Ranking stormwater control strategies under uncertainty: the River Cam case study

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Abstract Mont Carlo simulations taking uncertainty in model parameters into account were performed on a river water quality model. The simulation results were used to rank wastewater treatment plant control strategies according to their impacts on river water quality. This impact is estimated by the maximum ammonium concentration and by the duration of dissolved oxygen concentration below 4 g/m³ at the downstream boundary of the system. The strategies were classified according to the previous criteria using 4 ranking methods, one of them being based on the concept of stochastic dominance. Results are presented for a case study based on a 10 km stretch of the River Cam as it passes through the city of Cambridge in Eastern England. It was found that ranking was robust in face of uncertainty in the parameter values for the control strategies considered as being superior in terms of river water quality impacts.

Keywords Monte Carlo simulations; parameters uncertainty; receiving water quality; stochastic dominance; stormwater overflows; wastewater treatment plant control

Introduction
Stormwater control usually aims at avoiding flooding of urban areas while preserving the attributes of receiving waters. This control can be applied on many locations across the urban drainage system, which comprises the catching basins, the sewer network, the wastewater treatment plant and the receiving river. Several examples of stormwater control have been reported in the literature (Bechmann et al., 1998, Mailhot et al., 1999). In recent developments, control of drainage systems tends to be integrated, as decisions affecting a particular part of the system are taken according to the state of another part of the system (Beck and Reda, 1994; Schilling et al., 1996; Pfister et al., 1998; Schütze et al., 1998).

Selection and performance evaluation of a control strategy require the use of different models to predict its compliance with the control objectives. However, within every model prediction lies an uncertainty. This uncertainty is mostly linked to the model structure and to the parameters estimated by calibration or can be attributed to errors in observing the initial state, to input observation errors or to undetected numerical problems. The propagation of errors in models is commonly investigated within a stochastic setting by means of first-order variance propagation or of Monte Carlo simulation analysis (van Straten and Keesman, 1991; Lei and Schilling, 1994). But as stated by Reda and Beck (1997), the sensitivity to uncertainties of decisions taken based on model predictions is a more valuable information than these uncertainties alone.

In this paper we investigate how uncertainties linked to the parameters of a river water quality model can interfere on the ranking of strategies controlling a wastewater treatment plant (WWTP) during storm surges according to their impacts on the receiving river water quality. We also illustrate how a methodology developed by Tung et al. (1993) can be used to rank WWTP control strategies under parameters uncertainties according to water quality criteria.

The seven control strategies to be classified have previously been set up and modeled by Lessard and Beck (1990) on Whitlingham Sewage Works to provide their associated...
WWTP discharge and sewer overflow characteristics for two rain events. These discharges and overflows, adjusted by Reda (1996) for the city of Cambridge (eastern England) sewer network, are assumed to be discharged in the River Cam, a tributary of the Bedford Ouse River. These discharges are used as inputs to the river water quality model for two different scenarios of upstream boundary and initial conditions. The WWTP control strategies, which modify the characteristics of the discharges, are then ranked according to water quality computed downstream of the river stretch included in the model, using two criteria and four ranking methods. The only uncertainty taken into account for this analysis is related to the parameters of the river water quality model. Inputs as well as upstream and initial conditions of the model are assumed to be certain.

The model
In this case study, the continuously-stirred-tank-reactor (CSTR) model is used to route simultaneously river flow, transport of solutes and biochemical transformations of solutes. Beck (1973) first applied this model to river water quality interactions to predict dissolved oxygen (DO) concentrations and biochemical oxygen demand (BOD). Whitehead et al. (1979, 1981) originally implemented the complete form of the model, but Beck and Finney (1987) were the first to use it to model river water quality from a biological perspective. Reda (1996) later modified the model to perform hourly simulations in order to assess and rank stormwater control strategies (Beck and Reda, 1994; Reda, 1996; Reda and Beck, 1997).

Simulations are performed using the CSTR model on a river stretch previously separated into a certain number of reaches as a function of local attributes. All reaches are divided in a sequence of reactors or tanks in which water and solutes are assumed to be instantaneously and continuously mixed. The number of tanks in every reach \( n_r \) may be chosen to match the results of the model to the available observations with respect to both fluid mass and solute movements. The CSTR model comprises three components ran simultaneously: the hydraulic, the solute transport and the biochemical modules.

