CSO management from an operator’s perspective: a step-wise action plan
G. Dirckx, Ch. Thoeye, G. De Gueldre and B. Van De Steene

ABSTRACT

Combined sewer overflows (CSO) are the “ugly ducklings” of urban wastewater infrastructure, rather unknown, rarely loved. Contrary to wastewater treatment plants (WWTP) where, commonly, process parameters are carefully registered, still relatively little is known about the spill behaviour of CSOs. In spite of the considerable bandwidth of pollution magnitude reported in literature, it can be generally accepted that CSO impact certainly is not negligible. As the sole wastewater utility in Flanders (6,100,000 inhabitants), Aquafin operates, next to 230 WWTP’s and almost 1,000 pumping stations, some 3,100 CSOs. In search for an optimum CSO management strategy, Aquafin prospected several modelling and monitoring possibilities. As a result, a CSO action plan could be drawn up tailored to the estimated relevance of the CSO under consideration. In a further step a cost-benefit analysis of several static and dynamic remediation measures was undertaken. Real Time Control (RTC) strategies turned out to be the most cost efficient solution for CSO impact mitigation.

Key words | combined sewer overflows, disconnection, modelling, monitoring, real time control, storage tanks, throttle structures

INTRODUCTION

This paper aims at giving an overview of the challenges faced by a typical medium-sized waste water operator with regard to mitigating the impact of Combined Sewer Overflows on receiving waters, an issue gaining importance with water quality driven legislations as the Water Framework Directive (WFD) in Europe. Data to support the premise that the impact of CSOs on receiving waters cannot be disregarded are provided in the course of this paper. First, however, current design strategies in Western Europe and typical performance indicators are discussed. Further, this article pursues the issue of determination of spill behaviour via modelling and monitoring. Besides a state-of-the-art overview of monitoring and modelling practices, strengths and weaknesses are summarised, both for a water quantitative and a water qualitative approach. In the last part some typical measures to reduce CSO spills, such as the construction of storage tanks and RTC, are critically analysed and compared, including some cost efficiency considerations.

In Belgium’s Flemish region (13,500 km², 6,100,000 inhabitants in early 2008) the task of the development and operation of the supra-municipal wastewater infrastructure was entrusted to Aquafin NV. Since its foundation in 1990 only, a rapid investment pace was maintained in order to catch up with the implementation of European standards. As nowadays almost all the region’s wastewater treatment plants (WWTP) are in place and comply with requirements, a shift from investment towards optimising operation of the assets is taking place. In Flanders more than 90% of the sewer systems are of the combined type. These include around 3,100 CSOs plus an extra estimated number of 1,000 CSOs at municipal level. Contrary to the frequently monitored wastewater treatment plant effluent, still relatively little is known about the pollution impact of CSOs. Considering this large number of CSOs, awareness is rising that considerable efforts will need to be spent in a close(r) follow-up.
DESIGN OF CSOS IN EUROPE

As a standard practice, CSO design in Europe follows an emission based approach; in most cases a simple throttle flow limitation is used as a basis criterion, mostly linked to the accepted waste water treatment plant capacity. Furthermore, diversity of standards and design rules is striking, though they can be roughly divided following the two general approaches for controlling direct discharges into water courses: the use of the Environmental Quality Objectives/Environmental Quality Standards (EQO/EQS) and the Uniform Emission Standards (UES). The EQO/EQS approach seeks to define the use that is to be made of a given water body, which defines an Environmental Quality Objective (EQO). In order to secure the objective in presence of dangerous chemicals, Environmental Quality Standards (EQS) are needed. Emission limits can then be established by taking into account the dilution capacity within receiving waters outside the immediate impact zone. The UES, or limit value, approach sets limits for the concentration of dangerous substance in the effluent, without taking specific account of the available dilution capacity. They are usually expressed as effluent concentrations (Harrison 2001).

At a technical level there has been a growing recognition that the most sensible approach to pollution control is a fusion of the two approaches as adopted in the Integrated Pollution Control system. This also entails the philosophy of the Water Framework Directive.

