Monitoring of Combined Sewer Overflow Tanks: Results of 500 Years of Measurement Records

G. Weiss*, H. Brombach and Ch. Wöhrle

UFT · Umwelt- und Fluid-Technik Dr. H. Brombach GmbH,
Steinstrasse 7, D-97980 Bad Mergentheim, Germany
*Corresponding author, e-mail uft@uft-brombach.de

ABSTRACT
In Germany, today about 24,000 combined sewer overflow tanks (CSO tanks) are in operation. For their dimensioning and design, German standards are available and respected. However, efficiency and performance of these costly structures are usually not known by the operator nor by the local water authority. Thus, a trend towards monitoring the overflow activity is observed. This paper points out the state-of-the-art in CSO overflow monitoring. Basic features of water level measurement as well as some plausibility checks for the data are shown. Evaluation of overflow data is rather difficult. Assessment of the overflow activity versus hydrological data, e.g. by comparison with simulation results, is costly. A much simpler way of evaluation is the ranking and rating of measured overflow activity. On the 8th ICUD 1999, already a paper on this subject was presented. Now, 6 years later, the database of the ranking has grown to more than 500 years of measurement.

KEYWORDS
Combined sewer system; CSO tanks; monitoring; overflow duration; overflow frequency

INTRODUCTION
In the past 30 years, around 24,000 combined sewer overflow tanks (CSO tanks) went into operation in Germany, cf. (Brombach, 2002). There is no doubt that this investment of approximately estimated 60 billion € all over the country has well contributed to a considerable improvement of river quality. However, reliable data on the effect of CSO tanks are rare. To gain at least some information on their overflow activity, an increasing number of CSO tanks in Germany is equipped with monitoring devices in order to record overflow events. This is, in general, in accordance with the EC Directive 200/60/EC calling for a “combined approach”; see (EC, 2000). Usually, the water level is measured by some kind of electronic level gauge, see Fig. 1. Other indicators such as overflow duration, frequency, and spilled volume to the receiving waters can be derived, see below.

The present paper attempts to compile today’s state-of-the-art in CSO tank overflow monitoring, to point out some new features such as an insensitive yet rather precise method to detect overflow events, and, finally, to update the tools for data evaluation since the amount of collected data today allows a better assessment of overflow activity. The present paper restricts to long side weirs as most usual CSO overflow structures. Self-regulating overflow devices such as gates, siphons and movable weirs, cf. (Weiss et al. 1999), are not investigated here.
ESSENTIAL FEATURES OF CSO TANK MONITORING

An overflow event is detected by comparison of the actual water level with the weir crest, see Fig.1. From this record, the frequency (e.g. in times/year or, alternatively, in days per year during which any overflow events have occurred) and also the duration (in hours/year) of overflow can be derived. These data allow the assessment of overflow activity. A possible second step is the application of a weir formula. The instantaneous overflow in m³/s and also the total spilled water volume, e.g. in m³/year, can be derived approximately, see also our parallel paper in this conference, (Brombach and Weiss, 2005).

Measurement errors; calibration of water level gauges

Generally, proper recording of the overflow head $h_0$ requires careful adjustment of the gauge. In particular, the height of the overflow weir – this is the level which the gauge shows when the water level is exactly at the overflow crest – is crucial. It can be shown that even small measurement errors of 1-2 cm may lead to a coarse under- or overestimation of the overflow duration and frequency. This may be due to a zero offset of the gauge caused by electronic signal drift, by any mechanical shift of the sensor, or also by imprecise levelling when mounting the hardware, e.g. because the weir is hardly accessible from the spot where the gauge is fixed. Such error can happen easily even at a later time, e.g. by accidentally stepping on the sensor support. Thus, any level gauge should be fixed rigidly and installed such that it can be checked and re-calibrated. An investigation carried out at ten CSO tanks in Northern Bavaria in 1999 showed that only five tanks featured sensors where such a check was possible at all.
Ultrasonic gauges as shown in Fig. 1 are very frequently used for CSO tank monitoring because they are installed above the water and thus are not subject to pollution, but easily misled by temperature shifts. They can easily be checked and recalibrated by a horizontal plate, see Fig. 2. A new development is gauges using radar which are less sensitive to temperature changes. – Recalibration of any gauges should be done on a regular basis, e.g. every five years, as recommended in (BayLfW, 2001).

