RISK ASSESSMENT TOOL FOR THE DESIGN OF WASTEWATER TREATMENT PLANTS

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INTRODUCTION

In 1990, the private company Aquafin was founded and assigned with the task of the design, construction, operation and financing of the necessary infrastructure for sewage treatment. One of the challenges Aquafin is facing now is to upgrade the patrimonium of old municipal wastewater treatment plants (WWTPs). These plants need to be retrofitted towards strict phosphorus and nitrogen removal consents according to the European Directive for urban wastewater treatment 271/91 in areas sensitive to eutrophication.

Within the currently followed design/retrofit-procedure, deterministic dynamic models are used to evaluate different renovation scenarios on their merits. One of the remaining issues when dealing with these deterministic models is the degree of uncertainty linked to their predictions. In other words to what extent can the predictions of the model be taken for reality? The combination of stochastic modelling techniques with the currently available deterministic models (steady state or dynamic models) could provide the answer needed. By building a stochastic shell around the deterministic models one could quantify the uncertainty contained within the model predictions.

The concrete goal of this project is to determine the probability of exceeding the legal effluent standards of a WWTP. This percentage of exceedance should be accomponied by confidence intervals indicating the inherent uncertainty of influent characteristics and model parameters. Characterisation of uncertainty allows decision-makers to choose whether to adjust the design or whether to conduct additional research.

TIME SERIES ANALYSIS

The simplest way to evaluate the effluent quality is to compare the effluent time series with the legal standards and look for exceedances. Some preliminary calculations such as the number of exceedances and the minimum, maximum and average time of exceedance already provide valuable extra information about the systems performance. However, a concentration - duration - frequency (cdf) curve based on time series analysis is a more powerful tool for the purpose of risk assessment (Fronteau *et al.*, 1995). These cdf curves are generated by dividing the norm exceedance times into a number of classes and by determining the number of exceedances for each class.

The cdf tool can be used in three ways. (i) First of all, several different effluent limits can be selected, resulting in as many cdf curves. These curves illustrate some characteristics of the effluent. (ii) A second application of the cdf-tool is a sensitivity analysis of particular model parameters. The more sensitive a parameter, the more the effluent time series and the resulting cdf curves will change if the value of the parameter is changed. (iii) The third part of the time series analysis is that, for a fixed effluent limit, input variables as well as several model parameters can be varied, a.o. via Monte Carlo simulations. The combination of the Monte Carlo algorithm and the time series analysis results in a series of cdf curves, from which a probability distribution of the cdf results can be calculated. It is thus possible to determine the chance that effluent standards will be exceeded together with the uncertainty of this prediction. This approach will be demonstrated further on by means of a case-study.

OVERALL APPROACH

The stochastic simulation takes into account both parameter and input uncertainty, in this way dealing with the difficulties to estimate model parameters and taking into account the inherent uncertainty in specific processes.

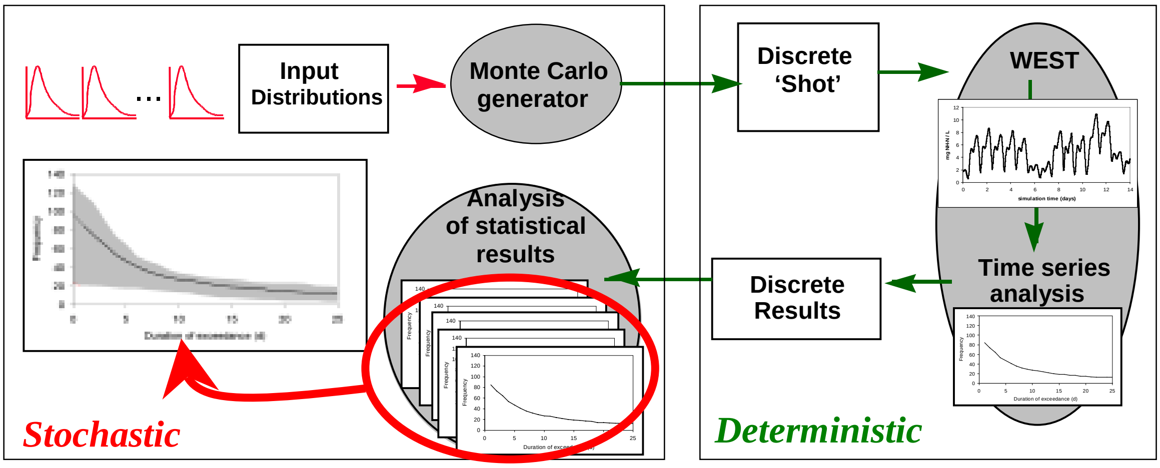

Fig. 1. Monte Carlo methodology for risk assessment based design/retrofit of WWTPs.

For each model input that is considered to be a random variable, a probability distribution is specified. Random samples are taken for each of the input distributions. One sample from each input distribution is selected, and the set of samples ('shot') is entered into the deterministic model. The model is then solved as it would be for any deterministic analysis. The model results are stored and the process is repeated until the specified number of model iterations is completed. Using Monte Carlo techniques, it is therefore possible to represent uncertainty in the output of a model by generating sample values for the model inputs, and running the model repetitively. Instead of obtaining a discrete number for model outputs as in a deterministic simulation, a set of output samples is obtained (Cullen & Frey, 1999).

In this case, the resulting model outputs are concentration-duration-frequency curves. After a large number of 'shots', one obtains a large number of cdf curves, which can be used to construct an 'uncertainty band' on the cdf curves (see Figure 1).