Table 1 indicates which of these approaches is used in several European countries, next to other relevant CSO design criteria, simplified after (Fenz 2002) and/or (Zabel et al. 2001). Besides the throttle limitation, some countries, such as Denmark, the Netherlands and Belgium, also enforce a design norm based on the annual overflow frequency; others, such as Luxemburg, Germany and Austria, apply an overflow volume based standard. Some countries or regions, like Denmark, Flanders, Scotland and Portugal, also consider the receiving water in a very qualitative way; in Flanders, e.g., the so-called “vulnerability” – i.e. sensitivity of the receiving water, as listed by the water authorities – is taken into account. Others, like the UK, France, the Netherlands and Denmark, implement or aim to implement an

<table>
<thead>
<tr>
<th>Country</th>
<th>Throttle flow limitation Q_{p, max}</th>
<th>Equivalent Mean DWF Qm</th>
<th>CSO criterion</th>
<th>UES or EQO/EQS approach</th>
<th>pollution loading?</th>
<th>modelling required?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium (Flanders)</td>
<td>6Qp</td>
<td>10</td>
<td>f = 7</td>
<td>UES +</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Denmark</td>
<td>5Qp</td>
<td>8–10</td>
<td>f = 2–10</td>
<td>UES + and EQO/EQS –</td>
<td>yes</td>
<td>yes?</td>
</tr>
<tr>
<td>France</td>
<td>3Qp</td>
<td>4–6</td>
<td>–</td>
<td>UES and EQO/EQS –</td>
<td>yes</td>
<td>yes?</td>
</tr>
<tr>
<td>Germany</td>
<td>7Qm**</td>
<td>7</td>
<td>V = 10–40 m/ha_{red}</td>
<td>UES</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Greece</td>
<td>3–6Qm</td>
<td>3–6</td>
<td>–</td>
<td>UES +</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Ireland</td>
<td>6Qm</td>
<td>6</td>
<td>–</td>
<td>UES and EQO/EQS –</td>
<td>no?</td>
<td>no</td>
</tr>
<tr>
<td>Italy</td>
<td>3–5Qm</td>
<td>3–5</td>
<td>f (?)</td>
<td>UES</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Luxemburg</td>
<td>3Qp**</td>
<td>4–6</td>
<td>V = 10–40 m/ha_{red}</td>
<td>UES</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Netherlands</td>
<td>7Qm</td>
<td>7</td>
<td>f = 3–10 V = 70 m/ha_{red}</td>
<td>UES + and EQO/EQS –</td>
<td>no?</td>
<td>no</td>
</tr>
<tr>
<td>Portugal</td>
<td>6Qm</td>
<td>6</td>
<td>–</td>
<td>UES</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Spain</td>
<td>3–5Qm</td>
<td>3–5</td>
<td>–</td>
<td>UES</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>UK (England &amp; Wales)</td>
<td>6.5–9Qm*</td>
<td>6.5–9</td>
<td>–</td>
<td>EQO/EQS</td>
<td>yes?</td>
<td>yes</td>
</tr>
<tr>
<td>UK (Scotland)</td>
<td>6.5–9Qm*</td>
<td>6.5–9</td>
<td>–</td>
<td>EQO/EQS</td>
<td>yes?</td>
<td>yes</td>
</tr>
</tbody>
</table>

UES: Uniform Emission Standard; UES +: UES with some consideration of the receiving water; EQO/EQS: Environmental Quality Objective/Standards; EQO/EQS –: EQO/EQS approach introduced but unknown to what extent it is used; f – spill frequency, V – volume of storage facility, A_{red} – reduced area of connected surface; Qp – peak DWF, Qm – mean DWF

*As a common result of the so-called Formula A (also used in Ireland)
**German ATV-128 implied requiring 90% of load needs to be conveyed to treatment plant
EQO/EQS based evaluation allowing for water quality standards of the receiving water.

