Wastewater treatment plant influent disturbance models

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Abstract
Availability of dynamic wastewater treatment plant (WWTP) inputs is a necessity to obtain a realistic picture of the simulated treatment plant performance. Collection and analysis of samples from the influent of a full-scale WWTP is an expensive way of generating dynamic WWTP influent data. Model-based influent scenario generation is an alternative that has gained considerable interest recently. This short paper brings a summary of different concepts developed over the past years for generating dynamic WWTP influent flow rate and load scenarios. The paper forms a basis for identifying critical knowledge gaps in current WWTP influent disturbance models, and to define specific research tasks that should be addressed in the future to promote more general acceptance and use of WWTP influent disturbance models.

Keywords
Dynamics; Flow rate; Influent disturbance; Modelling; Pollutant concentrations; Simulation

INTRODUCTION

The focus in a typical wastewater treatment plant (WWTP) modelling study is most often on obtaining a well-calibrated model that can be used later on for a specific purpose such as the simulation-based evaluation of different control strategies or the simulation-based comparison of several potential treatment plant extension alternatives. Several studies have therefore focused specifically on developing a standardized procedure for the calibration of a WWTP model (Hulsbeek *et al*., 2002; Petersen *et al*., 2002; Melcer *et al*., 2003; Langergraber *et al*., 2004), efforts that have also resulted in the formation of the IWA Task Group on Good Modelling Practice. In essence, following the definition of a clear purpose of the specific modelling study, the success of the model calibration step depends to a large extent on the availability of a set of informative data – consisting of on-line as well as off-line measurements – that allows to estimate and/or tune relevant parameters in the WWTP model as to obtain a good model fit to the available data.

Once a calibrated model is available and applied in the frame of WWTP simulation studies, the current standard is more and more to simulate the plant for a relatively long period of time, preferably with dynamic plant inputs. Indeed, the WWTP influent is the largest disturbance threatening stable WWTP operation. For most municipal treatment plants the influent dynamics reflect rather regular diurnal, weekly and seasonal variations, with unexpected events such as rain or toxic spills superimposed on it. It should be emphasized here that dynamic plant inputs are a necessity to obtain a realistic picture of the simulated plant performance, where the use of steady-state model inputs will not sufficiently push the system towards its limits and will thus result in a too optimistic picture of the simulated overall treatment plant performance (e.g. Ráduly *et al*., 2007).

This paper is entirely focused on influent disturbance models, mainly due to the importance of such disturbances for treatment plant performance. More specifically, this paper provides a description of the different concepts that have been developed over the past years for generating dynamic WWTP influent flow rate and load scenarios.

DYNAMIC INFLUENT FLOW RATE GENERATION

Influent disturbances are both related to flow rate and concentration changes. Dynamic influent flow rate data can be obtained rather easily from the on-line measurements that are installed on the WWTP. If such influent flow rate data are available and one would be tempted to use them as such, one should be cautious to validate the data quality, as there is often a severe mismatch between measured (assumed) flow rates and the real flow rate entering the treatment plant. If measurements are not available, dynamic influent flow rate data can also be generated by means of a simple equation such as a Fourier series (sum of sinusoids with varying frequencies and phase shifts) whose parameters are fitted to dynamic influent data (e.g. Carstensen *et al*., 1998; Langergraber *et al*., 2008), a more complex phenomenological model (e.g. Gernaey *et al*., 2005) or a very complex and detailed deterministic model of the complete catchment area (e.g. Hernebring *et al*., 2002).

DYNAMIC INFLUENT POLLUTANT CONCENTRATION GENERATION

Contrary to influent flow rate, it is not that easy to obtain long dynamic influent pollutant concentration time series. A first bottleneck is the amount of work and the cost involved with sampling and analyzing grab samples taken on the influent for the most relevant influent pollutants (soluble and total COD, total suspended solids, ammonium nitrogen, total Kjeldahl nitrogen, orthophosphate phosphorus, total phosphorus, etc.). One should indeed count on a sampling interval of maximum 2 hours if influent dynamics should be represented realistically in the measured influent data. If a one hour sampling interval is adopted, and if the aim is to obtain one year of dynamic influent data, then 8760 samples need to be analyzed to complement the influent flow rate data.

A second bottleneck is that on-line collection of dynamic influent pollutant concentration data is expensive as well (e.g. cost of sensors, maintenance and calibration of sensors, consumption of chemicals), and does by far not guarantee that an influent pollutant concentration data set of high quality will be obtained. Indeed, several off-line lab analyses can still not be performed very reliably on the influent of a WWTP.