Detection of begin and end of overflow
The recorded overflow frequency may be influenced by short-period surface waves. It is thus reasonable to make the sensor “slow” and less sensitive to these influences. Additionally, as proposed by (BayLfW, 2001), a hysteresis may be introduced, see Fig. 3: An overflow event starts when the water level exceeds the weir level, and it ends when the water level falls short of a value 5 cm below. Anyhow, precise levelling of the weir is required.

A second method to determine overflow begin is somewhat more complicated. However if good data are available, the method accounts automatically for the weir level. It is shown here somewhat more in detail. From the raw water level data shown in Fig. 4, it is possible to generate a diagram in which the water level, as a “stack of lamellae”, is shown on the ordinate. On the abscissa, it is shown how frequently the water level passes the lamella in rising direction; see Fig. 5, left graphics. Falling water level is not detected. Simultaneously, a second diagram is generated in which the abscissa shows the time during which the water level exceeds the lamella (cumulated duration, see right graphics in Fig. 5). If the level of the overflow weir is known, it can be drawn in as a horizontal line.

During overflow, it is typical that the water level exceeds the weir crest for a short while only while going frequently up and down within a narrow margin close to the weir: the effect of water level control. This produces a distinctive “peak” in Fig. 5, left plot. The cumulative curve, right-hand drawing, Fig. 5, shows, correspondingly, a plateau. The idea is to determine the weir level which is regarded as “begin of overflow” from the recorded data rather than from an extra careful levelling. The weir crest must be slightly below the “peak” and very near the distinctive sharp bend which forms the right edge of the plateau in Fig. 5 (right graphics). Brombach et al. (1999) recommended using the level of the “waist” visible in Fig. 5, or, alternatively, “a thumb’s breadth” below the peak. The ranking curves shown further below are gained by applying this “waist criterion”. The above definition of Fig. 5 left is such
that the number of overflow events is given directly from the abscissa value without further calculations. No hysteresis is used here. Note that the level may be determined rather precisely. To gain $\pm 1$ cm of exactness would otherwise require very careful levelling of the weir.

![Figure 5](https://iwaponline.com/wpt/article-pdf/1/1/wpt2006011/383483/11.pdf)

**Figure 5.** Determination of the threshold of overflow begins directly from the recorded data. (CSO tank “Lautertal” from Fig. 4)

**Data recording**

At every instant, the electrical signal of the water level gauge is recorded in a data logger. With today’s cheap memory chips, high-resolution hydrographs, e.g. in 1-minute steps, over several months are possible. This allows also a sufficiently exact determination of the duration of single overflow events. Some data loggers are battery-powered and work as standalone units. On the other hand, in many CSO tanks electrical power is available. Care must be taken that the data are kept e.g. in the case of a power loss. The data are usually stored on a memory card or similar which should be read out regularly by the operator to avoid overwriting. Some CSO tanks feature even remote supervision which may be able to collect the data on-line.

It is clearly recommended that not only converted data, but also raw data are stored. If, during evaluation, a zero offset is detected, it is possible to correct this error; otherwise the whole record is unusable. For evaluation, frequently on a PC rather than in the data logger, the data are condensed e.g. to monthly and annual reports (begin, end and duration of any overflow event, total frequency and duration over the time period under investigation). It should be tried to gain continuous records over at least one year since short-duration records may be biased too much by a high or low rainfall, see Fig. 6.

![Figure 6](https://iwaponline.com/wpt/article-pdf/1/1/wpt2006011/383483/11.pdf)

**Figure 6.** The longer the measurement record length, the more significant are the results. Data of short record periods may be considerably erratic, e.g. caused by wet or dry weather periods.
DATA EVALUATION

Plausibility check, data validation
Data logging and report generation is done usually automatically. However, the results require interpretation. The first step should be a proof of plausibility of the data in order to validate them. Any such check should look particularly on a possible zero offset as most frequent source of error. A powerful plausibility check is possible by arranging the data as in Fig. 4. If the distinctive “peak” is visible and if it is somewhat higher than the level of the weir, the data are ideally plausible. If needed, the weir may be “re-levelled” using the described criterion, e.g. if there is a remaining difference of some cm between the “peak” and the weir. Moreover, if a comparison with former evaluations is possible, it can be judged whether the recorded overflow activity is in the same order of magnitude.

