ESTIMATION OF STORM WATER QUALITY CHARACTERISTICS AND OVERFLOW LOADS FROM TREATMENT PLANT INFLUENT DATA

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ABSTRACT.

A simple model, based on tanks in series, for the estimation of mean annual loads and frequency distributions of loads from combined sewer systems is presented. The input data, dry weather flow, dry weather quality, and storm water quality are estimated from treatment plant influent data. Two similar methods for the estimation of flow-average storm water quality were tested by using treatment plant influent data generated by the model in comparison with the model input. Both methods are based on daily mass balances, but differ slightly with respect to the averaging procedures used. The performance of both methods is about the same. They show a small bias, but the variability introduced is small when compared with the variation occurring in real storm water quality data. Application of one of the methods on field data revealed no distinct relationships between the flow-averaged storm water quality concentration and the dry weather period or the total daily rain depth. By combination of continuous and Monte Carlo simulation techniques the model can be used to estimate mean annual loads and frequency distribution of loads from combined sewer overflows. For the extreme events a large 90% confidence interval was found due to the large variations in storm water quality.

KEYWORDS.

Combined sewer overflows; Continuous Simulation; Monte Carlo Simulation; Estimation of Storm Water Quality.

INTRODUCTION.

The statistical properties of urban storm water pollutants are very important for the description of their impact upon receiving water bodies. Depending on the rates of the underlying processes in the receiving water, the mean annual load (for slow processes) or the frequency distribution of the loads (for high rate responses) should be known in order to evaluate the effect upon the receiving waters (Hvitved-Jacobsen, 1986, Aalderink et al., 1985 and Lijklema et al., 1988). Due to the stochastic nature of storm events, the assessment of the magnitude and characteristics of urban runoff loads is not easy. Intensive measurement of flows and direct sampling of overflow concentrations are needed. Long records of measured loads are required to estimate average annual loads or the statistics of extreme events. An alternative for this time-consuming task is the use of storm water quality models. An estimation of the statistical characteristics of the pollutant loads can be obtained by either a statistical or a deterministic approach. The statistical approach, in which the distribution of the characteristics of the rainfall (intensity, duration, volume and antecedent dry weather period) are transformed directly to the distribution of the detrimental effects, has been tested by van der Heijden et al. (1986). Benoist (1989) showed that this methodology is not promising, due to the correlation that exists between the input variables used in the transformation models (i.e. intensity and duration of rain storms). The deterministic approach has been applied in several pollution emission models developed so far.
This paper discusses the complications of applying existing storm water quality models on Dutch sewer systems. An alternative simple approach will be presented that is more suitable for Dutch conditions. A method to estimate the quality input variables for this model from the analysis of treatment plant influent data will be demonstrated and an application of the model will be shown. Special attention will be paid to the stochastic properties of the quality under dry and wet weather conditions.

CONTINUOUS MODELLING OF STORM WATER QUALITY.

Well known and widely applied storm water quality models are, for example the EPA's Storm Water Management Model (Huber et al., 1981) and the model SAMBA (Johansen, 1984), a module of the Danish MOUSE package. Frequency distributions and mean annual loads are obtained using continuous simulation techniques. Historical time series of rain data are used as the input of these models and the statistics of the resulting loads are determined. The two models mentioned above differ completely in the level of detail used in the description of the runoff quality. In SWMM a very detailed description has been used, incorporating processes such as accumulation of pollutants on the impervious area, the wash off of constituents and settling and scour of suspended solids in the sewer system. The calibration of a model based on a detailed deterministic description is difficult. A great number of unknown parameters should be estimated. Calibration is generally performed on a limited number of single events (Maalel et al., 1984) and followed by continuous simulation. Such a calibration on a few events may lead to serious errors, because a considerable variation is found in the parameters due to the inherent randomness introduced by the hydrological and other factors (Huber, 1987).

The SAMBA model is based upon a simple approach. A simple mixing model for storm water runoff and dry weather flow is used, with a fictional storm water quality that represents the pollutant wash off from the catchment and the interceptor scour. Hence the model uses a constant value for dry weather flow and quality and for storm water quality it is used as well.

