Factors Influencing the Simplified Quality Model Performance

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Abstract. During the last few years, the integrated real-time control (RTC) of both the urban sewer network and the wastewater treatment plants (WWTP), has attracted increasingly attention. In order to apply integrated RTC control approach efficiently considering both the hydraulic and quality variables, models, simplified conceptual quality modelling approaches are required. This paper presents research work based on simplified water quality models in sewers, which have been developed in the European project LIFE EFFIDRAIN (Efficient Integrated Real-time Control in Urban Drainage and Wastewater Treatment Plants for Environmental Protection). The contribution of this paper is to analyze the potential factors that would influence the performance of the proposed modelling approach and consequently the corresponding integrated RTC control. A real sewer pilot the Perinot sewer network has been used as case study. Results and conclusions have been provided which would be useful for the users of these models.

1   Introduction

Combined urban drainage networks (CUDN) collect and convey wastewater and storm water together to be treated by waste water treatment plants (WWTP) before being released to the receiving environment [5]. In case of storm weather, the capacity of the urban sewer network and also the WWTPs may be overloaded, and combined sewer overflow (CSO) may happen, which is harmful to the environment [6][7][8][9]. In order to manage the CUDN efficiently, integrated control of both sewer network and WWTP is a suitable solution, which is the main goal of the European project LIFE EFFIDRAIN (Efficient Integrated Real-time Control in Urban Drainage and Wastewater Treatment Plants for Environmental Protection), to demonstrate an integrated RTC strategy of urban drainage networks and wastewater treatment plants to minimize the pollution of receiving waters, through the use of real-time quantity and quality data.

The complexity of quality dynamics in CUDN requires simplified quality models to apply RTC [2], which should allow RTC to compute estimations of the quality evolution in CUDN during storm event [3]. Because of the input data uncertainty and calibration difficulty, modelling the generation and transportation of pollution in sewer network during a storm event is complex. Some physically-based models which can present quality dynamics in the sewer network are proposed [10][11][12][13], but the mathematical equations have a high computation time requirement. Total suspended solids (TSS) are chosen in [1] as a representative variable of water quality, and three simplified conceptual sewer models of TSS are proposed to represent the main dynamics of TSS with simple equations suitable for RTC optimization.

This paper is a further research work based on the simplified sewer models of TSS proposed in [1] to analyze factors influencing performance of the proposed simplified TSS models which is necessary for improving the models and achieving better efficiency in the RTC optimizations. In order to test these simplified dynamic models for TSS, two possible factors, rain intensity and sewer length, are supposed very likely to affect the model performance. A series of tests are carried out to seek for the potential relationships among them. On the other hand, flow rate and TSS are normally considered as the main variables to integrate the hydraulics of sewers and WWTP. On the other hand, to better understand the whole dynamic behavior in CUDN, this paper also tries to find the underlying relationship between flow rate and TSS behavior.

1.1 Simplified Dynamic Models for TSS

Physically, the dynamic of TSS in a sewer is affected by deposition, sedimentation, erosion and also time delays. Based on the hydraulic model of a water tank [3], a sewer trunk in CUDN can be assumed as a water tank container which collects water based on volumetric difference between upstream and downstream [3][14] flows. Considering the TSS, three dynamic models to represent TSS behaviour are designed based on the water tank model, where the details can be referred in [1] and the general equations can be presented as follows:

Model 1

$$TSS_{out}(k+1) = (1-a)TSS_{out}(k) + aTSS_{in}(k) \tag{1}$$

Model 2

$$TSS_{out}(k+1) = a_1 TSS_{out}(k) + a_2 TSS_{in}(k) \tag{2}$$

Model 3

$$TSS_{out}(k+1) = c_{vc} TSS_{in}(k-d) + ep \tag{3}$$

where TSS_{out}/TSS_{in} represents the input/output TSS ratio (mg/l) in a sewer; k is the current time; d means delay of TSS; a, a_1, a_2, c_{vc} and e_p are parameters that need calibration for each sewer. More details for the three models can be referred in [1].

2 Material and Methods

2.1 Analysis tools

The tools used for producing the training data and analysing the performance are based on SWMM5 [15], Matlab and GAMS optimization software [16]. In particular, for quality modelling, a new quality model based on SWMM5 has been developed in LyRE (R+D centre of Suez) to reproduce TSS transport, sediment accumulation and erosion in sewers [4] and retention tanks [17], as shown in Figure 1. This quality model uses the extended Barre de Saint Venant equation set from SWMM5.

