Stormwater quality models: do they work?

C. B. S. Dotto1,*, A. Deletic1, T. D. Fletcher1 and D. T. McCarthy1

1) Institute for Sustainable Water Resources, Department of Civil Engineering and eWater CRC, Monash University, Victoria, Australia, 3800
* Corresponding author, e-mail: cintia.dotto@eng.monash.edu.au

1. Introduction

Stormwater models underpin decision-making processes in stormwater management. Runoff generation and flow routing models are now well developed and widely adopted. However, stormwater quality models are less well developed. Model calibration and sensitivity analysis are crucial in order to estimate realistic stormwater pollution concentrations. The Metropolis algorithm (Metropolis et al., 1953), a general Monte Carlo Markov Chain (MCMC) sampling method, has been widely used for model calibration and sensitivity analysis (e.g. Kuczera and Parent, 1998; Kanso et al., 2003). The robustness of the Bayesian approach compared to other methods is apparent from several studies (e.g Makowski et al., 2002; Gallagher and Doherty, 2007).

The aim of this paper is to evaluate the performance and the uncertainty in the outputs of water quality models due to their parameters in order to define their reliability for various applications. The models tested in this study are derived from those used in practice, such as XP-AQUALM (1999), SWMM (Huber and Dickinson, 1988) and P8-UCM (Palmstrøm and Walker, 1990).

2. Materials and methods

Three empirical concentration models have been investigated to date. Model 1 is based on a power function of rainfall intensities; Model 2 is a power function of routed intensities, in which the Muskingum Cunge method was used to translate and attenuate rainfall; Model 3 is a power function of the routed runoff. The models and their respective calibration parameters are summarised in Table 1. The models were calibrated using concentrations rather than loads because loads are highly dependant on flows, thus resulting in spurious correlations which mask the real predictive capability of the models (McCarthy, 2008).

<table>
<thead>
<tr>
<th>Models</th>
<th>Parameters</th>
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<tbody>
<tr>
<td>Model 1</td>
<td>$C_i = a I_i^b$</td>
</tr>
<tr>
<td>Model 2</td>
<td>$C_i = a I_{routed_i}^b$</td>
</tr>
<tr>
<td>Model 3</td>
<td>$C_i = a R_i^b$</td>
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</tbody>
</table>

The models were applied to a comprehensive Melbourne stormwater dataset which contains stormwater flows and pollutant concentrations from urban catchments of different land uses and sizes. Hundreds of events are available for which TSS, TN and TP were monitored. Calibration and sensitivity analysis were carried out with MICA (fully explained in Doherty,
2003), which searches for parameter distributions using a Markov Chain Monte Carlo (MCMC) approach.

3. Results and discussion

Contrary to rainfall and flow data, water quality data obtained by discrete sampling is not continuous, which makes pollution model calibration very complex. In general, the models did not perform well (Table 2). The models seemed to be sensitive to all parameters involved (Figure 1). The clear peaks in the histograms indicates that Model 1 was sensitive to both $a$ and $b$ when estimating TSS concentrations. Parameters $a$ and $b$ are highly correlated ($R^2 = 0.88$) suggesting that different combinations give similar results. Despite the robustness of the method and the long time needed to run the chains with several iterations, MICA runs did not produce very satisfactory results.

Table 2. Nash and Sutcliffe coefficient obtained for the models.

<table>
<thead>
<tr>
<th>Model</th>
<th>Madden Groove, Richmond – TSS</th>
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<tr>
<td>Model 1</td>
<td>E⁻¹ 0.17</td>
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<tr>
<td>Model 2</td>
<td>0.12</td>
</tr>
<tr>
<td>Model 3</td>
<td>0.08</td>
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*E is the Nash and Sutcliffe.

Figure 1. Histograms for Model 1 $a$ and $b$ parameters and cross-correlation plot for TSS.

4. Conclusions

Even with this robust calibration and parameter sensitivity approach, it is clear that the tested water quality models poorly represent reality and result in a high level of uncertainty. As expected, preliminary results suggest that the models with routed rainfall intensities and routed runoff perform slightly better than the model which uses ‘unrouted’ rainfall intensities. In an attempt to improve the models’ performance, other routing methods will be implemented and other model formulations tested. Complete results will be presented in the full paper.

5. References