The results of a comprehensive nationwide study in the Netherlands (Gast, 1988) however, show a large variation in the observed concentration of the runoff quality. No distinct relationships were found between the quality and the characteristics of the storms, only a weak correlation was found between the mean event concentration and the maximum inflow intensity during 30 minutes. This lack of correlation can be explained by the typical situation in the Netherlands. The Dutch sewer systems are exceptionally flat and large conduits are being used to increase the storage in the system. During dry weather flow settling of suspended solids and associated pollutants will occur. High flow velocities during storm events will cause resuspension and flushing of conduits in some parts of the system, but the pollutant plug may not always reach the outfall during the event. During the next event, which may be small, this plug can be discharged. Such phenomena can explain the large variation in storm water quality and the fact that no distinct relationships have been found between, for example, the preceding dry weather period and the mean event concentration. Hence a detailed deterministic approach is not considered appropriate for the Netherlands and that is why we have chosen a simple description similar to the one used in SAMBA. The developed model incorporates the variations in dry weather flow and storm water quality and is outlined in the next section.

MODEL CONCEPT.

The storage in the Dutch sewer systems is large due to the large diameters of the conduits used. Hydraulic gradients are small and most systems are essentially networks with several loops. Hence backwater effects and flow reversal during wet weather conditions are normal phenomena in most systems. This means that flow routing methods like the modified time area approach used in the Samba model or the kinematic wave method used in the SWMM TRANSPORT block (Huber, 1983) are less appropriate. For both methods, the flow directions have to be fixed. Particularly in the case where an overflow structure is not situated in the main trunk, but somewhere upstream in the system, this will lead to serious problems and the schematisation of the system must be adapted.
For the dynamic simulation of these systems a dynamic pipe flow model, based upon the full St Venant equation must be used. However, this method is very time consuming and hence less suitable for continuous simulation techniques. For this reason a simple approach is used. The sewer system is described as a number of tanks in series. The storage capacity equals the internal storage of the part of the system represented by the tank and the interceptor capacity is equal to the capacity of the conduit connecting the tank to a downstream tank or to the pumping capacity. For each tank the following equations apply:

\[Q_{\text{out}}^{i}(t) = \text{MIN}(Q_{\text{in}}^{i}(t) + (V^{i}(t) - V_{\text{d}}^{i})/dt; Q_{\text{t}}^{i})\]  \hspace{1cm} (1)

\[Q_{\text{in}}^{i}(t) = Q_{\text{d}}^{i}(t) + A^{i} \cdot R \cdot I(t) + \sum_{j=1}^{n} Q_{\text{out}}^{i-1}(t)\]  \hspace{1cm} (2)

\[Q_{\text{out}}^{i}(t) = Q_{\text{in}}^{i}(t) - Q_{\text{out}}^{i}(t) - dV^{i}/dt\]  \hspace{1cm} (3)

\[dV^{i}/dt = \text{MIN}((V_{\text{max}}^{i}-V^{i}(t))/dt; Q_{\text{in}}^{i}(t) - Q_{\text{out}}^{i}(t))\]  \hspace{1cm} (4)

\[V^{i}(t+dt) = V^{i}(t) + dt \cdot dV^{i}/dt\]  \hspace{1cm} (5)

\[t, V_{\text{d}}, V_{\text{max}}^{i}\] volume, min. volume left and storage in tank i (m³)
\[Q_{\text{in}}^{i}, Q_{\text{out}}^{i}\] total inflow and outflow tank i (m³/s)
\[Q_{\text{d}}^{i}\] dry weather flow and overflow discharge (m³/s)
\[A^{i}\] interceptor capacity (m³/s)
\[R, I(i)\] connected impervious area (ha), runoff coefficient (-)
\[t, n\] time step of calculation, number of upstream tanks

If the inflow into the tank is greater than the interceptor capacity then the tank starts to fill up. When the storage capacity is exceeded the overflow starts to function. If the inflow becomes smaller than the capacity of the interceptor, the stored volume is emptied into the interceptor. This concept is illustrated in fig 1, which is a schematisation of the sewer system of Chaam, a village in the South of the Netherlands.

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**Fig. 1.** Schematisation of the sewer system of Chaam, using a tank in series model.

This schematisation has been derived by comparison with the results of a dynamic simulation of the real sewer system, using a design storm of constant intensity. Upon examination of the output, the total system was divided into 3 tanks. From a water balance for each tank the connected impervious area was calculated and the storage capacity was determined as the volume of water in the system at the crest level of the weir within the tanks.