The hydraulic sub-model routes flow from one tank into another in the downstream direction. It assumes a horizontal water surface in each tank and the outflow is related to the tank level by a stage-discharge relationship. For the complete derivation of the hydraulic sub-model’s equations, the reader should see Reda (1996). Let us just recall that the discharge leaving a tank at a particular instant \( t \) is calculated by resolving the following equations:

\[
\frac{dQ(t)}{dt} = n \frac{Q(t) - Q_g(t)}{V_w(t)}(Q_I(t) - Q_o(t)) + \frac{dQ_g(t)}{dt} V_w(t) = \frac{w l h_a}{K_w} \left( \frac{Q(t) - Q_g(t)}{K_w} \right)^{1/n}
\]

where \( Q(t) \) = total outflow from the tank at instant \( t \); \( t = \) time; \( n \) = dimensionless exponential parameter of the stage-discharge curve of the tank; \( Q_g(t) \) = flow through the gate downstream of the tank; \( V_w(t) \) = water volume of tank above the weir crest at instant \( t \); \( w \) = tank width; \( l \) = tank length; \( h_a \) = added depth (parameter to be calibrated); \( Q_I(t) \) = summation of all inflows into the tank; \( Q_o(t) \) = summation of all outflows from the tank; and \( K_w \) = time-invariant factor, function of weir shape downstream of the tank.

Parameter \( h_a \) represents an initial channel capacity to store water and to lag wave propagation downstream independently of water head. The uncertainty linked to this parameter will be examined in the following uncertainty analysis.

The second sub-model routes the mixing and transport of solutes, of other substances in suspension and of microorganisms. The simulation scheme is based on a mass-balance relationship, with solute mass conservation within each elementary tank. Once again, we will not present the formal derivation of the model (detailed in Reda, 1996), but simply...
state that the concentration of a given solute, assumed homogeneous in each tank, is calculated by solving the following equation:

\[
\frac{dx(t)}{dt} = \frac{Q_f(t)}{V(t)(1 - F_d)} [x_f(t) - x(t)]
\]

where \(x(t)\) = solute concentration at the outlet, at time \(t\); \(t = \text{time}\); \(Q_f(t)\) = summation of all inflows into the tank (considered similar to the total outflows at each instant \(t\)); \(F_d = \text{dead fraction (parameter to be calibrated)}\); and \(x_f(t) = \text{weighted average of all inflow concentrations.}\)

Parameter \(F_d\) represents the fraction of the tank which does not participate in the mixing process, and may vary between zero and unity. The uncertainty linked to this parameter will also be considered in the following uncertainty analysis.

In the biochemical sub-model, five variables represent the water quality in each tank: the concentrations of DO, BOD, ammonium (Amm-N), nitrate (NO\(_3\)) and chlorophyll-a (Chl\(_a\)). The conventional mechanisms of reaeration, degradation of easily degradable matter (BOD), production of BOD by algal mortality, photosynthetic production of DO and consumption of DO by algal respiration, nitrification, denitrification, uptake of Amm-N and NO\(_3\) by algal growth and growth of algae (as a function of solar radiation and of temperature) are included in the model. The state equations representing the relationships among the water quality characteristics are (Beck and Finney 1987; Reda, 1996):

\[
\begin{align*}
\frac{dx_2(t)}{dt} &= -c_{21}x_2 + c_{22}c_{62}x_6 + s_2 \\
\frac{dx_3(t)}{dt} &= -c_{31}x_3 + c_{32}c_{67}x_6 + s_3 \\
\frac{dx_4(t)}{dt} &= -c_{31}x_3 - c_{32}(1 - c_{33})c_{67}x_6 - c_{41}x_4 + s_4 \\
\frac{dx_5(t)}{dt} &= c_{51}(c_{52} - x_5) - c_{21}x_2 - 4.33c_{31}x_3 + (c_{33} - c_{34})x_6 + s_5 \\
\frac{dx_6(t)}{dt} &= (c_{67} - c_{62})x_6 + s_6
\end{align*}
\]

where \(x_i\) = river concentrations of, respectively, BOD, Amm-N, NO\(_3\)-N, DO and Chl\(_a\); \(s_i = \text{advective source-and-sink terms for the five constituents}; and \(c_{ij} = \text{biochemical parameters, some of them being calibrated and varying with temperature, some others being calculated at each time step (see Reda (1996) and Table 1 for more details).} \)