**CSO indicators**

Regardless of the discussion over whether UES or EQO/EQS standards should be used, waste water operators responsible for hundreds or thousands of CSOs seek for simple and easy-to-determine standards, being preferential to tedious and complex integral modelling or monitoring. (Engelhard et al. 2008) investigated whether it was possible to describe the impact on the receiving water by emission based CSO indicators. A simplified version of the findings is presented in Table 2. Main conclusions are that acute impacts (oxygen depletion, acute toxic impact) cannot be described by CSO indicators. Conversely, volume based parameters showed a (very) good relationship to load based impacts (hydraulic impact, eutrophication and persistent pollutants). Another remarkable conclusion was that, for none of the possible impacts, overflow frequency based indicators showed a good correlation. (Lau et al. 2002) concluded, however, that, for both acute impacts of oxygen depletion and ammonia intoxication, overflow frequency (and volume) can be used within certain limits of applicability. Probably this parameter has its greatest value for aesthetic and hygienic impact assessments.

As a conclusion, none of the proposed CSO indicators is able to represent the marker for the most common impacts on the receiving water. Volume based indicators seem at least to be representative for load based impacts, while the potential of the indicator spill frequency is questionable; at the most it could be of value within certain limits for acute impacts. As it is nowadays still impossible to set up an automated continuous water quality monitoring network in a cost efficient way, it seems that, for the time being, CSO spill volume indicators are preferable to non-volume based indicators.

**IMPACT OF CSOS**

In spite of the fact that most countries have drawn up their own legal practices regarding CSOs, very few data on spill magnitude are available. Subsequently—some authorities seem already happy just having listed their CSOs’ positions—it is certainly not trivial to find information about their impact on the receiving water. This makes some decision makers sceptical about whether CSOs can possibly endanger the environment at all.

In order to balance efforts and remediation investments it is of particular interest to compare CSO spills with treatment plant effluent. Exactly, assuming that for compliance to river water quality based legislation such as the WFD a high sewer outlet connection rate must be achieved, CSO and WWTP remain as the only point sources of pollution impact. During the course of the further described case study in the town of Kessel-Lo (Dirckx 2010), CSOs’ potential impacts were in such a way balanced against the WWTP’s effluent. It was found that, for this case, the eight CSOs present in the catchment contributed proportionally to the WWTP for 5 to 6% of the annual flow discharged into the receiving waters, a figure that is neither disproportionally high nor negligible. When looking at pollution impact, more interesting figures, however, appear. For this purpose median figures from the German ATV-DVWK Datenpool 2001 database as described in (Brombach et al. 2005) were used. As the authors correctly outline, care should be taken in using these figures, but as an analysis of first order their application was deemed acceptable. Notifying this, it was found that potential CSO impact relative to the WWTP effluent is depending on the parameter considered. For nutrient load (TN, TP, NH₄...) CSO impact seems to be in the same line with the flow, order of magnitude of 5–10%. On the contrary, for oxygen related impacts, BOD and SS, the total annual loads spilled by CSOs were found to be 50–70% higher than the WWTP effluent load; this was

<table>
<thead>
<tr>
<th>Impact type</th>
<th>Receiving water indicator</th>
<th>(\eta) (^1)</th>
<th>(f)</th>
<th>(VQO)</th>
<th>(Q_{\text{max}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morphology</td>
<td>Erosion frequency</td>
<td>GOOD</td>
<td>BAD</td>
<td>GOOD</td>
<td>POOR</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>Nitrogen load</td>
<td>GOOD</td>
<td>BAD</td>
<td>GOOD</td>
<td>POOR</td>
</tr>
<tr>
<td>Accumulation</td>
<td>Copper load</td>
<td>GOOD</td>
<td>BAD</td>
<td>GOOD</td>
<td>POOR</td>
</tr>
<tr>
<td>Acute toxic</td>
<td>Ammonia</td>
<td>POOR</td>
<td>BAD</td>
<td>BAD</td>
<td>BAD</td>
</tr>
<tr>
<td>Oxygen depletion</td>
<td>Critical oxygen deficit</td>
<td>BAD</td>
<td>BAD</td>
<td>BAD</td>
<td>POOR</td>
</tr>
</tbody>
</table>

\(^{1}\eta = (1-VQO/VQR)\times 100\) with VQO: mean annual overflow volume; VQR: rain runoff
partially due to high WWTP performance. For COD, CSO load is proportional to 30% of the effluent load, a figure that is substantially lower than the ones found for BOD and SS, but still emphasising the importance of CSO spills in the total catchment balance. Not surprisingly, these figures were very similar to the ones calculated by (Brombach et al. 2005).