With less plausible data, it is recommended to re-calibrate the measurement gauge; however the “old” weir height should be noted so that data correction is possible. Anyhow, even fair data need not show a peak, e.g. if only few rare but strong storm events have been recorded or if no overflow occurred at all. Prolonged water levels higher than the weir may also be caused by backwater by a flood in the river, see further below.

Overflow activity versus hydrological catchment data
Finally, an interpretation of the measured overflow activity is possible. A straightforward, direct evaluation will try to correlate the overflow frequency, duration and also the overflow volume to some hydrological properties of the catchment and the CSO structure under investigation. Low overflow activity could e.g. indicate that the actual sealed surface in the catchment is overestimated. It could even be attempted to derive or to “calibrate” actual catchment data from the recorded overflow data. One could simulate the actual state using e.g. a hydrologic runoff simulation model and compare the results with the measured data to fit the parameters. In practice, however, this approach is very ambitious and science rather than engineering. Generally, measurements in urban hydrology may show large uncertainties, see e.g. (Uhl 1993) and (Bertrand-Krajewski et al. 2003). Moreover, a lot of additional data are needed which are usually not proper documented or even hard to obtain, such as actual (!) sewage and infiltration flows or historical storm records which, moreover, should be representative for the catchment. For these reasons, any predictions gained by such an approach will show considerable scatter in spite of the inherent difficulties.

Ranking and rating method for easy assessment of overflow activity
A more easy way of evaluating overflow data thus was sought, without the need of using additional data. Since most CSO tanks are dimensioned by similar approaches, their overflow activity can be compared directly. We have collected measured overflow data for many years. This database is forming a ranking which shows the total range of overflow activity for CSO structures. Former versions of this ranking have already been published earlier; see e.g. (Brombach et al. 1999). In the meantime, the database has grown to a total of 564 years of overflow measurement at 128 individual CSO structures in Germany. Thus, an important part of the present publication is to show the updated ranking. The larger the database, the more valuable the ranking. Fig. 7 compares ranking curves for specific types of CSO structures.

The ranking distinguishes between two main types of CSO tanks: first-flush type CSO tanks and clarifier-type CSO tanks. The first are used mainly in the outskirts of a town where there are usually no further CSO tanks upstream. The latter are in many cases key structures within the main trunk sewers; typically, there are several other CSO tanks upstream. Even if both
structure types are designed with the same specific volume in m³/ha, it has been expected that the overflow activity of both structure collectives might be different due to the placement within the sewer system. This is confirmed by different ranking curves (bold and thin solid lines). The data allowed even distinguishing of overflow activity of the two overflow weirs which clarifier-type tanks typically feature. The main overflow activity is, of course, due to the clarifier overflow. Most of the annual spilled water is allowed to pass the CSO tank while the sewer sediments are settling. The emergency overflow by-passes the CSO tank for large flows to avoid resuspension of sediments. It is active at rather strong storm events and during short time only. The median frequency is 2.8 times or 2 hours per year while the clarifier overflow spills water during 72 events and for 223 hours per year.

![Figure 7. Ranking and rating of overflow duration and frequency for different types of CSO structures](https://iwaponline.com/wpt/article-pdf/1/1/wpt2006011/383483/11.pdf)

In Fig. 7, also a ranking for CSO structures without volume is shown (thin dashed lines). Such simple overflows are used very frequently in any sewer network, particularly for hydraulic relief of the sewer. For this structure type, no data had been published yet. The flow control is usually set to a much larger flow than that of a CSO tank. Anyhow, it typically shows nearly the same frequency of overflows (median value 31 times per year), however much less overflow duration (median value 15 hours per year) than a typical CSO tank.
Rating of the overflow activity of any given CSO tank immediately from the measured data is now very easy, see Table 1. If overflow duration and frequency are average or at least not extreme, no alert shows up and the structures behave inconspicuously. If, however, duration or frequency is rather high or else particularly low, it should be tried to find out why. The clarifier-type CSO tank “Lautertal” known from Fig. 4 shows “very rare” overflow frequency, but surprisingly also “average” overflow duration (13 overflow events and 242 hours of overflow within one year). The low frequency is explained by the rather dry measurement period in 2003, while the comparatively long duration may be caused by a flood in the river lasting some days (probably the first overflow event shown in Fig. 4 of March 2003).

