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Experimental design to support water quality modelling of sewer systems

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Abstract: The paper proposes a model-based experimental design to calibrate a sewer water quality model for the Clos de Hilde catchment in Bordeaux, France. In order to carry out an experimental design, a preliminary calibrated model is developed and the influential parameters are identified. Subsequently the model is used to select the most information-rich experiment for calibration of the final model. This is done by simulating proposed experiments and evaluating the Fisher Information Matrix that quantifies the experiment's information content. The selected experiment will be carried out during the upcoming measurement campaign in summer 2018.

Keywords: Conceptual sewer model; model calibration; optimal experiment; particle settling velocity distribution

1. INTRODUCTION

Recent developments in legislation are increasingly asking to consider not only water quantity, but also quality. Therefore, water quality modelling at catchment and sewer level is of growing interest. Even though gains from water quality modelling are known, for instance for control of overflow structures (Schütze et al., 2004), water quality modelling in sewers is still relatively new and remains challenging, especially for total suspended solids (TSS).

To predict water quantity as well as quality at key points throughout the sewer system, such as overflow structures, a model has been developed. The chosen modelling approach for catchments and sewers combines conceptual, also known as hydrological, modelling with the PSVD (particle settling velocity distribution) approach for particulate water pollution (Maruéjouls et al., 2015). This approach allows for fast calculations and is easily extendable to the integrated level taking the water resource recovery facility (WRRF) into account.

However, water quality modelling in sewers remains challenging. A major part of the challenge is obtaining the water quality data necessary for model calibration. Indeed, in many cases, flow data are available, but extensive water quality data are missing. Moreover, obtaining the required quality data in a measurement campaign requires a non-negligible amount of time and resources. Especially the manual cleaning of the sensors is very time consuming and needs to be done on a regular basis.

It is known that not every data point contains the same level of information and therefore not all data has the same value for model calibration (Dochain & Vanrolleghem, 2001). It is also known that often experiments are conducted which unfortunately deliver data of too low quality resulting in a model calibration with very uncertain and correlated parameters (De Pauw & Vanrolleghem, 2006). It is therefore important to measure under experimental conditions that provide data containing the most information possible (data of high information content). For this, an experimental design (ED) is applied using a preliminary model, which aims at an experiment resulting in high quality data (De Pauw & Vanrolleghem, 2006).

The aim of this work is to evaluate different proposed experiments with a preliminary model. The results are used to design a measurement campaign in Bordeaux, France planned for the summer of 2018. The measurement campaign is strictly limited to three months and two water quality measurement stations. For the two measurement locations, experience shows that, for practical reasons, a measurement period is best limited to 12h. The experimental design will select the most information-rich period to obtain the best data possible for further model improvements.

2. MATERIALS AND METHODS

2.1 Software and Modelling Approach

The model is implemented in WEST by DHI (Horsholm, DK). The catchment model used is the KOSIM-WEST model with the extensions proposed by Pieper (2017). It is a coupled model that includes sub-models for flow and pollutant generation during wet weather flow (WWF) and dry weather flow (DWF). The sewer model uses the PSVD linear reservoirs in series that include settling and resuspension for ten different particle classes (Maruéjouls et al., 2015).

2.2 Case Study

The studied catchment "Clos de Hilde" is located in Bordeaux, France. Key structures, such as retention tanks, pumping stations and overflows are mainly located along the Garonne river (see Figure 1). The catchment covers about 8000 ha and is a typical urban catchment consisting of both housing and industrial areas. It is drained with a combined sewer system in the older parts while separate sewers are found in the newer neighbourhoods. Preliminary water quality data have been collected at the pumping station Noutary and the inlet of the WRRF Clos de Hilde (Figure 1). During summer 2018, a second measurement campaign is conducted at the same two locations to collect data for improvements of the preliminary model.

