A SWMM model for the Astlingen Benchmark Network

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Abstract: Real-time control of urban drainage systems is getting increasing attention due to its potential to reduce urban flooding and pollution to the receiving waters. Considering confidentiality requirements from the water companies, it is not easy for researchers or interested engineers to share models and data of real life urban drainage systems. However, it is very practical to use a benchmark to test and compare different methodologies. This paper contributes: (1) A hydrodynamic SWMM model of the Astlingen benchmark network, developed by working group 'Integral RTC' of the German Water Association, which enables a more widespread usage of the network due to SWMM being free and open source; (2) Applications of base case and equal-filling-degree rule-based control concepts to confirm usability of the SWMM model; (3) Preliminary result of model predictive control using this SWMM model.

Keywords: SWMM model; Real-time control; Astlingen Benchmark network

Introduction

The Astlingen network, which is a benchmark urban drainage system (UDS) for real time control (RTC) strategies, presented by the working group 'Integral Real Time Control' of the German Water Association (DWA) (Schütze *et al.,* 2017), serves as an illustration of the methods suggested in the German guideline on RTC (DWA, 2005). This network fills the gap of having a comprehensive UDS example oriented to testing and comparing different RTC approaches. As an illustration, the Astlingen network has been implemented using the hydrological modules of the Simba# simulator (ifak, 2018) illustrating, besides the base case (BC) of locally controlled throttle settings, the rule-based equal-filling degree (EFD) concept.

The purpose of a benchmarking model is to allow as many experts (researchers, practitioners) as possible to test and compare their control methodologies. For such purpose, the model should preferably also be implemented in a free, widely used, open source software. For this reason, the current paper presents a detailed model of the Astlingen network implemented in SWMM 5.1.013 (Rossman, 2015). The BC and EFD approaches are applied to confirm usability of this model. Also the use of MPC to this SWMM model is discussed in this contribution.

Material and Methods

The fundamental information can be obtained from the conceptual Astlingen network definition (DWA, 2018; Schütze et al. 2017) such as network layout, overflow structures and a 10-year rainfall series (as provided by the Erft water association in Germany for Astlingen-related studies). Besides, 1-year simulation results obtained with the hydrologic modelling option in Simba# in the form of total combined sewer overflow volumes (CSO) have also been presented in these references using BC and EFD approaches. However, there are still several uncertainties about the network details (e.g. geometric element information; topology between tanks, etc.) which can result in different implementation in detailed models such as SWMM. In this paper, two criteria are defined for setting up a SWMM-based implementation of the Astlingen benchmark network: (1) Less than 10% deviation between detailed and conceptual models; (2) Minimal extra elements to be added.

The modelling approach is divided into four steps: (1) *Rainfall Data Pre-treatment*: transfer the rainfall data into time series with the compatible format for SWMM; (2) *Rainfall-Runoff Calibration*: calculate rainfall-runoff using linear reservoir model (LRM) and use them to calibrate sub-catchments in SWMM; (3) *BC Calibration*: based on tanks and CSO structures for BC to calibrate the added sewers and junction nodes due to the defined criterions; (4) *EFD Validation*: apply EFD to the new SWMM model in order to validate performance of it.

In SWMM, simple control rules can be applied directly by defining them in the control editor. A control implementation in Simba# allows the use of the control language IEC61131 "Structured Text" for implementation of control concepts (see Figure 1). Figure 1 also illustrates the linkage between system modelling and control algorithm. However, more complex control strategies like MPC need more efforts to be applied into the SWMM or Simba# models. Figure 2 presents a scheme to apply other RTC strategies (using MPC as an example) to the SWMM model. In this contribution, the optimizer is implemented in MATLAB using a simplified conceptual model of Astlingen, and the simulator is based on the detailed SWMM model wrapped in PySWMM. At each time step, the optimizer generates optimal control actions and sends them as set-points to the simulator, which computes effect of these control actions and updates state measurements to initialize a new optimization. This process is repeated at each time step. A similar scheme can be used for other RTC approaches.