Calibration of the biochemical model requires the identification of 19 parameters in addition to \(n_r\), the number of tanks per reach, that must be chosen so that both flow and solute concentrations are acceptably matched with the available observations. The biological model in its original form was not calibrated to compute DO concentrations lower than 3 g/m\(^3\). However such low DO concentrations can occur in rivers following storm events and this situation can be magnified by the wide ranges of parameters used in the uncertainty analysis. In order to compute water quality during low DO concentration periods, the structure of the model was modified to include a term of the form \([x/(K+x)]\), where \(x\) is the DO concentration, to restrain BOD decay, nitrification, algal respiration and algal growth processes according to the DO concentration.

Reda (1996) has calibrated the CSTR model on a 10.2 km stretch of the River Cam, based on 145 days of data collected during the summer and autumn of 1975. This stretch, receiving WWTP effluents and combined sewer overflows (CSO) from a population of about 100,000, is divided into eight reaches. Along those reaches, the bottom slope is of the order of 0.01% and the average width varies between 20 and 30 m. The discharge flow observed downstream
the stretch is around 2 m$^3$/s in dry-weather while it can go up to 4 m$^3$/s in wet-weather conditions. Figure 1 shows the longitudinal profile of this river stretch.

The control strategies

The stormwater control strategies to be assessed were developed and simulated by Lessard (1989) on the Norwich-Whitlingham treatment plant (UK), based on flow and rain measurements of two storm events, one of short duration and high intensity (storm 1) and one long-lasting event of lower intensity (storm 2). The resulting outputs were adapted by Reda (1996) to be used as inputs in the CSTR model of the River Cam. The seven strategies are numbered as below for further reference:

- **BC01**: Treatment of all flows less than 3 × dry weather flow (DWF); overflow from plant inlet to the river.
- **SC01**: Treatment up to 3.5 × DWF; overflow from plant inlet to the river.
- **SC02**: Treatment up to 4 × DWF; overflow from plant inlet to the river.
- **SC03**: Primary treatment of all flows; secondary up to 3 × DWF, and overflow from aerator inlet to the river.
- **SC04**: Storm tank for flows higher than 3 × DWF in fill-and-treat mode at plant inlet.
- **SC05**: Storm tank in fill-and-treat mode after primary clarifiers; primary treatment for all flows and secondary for up to 3 × DWF.
- **DC02**: Step-feed process in the aerator (on-line storage of microorganisms) with storm tank as in SC04.

The criteria and ranking methods

The impact of the strategies on the river water quality is estimated by the peak Amm-N concentration in the river and by the duration for which DO concentration remains below 4 g/m$^3$, both at the Bottisham Lock location. Examples of distributions for the two ranking criteria according to BC01 and SC05 control strategies are shown in Figures 2 and 3. These graphs show that the strategies are more distinct when the comparison is made using the Amm-N rather than the DO criterion; this is also noted for the other storm event and river scenario.

For each storm event and river scenario, the WWTP control strategies are ranked according to the two previous criteria using four different ranking methods and are finally...
compared to the results obtained by Reda (1996), who previously ranked the control strategies without considering the parameters uncertainties. The four ranking methods used are as follows. The best strategy is first considered to be the one leading to the lowest mean value of the criteria over the 500 Monte Carlo simulations (the “mean” ranking method) and the strategy conducting to the lowest maximum value simulated (the “maximum” ranking method). The two other classifying methods take into account the distribution functions of occurrence of the criteria over the 500 simulations. One considers the best strategy to be the one leading to the lowest value of the mean added to the standard deviation of the criteria over all simulations (the “mean+stdev” method), while the other method is derived from the methodology developed by Tung et al. (1993) to assess and rank water resource projects in the presence of uncertainties (the “SD tests” method).

