Quantification of pollution loads from CSOs into surface water bodies by means of online techniques

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Abstract Based on novel technologies, a modular online monitoring station suitable for continuous application in sewer networks, wastewater treatment plants and receiving water bodies has been designed. The monitoring station serves as the backbone of a water quality pilot network. As one part of this network a sewer monitoring station has been installed at a combined sewer overflow in Graz to quantify pollution concentrations and loads in the combined sewer and into the receiving water and is operated since October 2002. The design and equipment of the measurement station and first operating experiences and results are given in this paper.

Keywords Combined sewer overflow; CSO control; pollution load; sewer monitoring; UV/VIS spectroscopy

Introduction

It is evident that combined sewer overflows (CSOs) are substantial contributors to the total emission into surface water bodies. The emitted pollution loads result not only from dry weather flow and surface runoff but also from the remobilisation of sewer deposits and sewer slime during stormwater events. Re-suspended deposits often cause the main part of the total pollution, but the processes which lead to remobilisation and prior to formation of sewer sediments are highly complex and can be described with limited accuracy only by deterministic models.

One reason for the remaining problems with regard to a dynamic description of these processes is the lack of dynamic data with sufficient quality for model calibration and validation. Since a lot of time and manpower has to be invested to quantify the emitted loads, often they are not measured but calculated based on flow simulation models and typical concentration values taken from literature. While sewer flow simulation models have been developed to a high standard already, the same does not hold for load quantification models.

In literature, a large number of investigations are reported which were targeted to quantify pollution discharges from sewer networks. Brombach and Fuchs (2003) compiled the results of a vast number of such monitoring campaigns. The result of their work is a unique collection and statistical analysis of global data on pollution concentration in four major components of the urban water pathway (dry weather conditions/wastewater, storm water runoff, combined sewer flow, combined sewer overflow). More than 3,000 studies were reviewed for the period from 1968 to 2001. After excluding all recitations, model results and studies without identified sampling sites 2,876 records were compiled into a new database. Statistical and graphical analyses were carried out for 20 parameters. This includes a table
listing the number of records found for stormwater runoff, dry and wet weather flow in
combined sewer systems and combined sewer overflows as well as the most statistical values
for both the worldwide database and a reduced database representing Central Europe. Due to
the high number of records in the database and the consideration of the different components
this database is surely unique although these data do not give an answer to the question which
value is to be taken for a specific site.

Macke et al. (2002) compared several German studies on the potential pollution load of
sewer networks of different topography. It was shown that the transported loads are smaller
in steeper networks since deposition is smaller during dry weather. However, it is difficult to
transfer the results of individual studies to other areas because of the interaction between the
already mentioned complex processes, like the formation and remobilisation of sewer
deposits especially during flow conditions which are likely to create backwater.

One of the most comprehensive measurement programmes to quantify the pollution loads
from combined sewer systems in central Europe was started in Braunschweig in 1988
(Macke et al., 1987 and Schulz, 1995) and is still going on. In the period from 1988 till 2000
nearly 500 stormwater events were investigated at three measurement locations by means of
automated spot sampling. Together with thirty-two 24-h-sampling campaigns during dry
weather conditions nearly 12,000 probes were analysed during this period. Thereby the main
focus was given to the parameters COD and TSS.

Till now only few measurement programmes are known that try to quantify the waste-
water concentrations in sewer systems directly by means of online techniques. Scheer and
Schilling (2003) give an overview regarding online measurements in sewer systems and
describe the possibilities and particular difficulties of measuring combined sewage quality in
sewers.

**Innovative technology for integrated water quality measurement**

In 2001 a research project with the title “Innovative technology for integrated water quality
measurement (IMW)” (Winkler et al., 2002a) was started in Austria. The research project is
carried out by three Austrian Universities in cooperation with a civil engineer. The main
focus of the project is the design and operation of an online water quality network which is
suitable to support decision making on a catchment scale.

Special emphasis was put on the uniform design of the monitoring stations which supports
a given set of sensors, measurement devices and aims at a consistent data collection. A
central database was designed to collect the data from all stations within the network and
process all data in a standard format. The telemetric network has two tasks: data will be
presented and continuously updated on a project homepage (http://www.imw.ac.at) and
remote control and maintenance on demand is possible.

**The modular water quality monitoring station**

The main goal for the design of the monitoring station was that the station can be applied in
surface water, sewers and WWTPs in a uniform assembly. The selection of the applied
sensors was based on the requirements of the different monitoring locations and experience
within the group concerning the reliability and precision of available sensors.

All the selected sensors are compact in size, can be installed submerged in the water and
do not require sample preparation or periodic refill of chemical reagents. All but one sensor
are equipped with an automatic cleaning system using pressurised air. Besides standard
parameters like dissolved oxygen, pH-value and conductivity focus is given on the contin-
uous monitoring of nutrients and organic compounds.