Another study in the catchment of Kessel-Lo (Blumensaat et al. 2007) revealed high potential for acute ammonia intoxication caused by CSOs, as shown in Figure 1. Continuous water quality monitoring of a river stretch right downstream of two CSOs exposed sudden ammonia peak concentrations, sometimes lasting for hours, of more than 15 mg/L.

A very recent project in the Berlin area showed that at the downstream part of the river Spree, close to the conjunction with the Elbe river, 15 out of 17 oxygen depletion periods were caused by CSOs. Also, acute ammonia intoxication due to CSO spills could be an issue, especially in spring time (Matzinger 2009). In the NIEDERSCHLAG project (Hahn et al. 2000) a systems analysis for the river catchments of Neckar and Lahn in Germany was set up to determine impact pressures from either diffuse or point source pollutions. Regarding nutrients, diffuse pollution (such as agriculture) was in the case of phosphorus responsible for 40% of the impact and in the case of nitrogen responsible for 60% of the impact. From the remaining point source load the WWTP was revealed to take up the major part: between 75% and 95%. Concerning nutrients, this could indicate the following prioritisation order of remediation efforts: agriculture, treatment plants, CSOs, although the order of the latter two will depend on the already available treatment capacity regarding nutrients (tertiary treatment). Conclusions regarding oxygen consuming matter, represented by e.g. COD, though, were very different; agricultural impact is ignored, but the relevance of the WWTP impact, being 50–70% of the total amount, declines proportionally to the CSO impact, estimated at 25–30% of the total load. For heavy metals there is a larger bandwidth but figures for WWTP and CSO impact are rather in the same order (50 vs. 40%).

To conclude, following the scarcely available data sets, CSO pollution impact exposes a large scatter and is to be determined case by case. Nevertheless it is clear that in
general terms its impact cannot be ignored; this is all the more true for oxygen demanding matter such as COD.

CSO MODELLING & MONITORING

The following part prospects the possibilities for waste water operators to quantify spills from CSOs on larger scale. Roughly these are either modelling or monitoring, and either considering water quality or just the quantity. Emphasis in this overview is on practicability, assuming that operators may need to deploy a vast monitoring network or establish an extensive database of operational models.

Modelling

Water quantity modelling

Sewer water quantity modelling is nowadays considered as state-of-the-art for some time. In Flanders a standard procedure called Hydronaut is used for sewer infrastructure design (other examples are the Wallingford procedure in the UK and ATV-series in Germany) since the early nineties. The Hydronaut procedure and subsequent initiatives have resulted in a vast digitalisation of sewer systems into sewer databases and/or hydrodynamic sewer models (Van Assel & Dirckx 2007). While in the early days of deterministic sewer modelling, i.e. the mid-nineties, emphasis was mainly on the design of trunk sewers, nowadays these models have become more and more operational up-to-date-models suitable for developing strategies and for overcoming existing bottlenecks. As such they are also suitable for CSO design and system optimisation.

For quite some time, hydrodynamic modelling was restricted to the simulation of one or more design storms, assuming that the statistical characteristics (i.e. return period) of cause (i.e. rainfall) and consequence (i.e. flooding, for example) are alike. As sewer systems behave in a non-linear way, cause and consequence are not linearly interrelated. This is all the more true for determining the statistical behaviour of overflow spills. Using design storms will only give an approximate answer about real spill behaviour (duration, time, etc.). The only way to overcome this problem is to use long time rain series as input to the model and statistically post-process the output signal, in this case the weir spill flows. Until rather recently the simulation of long time series was seriously burdened by the existing computer performance and capacity.

Another strategy that can be used to overcome long simulation times is to relax on the model complexity. For this purpose models can be simplified to a certain extent: in theory a spectrum of simplification possibilities is available, ranging from some simplification of the hydrodynamic model to a full conceptualisation of the sewer system (so-called reservoir models). Care should, however, be taken over a too stringent conceptualisation in sewer systems that are heavily affected by backwater conditions, as is the case with typical flat area systems, like in Flanders. In this particular condition throttle structures can indeed be influenced by backed up water at the downstream side of the throttle, thereby automatically restricting flow through the throttle and consequently inducing a higher potential spill behaviour (Kroll et al. 2011).