The quality part of the model is based on a simple mixing model, like the one used in the SAMBA model (Johansen, 1985). For each tank the following equation holds:

\[dC^{i}/dt = Q_{\text{d}}^{i}(t) \cdot C_{\text{d}}^{i}(t) + Q_{\text{s}}^{i}(t) \cdot C_{\text{s}}^{i}(t) + \sum_{j=1}^{n} Q_{\text{out}}^{i-1}(t) \cdot C^{i}(t) - Q_{\text{out}}^{i}(t) \cdot C^{i}(t) - dV^{i}/dt\]  \hspace{1cm} (6)

\[C^{i}\] concentration in tank i (g/m³)
\[C_{\text{d}}^{i}\] dry weather and storm water quality (g/m³)
\[Q_{\text{s}}^{i}\] storm water inflow into tank i (m³/s)
The dry weather flow and quality and the storm water quality are the main input variables of the model. In the next two sections a method for the assessment of these input variables from treatment plant influent data is presented.

ANALYSIS OF DRY WEATHER FLOW AND QUALITY.

A historical record of 6 years of treatment plant influent data has been analyzed. The volume of sewage treated per day was recorded every day. Flow-weighted samples of the influent to the treatment plant were taken every two weeks. A daily composite sample was taken on two succeeding days. The sampling was done on different days of the week, including weekends. The daily total rain depth was measured also. From the total record the dry weather flow conditions were selected. The daily flow was considered to represent dry weather flow if the total rain depth on that day and the day before was less or equal to 3 mm.

Table 1 shows some characteristics of the dry weather flow quality. The variation in the suspended solids concentration is high. For chloride the variation is much smaller. The large variability in the suspended solids and related constituent concentrations can be explained by the inhomogeneity of the waste water, which renders representative sampling difficult. There is no significant correlation between the flow rate and the constituent concentrations. All correlation coefficients are less than 0.1. The average concentration and the median value are for all variables (except for suspended solids) about the same, which means that the distributions are not very skewed. A D'Agostino test (Gilbert 1987) on normality showed for all constituents, except for suspended solids, that the data can be described by a normal distribution at a 90 % significance level.

Table 1. Statistical characteristics of the dry weather flow quality

<table>
<thead>
<tr>
<th>Sample size</th>
<th>COD mg/l</th>
<th>BOD mg/l</th>
<th>Kj-N mgN/l</th>
<th>Tot-p mgP/l</th>
<th>Cl mg/l</th>
<th>SS mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>122</td>
<td>125</td>
<td>118</td>
<td>119</td>
<td>110</td>
<td>116</td>
</tr>
<tr>
<td>Median</td>
<td>755</td>
<td>278</td>
<td>72.1</td>
<td>17.8</td>
<td>93</td>
<td>392</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>147</td>
<td>59</td>
<td>12.8</td>
<td>4.2</td>
<td>8</td>
<td>192</td>
</tr>
<tr>
<td>Coeff. of variation</td>
<td>0.19</td>
<td>0.21</td>
<td>0.18</td>
<td>0.24</td>
<td>0.09</td>
<td>0.49</td>
</tr>
<tr>
<td>Correlation between flow and quality</td>
<td>-0.08</td>
<td>-0.01</td>
<td>-0.10</td>
<td>-0.09</td>
<td>0.10</td>
<td>-0.07</td>
</tr>
</tbody>
</table>

A nonparametric Mann-Kendall test showed that the flow rate has no significant trend. No seasonality on a monthly scale was found. However the data show a significant variation within a week (fig. 2). On Mondays the average flow is somewhat higher than during the rest of the week, and during the weekends the daily treated volume is much less. The variation in the daily flow is about the same for all days of the week. A test on normality on the flow data showed that the daily treated volume on a certain day could be described as normally distributed.

Fig. 2. Daily variation of dry weather flow.
The analysis of the dry weather data should be considered as an example data analysis protocol, resulting in the statistical properties of the dry weather flow and quality, which can be incorporated in the model described above and in the estimation method for the storm water quality outlined in the next section. The data should be tested on trends and seasonality. Average concentrations and standard deviations should be calculated and the data must be described by some distribution function.

