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Semi-automated buildup and calibration of conceptual sewer models

S. Kroll [a,*], T. Wambecq [a], M. Weemaes [a], J. Van Impe [b], P. Willems [c]

[a] Research & Product Development, Aquafin NV, Dijkstraat 8, 2630 Aartselaar, Belgium
[b] Sustainable Chemical Process Technology TC, Technology Campuses Ghent and Aalst, Gebroeders De Smetstraat 1, 9000 Gent, Belgium
[c] Hydraulics Laboratory, Katholieke Universiteit Leuven, Kasteelpark Arenberg 40, B-3001 Leuven, Belgium

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ABSTRACT

Building conceptual sewer models can be a time-consuming task, especially for large or complex models or models that require input data that might be difficult/tedious to obtain manually.

This paper presents a semi-automated procedure for the buildup and calibration of one conceptual model that requires detailed input data such as throttle dimensions, pump curves or water level-storage relations. The procedure uses a hydrodynamic model as basis for sewer network data to create the model layout. A standardised series of composite rainfall events is applied to the hydrodynamic model in order to obtain the necessary reference data for the automated calibration of the conceptual model.

Both model buildup and calibration are illustrated by means of a case study. Comparison of results of the hydrodynamic and conceptual model for a 1 year long-term series shows that the automated buildup and calibration can lead to an accurate conceptual model in short time.

1. Introduction

The physically accurate description of free surface water routing processes, as they occur in sewers, is a fairly complex problem. These processes can be characterised by the so called Navier-Stokes equations, or when reducing vertical pressure gradients to the hydrostatic case, by the de Saint Venant equations. These equations allow the description of flow velocities and piezometric levels for any given time at any position in a partially water filled conduit and with extensions such as the Preissman slot (for a comparison of methods see e.g. Vasconcelos and Wright, 2007) for pressurised conduits. As the analytical solution of these partial differential equations is classified as one of the most complex unsolved mathematical problems to date (Fefferman, 2006), many software packages solve these equations for discrete locations in the network by advanced numerical schemes (Rossman, 2005; Innovyze, 2011). The application of those numerical methods to practical cases of long-term simulations in the area of urban drainage, where solutions might have to be found for up to several thousand locations over a simulation period of several years or decades, is usually very time consuming. Even though continuous increase of available computer power over the last years now allows long-term simulations of fairly large and detailed models in only a few hours, there are many applications that require smaller simulation times. Examples of such applications are model predictive real time control or the analysis of a large amount of scenarios. For other applications, the high accuracy that might be offered by the solution of the dynamic wave equations is simply not required when the input used for the setup of the model is afflicted by so high uncertainties that a probabilistic approach using the results of many simulations of a less accurate but faster model delivers more meaningful information than one single run of an accurate model (Willems, 2006; Vanrolleghem et al., 2009). Depending on the aims of the modelling study, results might only be required for a small subset of the modelled entities or locations making the use of very detailed models unnecessary. Also the need for coupled models with a wider scope on the integrated waste water system frequently calls for reduced computation times for the individual models in order to keep the overall complexity of the integrated model at a manageable level while demanding high accuracy at the model interfaces. Generally, the reduction of the computational times is possible by either parallelisation of the modelled processes or through reducing the number of calculations. For the latter, different approaches can be identified in literature. They can be roughly divided into the three following categories:

* Corresponding author.
E-mail addresses: stefan.kroll@aquafin.be (S. Kroll), tom.wambecq@aquafin.be (T. Wambecq), marjoleine.weemaes@aquafin.be (M. Weemaes), jan.vanimpe@kuleuven.be (J. Van Impe), patrick.willems@kuleuven.be (P. Willems).

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- **Reduction of the modelled network structure:** Not all sewer network objects have an equally high influence on the model result at specific network locations. It is thus possible to remove less important objects from the model or replace a high number of detailed objects by less detailed ones, e.g. merging a number of conduits into one single pipe if the local flow conditions allow this. Relocation of systems boundaries is another way of reducing the number of modelled items by defining areas that require detailed modelling, areas for which a rough model is sufficient or zones that can be excluded from the model without negative impact on the model results.
- **Simplification of the underlying computations:** Most software packages that feature the solution of the de Saint Venant equations allow the reduction of these equations to diffusive or kinematic wave approximations. This can be done either for entire drainage systems that are not considerably influenced by backwater effects or for parts of the system. In some cases these simplifications might require structural changes to the network data, e.g. in order to avoid loops.
- **Conceptualisation – Replacing the detailed physically based modelling framework by a less detailed macroscopic (conceptual) schematisation of the system.** “Macroscopic” refers to the averaging of processes, e.g. in space. This means that not every single conduit will be hydraulically modelled, but a subsystem consisting of a number of sewer reaches in a lumped way. These conceptual models are frequently also referred to as hydrological, phenomenological, empirical, grey box or lumped models. Their aim is to describe the routing process of water on the catchment surface and in the sewer system without the use of a spatially detailed physically based modelling approach.

