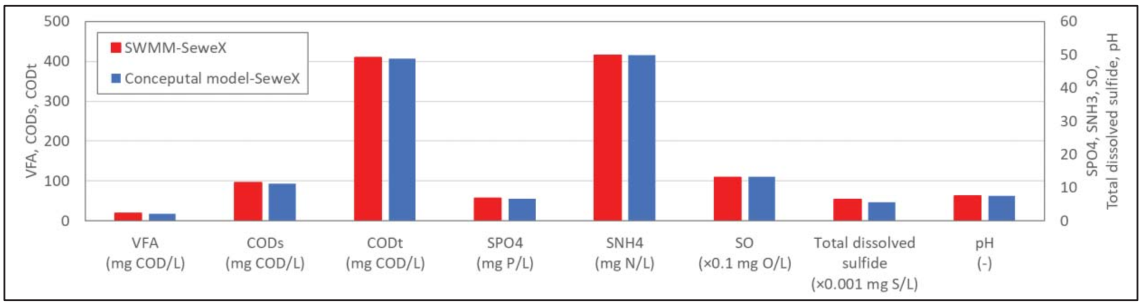

Figure 6. Comparison between whole-network and conceptual modelling in terms of biochemical processes

4. CONCLUSION

In this study, a conceptual modelling and calibration method was proposed for sewer biochemical modelling purposes. The method can quickly simplify a complex network into a series of conceptual tanks and satisfy calibration goals on sewer flow and volume. It serves as an important component to a new modelling tool, which is capable to handle different scales of collection systems and to incorporate different biochemical models. The whole-network (SWMM-based) modelling and the conceptual modelling have each their own advantages. In practice, the two methods can be selected or combined according to specific purposes. On the one hand, the whole-network modelling method runs simulations for all pipes of a sewer network to show the spatial distribution of pollutants throughout the system. This method can be used to identify hot spots in a large network. On the other hand, the conceptual modelling method shows advantages in terms of fast simulation and easy calibration. Given those reasons, it has a great potential in sewer-WWTP integrated modelling and long-term simulation.

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