For ammonium monitoring an ion sensitive in-line sensor was chosen, since it is a
comparably low-cost sensor requiring relatively low maintenance when applied within a
WWTP (Rieger et al., 2002). At the start of the project, no experience with this sensor was available within the research group with respect to its application in sewer networks or surface water. An advantage of this sensor type is that two electrodes can be fitted into one probe head, which enables easy change to other ion-sensitive electrodes, like for example chloride, potassium or bromide.

For continuous monitoring of organic compounds a submersible UV/VIS-spectrometer is applied. Spectrometric measurement methods are defined for single substances (e.g. nitrate, nitrite, benzene, xylene and toluene) as well as for surrogate parameters (SAC, turbidity/suspended solids, CODeq, DOCeq, TOCeq). Surrogate parameters resulting from spectrometric measurements are indicated with an appendix “eq” which means equivalence. Experiences with this instrument have already been made through applications with river-bank filtrate (Staubmann et al., 2001) and at different measurement locations within wastewater treatment plants (Winkler et al., 2002b). An advantage of this instrument is that a large number of parameters – for example CODeq, DOCeq, TSS and nitrate – can be measured simultaneously with only a single instrument.

**Sewer monitoring station Graz**

The main project goal of this monitoring station is to evaluate the available sensor technology with respect to its applicability for continuous monitoring in sewer systems.

A first sewer monitoring station has been installed at a combined sewer overflow in Graz; another sewer monitoring station will be installed at a CSO in Vienna. The main goals of these sewer monitoring stations are:

- measurement of the frequency and duration of overflow events into the receiving water
- measurement of the pollution concentrations and loads into the receiving water
- monitoring the river water quality upstream the measurement location and the impact of upriver CSOs

The selected catchment in Graz serves a population of 13,000 inhabitants and has a total catchment area of 351 ha. The overflow channel of the CSO discharges in the river Mur which – at Graz – has an average flow of 117 m³/s.

Figure 1 shows the ground plan and the geometrical boundary conditions of the selected CSO-R05 in Graz with the inflow, the outflow and the overflow channel. The main collector from North to South of the city runs alongside the right river bank of the Mur. Unfortunately, this collector crosses right through the chamber which complicates access into the chamber since the passage height below the collector is only 70 cm. During the installation of the monitoring station some adaptations had to be made. For installation of the required cables and hoses three core drillings through the bridge wall into the CSO-chamber were made. An additional manhole onto the overflow channel was built in order to provide continuous and secure access to the chamber.

**Instrumentation**

Figure 1 also lists the installed equipment. A spectrometer is situated in a swimming pontoon installed directly in media. In order to keep the pontoon at its measurement location, it is fixed to the chamber walls by steel ropes. The installation is such that the position of the pontoon automatically adjusts to varying water levels but also ensures that the pontoon is guided back to its dry-weather measurement position after storm flows. The swimming pontoon keeps the spectrometer at a position some centimetres below the water surface and subsequently at a representative sampling spot.

The used flow-through-ISE-sensor-cells for NH4-N and NO3-N are not EX-proofed and therefore installed in the container. The flow-through-cells are also equipped with a pH and
a conductivity sensor. Sample supply is by means of a suction pipe ("bypass") and a peri-staltic pump (max. flow 3 l/min). The “bypass”-pump is operated when the water level in the inflow channel exceeds a defined threshold value. The “bypass” is also equipped with an electromagnetic flow meter.

To measure the water level in the chamber a sonar probe is installed at the ceiling of the chamber which also triggers the “bypass”-pump, a water sampler and a video-recorder for recording the overflow events. The chamber is equipped with lighting and a video camera; the video picture is permanently accessible via the project home page. To measure the water flow a contactless radar flow meter is installed in the inflow channel and an ultrasonic device in the overflow channel. For the measurement of the discharge through the throttle a suitable device could not be found.

Results and discussion
Overflow events
Since January 2003 till the end of August 2003 in total 18 overflow events could be observed. Table 1 gives a summary about the observed events during this period, the overflow discharges and the pollution loads resulting from the spectrometer values into receiving water. Table 1 shows the number of events, the total duration of overflow events and the total overflow volume discharged to receiving water for each month, whereby the first events of this period could be observed in May 2003. During dry weather conditions all data are generally logged with a standard interval of 3 minutes. In the case of stormwater flow and after the water level in the inflow channel exceeds a defined threshold value data are logged with the smallest reachable interval which is 1 minute. The also shown discharged loads for COD (total and soluble) and for TSS were calculated by multiplying the logged spectrometer values with the water flow values of the ultrasonic device in the overflow channel.

Figure 2 exemplarily shows the online curves for inflow and overflow discharge and the total CODeq concentration from the overflow event from 9th June, 2003.
Spectrometer calibration

The spectrometer provides so-called “global” calibrations, i.e. typical relationships between the parameters of interest (i.e. COD, DOC, TSS, NO₃-N) and the measured UV/VIS absorption. With a simple “local” calibration, the “global” calibration can be adjusted to the specific wastewater matrix of the measurement location. This “local” calibration uses the same wavelengths as the “global” calibration, but the correlation parameters are adapted based on the results from reference measurements (Langergraber et al., 2003).