**ESTIMATION OF STORM WATER QUALITY.**

Mueller and Anderson (Mueller et al., 1979) presented a method for the estimation of combined sewer runoff and overflow characteristics from treatment plant data. They used a daily mass balancing technique, dividing the day into a wet and dry period. Applying a flow and mass balance over both periods they estimated the flow-weighted runoff and overflow concentrations. Irrespective of whether the system is overflowing or not, a mass balance during the wet period yields:

\[ C_{S,w} Q_{S,w} + C_{D,w} Q_{D,w} = C_{ovf,w} (Q_{S,w} + Q_{D,w}) \]  

(7)

The index \( w \) refers to the wet period.

The use of eq. 7 implies that the net storage of water over a day can be neglected and that the overflow concentration, if occurring, is equal to the influent concentration of the treatment plant. Integration of eq. 7 over a day period and assuming that the dry weather flow is fairly constant within a day results in two models depending on the sampling strategy followed at the treatment plant. If flow weighted sampling is used the overflow concentration can be obtained from:

\[ \bar{C}_{ovf} = \frac{\bar{C}_{P} V_P - \bar{C}_{D} (1-\alpha) V_D}{V_P (1-\alpha) V_D} \]  

(8)

\( \bar{C}_{P}, \bar{C}_{D} \) flow-weighted overflow, treatment plant and dry weather flow concentration (g/m³)

\( V_P, V_D \) total daily treated volume, daily dry weather volume (m³)

\( \alpha \) wet fraction of the day (-)

Using eq. 7 for both sampling strategies the equation for the runoff concentration yields:

\[ \bar{C}_{S} = \bar{C}_{ovf} + \frac{\alpha V_D}{V_S} (\bar{C}_{ovf} - \bar{C}_{D}) \]  

(9)

\( \bar{C}_{S} \) flow-weighted storm water concentration (g/m³)

\( V_S \) total storm water volume (m³)

Mueller and Di Toro (Mueller et al., 1981) tested the method on the data of the 26th Ward Treatment Plant of the New York City Environmental Protection Agency. They used a simple model for the sewer system and generated a long time series of treatment plant data. An equal volume composite sampling strategy was applied, similar to the one used at the treatment plant. Samples were taken 5 times a day and the results of the daily mass balance method were compared with the input of the model. The results showed a significant bias for the estimated runoff concentration and the variation in the estimated concentration was rather prominent. The coefficient of variation was about 1.

The same method was used in this study. The model described by eq. 1 to 6 was applied to the sewer system of Chaam. A constant storm water quality BOD concentration of 100 mg/l and the characteristics of the dry weather flow and BOD concentration were used (see table 1). A 12 year historical time series of 5 minute rain data was used as an input to the model. For the purpose of the test the runoff coefficient was set equal to 1. The estimates of the BOD storm water concentration using eq. 9 were compared with the input concentration of 100 mg/l. To investigate the sensitivity of the method for variations in dry
weather flow and quality, the standard deviations of flow and concentration were varied. The results are presented in table 2.

The estimates show a small positive bias and the variation is much smaller than was found in the study by Mueller and Di Toro, which might be expected, because the flow proportional sampling takes better account of the variation in flow within the day. The standard deviation of the results decreases strongly if the days with small rain depth are excluded from the analysis. The additional variability introduced by including the variable dry weather flow and quality is small when compared with the variability innate to the method. This inherent variability is due to the errors made by neglecting the net stored volume over a day and the fluctuation of the flow within a day.

Table 2. Estimated Storm water BOD concentrations, using the method of Mueller and Di Toro.

<table>
<thead>
<tr>
<th>Assumed variations in dry weather flow and quality</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>STD BOD 0 mg/l</td>
<td>STD BOD 30 mg/l</td>
<td>BOD 60 mg/l</td>
</tr>
<tr>
<td>Min. rain depth analyzed in mm</td>
<td>STD QD 0 m3/min</td>
<td>STD QD 0.028 m3/min</td>
<td>QD 0.056 m3/min</td>
</tr>
<tr>
<td>3 (852)</td>
<td>105.8 16.2</td>
<td>105.5 18.1</td>
<td>105.3 21.5</td>
</tr>
<tr>
<td>5 (547)</td>
<td>105.9 12.7</td>
<td>106.1 14.2</td>
<td>106.1 16.7</td>
</tr>
<tr>
<td>7 (386)</td>
<td>105.6 10.6</td>
<td>105.9 11.8</td>
<td>106.1 13.7</td>
</tr>
<tr>
<td>10 (212)</td>
<td>104.6 8.4</td>
<td>105.0 9.1</td>
<td>105.3 10.4</td>
</tr>
</tbody>
</table>

The method of Mueller and Di Toro requires information on the wet period of the day. For most Dutch locations only the daily rain depth is on record at the treatment plant and no information on the wet fraction of the day is available. Hence a more simple approach was tested as well, which requires information on the daily rain depth only.