<table>
<thead>
<tr>
<th>First-flush type CSO tanks</th>
<th>Clarifier-type CSO tanks</th>
</tr>
</thead>
<tbody>
<tr>
<td>percentage</td>
<td>overflow frequency in events per year</td>
</tr>
<tr>
<td>0-20 %</td>
<td>0-9</td>
</tr>
<tr>
<td>20-40 %</td>
<td>9-27</td>
</tr>
<tr>
<td>40-60 %</td>
<td>27-45</td>
</tr>
<tr>
<td>60-80 %</td>
<td>45-103</td>
</tr>
<tr>
<td>80-100 %</td>
<td>&gt; 103</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CSO structures without volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>percentage</td>
</tr>
<tr>
<td>0-20 %</td>
</tr>
<tr>
<td>20-40 %</td>
</tr>
<tr>
<td>40-60 %</td>
</tr>
<tr>
<td>60-80 %</td>
</tr>
<tr>
<td>80-100 %</td>
</tr>
</tbody>
</table>

Table 1. Rating of overflow activity of CSO tanks (updated, cf. Brombach et al. 1999)

Reasons for very frequent and very long overflows may be:
- Backwater caused by a flood in the river may fill a CSO tank during some days so that a long “overflow event” is faked. Many CSO tanks are located close to a river so that this may occur rather frequently.
- The measurement period was rather “wet”, i.e. the rainfall was more than average. The shorter the measurement period, the larger the influence of rainfall.
- Some planned CSO tanks upstream of the investigated structure are not yet in operation; consequently the catchment area served by the CSO tank is larger than planned.
- High infiltration inflow (I/I), particularly during winter and spring. In practice, this is really a large problem. In extreme cases, I/I larger than the flow to the WWTP may prevent CSO tanks from emptying during several weeks.
- The flow control is set to a too small outflow to the WWTP.

On the other hand, very rare and very short overflows may be caused by:
- “Dry” measurement period with little rainfall.
- The catchment is not yet fully developed, but the CSO tank is already designed for the full area.
- Dimensioning of the CSO tank has accounted for large hidden safeties, leading to a rather large specific volume.
- The flow control yields a too large flow to the WWTP.
• Very low infiltration inflow (I/I)
• The actual sewage flow, e.g. of an industrial area, is much smaller than predicted

Extreme overflow activity in any direction may be caused by one or more of these factors. It is recommended that in this case, some more detailed investigations follow. Some of the mentioned effects require even immediate actions in order to prevent acute pollution of the river. Altogether, it can be pointed out that the described rating is a very valuable tool as an “early warning system” for possible errors in stormwater treatment in combined sewer systems.

CONCLUSIONS
Monitoring of the overflow activity of CSO tanks in combined sewer systems may be used to get some feedback on the operational performance of these costly structures. However, reliable measurement data can be obtained only if some rules for the arrangement of the measurement gauge and the sampling of the data are obeyed. Any water level gauge should be arranged such that it can be recalibrated. Moreover, raw data should be recorded so that possible errors can be corrected later. All data should then be checked for plausibility.

A direct evaluation which tries to compare the measurement data with hydrological properties of the catchment and the CSO tank is difficult and will lead to results which are blurred, anyhow. For this reason, an evaluation method is proposed which compares the overflow activity of a given CSO tank with a large collective of other structures. No additional data are required for this ranking and rating. The database comprises more than 560 years of measurement at 128 single structures. Overflow frequency and duration can thus be assessed very easily.

The procedure serves well as an early warning system. If extreme overflow activity in any direction is found, additional investigations may follow which allow in some cases immediate actions to avoid acute river pollution.

ACKNOWLEDGEMENT
Some of the presented statements were gained in a study on behalf of the Bavarian Authority of Water Management, 1999-2001. We thank for generous funding.

REFERENCES