# UNCERTAINTY REDUCTION IN RIVER WATER QUALITY MODELLING. APPLICATION ON THE RIVER DENDER IN BELGIUM

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## 1 INTRODUCTION

Recently the European Union has approved the EU Water Framework Directive (EU-WFD). This directive claims that by the end of 2015 a "good status of surface water" and a "good status of groundwater" should be achieved (EU, 2000). To that end, the EU-WFD provides several guidelines for monitoring the water bodies, leaving the practical implementation to the local governments. Each region has to develop a consistent monitoring strategy and assessment methodology. To make sure that the new water policy will succeed, a profound analysis of the actual and future state of the water is necessary. In this context, the evaluation of emissions into river water will be important. The effects of a pollution load into the river can be evaluated using models. After the calibration of a model with a certain data set, the model generates predictions over a period of months or even years. However, those predictions are uncertain. Model outcome uncertainties can become very large due to:

- measurement errors,
- uncertainty in the estimated model parameter values,
- model structure uncertainty and
- the stochastic nature of the biological processes in river water.

This paper presents a methodology to reduce the uncertainty on model parameters and as a result reduce the uncertainty in the final model outputs. Three main steps are described. The methodology is applied to the Dender basin in Belgium. The river water quality model used is implemented in the ESWAT simulator.

## 2 THE DENDER BASIN

The catchment of the river Dender has a total area of 1384 $km^2$ and has an average discharge of 10 $m^3/s$ at its mouth. As about 90% of the flow results from storm runoff and the sources make very little contribution, the flow of the river is very irregular with high peak discharges during intensive rain events and very low flows during dry periods. To allow for navigation and to temper the high flows, the Dender is canalised and regulated by 14 sluices in between. (Bervoets et al., 1989).

## 3 ESWAT

ESWAT is the extended version of SWAT. The SWAT-simulator (Soil Water and Assessment Tool) was developed at USDA, the Agricultural Research Service and Blackland Research Center, Texas to study the impact of climate change, agricultural management, water supplies management and economic change. (Arnold et al,1996). Changes were made at the Laboratory of Hydrology (VUB) to be able to predict the impacts of eutrophication and to be able to present changes on a sub-daily time step (van Griensven and Bauwens, 2000). The river water quality model implemented in it is based on QUAL2E (Brown and Barnwell, 1987).

## 4 REDUCTION OF UNCERTAINTY

To reduce the uncertainty on the model results three main steps are followed. In this research only the parameter uncertainty is considered. The methodology starts with a sensitivity analysis, continues with an uncertainty analysis and finally an optimal experimental design is applied to reduce the uncertainty.

### Sensitivity analysis

Due to the complexity of river water quality models many parameters need to be determined before the model describes the system well. Two problems arise, either there are just too many parameters to calibrate or some parameters are unidentifiable due to correlation. As some parameters are more essential to the model outcomes than others, a subset of parameters can remain fixed, based on literature values or previous experience with the model. To find the parameters that are most influential a sensitivity analysis is first performed (Vandenberghe et al., 2001). An effective Monte Carlo approach based on Latin Hypercube sampling is used (McKay, 1988). Table 1 gives the most important parameters obtained for this model after the sensitivity analysis with their normalised regression coefficient and rank.

Table 1. Normalised regression coefficient and rank of the parameters after sensitivity analysis.

| Parameter | NRC | rank |
|---|---|---|
| Ai5, $O_2$ uptake per unit of $NH_3$ oxidation | 0.261 | 1 |
| Bc1, Rate constant for biological oxidation of $NH_4$ to $NO_2$ | 0.162 | 2 |
| Ai4, $O_2$ uptake per unit algae growth | 0.143 | 3 |
| Rk1, BOD deoxygenation rate coefficient | 0.130 | 4 |
| Ai3, $O_2$ production per unit algae growth | -0.110 | 5 |
| Ai6, $O_2$ uptake per unit of $HNO_2$ oxidation | 0.072 | 6 |
| Rk3, rate of loss of BOD due to settling | -0.071 | 7 |
| Rk2, oxygen reaeration rate | -0.710 | 8 |
| Rktem, rate constant for heat exchange | -0.043 | 9 |