Confronted with the above practical and technical problems related to the collection of long dynamic influent pollutant concentration time series, a third approach is to generate influent pollutant concentration time series using a model. The same methods described in the influent flow rate generation can be applied here to dynamically describe the behavior of the different pollutant concentrations (e.g. Bechmann *et al*., 1999, Gernaey *et al*., 2010).

MODEL EXAMPLES

Langergraber *et al*. (2008) and Alex *et al*. (2009) created a model-based generator of diurnal influent disturbances to create influent data for dynamic simulation of specific treatment plants under dry weather conditions. In the very practical study of Devisscher *et al*. (2006) statistics on typical data collected daily at treatment plants under dry and wet weather were used to generate synthetic influent data by using factors to account for diurnal variations, weekends, and first flush events. The main objective of the work presented here – to a large extent similar to the approach reported by Carstensen *et al*. (1998) and Bechmann *et al*. (1999) – was to decrease the additional effort during the calibration/validation and create reliable models for plant optimization.

One dynamic influent model was developed as part of the plant-wide Benchmark Simulation Model no 2 (BSM2; Jeppsson *et al*., 2006). Basic concepts of this influent model – a phenomenological model – are reported in Gernaey *et al*. (2005, 2006), whereas a full technical report will be published as part of an IWA Scientific and Technical Report (Gernaey *et al*., 2010). The transition from the Benchmark Simulation Model no. 1 (BSM1, evaluation period = 1 week) to the plant-wide BSM2 (evaluation period = 1 year) was boosted by the recognition of the importance of plant-wide control as opposed to local control. A plant-wide simulation benchmark would for example allow studying the effect of reject water dosage as a disturbance, an internal disturbance which on full-scale plants may account for up to 20% of the total nitrogen load on the activated sludge plant.

Specifically for the BSM platform, the development of phenomenological models for the generation of dynamic influent flow rate and pollutant concentration time series was chosen on purpose, first of all due to the relatively low complexity and the modularity of this approach (see Gernaey *et al*. (2006) for details). Moreover, another argument for generating influent data with a model was that the use of influent data collected on a full-scale system might result in a very specific data set, where certain types of influent disturbances (for example seasonal flow rate variations) that were desired for the BSM2 influent data set would be lacking. Availability of an influent model would allow the benchmark developers to generate an influent file containing all the characteristics that are considered to be necessary for a thorough evaluation of the control systems in the BSM2. Of course, this argument is equally valid for other plant models where simulation is applied for control strategy validation.

The initial efforts of the WWTP benchmarking community in developing influent disturbance models has slowly found its way into several other modelling studies. Originally developed for the ASM1 model (Gernaey *et al*., 2006), influent disturbance models have been reported that are compatible with ASM2d (Benedetti, 2006) and ASM3 (Ráduly *et al*., 2007) as well. Moreover, the flexibility of such influent models was demonstrated by Benedetti (2006), who combined an influent model with different rainfall time series to come up with a wide range of influent conditions including variation in weather scenarios (alpine, oceanic, continental, Mediterranean), loading (ratio between households and industry), seasonal activities (tourism) to evaluate the robustness of plant designs. Pons *et al*. (2009) translated model-based influent generation concepts to different real WWTPs. A similar application was reported by Béraud *et al*. (2007), where an influent disturbance model was used to obtain dynamic influent concentration patterns based on the available daily average data.

Model-based influent disturbance generation for WWTPs has not been limited to flow rate and traditional activated sludge model (ASM) influent fractions. Lindblom *et al*. (2006) combined an influent model for ASM variables with the generation of influent pollutant profiles for two xenobiotic compounds, and used the resulting influent pollutant profiles to model the fate of pollutants in the WWTP. De Keyser *et al*. (2010), within the framework of the EU ScorePP project, developed a model that generates time series of traditional and micro-pollutants from their emission sources in the urban catchment. Additionally, during the development of the BSM1_LT platform (BSM1 Long Term, Rosen *et al*., 2004), the influent model for ASM variables is combined with a Markov chain approach to describe the occasional occurrence of either toxic or inhibitory influent shock loads in the influent (Rosen *et al*., 2008).

PURPOSE OF THE PAPER

The first purpose of this paper is to summarize the different concepts that have been developed over the past years for generating dynamic WWTP influent flow rate and load scenarios. The second purpose – on the basis of discussion with experts at the WWTmod seminar – is to identify critical knowledge gaps in current WWTP influent disturbance models, and to define specific research tasks that should be addressed in the future to promote more general acceptance and use of WWTP influent disturbance models. Comments received at the conference will be incorporated in a future overview paper on influent disturbance modeling, highlighting advantages and disadvantages of different approaches, illustrating model concepts with case studies where relevant, and establishing a prioritized list of research tasks necessary in this area.

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