This paper focuses on the third category: the use of conceptual models. Popular examples of this approach are reservoir based models. The most basic form is the linear reservoir model, where it is assumed that the storage inside and outflow of a catchment area and the underlying sewer system are in direct linear relation. This approach is not frequently applied for the description of both surface runoff and sewer routing, exceptions are the water quality models Cossmoss (Calabrò, 2001) and Rebeka (Rauch et al., 2002). Another application is the modelling of rainfall-runoff processes on catchment surfaces. Also nonlinear reservoirs where the reservoir outflow is modelled as a power function of the storage are used for surface routing as for example in the Storm Water Management Model SWMM, developed by US EPA (Rossman, 2005). A particular type of reservoir is the multilinear reservoir model suggested by Ostrowski (1992) using time-variant reservoir constants in order to approximate the non-linear behaviour of the system with minimal volumetric error. The non-linear reservoir is here modelled by a piece-wise linearized function. Another model using this piece-wise linearization is applied by Vaes (1999) in the model Remuli, where the outflow of the reservoir is described by a concatenation of several linear functions of the reservoir storage. Also cascades of reservoirs (Nash, 1957; Engel, 1994) are commonly considered, as in Kosim (itwh, 1995), SimbaSewer (Alex, 2009), Upsim (Maglionico, 2002) and WaterAspects (Grum et al., 2004). Another important approach to conceptual modelling is the time area method (e.g. described by Ponce, 1989), which is based on the travel time of water through a catchment rather than the stored volume. It is used in the software packages Samba (PH-Consult, 2005) and Water-Aspects (Grum et al., 2004). All of the above mentioned models focus on the modelling of mass balances in the sewer system but ignore the energy balance. They are therefore not able to model water levels. To overcome this problem, there have been numerous methods to consider the energy balance in a simplified way. The most prominent among these methods is the Muskingum method (Cunge, 1969). It essentially extends the linear reservoir approach by an additional parameter that allows for the consideration of an inclined water table due to flood waves. It was initially developed for modelling a system of channel stretches (as done in the simplified simulation mode of Canoe (Alison, 2013)), but is also used for the description of lumped catchment areas as in Citydrain (Achleitner, 2006; Achleitner et al., 2007). Also the approach introduced by Kalinin and Miljukov (e.g. in Apollov et al., 1964) focuses on the description of channel flow under inclined water tables in unbranched reaches. It allows to define the parameters of a linear reservoir cascade by analysis of the stage-flow-relation of the reach under consideration. As this relation is attributed to the channel geometry, the parameters of the reservoir cascade can be directly derived from structural data of the sewer to be modelled (Euler, 1983). The resulting lack of need for calibration makes the Kalinin-Miljukov approach a widely used method for modelling collectors of sewer systems, e. g. in Kosim (itwh, 1995), Cosimat (Cuppens, 2006) and SMUSI (Muschalla and Ostrowski, 2004). Another approach that describes channel flow in a series of reaches in a collector is the “combiner-splitter” approach developed by Solvi et al. (2005). It allows to route any flow exceeding a maximum assigned to each conduit reach back to the next upstream reach. The used maximum flow can either be the result of calibration or hydraulic considerations based on the conduits structural data (Solvi, 2006). This method is used for modelling collectors in Kosim-West, an implementation of the discrete Kosim model on the continuous modelling platform West (Vanhooren et al., 2003). Such models, however, would not be able to include internal system details such as water levels or accurately simulate backwater effects depending on these water levels. The method introduced by Motiee (Motiee, 1996; Motiee et al., 1997) is a storage based approach that closes the gap between the empirical and the physically based models. It explicitly models the water level in each storage unit and can simulate backwater and even backflow in a sewer system. Duchesne et al. (2001) developed a similar approach and comment on difficulties using it for branched or looped networks. The simulation speed of the latter two approaches is about the same order of magnitude as for detailed hydrodynamic models (Duchesne et al., 2001).

While the selection of a suitable modelling approach is mostly a result of the required modelling speed and accuracy, it will itself strongly reflect on the complexity of model parameter identification. Simple models usually require a small set of parameters to be defined, but a high level of abstraction. More complex models mostly require a higher number of parameters. Manual parameter identification and model buildup are in most cases tedious and time consuming tasks that ask for considerable modelling experience for both types of models alike.

Once the model parameters are identified and the model is built, most of the simplified modelling approaches require calibration. Parameters to be calibrated can – depending on the applied modelling approach – include simple scalars such as the runoff coefficient, runoff concentration time or maximum flow capacity of a conduit. More complex formats such as vectors might be used for the description of pumping schemes or the storage distribution within parts of the modelled sewer system. Calibration can be either achieved on the basis of monitored field data or using the simulation results of accurate detailed hydrodynamic models as suggested by Vaes (1999), Meirlaen et al. (2001) and Wolfs et al. (2013). The latter case bears the advantage of detailed knowledge on the systems state variables (e.g. flows and water levels in all parts of the modelled system) while monitoring data are usually only available for a very limited amount of locations. In many cases model calibration is carried out manually through trial and error