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Considering The Effect Of Uncertainty And Variability In The Synthetic Generation Of Influent Wastewater Time Series

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CONSIDERING THE EFFECT OF UNCERTAINTY AND VARIABILITY IN THE SYNTHETIC GENERATION OF INFLUENT WASTEWATER TIME SERIES

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Abstract
In this paper we discuss the development of an influent generator used to produce more realistic dynamic influent time series by incorporating current and projected information on climate and sewershed characteristics into the generation of the influent time series. The time series of rainfall and influent in dry weather conditions were generated using a Markov-Exponential (Richardson [1]) and a multivariate autoregressive model respectively. The CITYDRAIN model (Achleitner *et al.* [2]) with uncertain parameters was employed for modeling the behavior of the influent under wet weather conditions. The influent generator was calibrated using a Bayesian algorithm and then used to generate days of wastewater time series for the entire sewershed served by the 700,000 PE Eindhoven WWTP (The Netherlands). The statistical properties of the generated influent time series are consistent with observed ones and the effect of total model uncertainty is captured and communicated by constructing uncertainty bands for the different influent constituent's time series.

Keywords
Bayesian analysis; uncertainty analysis; urban hydrology; wastewater composition

INTRODUCTION

One of the major sources of uncertainty/variability that both plant designers and operators should deal with is the dynamics of the influent. Therefore, the synthetic generation of influent time series is crucial for assessing the performance of a WWTP under dynamic flow and loading conditions.

One of the simplest approaches in synthetic generation of the influent time series is the application of stochastic models (Capodaglio *et al.* [3]; Berthouex and Box [4]; Martin *et al.* [5]). However, these models may have a poor performance especially during wet weather flow conditions as different complex processes affect the dynamics of the influent. Moreover, such statistical models do not consider the underlying elements and processes that govern the generation and the dynamics of the influent. To consider the underlying phenomena that are involved, some researchers have advocated the use of detailed and physically-based models (Hernebring *et al.* [6]; Temprano *et al.* [7]).

Although the application of these complex models might be useful for certain purposes, (e.g. evaluating the performance of different operation strategies in a sewer system) in cases in which the overall behavior of the influent time series is of interest, they might not be very useful as they require detailed information on the sewage system and running them for a large number of times could be computationally expensive.

To tackle these problems, an influent generator was developed using a set of statistical and conceptual models for simulating the dynamics of the influent under both dry weather flow (DWF) and wet weather flow (WWF) conditions. The generated influent time series can serve, for instance, as input to the probabilistic design of nutrient removal plants and also to assess the performance of a plant under different dynamic flow and loading scenarios due to climate change or future catchment development.

METHODOLOGY

In the adopted approach, two types of statistical models are used, one for the synthetic generation of rainfall series and one for the time series describing the influent during DWF conditions. These two time series (e.g. rainfall and influent in DWF conditions) serve as stochastic inputs to a conceptual model of the sewershed in order to generate the influent time series during both WWF and DWF conditions. The case study of this research is the entire sewershed that is served by the 700,000 PE Eindhoven WWTP located in The Netherlands.

Synthetic generation of influent time series in DWF conditions

The characterization of wastewater into different constituents depends on the type of physical, chemical, and biological processes taking place in a WWTP system and also the degree of complexity and sophistication of design procedures which in turn is largely determined by the required effluent standards (Henze *et al.* [8]). A combination of Fourier series analysis and a multivariate autoregressive time series model (Neumaier and Schneider [9]) was used for the synthetic generation of the influent during DWF conditions. First, different Fourier series estimates are used to capture the average daily periodic behavior of the wastewater constituents and then a multivariate autoregressive model is used to model the stochastic behavior of the different influent time series.

Synthetic generation of rainfall time series

Realistic generation of rainfall time series is crucial as it is one of the most important factors that affect the dynamics of the influent during WWF conditions. Here, we used a two-state Markov chain model originally proposed by Richardson [1] for stochastic generation of the daily rainfall time series and then applied two successive time series disaggregation techniques to convert the daily rainfall time series into a rainfall time series with 15-minutes temporal resolution (comparable to the dynamic influent model for Benchmark Simulation Model 2 by Gernaey *et al.* [10]). The main objective of this procedure is to better extract and incorporate the important statistics of the rainfall records (e.g. the average rainfall amount, the number of wet days, seasonal variation of both frequency of and intensity of rainfall, and etc.) into the synthetically-generated rainfall time series.