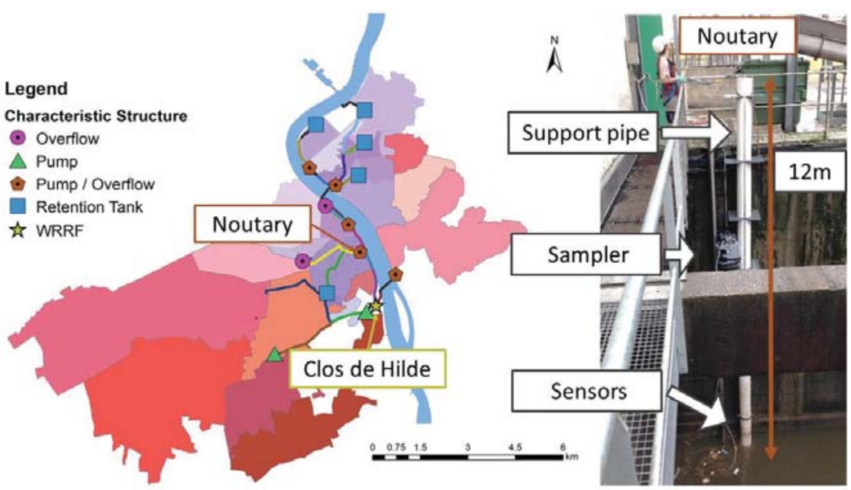

Figure 1. The left figure shows the Clos de Hilde catchment with key structures, the two measurement locations (Noutary and Clos de Hilde) are highlighted. The right figure shows the measurement location at the pumping station Noutary with the sensors and the sampler used for sensor calibration.

3. RESULTS

3.1 Results Preliminary Model

The model results for the validation period of the preliminary model are illustrated in Figure 2 and compared to measurement values for the two water quality measurement locations: inlet WRRF Clos de Hilde and pumping station Noutary.

The water quantity model has initially been calibrated (NSE=0.94) and validated (NSE=0.95) on an existing Mike Urban by DHI model. Only the DWF parameter have been recalibrated on actual flow measurements. The upper part of Figure 2 compares the model results with the flow measurements and shows a good performance at both locations during the validation period (Clos de Hilde: NSE=0.79, RMSE= 0.068 m^3/s; Noutary: NSE=0.41, RMSE=0.018 m^3/s). A conceptual shortcoming is the rainfall-derived inflow and infiltration (day 61 - 65) which was not considered in the Mike Urban model. This will be considered in a next model version.

The second row in Figure 2 shows the water quality results of the preliminary model during the validation period. Some shortcomings are still visible: At the WRRF the dynamics of the DWF are generally overestimated (NSE=0.05, RMSE= 51.2 mg/l), whereas they are underestimated at the pumping station Noutary (NSE=0.39, RMSE= 59.8 mg/l). Since the available data was limited, some of the quality parameters of the preliminary model were obtained from external sources or were not differentiated for different sub-catchments and sewers. Nevertheless, knowing that this is still a preliminary model, the results are in the right order of magnitude and the dynamics resemble the measured ones. This model can therefore be used for the experimental design, which will allow getting the most information-rich data during a subsequent measurement campaign for improvement of the model.

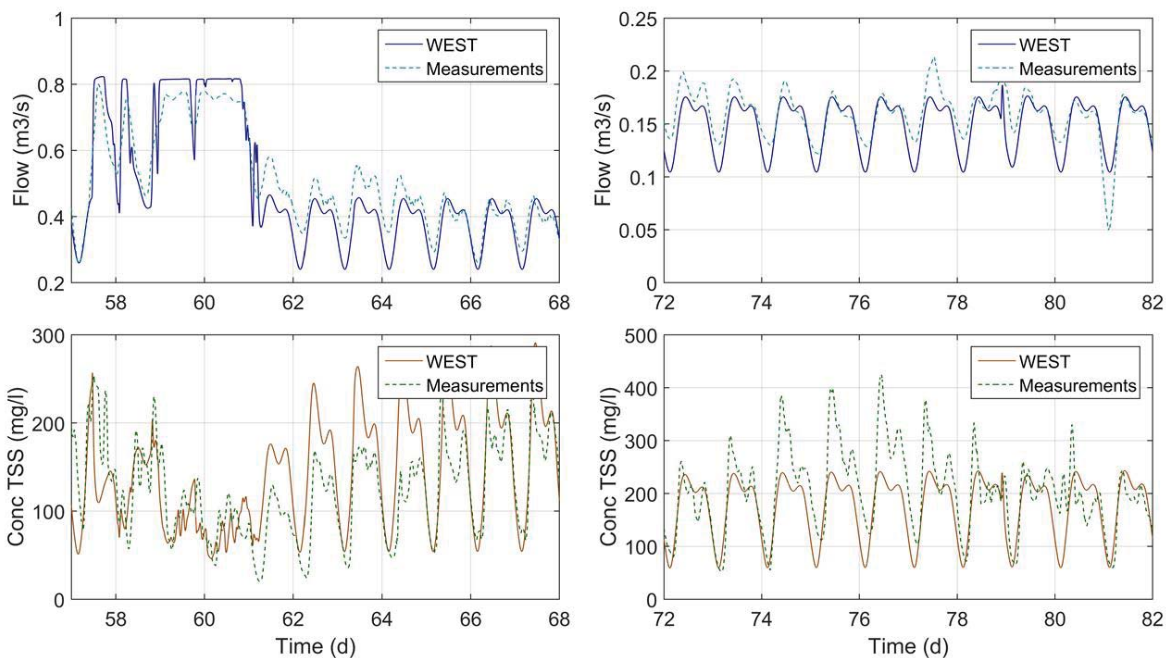

Figure 2. Model results in comparison to the measurements of flow and TSS at the inlet of the WRRF Clos de Hilde during WWF (left side) and at the inlet of the pumping station Noutary during DWF (right side) during the model validation period.