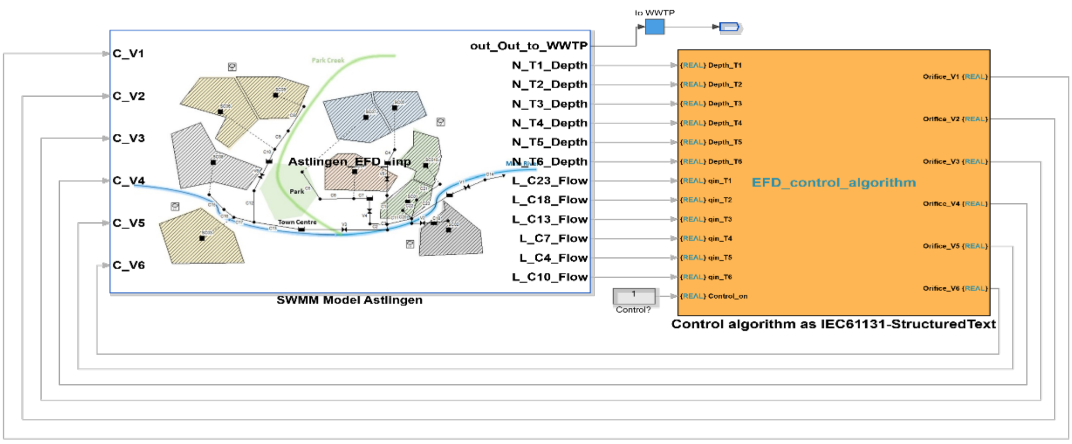

Figure 1 Linking hydrodynamic system modelling (SWMM) with control, exchanging sensor and actuator information at every time step (Simba# implementation).

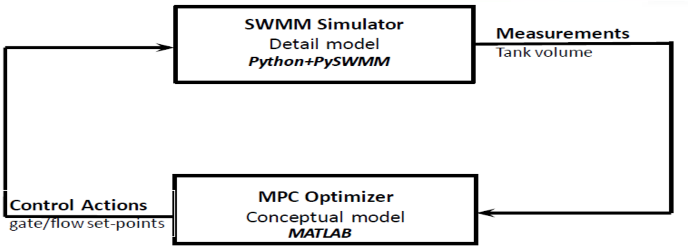

Figure 2 The closed-loop RTC scheme.

Results and Discussions

Figure 3 shows the SWMM model of Astlingen (also on https://github.com/open-toolbox/SWMM-Astlingen). Table 1 shows results for different modelling approaches (hydrodynamic in SWMM and hydrologic in Simba#) using BC control. The throttle flow and CSO comparisons (less than 4.5% deviation) confirm the SWMM model works as expected. Table 2 shows results of EFD and BC using different models. Comparing with BC, the EFD control can reduce CSO with 6.4% using the SWMM model and 8.3% using the Simba# model. Considering the differences between conceptual and detailed models, this performance is acceptable. Preliminary results of MPC are presented in Figure 4, which shows that, compared to EFD, MPC can achieve 7.2% reduction of CSO, based on the SWMM model estimations for both strategies.