Synthetic generation of influent time series in WWF conditions

Synthetic generation of the influent time series during WWF conditions is relatively more complicated than the generation of the influent time series during DWF conditions. The difficulty arises as various phenomena are involved during WWF conditions and as the availability of measured data is usually scarce during these periods. Hence, using a purely statistical model may result in significant discrepancies between the simulated and observed time series. Therefore, we used a combination of statistical modeling techniques and a conceptual model to generate the time series of the influent during WWF conditions. The CITYDRAIN model was selected as the conceptual model as it takes into account the basic phenomena that govern the amount and dynamics of the influent and also requires only a small number of parameters whose values or ranges of values can be inferred from the basic information of a sewershed.

However, one should be aware of the fact that modeling the influent time series in WWF conditions using a conceptual model may not lead to reliable results unless the model is calibrated and the effect of different sources of uncertainties on the outputs (e.g. flow and other pollutants) are taken into account. To this aim, a Bayesian framework was used to update the ranges of values that were initially assigned to the parameters of the CITYDRAIN model (i.e. estimating the posterior distribution of parameters using their prior distribution and the measured data on flow, Soluble COD, Total COD, Ammonia, and TSS). It should be noted that the proposed Bayesian approach is not only capable of capturing the effect of model parameter uncertainty, but also of capturing the effect of other sources of uncertainties that could result in some discrepancies between the simulated influent time series and the observed one.

Once the uncertainty ranges of the CITYDRAIN model parameters are updated, synthetic influent time series can be generated for a desired number of years considering the variability in the inputs of the CITYDRAIN model (i.e. rainfall and influent time series in DWF conditions). The total uncertainty of the influent time series can be obtained as follows:

1. Synthetic generation of the 15-minute time series of rainfall for one year
2. Synthetic generation of the 15-minute time series of the influent in DWF conditions for one year
3. Sampling a point from the posterior distribution of the CITYDRAIN model parameters
4. Inputting the generated time series 1) and 2) and the parameters sampled in 3) and running the CITYDRAIN model for one year
5. Repeating 1) to 4) for a desired number of years

RESULTS

The parameters of the statistical Markov-exponential model were estimated using the recorded rainfall data in the region. The results indicate that not only are the basic yearly statistics (i.e. average and variance) of the generated rainfall time series consistent with the recorded rainfall time series, but, also the seasonal variations in rainfall intensity and frequency of wet days are respected.

The results of the influent generator in DWF conditions are also consistent with the observed influent time series (Fig. 1-2). Besides capturing the periodic behavior of the different wastewater constituents in time, the autocorrelation and cross-correlation among the different wastewater constituents are respected in the generated time series (Table1). This is important as the performance of a nutrient removal plant is affected not only by the concentration of a certain nutrient but also by the ratio of that nutrient to other wastewater constituents. For the WWF conditions, the performance of the influent generator is illustrated for a 4-day rain event on the Riool-Zuid sewershed (Fig. 4). As explained in the methodology section, the prior distribution of the CITYDRAIN model parameters was updated using the measured influent data to estimate the posterior distribution (Fig. 3) and at the end, all sources of uncertainties that would result in some discrepancies between the output of the CITYDRAIN model and the observed values of the influent are taken into account and communicated to users by constructing the uncertainty bands with a certain level of confidence.