Till now two calibration experiments were carried out by means of a 24-h-sampling campaign based on spot samples taken every hour during a day with dry weather conditions. The samples were taken by an automatic sampler in the station container and analysed in the laboratory immediately (max. time delay between drawing of sample and start of analysis 20 min). Only samples taken during the night hours were immediately preserved and cooled until start of the laboratory analysis of these samples on the following day.

Figure 3 shows the absolute and relative differences between the laboratory and on-line measurements of the second 24-hour-measurement campaign. Both campaigns have shown the same principal results. At early morning when the influence of infiltration water is high the residuals change from negative to positive. The maximum residuals are in the range of 100 mg COD/l for the low measurement range and 300 mg/l for the high measurement range.

Table 1  Summary of observed overflow discharges during period of January through August 2003

<table>
<thead>
<tr>
<th>Month 2003</th>
<th>Number of events</th>
<th>Duration [hh:mm:ss]</th>
<th>Q_{spillflow} in [m³]</th>
<th>Total-COD-load in [kg]</th>
<th>Soluble-COD-load in [kg]</th>
<th>Total-solids-load in [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>0</td>
<td>00:00:00</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>February</td>
<td>0</td>
<td>00:00:00</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>March</td>
<td>0</td>
<td>00:00:00</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>April</td>
<td>0</td>
<td>00:00:00</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>May</td>
<td>2</td>
<td>03:28:00</td>
<td>270</td>
<td>111</td>
<td>31</td>
<td>73</td>
</tr>
<tr>
<td>June</td>
<td>9</td>
<td>12:20:00</td>
<td>15,559</td>
<td>4,721</td>
<td>1,371</td>
<td>3,429</td>
</tr>
<tr>
<td>July</td>
<td>6</td>
<td>13:29:00</td>
<td>24,079</td>
<td>6,832</td>
<td>2,315</td>
<td>4,576</td>
</tr>
<tr>
<td>August</td>
<td>1</td>
<td>01:08:00</td>
<td>779</td>
<td>257</td>
<td>69</td>
<td>173</td>
</tr>
</tbody>
</table>

Figure 2  Overflow event from 9th June, 2003 with a significant first flush
Although the absolute deviation is lower for the low measurement range, the relative error is almost 60%, which is not satisfactory since during long storm flow events the spillflow can become quite diluted and subsequently the measured concentrations will be in the lower range.

Figure 4 shows the correlation between the laboratory and on-line measurements of the spectrometer for the parameter total-COD. The above (black) regression curve results in a high value for the coefficient of correlation ($r^2 = 0.90$), but also in a high offset of 173 mg COD/l, which is one reason for the very large relative error in the lower measurement range (Figure 3). If a regression is calculated for an offset of zero, the correlation coefficient decreases to a value of $r^2 = 0.77$.

For comparison, five COD spot sample concentrations taken during storm flow conditions within a period of 15 minutes are also shown in Figure 4. Although these five storm flow values fit quite well to the black correlation curve, it can be seen that they occurred in the lower measurement range where generally very large relative errors were observed in comparison to laboratory measurements. Summarizing the above, it is clear that the calibration of the spectrometer needs further investigations and supporting experiments especially during storm flow condition.

**Operational experiences**

At the beginning of the measurements clogging due to particles and sediment was observed between the keel of the pontoon and the channel invert during low flow periods. With the installation of a small steel sheet the wastewater is now dammed for a few centimetres, subsequently the pontoon could be positioned higher which avoids clogging.

The permanent video control reduces unnecessary maintenance work, since the correct position of the pontoon can be controlled permanently.

Some problems are still observed with the “bypass”-line due to clogging. At the moment this line cannot be operated continuously. Further improvements of the installation of the “bypass”-line are under progress.

**Figure 3** Results of “local” calibration of the spectrometer (1): Absolute and relative differences between laboratory and spectrometer measurements for total COD
Conclusions
A monitoring station for continuous measurement of the water quality at a CSO in the city of Graz is operated since October 2002. The main goal of the monitoring station is to record frequency and duration of overflow events and the subsequent pollution discharge to the receiving water body.

Experience so far shows that the sensors installed directly in the CSO chamber can be operated with comparably low maintenance. In contrast, sensors which had to be installed in a measurement container could not be operated continuously due to clogging of the sample supply line during periods of low wastewater flow.

A calibration experiment of the spectrometer for the parameter total-COD resulted in an absolute error in the range of 30–300 mg COD/l and a corresponding relative error in the range of 8–60%. The maximum relative error of 60% occurred in the low measurement range during night hours. Further detailed investigations of the spectrometer calibration are currently under progress.

The presented sewer monitoring station is an example for continuous and consistent data collection and processing, which could strongly improve data to information transfer with respect to water quality management on a catchment scale.

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References