A final point of attention, independent from the conceptualisation level of the model, is the discharge coefficient of the weirs. Conversion formulae often assume a specific type of the overflow structure for which the overflow formula generates results of sufficient accuracy. Obviously this condition seldom occurs in reality. A potential solution to this problem is the calibration of the CSOs weir, either on site or at laboratory scale. Relatively new is the use of Computational Fluid Dynamics (CFD) to determine spill characteristics of CSOs; see e.g. (Fach et al. 2009).

Water quality modelling

Current commercially available software for water quality modelling of sewer systems does not guarantee a reliable prediction of pollutant transport through sewers (Bouteligier et al. 2002; Ashley et al. 2004). Generally, uncertainty rises high due to the location and time dependent inflow of sediments and the very complex (sediment) transport behaviour within the sewer system. These phenomena are extensively described in literature. Progress in solving these problems seems to be going slowly and the question may arise if there will ever exist a simple and easy-to-use water quality sewer model incorporating all complexity with acceptable accuracy.

As a consequence, the prediction of pollutant impact on receiving waters due to CSO spills by means of water quality models is a rather challenging task and should only be envisaged for specific small case studies where enough resources and time are available for model calibration.

Monitoring

As sewer models are not always readily available, and given the fact that modelling techniques also have their restrictions as explained above, it is often worth while to look into CSO
monitoring to determine CSO spills. Obviously monitoring can also support the actual building of the model.

Water quality monitoring

Water quality monitoring in sewer systems and more particularly at CSOs is generally accepted to be a time consuming and rather complex process. This fact especially holds in the case that no continuous power supply is available, which unfortunately is the default case. Set-ups using alternative power supply such as batteries combined with specific power requirements often are unreliable and need high maintenance schemes. On top of that, available resources sometimes might be insufficient to capture the complex processes occurring in sewers entirely. Furthermore, due to fast rising water levels and flows, coarse material fragments are carried along, sometimes damaging the monitoring equipment. Smaller particles, in particular sediments, can obstruct the exact recording of the processes occurring.

Roughly two techniques can be distinguished: discontinuous sampling and – as application within sewers relatively new–continuous monitoring (Grüber et al. 2005).

In order not to miss out on vital information samplers have to monitor with a high frequency, which can be guaranteed by the on-line equipment. Referring to Figure 1, the continuous water quality monitoring result shows the ammonia peak concentrations, which could to no extent be captured by the regular grab samples (that were taken for validation and/or calibration of the ammonia probe). In any case the presence of continuous power supply is recommended; as well as a close follow-up of the equipment due to the harsh sewer conditions. The on-line monitors also require occasional (re-)calibrations (Grüber et al. 2005). Once put on site it has the advantage of low cost against systems is not impossible, yet still rather pricey and labour-intensive; default application therefore seems not advisable (Scheer & Schilling 2005). As concentrations as such are only valuable for acute impact considerations, spill flows need to be determined also when load impacts are considered.

Water quantity monitoring

Regarding water quantity monitoring, the most logical solution is to monitor the spill flow directly. This, however, requires the not trivial presence of a control section, i.e. an overflow pipe or canal with known dimensions. Also balancing methods incorporating a balance of the flows registered at the up and downstream side of CSOs are unlikely to be successful in determining the spill flow for such structures (Blumensa et al. 2007). Indeed, during a spill event water is usually backing up at the upstream side of the throttle structure, inducing very low velocities, thereby often under-shooting the accuracy detection limit.

Subsequently, since during rain conditions (when CSOs are supposed to be active) water is usually backed up at the location, only level measurements in the carry-on chamber can be used as a general practice to determine spill behaviour (velocity drops under detection limit).