CASE STUDY WITH A DENITRIFYING PLANT MODEL

A case-study was performed on a denitrifying plant model inspired by the benchmark described by Spanjers *et al.* (1998). This model was implemented in the WEST modelling and simulation software (Hemmis NV, Kortrijk, Belgium). Details on the model can be found in Rousseau *et al.* (2000). Simulations were done over a period of 180 days, starting in the winter period and ending in the summer period. For this case study, 300 Monte Carlo shots were simulated on a Pentium III – 650 MHz based PC. The effluent series were analysed for nitrate-N, ammonium-N and total-N with the effluent standards set to 10 mg N/L, 4 mg N/L and 18 mg N/L respectively. Concentrations were first time-averaged over a 2 hour period as imposed by environmental legislations in several countries.

Norm compliance

The 300 cdf histograms resulting from the 300 Monte Carlo shots allowed to calculate the median and 5-95 percentiles for every class. The results are shown in Figure 2. The first class represents the total number of exceedances. For ammonium-N for instance, the conclusion is that there is 95 % certainty that the effluent limit will be exceeded less than 2.6 % of the time. The nitrate-N limit will be exceeded less than 4.8 % of the time (95 % certainty) and the total-N limit will be exceeded less than 5.7 % of the time (95 % certainty).

The European legal standards state that an installation must not exceed the effluent standards more than 5 % of the time. We are therefore 95 % certain that the effluent concentrations of NH_4-N and NO_3-N comply to this standard, but there is only 74 % certainty that TotN complies to its standard.

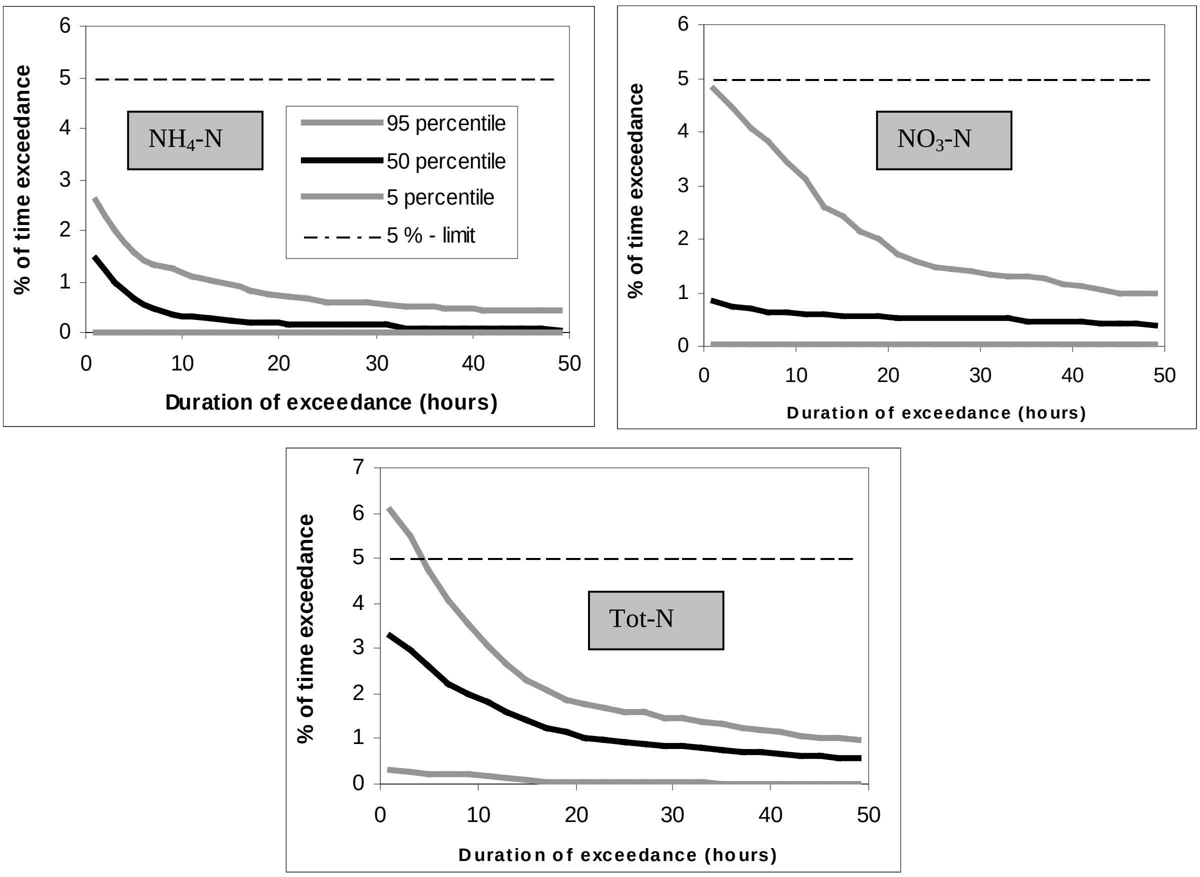

Fig. 2. Cdf-curves of the first class based on 2-hour averaged effluent concentrations of ammonium-N, nitrate-N and total-N.

CONCLUSIONS

The combination of stochastic modelling techniques with the currently available deterministic models (steady state or dynamic models) allows to efficiently assess the uncertainty of model predictions.

A new tool was developed to determine the probability of exceeding the effluent limits of a WWTP. This percentage of exceedance is accomponied with confidence intervals indicating the inherent uncertainty of influent characteristics and model parameters. This characterization of uncertainty allows decision-makers to choose whether to adjust the proposed design or whether to conduct additional research.

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