Integration of eq. 6 for 1 tank over a day yields:

\[ D(V*C) = V_oC_o + V_sC_s + V_rC_r - V_{orf}C_{orf} \]  \hspace{1cm} (10)

\[ D(V*C) \] the net storage of mass over a day

If no overflow occurs and the net storage over a day is neglected eq. 10 yields:

\[ \bar{C}_s = \frac{V_rC_r - V_oC_o}{V_p - V_o} \]  \hspace{1cm} (11)

The difference between eq. 11 and the method of Mueller and Di Toro is that in eq. 11 no distinction between dry and wet periods is made. A flow and mass balance is applied over the whole 24 hour period. Eq. 11 was applied on the same data generated by the model. The results are summarised in table 3.

Table 3. Estimated Storm Water BOD concentration, using the simple method.

<table>
<thead>
<tr>
<th>Assumed variations in dry weather flow and quality</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>STD BOD 0 mg/l</td>
<td>STD BOD 30 mg/l</td>
<td>BOD 60 mg/l</td>
</tr>
<tr>
<td>Min rain depth analyzed in mm</td>
<td>STD QD 0 m3/min</td>
<td>STD QD 0.028 m3/min</td>
<td>QD 0.056 m3/min</td>
</tr>
<tr>
<td>3 (852)</td>
<td>105.1 13.8</td>
<td>104.0 18.7</td>
<td>104.1 21.6</td>
</tr>
<tr>
<td>5 (547)</td>
<td>104.4 10.1</td>
<td>103.9 14.0</td>
<td>104.0 16.0</td>
</tr>
<tr>
<td>7 (386)</td>
<td>103.5 8.0</td>
<td>103.4 10.6</td>
<td>103.6 11.2</td>
</tr>
<tr>
<td>10 (212)</td>
<td>101.8 6.6</td>
<td>102.4 8.0</td>
<td>102.6 8.6</td>
</tr>
</tbody>
</table>
Again the estimates show some positive bias, which decreases when days with small rain depth are omitted. The variations are somewhat smaller than found in the method of Mueller and Di Toro. Both methods show about the same performance. The standard deviation of the estimates is in the order of 9% when the variability of the dry weather flow is considered. This is small when compared with the natural variations expected in the storm water quality. These errors even may be small with respect to the measurement errors. Both methods show a small positive bias, which should not be considered to be a problem.

APPLICATION ON REAL DATA.

The method represented by eq. 11 was applied on the 6 year record of treatment plant data. To reduce the variability introduced by the method, only days with a total rain depth of 7 or more mm were included in the analysis. The results are shown in table 4.

Table 4. Estimated storm water quality from historical treatment plant data. Days with a total rain depth less than 7 mm are omitted.

<table>
<thead>
<tr>
<th></th>
<th>COD (mg/l)</th>
<th>BOD (mg/l)</th>
<th>Kj-N (mg/l)</th>
<th>Tot-P (mg/l)</th>
<th>Cl (mg/l)</th>
<th>SS (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean concentration</td>
<td>462</td>
<td>120</td>
<td>27.7</td>
<td>5.1</td>
<td>47.2</td>
<td>299</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>258</td>
<td>71</td>
<td>11.8</td>
<td>2.1</td>
<td>12.1</td>
<td>168</td>
</tr>
<tr>
<td>Coeff. of variation</td>
<td>0.56</td>
<td>0.59</td>
<td>0.43</td>
<td>0.42</td>
<td>0.26</td>
<td>0.56</td>
</tr>
<tr>
<td>Number of samples</td>
<td>27</td>
<td>29</td>
<td>24</td>
<td>23</td>
<td>25</td>
<td>29</td>
</tr>
</tbody>
</table>

The results show large variations in the estimated runoff concentrations. For suspended solids and related constituents, the variations are largest, but for Chloride a smaller coefficient of variation is found. Compared with the errors made by the method of analysis (table 3) the variability in the real data is much higher. Although the number of samples is small, we checked for relationships between the storm water concentration and the dry weather period. No distinct correlation was found. Further, no relationship between the daily rain depth and the storm water concentration seemed to exist. This shows the true stochastic nature of the runoff quality. In particular, the high variability for the suspended constituents shows that the runoff quality characteristics are controlled by stochastic processes and that a deterministic description of resuspension and sedimentation will be very complicated and not suitable for continuous simulation.