Figure 1 presents the scheme illustrating the modifications made in the SWMM5 library model. Boxes correspond to the existing modules in SWMM5 and grey boxes are for added quality module. WW and DW represent wet and dry weather.
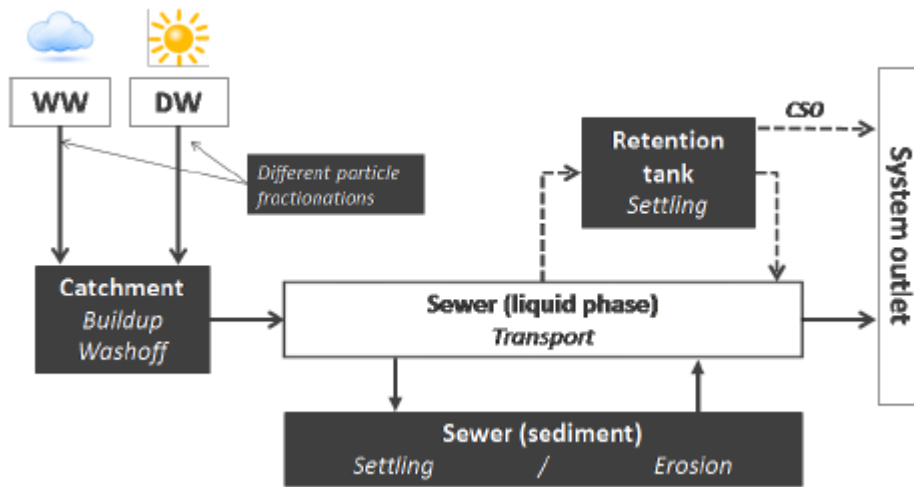
Figure 1   New Strucure of Quality Module SWMM-TSS

2.2   Pre-treatment of Case Study

The case study is the Perinot sewer network in Louis Fargue catchment of Bordeaux Metropole (Figure 2a), which covers a total area of 260 ha with mainly residential uses. In Perinot sewer network, the sewer length is 3 km with an average slope of 0.007, which is quite constant over the whole catchment. The Perinot sewer network includes a retention tank separated in three hydraulically connected bodies for a total storage volume of 35000 m^3. Even if the slope is generally low, there is no sediment issues on the sewer reported from the operators. The proposed simplified TSS models for the sewer will be applied and validated to the Perinot sewer network. Impact factors for the considered modelling approaches will be analysed based on these results. In order to simplify the tests and control afterward, sewers of similar dynamics in series are integrated as one, where 5 main sewers are presented (Figure 2b).
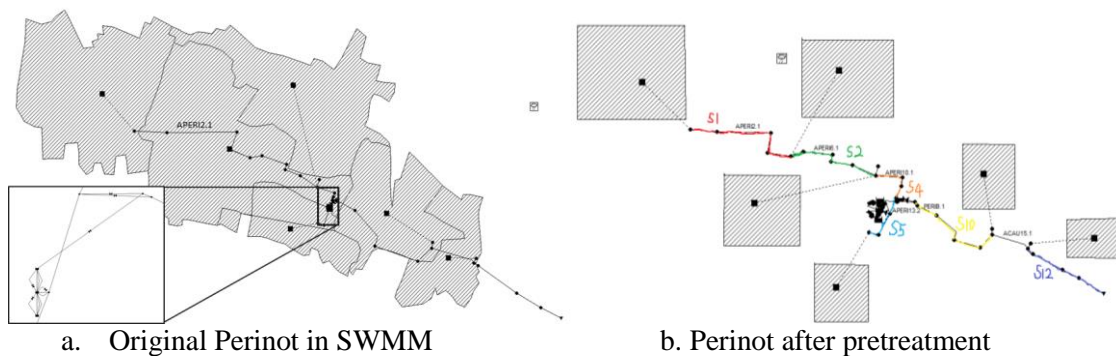

a.   Original Perinot in SWMM   b. Perinot after pretreatment

Figure 2 Perinot Sewer Network

2.3   Rain Scenarios

Rain scenarios for calibration and validation come from real rainfall measured at France in the year of 2003, 2007, 2011, 2013. Besides, four different scenarios (Table 1) have been selected from historic data of 2007 (Figure 3).
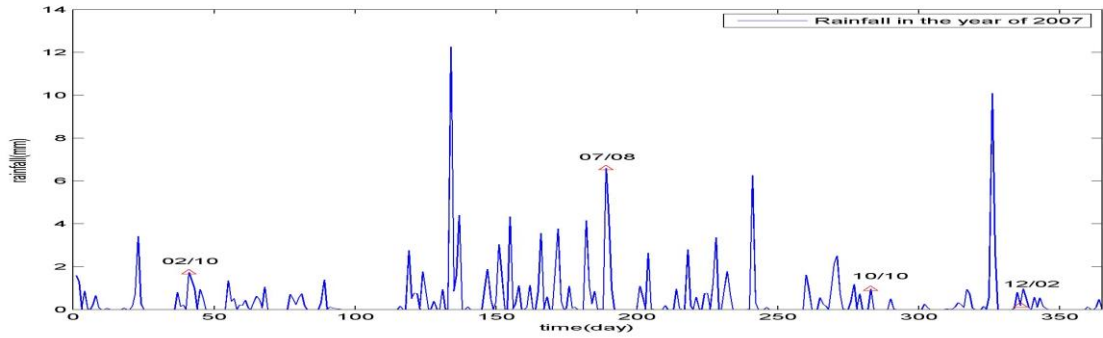
Figure 3 Rain Scenario of Perinot in the year of 2007