### Uncertainty analysis

After detection of the most influential parameters, the model is calibrated with those parameters while the others remain fixed on a literature value. For the calibration the

PEST (Parameter Estimation) program (Anonymous (1994) is used which is based on a Gauss-Marquardt-Levenberg Method. This method also calculates the covariance matrix of the parameters which allows to obtain the confidence regions of the parameters.

## Optimal experimental design

The amount and quality of the data available for the calibration of a model are very important to obtain more reliable predictions (Vanrolleghem et al, 1999, Reichert & Vanrolleghem, 2000). However, the collection of data is difficult, time consuming and very expensive. To make the uncertainty on the model outcomes smaller, the best measuring points that make the parameter uncertainty as small as possible must be found, given the fact that it is not possible to sample every point on a river and a very large number of measurements is too expensive.
The optimal experimental design methodology used here is based on the D-optimal design (Dochain & Vanrolleghem, 2001). Hereby, the precision of the parameters is assessed by considering the determinant of the inverse of the covariance matrix of the parameter estimates or the Fisher Information Matrix (FIM) (Godfrey and Distefano, 1985).

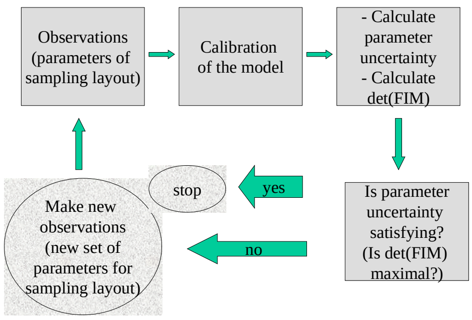


Figure1 Scheme of optimal experimental design

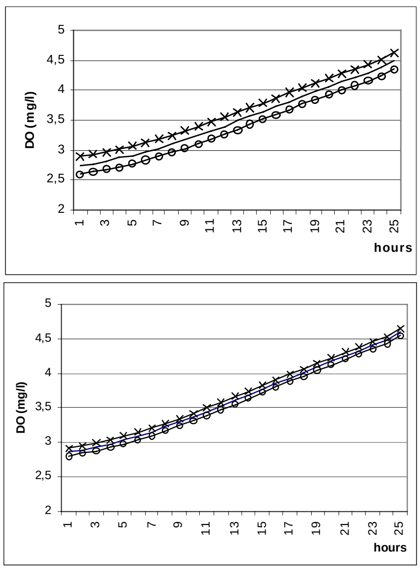


Figure 2 Comparison of dissolved oxygen model output with 95 % confidence bounds for the river Dender

For a limited amount of experimental conditions that are well defined, it is possible to find the experiment that provides the maximum det(FIM), by considering all possible experiments (Baetens, 2001). However, for a river water quality problem, the possible experimental schemes are unlimited. Therefore, in a second optimisation process, the design parameters of the sampling schemes (the amount, the place and frequency of sampling, the kind of variables measured…) are being optimised by searching for the combination of design parameters that maximises det(FIM) (Vandenberghe et al., 2002). In Figure 1 the scheme of the optimal experimental design is given. Figure 2 gives a comparison of the model output with confidence bounds of dissolved oxygen with two different sampling schemes, clearly showing the reduction in output uncertainty.

## 5 CONCLUSIONS

Three steps, sensitivity analysis, uncertainty analysis and optimal experimental design are applied to river water quality modelling to obtain a better modelling accuracy.

Following this strategy it becomes possible to sample a river in a way that the parameters have an acceptable uncertainty after calibration of the water quality model. The sampling strategies can be evaluated in view of the limitations of costs and other practical limitations.

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