This last method, in a form adapted for our stormwater control strategies ranking problem, consists of two tests performed successively: the first-degree and second-degree stochastic dominance tests. The first-degree stochastic dominance (FSD) test checks if the value of the cumulative density function (CDF) of a ranking criterion for a control strategy \( j \) is monotonically superior than or equal to that of a strategy \( i \), over the possible range of the random criterion values for the two strategies. Compliance to this condition would lead to a conclusion that project \( j \) dominates project \( i \) from the FSD test. As an example, if the CDF of strategy \( j \) in Figure 4 was always higher than the CDF of strategy \( i \), this would mean that lower probabilities of leading to higher Amm-N peaks are linked to strategy \( j \). This strategy would then be considered as a better strategy than strategy \( i \) according to the Amm-N peak criterion.

If the FSD test is indecisive, which occurs when the CDF curves for the strategies to be compared cross within the possible range of the random criterion values, the second-degree...
stochastic dominance (SSD) test must be performed. This second test assumes that the decision-maker is risk-averse. To carry out this test, cumulated difference in area between the two CDFs of the random values of a criterion for strategies \( i \) and \( j \) is calculated. The non-negative cumulative difference for all values of the criterion indicates that strategy \( i \) is dominated by strategy \( j \) in the SSD test. Mathematically, this would mean that project \( j \) dominates project \( i \) if:

\[
\partial F_{ji}^{(2)}(y) = \int_{-\infty}^{y} \left[ F_i(z) - F_j(z) \right] dz = \int_{-\infty}^{y} \partial F_{ji}^{(1)}(z) dz \geq 0
\]

where \( F_x(y) \) = the CDF of the ranking criterion for strategy \( x \). Graphically, the SSD test is illustrated in Figure 4.

On this graph, if the area B is larger than or equal to the area A, strategy \( j \) dominates strategy \( i \) in the SSD test sense. If the CDFs cross more than one time within the possible range of the criterion values, the SSD test do not yield a decision on which strategy to prefer. The SD tests ranking method is then non conclusive. The evaluation procedure made of the FSD and SSD tests is used for ranking purposes by applying the two tests to all possible pairs of strategies.

The Monte Carlo simulations

Monte Carlo simulations were conducted for each of the seven control strategies, for the two storm events (storms 1 and 2) and for two river scenarios of different upstream and initial conditions (the dry and extradry scenarios). Every simulation consisted of 500 runs, with parameters selected randomly from the ranges presented in Table 1, assuming a uniform distribution. These ranges were selected from values reported in the literature (Scavia, 1980; Bowie et al., 1985; Reda, 1996). In Table 1, parameters varying with temperature are denoted \( c_{ij}(T_B) \) and are calculated at each time step according to Arrhenius expression:

\[
c_{ij}(T) = c_{ij}(T_B) \theta_j^{(T-T_B)}
\]

where \( T \) = temperature in °C; and \( T_B \) = base temperature (20°C for \( c_{21}, c_{31}, c_{41}, c_{51}, c_{61}, c_{62} \) and 16°C for \( c_{54} \)).

Results

Figure 5 gives an example of simulation results obtained with BC01 strategy’s inputs, storm #1 and the dry river scenario. This figure clearly shows the BOD and Amm-N peaks as well as the DO decrease generated by the combined sewer overflow and the degraded effluent of the treatment plant during the rain event (around hour 20); the other simulations exhibit the same curve shapes.

To determine if the ranking of control strategies is sensitive to the ranking method used, we first compare the results obtained with each method, for all the river scenarios and for the two ranking criteria. We observe that the results are never sensitive to the ranking method employed for the four best strategies, except when using the DO criterion with the extradry river scenario. Table 2 shows an example of ordering results. We notice in this Table that ranking of the four best strategies is always the same even when parameter uncertainty is not taken into account (Reda’s ranking method).