Table 1 Relationship between sewer length and model performance

Scenario	1	2	3	4
Start time	Oct/10/2007 00:00	Dec/02/2007 00:00	Feb/10/2007 00:00	Jul/08/2007 00:00
Scenario	**5**	**6**	**7**	**8**
Start time	Aug/19/2003 23:05	Aug/02/2013 09:00	Jan/03/2011 10:00	Jan/03/2011 10:00
Duration	24h		**Time step**	5 min

2.4 Model Calibration and Validation

The calibration is carried out using SWMM5, Matlab and the GAMS optimization library. Besides, the new quality model based on SWMM5 developed at LyRE is used to produce the training data [4].

As in Table 2, rain scenarios 1, 2, 5 and 7 will be used for calibration. After calibrating all the models, rain scenario 3, 4, 6 and 8 will validate the calibration models.

Table 2 Test Arrangement

Rain	Calibration	Case1		Case2		Case3		Case4	
	Validation	3	4	3	4	6	8	6	8
Sewer	Si	Si -1		Si -2		Si -5		Si -7	
		Si -1-3		Si -2-3		Si -5-6		Si -7-6	
		Si -1-4		Si -2-4		Si -5-8		Si -7-8	

Si *includes S1, S2, S4, S5, S10, S12; xx-xx-xx means sewer-calibration-validation*

3 Results

3.1 Relationship between sewer length and model performance

Table 3 and Figure 4 show the relationship between length of sewer and model performance. It seems that all three models present a similar tendency changing the sewer lengths. However, the performance of model 3 changes more dramatically than model 1 and 2.

Table 4 shows how sewer length affects the parameters of model 3. Sewer 5 and 10 perform worse with lower value of c_{vc} but much higher ep. Model 3 is generalized from the physical characteristics in a sewer, where the dynamic of TSS is affected by the flow rate and time delays. Therefore, it seems to make sense that, to some extent, the length of sewer has an impact on the performance of model 3.

In conclusion, the length of sewer is more likely to influence the performance of model 3, compared to the other two models. But in general, model 1 and 2 seem to be good choices for sewers which length ranges from 400m to 900m.

Table 3   Relationship between sewer length and model performance

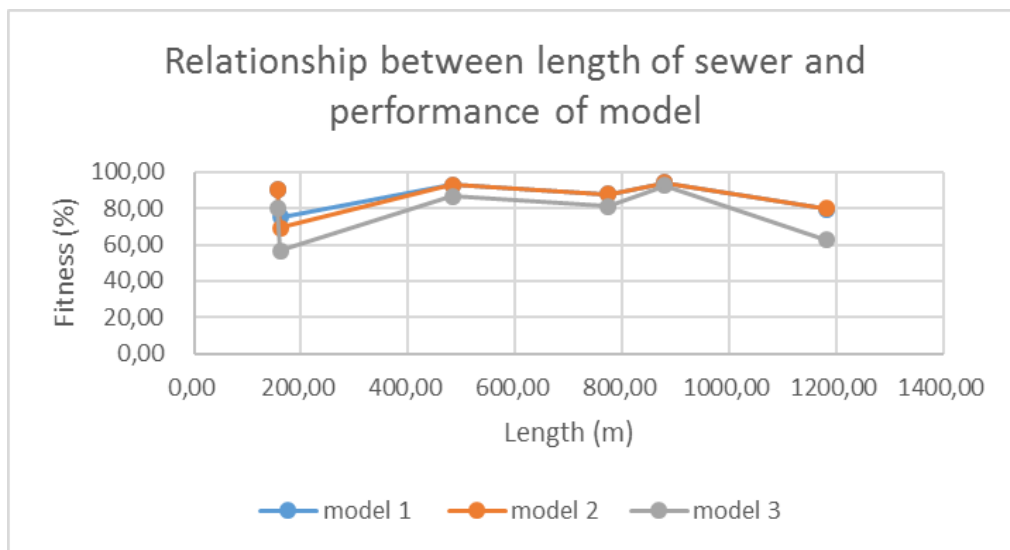| Sewer	Length (m)	Model 1 (%)	Model 2 (%)	Model 3 (%)
S4	156.20	90.31	90.45	80.37
S5	160.70	75.09	69.43	56.82
S2	482.60	93.10	93.12	86.61
S10	773.40	87.73	87.70	81.30
S12	879.20	94.02	94.09	92.46
S1	1181.90	79.53	79.91	62.63