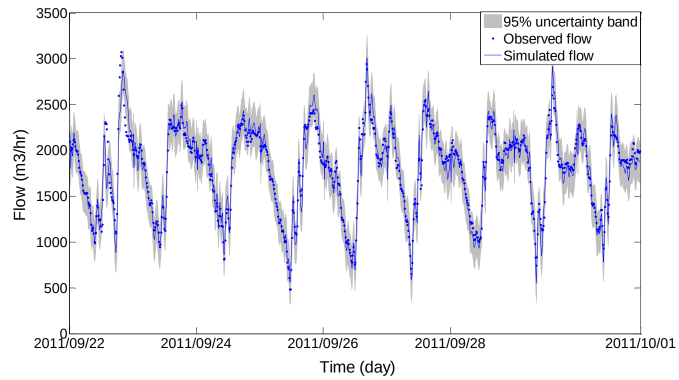

Figure.1 Observed and calibrated flow in a DWF series

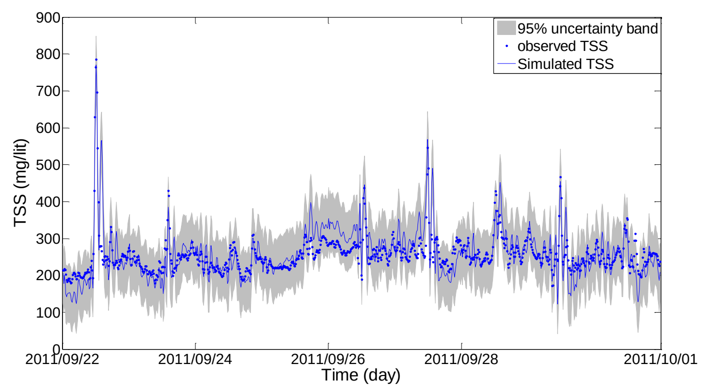

Figure. 2 Observed and calibrated influent TSS in a DWF series

Table1. Correlation matrix for the generated and observed influent time series in DWF conditions

Generated influent time series					
	Flow	Soluble COD	Total COD	TSS	NH4
Flow	1.00				
Soluble COD	-0.11	1.00			
Total COD	-0.04	0.77	1.00		
TSS	0.06	0.32	0.80	1.00	
NH4	-0.43	-0.04	-0.06	-0.04	1.00
Observed influent time series					
	Flow	Soluble COD	Total COD	TSS	NH4
Flow	1.00				
Soluble COD	-0.12	1.00			
Total COD	-0.06	0.77	1.00		
TSS	0.05	0.33	0.81	1.00	
NH4	-0.46	0.00	-0.02	-0.03	1.00

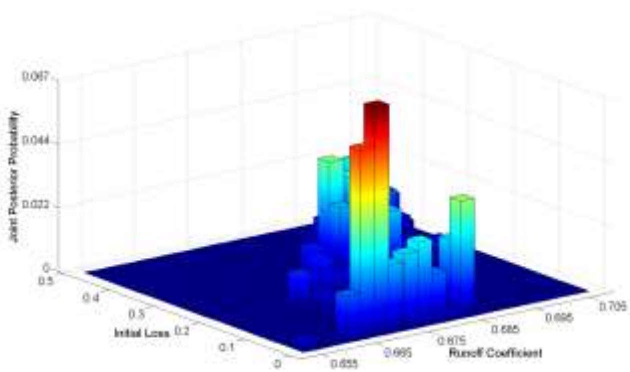

Figure 3. Posterior distribution of two CITYDRAIN parameters

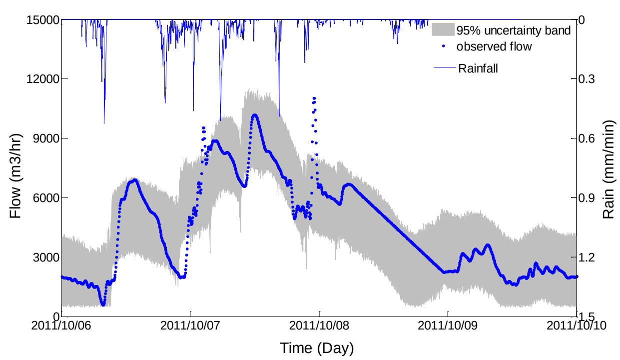

Figure 4. Uncertainty bands for flow in a 4-day wet weather event

CONCLUSION

Using the proposed influent generator, we managed to generate the time series of the influent with 15-minute temporal resolution considering both the effect of variability in inputs and also the total model uncertainty. The statistical properties of the synthetically-generated time series of influent are consistent with the observed ones. Overall the proposed methods provide a better way of incorporating the available information and knowledge on the weather condition of the region, influent composition, and also the characteristics of the sewershed into the generated influent time series. Moreover, the parsimony and flexibility of the proposed influent generator allows for incorporating the projected changes in climate and sewershed characteristics into model parameters (e.g. an increase in average rainfall or average flow in DWF conditions).

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