To fully take into account the distribution functions of the criteria values, the SD tests ranking method is selected to perform the subsequent analyses, which consist of finding if the classification of strategies is sensitive to ranking criteria and to simulation scenarios (see Tables 3 and 4 for examples of ordering results). As to this last basis, we find that ranking of the four best strategies according to Amm-N criterion (SC05, SC04, SC03 and
Table 1 Ranges of parameters selected for the Monte Carlo simulations

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Range</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fd</td>
<td>dead fraction</td>
<td>0.2 – 0.4</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>h</td>
<td>Added depth</td>
<td>0.08 – 1.6</td>
<td>m</td>
</tr>
<tr>
<td>c21(TB)</td>
<td>Overall BOD decay rate</td>
<td>0.05 – 1.5</td>
<td>d⁻¹</td>
</tr>
<tr>
<td>θ1</td>
<td>Arrhenius constant</td>
<td>1.01 – 1.15</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>c22(TB)</td>
<td>BOD due to dead algal mass</td>
<td>0.1 – 0.8</td>
<td>gBOD/mgChla</td>
</tr>
<tr>
<td>c31(TB)</td>
<td>Nitrification rate</td>
<td>0.04 – 1.3</td>
<td>d⁻¹</td>
</tr>
<tr>
<td>θ2</td>
<td>Arrhenius constant</td>
<td>1 – 1.1</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>c32</td>
<td>Yield coefficient for N uptake by algae</td>
<td>0.002 – 0.15</td>
<td>gN/mgChla</td>
</tr>
<tr>
<td>c33</td>
<td>N-uptake distribution</td>
<td>(c32x2)/(c32x2+x4)</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>θ34</td>
<td>Preference coefficient for uptake of Amm-N over NO₃-N</td>
<td>1.5 – 2</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>c41(TB)</td>
<td>Denitrification rate</td>
<td>0.002 – 1</td>
<td>d⁻¹</td>
</tr>
<tr>
<td>θ41</td>
<td>Arrhenius constant</td>
<td>1.02 – 1.09</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>c51(TB)</td>
<td>Reaeration rate</td>
<td>7 u⁰.⁶⁰⁷/h¹.⁶⁸⁹ to 11 u⁰.⁶⁰⁷/h¹.⁶⁸⁹</td>
<td>d⁻¹</td>
</tr>
<tr>
<td>θ51</td>
<td>Arrhenius constant</td>
<td>1 – 1.05</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>c52</td>
<td>DO saturation concentration</td>
<td>14.652 – 0.41002T + 0.007991T² – 0.00077777T³</td>
<td>g/m³</td>
</tr>
<tr>
<td>c53</td>
<td>Rate of photosynthesis DO production by algae</td>
<td>c55 ᵗ₀.⁵ to c55 ᵗ₀.⁸</td>
<td>gDO/(mgChla·d)</td>
</tr>
<tr>
<td>c54(TB)</td>
<td>rate of DO consumption through algal respiration</td>
<td>0.005 – 0.6</td>
<td>gDO/(mgChla·d)</td>
</tr>
<tr>
<td>θ54</td>
<td>Arrhenius constant</td>
<td>1 – 1.06</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>c55</td>
<td>Factor in the relationship between I and photosynthetic DO production</td>
<td>0.003 – 0.01</td>
<td>non-homogeneous relationship</td>
</tr>
<tr>
<td>c61(TB)</td>
<td>Maximum algal-growth rate</td>
<td>0.2 – 2</td>
<td>d⁻¹</td>
</tr>
<tr>
<td>θ61</td>
<td>Arrhenius constant</td>
<td>1 – 1.1</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>c62(TB)</td>
<td>rate of algal mortality</td>
<td>c61/8</td>
<td>d⁻¹</td>
</tr>
<tr>
<td>θ62</td>
<td>Arrhenius constant</td>
<td>1 – 1.1</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>c65</td>
<td>algal self-shading coefficient</td>
<td>-0.2 – -0.001</td>
<td>m²/mgChla</td>
</tr>
<tr>
<td>c66</td>
<td>half-saturation constant in the relationship between I and c67</td>
<td>20 – 40</td>
<td>cal/(cm²·d)</td>
</tr>
<tr>
<td>c67</td>
<td>effective algal-growth rate</td>
<td>(c61IE⁻c65x6)/(IE⁻c65x6+C66)</td>
<td>d⁻¹</td>
</tr>
</tbody>
</table>

Definitions: h: river depth (m); I: solar irradiance (cal/(cm²·d)); T: water temperature (ºC); u: average stream velocity (calculated by the model)