3.2 Results Experimental Design

As mentioned above, obtaining water quality data from sensors in a sewer system remains challenging (Ledergerber et al., 2017). A series of existing rain data, including series of DWF and WWF days, was used to calculate the sensitivity, which forms the basis of model-based experimental design. In total 37 parameters affecting water quality were considered, resulting in 74 model runs. Each of the parameters was changed by +/- 1% of its calibrated value.

Within the calculated series, a total of 7 different periods were identified to calculate the Fisher Information Matrix (FIM) (Dochain & Vanrolleghem, 2001). Each period last for 12h, as ample experience with the measurement stations at the site has shown that no sensor failing occurs within that period after a clean start. Four reoccurring DWF conditions and three WWF conditions were differentiated. For DWF, both a day period (09:00 to 21:00), respectively a night period, were identified. Both day and night were analysed, once following a series of DWF days (DD1, DN1) and once following a rain event (DD2, DN2). Additionally, a period of an entire small rain event (SRB) was chosen, respectively two distinct periods for the beginning, respectively the tail of a big rain event (BRB, BRT). It is noted that each rain event is different and prediction of rain events remains uncertain. Nevertheless, suitable rain events that actually happened during the simulated period, were chosen. For the big rain event, one period was analysed for which the campaign started during the rain event. To capture the tail of a rain event, on site intervention of the sensors during the event would thus be necessary, which is not without security risks. Nevertheless, this scenario was added as a possible measurement period to evaluate its value in terms of information content.

The 7 different periods are compared using the Modified A-optimal design criterion to evaluate the FIM. The higher the value of this criterion, the richer the given data period is (Dochain & Vanrolleghem, 2001). The results for the different measurement periods are summarized in Table 1. Generally, measurement data during a rain event appear to be richer in information than during dry weather flow. This is unsurprising as under such conditions in the model both DWF and WWF parameters are influential. However, during a DWF period, only DWF parameters are influential. Logically, collected data during such a period is unable to contain information for WWF parameters. It is, however, interesting to notice that the beginning of a big rain event contains more information than the end. For the DWF conditions, it is interesting to notice that data is information-richer during night than during day, and that a DWF day after a series of dry weather contains more information than a day following a rain event.

Table 1. Evaluation of the FIM using the modified A-optimal design criterion.

	Abbr.	Description	Mod. A-optimal	Evaluation
DWF	DD1	Day after long DWF period	1 730	
	DN1	Night after long DWF period	3 050	Best DWF
	DD2	Day following WWF	830	
	DN2	Night following WWF	2 570	
WWF	SRB	Entire small rain event	8 050	
	BRB	Beginning of big rain event	28 300	Best overall
	BRT	Tail of big rain event	11 400	

4. DISCUSSION AND CONCLUSIONS

Having a preliminary model allows comparing different data periods and identifying which data collection effort contains the most information. This allows then to plan the interventions on site in a way that there is a higher chance that the sensors are working during a period where the measurements are valuable.

It is obvious that the weather conditions as such cannot be influenced. But the results showed that during DWF night measurements contain more information than day measurements. It is therefore concluded that the measurement campaign with clean sensors is ideally started in the late afternoon, before leaving the site. This allows focusing on the night measurements instead of the day measurements that would follow a morning start.

The results also show that WWF measurements contain more information. However, it is also known that these are not only the more unpredictable conditions, but also the more difficult and dangerous to measure. Despite their intrinsic uncertainties, existing tools, such as radar and weather forecasts, can be used to optimally prepare for an upcoming rain event. It is more interesting to see, however, that the information at the beginning of a rain event contains more information than towards the end. Experience shows that sensors often fail during a rain event due to the particularly rough conditions. The results show that, fortunately, then the important data has already been collected. Going on site during a rain event is considered a major security risk and, given the results of the experimental design, does not seem to be necessary.

It has been shown that the experimental design gives valuable insights for the definition of the relevant measurement periods and allows therefore to better plan the necessary interventions. Using an experimental design does, however, not only result in information-rich data for a later improvement of the preliminary model, but also structures model calibration as well as the measurement campaign and results therefore in a more efficient overall modelling procedure.

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