Figure 4   Relationship between sewer length and model performance

Table 4   Relationship between sewer length and Model 3 parameters

Sewer	Length (m)	c_{vc}	e_p	Model 3 (%)
S4	156.20	0.96	10.35	80.37
S5	160.70	0.71	47.53	56.82
S2	482.60	0.97	9.65	86.61
S10	773.40	0.95	19.02	81.30
S12	879.20	0.97	11.74	92.46
S1	1181.90	0.73	86.04	62.63

3.2   Relationship between rain intensity and model performance

Table 6 shows relationship between rain intensity and model performance. As in Table 5, rainfall scenario 1 and 2 can be regarded as light rain, while scenario 5 and 7 is heavy rain. It seems that, with the increase of rainfall intensity, a decreases for Model 1; a_1 increases while a_2 decreases for Model 2; c_{vc} decreases while e_p increases for Model 3. Overall, there is a tendency that the heavier rainfall is, the worse models will be.

Table 5　Information of rainfall scenarios in calibration

Rainfall for Calibration	Total Depth of 24h(mm)	Intensity(mm/h)	Maximum Depth (mm)
1	5.53	0.23	0.04
2	0.25	0.01	0.06
5	1754.61	73.11	19.05
7	1667.78	69.49	45.71

Table 6　Relationship between rain intensity and model performance in calibration

Scenario	a	a_1	a_2	c_{vc}	e_p	Model 1 (%)	Model 2 (%)	Model 3 (%)
case 1	0.47	0.48	0.47	0.89	15.66	92.79	92.87	80.98
case 2	0.46	0.54	0.46	0.92	21.07	92.30	92.36	78.17
case 3	0.35	0.65	0.35	0.88	36.30	88.78	91.16	71.71
case 4	0.42	0.58	0.42	0.84	49.86	80.35	81.62	67.25

3.3　Relationship between flow rate and concentration of TSS out of a sewer

Figure 5 shows the relationship between flow and TSS out of a sewer. Although there is no distinct evidence of the relationship between these two variables, we can still find that the trend of discharge is likely to be opposite against the trend of concentration of TSS in a sewer. This can be understood that flow with large velocity will take away more TSS, thereby the concentration of TSS decreasing.
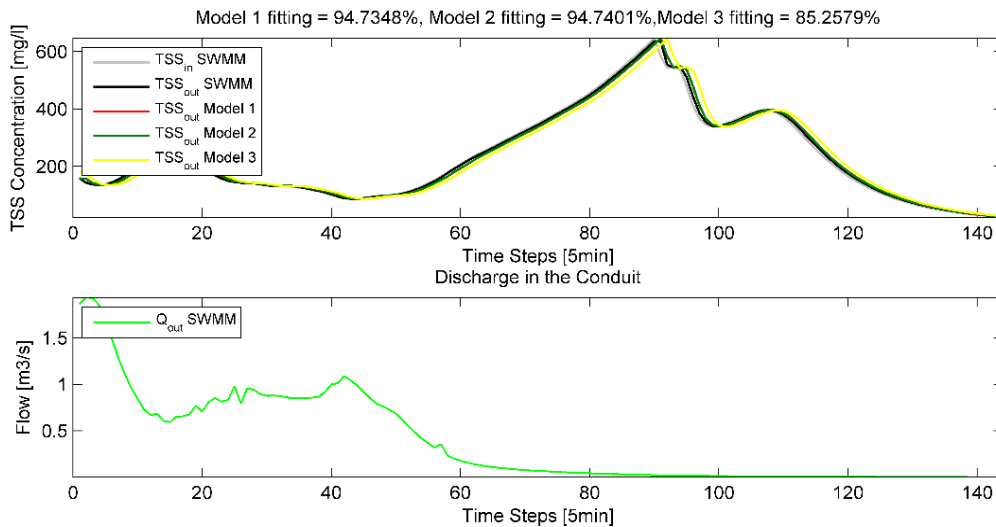

Figure 5　Flow rate and TSS behaviour out of Sewer 1

4　Conclusions

According to these calibrations and analyses, the sewer length is more likely to influence model 3 comparing to other two models. In general, model 1 and 2 seem to be good choices for sewers with length ranges from 400m to 900m. Also, there is a tendency that the heavier rainfall is, the worse models will be. But the model 1 and model 2 always perform better than model 3, no matter what the rainfall intensity is.

From Table 4 and 6, it may be concluded that it is better to have larger parameters a, a_2, c_{vc} and smaller a_2, e_p for models to perform better when there is lack of rainfall data for calibration. Besides, the trend of discharge is likely to be opposite to the trend of TSS in a sewer, which can be explained that flow with large velocity takes away more TSS.

Acknowledgment

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