Table 2 Ranking according to Amm-N criterion for storm #1 and dry river scenario

<table>
<thead>
<tr>
<th>Ranking method</th>
<th>BC01</th>
<th>SC01</th>
<th>SC02</th>
<th>SC03</th>
<th>SC04</th>
<th>SC05</th>
<th>DC02</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>4</td>
<td>6</td>
<td>7</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Maximum</td>
<td>4</td>
<td>5</td>
<td>7</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Mean + stdev</td>
<td>4</td>
<td>6</td>
<td>7</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>SD tests</td>
<td>4</td>
<td>6</td>
<td>7</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Reda</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 3 Ranking according to Amm-N criterion and the SD tests method

<table>
<thead>
<tr>
<th>Scenario</th>
<th>BC01</th>
<th>SC01</th>
<th>SC02</th>
<th>SC03</th>
<th>SC04</th>
<th>SC05</th>
<th>DC02</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry scenario and storm #1</td>
<td>4</td>
<td>6</td>
<td>7</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Dry scenario and storm #2</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Extrady scenario and storm #1</td>
<td>4</td>
<td>6</td>
<td>7</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>
BC01) and of the two best strategies according to DO criterion (SC05 and SC04) is constant, except once again when using the DO criterion with the extradry river scenario. Ranking is therefore sensitive to the ranking criterion applied, but only for the less favorable strategies.

These results show that, in that particular case study, ranking is robust in the face of uncertainty in the parameter values, at least for the superior strategies SC05 and SC04. However, ranking the strategies according to the DO criterion was a laborious task, the calculation of DO concentration being highly uncertain.

**Conclusion**

The first objective of this paper was to estimate if uncertainties linked to the parameters of a river water quality model could affect the ranking of stormwater control strategies

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**Table 4** Ranking according to the SD tests method for storm #1 and dry river scenario

<table>
<thead>
<tr>
<th>Ranking criterion</th>
<th>BC01</th>
<th>SC01</th>
<th>SC02</th>
<th>SC03</th>
<th>SC04</th>
<th>SC05</th>
<th>DC02</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration DO</td>
<td>6</td>
<td>7</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Peak Amm-N</td>
<td>4</td>
<td>6</td>
<td>7</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>

**Figure 5** Simulation results at Bottisham Lock for storm #1 and dry scenario according to BC01 control strategy
according to river water quality criteria. Reda and Beck (1997) had previously pointed out this issue by performing a sensitivity analysis on some parameters of the model. However, the analysis performed here is more complete since it takes into account the uncertainties of all parameters of the model and their entire possible ranges of values. It led to the conclusion that, in that particular case study, ranking is robust in the face of uncertainty in the parameter values, but only for the control strategies considered as being superior in terms of river water quality impacts.

This paper was also meant to demonstrate the usefulness of the SD tests ranking method of Tung et al. (1993) to rank stormwater control strategies under uncertainty according to water quality criteria. This ranking method was initially developed to estimate the economic value of water resources projects whose benefits and costs are uncertain. To our knowledge, it has never been employed to evaluate the impacts of uncertainty in model parameters neither using water quality criteria. We recognized its utility in that context and this leads us to assume that it could be applied to include uncertainty aspects in any water system analysis.

Concerning the insensitivity of ranking in face of parameters uncertainty, we should keep in mind that this conclusion is valid only for this particular case; a choice of control strategy should not be taken before a more thorough analysis, considering uncertainties in model formulation and inputs, is performed. Not only uncontrollable inputs such as sewer and river flows should be considered as uncertain, but also those that can be manipulated, namely the alternative control strategies. Indeed, we could never be entirely confident that the strategies would actually perform as stated by the WWTP model, which is all the more true for more complex strategies as SC05 or DC02. The WWTP discharges and sewer overflows should then be regarded as uncertain, by selecting them randomly for each Monte Carlo simulation from ranges having as mean value the value simulated by the WWTP model, and being wider for the more uncertain strategies.

Finally, when selecting the control strategy to establish, technical as well as economical criteria would also have to be considered along with the river water quality criteria, thence the importance of ranking the control strategies instead of exclusively selecting the best of them, in order to have as much information as we can to make an advised decision.

References