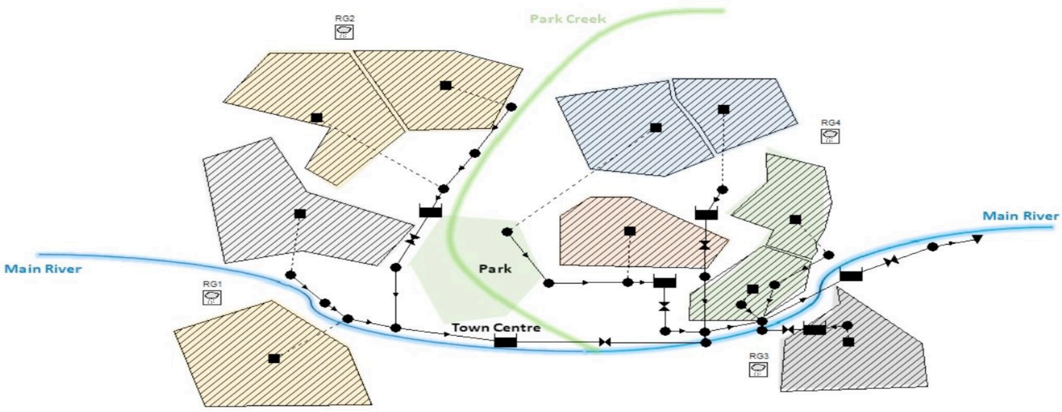

Figure 3 The detailed SWMM model of Astlingen benchmark network.

Table 1 Throttle flow and CSO comparisons between BC of SWMM model and Simba model

	Base Case flow in SWMM (L/S)	**Base Case flow in Simba (L/S)**	**Base Case CSOs in SWMM(m³)**	**Base Case CSOs in Simba(m³)**
Tank1	271	271.28	79,459	77,339
Tank2	33	32	32,875	31,605
Tank3	124	124	27,600	26,029
Tank4	28	28	11,157	10,058
Tank5	39	39	15,460	14,053
Tank6	75	76	69,593	66,095
CSO7	85	85.5	3,972	3,920
CSO8	487	485.33	15,902	15,862
CSO9	127	129.17	3,972	3,951
CSO10	202	203.67	4,741	4,711
TOTAL			**264,731**	**253,623**
Deviation	**< 2%**		**< 4.5**	

Table 2 CSO comparisons between EFD of SWMM model and Simba model

	SWMM(m³) EFD	**SWMM(m³) BC**	**SIMBA(m³) EFD**	**SIMBA(m³) BC**
Tank1	99,721	79,459	71,302	77,339
Tank2	24,882	32,875	26,371	31,605
Tank3	26,229	27,600	34,743	26,029

Tank4	9,356	11,157	8,886	10,058
Tank5	15,460	15,460	14,053	14,053
Tank6	43,552	69,593	49,557	66,095
CSO7	3,972	3,972	3,920	3,920
CSO8	15,903	15,902	15,862	15,862
CSO9	3,972	3,972	3,951	3,951
CSO10	4,751	4,741	4,711	4,711
TOTAL	**247,788**	**264,731**	**232,320**	**253,623**
CSO Reduction by EFD	**6.4%**		**8.3%**	

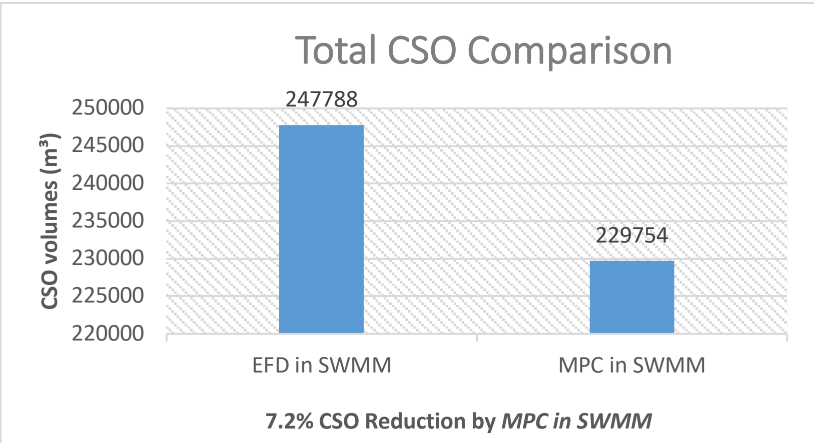

Figure 4 Preliminary MPC result

These preliminary results show how the Astlingen benchmark has been extended to allow validation and comparison of complex control strategies, ranging from simple rule-based controls, RTC approaches, and complex MPC strategies.

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