ESTIMATION OF OVERFLOW LOADS.

The model (according to eq. 1-6) was applied on the sewer system of Chaam. The 12 year 5 minute rain data record served again as an input to the model. A runoff coefficient of 0.8 was used and initially averaged values of dry weather flow, dry weather quality, and storm water quality were used. In total 104 overflow events occurred in the 140 month period. The mean annual loads for phosphorus and Kjeldahl nitrogen were calculated and the frequency distributions of the BOD load were determined. The results are given in table 4 and figure 3.

Table 4. Estimated mean annual overflow loads of total phosphorus and Kjeldahl Nitrogen for the sewer system of Chaam.

<table>
<thead>
<tr>
<th></th>
<th>Using model with average input variables</th>
<th>Using monte carlo simulations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean total P in kg P/y</td>
<td>20.0</td>
<td>20.0</td>
</tr>
<tr>
<td>Mean Kjeldahl N in kg N/y</td>
<td>104.4</td>
<td>104.4</td>
</tr>
</tbody>
</table>
To investigate the effect of the variability of the input variables the technique of continuous simulation was combined with Monte Carlo simulation. The statistical characteristics of the dry weather flow (fig. 2), concentration (table 1) and storm water quality (table 4) were used. Figure 3 gives the frequency distribution of the average BOD load for each event, resulting from 100 simulations. There is hardly any difference between the frequency distribution resulting from the simulation using the average conditions and the one resulting from averaging the Monte Carlo simulations. The 90 % confidence limits for these averages are also given. For the extreme events the 90 % confidence limits are very wide. This means that for events with a long return period the uncertainty in the BOD load is very high due to the great variability in the storm water quality. The influence of the variations of the input variables on the estimated mean annual loads is small. So, for this estimation the average values of the input variables can be used.

Fig. 3. Estimated frequency distribution of BOD load from the sewer system of Chaam (1 using average input variables, 2 average loads using monte carlo simulation, 3 90 % confidence interval for the average loads from the monte carlo simulations).

CONCLUSIONS AND DISCUSSION.

For flow-weighted composite sampling, the estimation method for the storm water quality introduced by Mueller et al. , 1982 and the simple method presented here both show about the same performance. Because detailed rain data are not available at most treatment plants in the Netherlands, only the simple daily mass balance technique can be used.

The method introduces a small bias ( < 2%) in the estimated storm water quality, which is not considered to be a problem. The variability introduced by the method is much smaller than the one found in real data. Application on real data did not reveal distinct relationships between flow-average runoff concentration and daily rain depth or antecedent dry weather periods.

Application of a combination of continuous and Monte Carlo simulation provides the opportunity to include the effects of the variability in the input variables into the statistical properties of the estimated loads. For this application no correlation between the input variables was found. If the analysis of the treatment plant data shows that there is a certain dependency between, for instance, the dry weather period and storm water quality, this dependency can be incorporated readily into the model framework. Also non-normal distribution functions for the stochastic behaviour of the input variables can be included without difficulty.

The model results show that the effect of the variability of the input variables on the mean annual loads is small, so average values can be used for the input variables and it is not necessary to run Monte Carlo simulations. For the estimations of the frequency distribution, the variability of the input
variable is reflected in the large uncertainty in the loads for the extreme events.

This study only presented one example of the method proposed. The results seem promising and the method can be used as a engineering tool for the assessment of the effects of combined sewer overflows upon receiving waters. A more systematic approach based on the model and the statistics of the input variables should be developed in order to assess the inherent errors of the method and relate them to the characteristics of the sewer system and the variations in dry weather conditions. Also, some more attention should be paid to the resulting variability of the overflow loads. The predicted statistics of the loads should be compared to measured overflow loads for one of the locations of the nationwide program on urban runoff performed in the Netherlands.

REFERENCES.