CSO monitoring strategy

Following the analysis regarding modelling and monitoring, CSO water level monitoring looks like, for the time being, the recommended monitoring strategy to be deployed on a larger scale; this as a trade-off between acceptable costs on the one hand and monitoring useful parameters in an accurate way on the other hand. Provided that the overflow discharge coefficient can be estimated with satisfying accuracy, and free outflow is guaranteed, water levels can be converted into flows via the CSO equation. Volume based assessment would then be possible. However, it would be inefficient to invest a substantial amount of resources to monitor CSOs that after all turn out to be hardly active. Therefore the following CSO monitoring strategy is suggested, going from “must do” to “only in case of strategic CSO”.

- Preliminary idea: very first idea composed by local operational experience (inquiry);
- Rough idea: off-line set-up of simple devices that are logged manually;
- Alarm surveillance: on-line water level monitoring with simple devices and data transmission;
- On-line surveillance: on-line water level monitoring with water level meters and data transmission.

This strategy is also represented by Figure 4 together with some cost order indications.

Current Flemish monitoring programme, on-going developments and future scope

In Flanders a CSO monitoring network was established in 1998 by the ecological regulator (VMM, Flemish Environmental Agency). Starting with 10 locations the network kept (and keeps) on growing steadily, nowadays comprising around 300 CSOs. A standard monitoring set-up includes a
sensor for conductivity, turbidity and level (pressure probe). Power supply is typically provided by a solar panel (4 m above ground level, attached to a concrete pole), unfortunately causing this measurement to be rather expensive. Aquafin R&D Dep. has tested a set-up with battery based logging and transmitting equipment. Both level monitors (pressure probes) and simple floating devices (overflow detectors) are used. An alarm is generated when a threshold level (e.g. CSO crest) is exceeded. A daily report containing flow levels and rest capacity of the battery is sent to a central location. The overflow detector is an in-house development and consists of a float that gets activated at a certain position (water level height) and a logging unit containing two displays: a pulse counter and a duration counter. This set-up is ideal for operators wishing to obtain a first rough idea about CSO spill behaviour in their catchment without demanding exact data such as spill time. For CSOs requiring a closer follow-up, this overflow detector could be used in combination with a logging/transmission unit. An alarm is generated when the level of the detector position is exceeded (float is triggered) and sent to a mobile phone (SMS) or e-mail account. Contrary to the off-line set-up, this also allows to detect the exact spill time (beginning and end) of a spill. When more details are desired, a level meter (pressure probe) needs to be installed instead of the simple overflow detector. Data can be sent to a central location via GSM or GPRS network. (See also Figure 3).

Since the investment cost of all aforementioned equipment has dropped significantly during the last years, the setup of an extensive (i.e. wide spread) monitoring network at a reasonable price seems feasible.

Impact mitigation measures

Based on a case study of Kessel-Lo (25,000 PE), representative of a typical Flemish catchment, Aquafin explored several
strategies in search of the most cost-efficient measure(s) to mitigate the impact of CSOs. Hereto ecological benefit, expressed as percentage of spill reduction volume, is balanced against investment cost of these measures. Static measures comprise single actions following a design strategy, such as the disconnection of a certain amount of impervious area from the combined sewer system, the building of one or more storage tanks or the adjustment of the throttle flow structures (pipes). The latter strategy entails a “sensible” resizing of the existing throttles in order to reduce the hydraulic loading of the overloaded (in this case downstream) CSOs. Installing smaller throttles will indeed decrease the locally inactivated storage. The core of the study consisted of an analysis of the potential opportunities to implement a Real Time Control strategy in the sewer system of Kessel-Lo as a dynamic measure adaptive to the event taking place. Several scenarios based on a strategy to equalise the activated storage between the different CSO catchments of the sewer system were developed.

Figure 5 summarises results for the Kessel-Lo catchment as a percentage of spill reduction plotted versus investment cost (logarithmic scale). As can be expected, disconnecting sealed surface from the combined systems lowers spill volume significantly, yet at very high prices, up to tens of millions of euros. Storage tanks also perform very well, at a cost being considerably lower than disconnecting combined systems; however, still reaching the order of millions of euros. Both RTC and throttle adjustment are considerably cheaper than the two aforementioned measures with cost prices in the range of a couple of hundred thousand euros. RTC being only marginally more expensive, though, outplays the throttle adjustment in performance. To be correct these figures need to be compared on basis of an annual equivalent cost (AEC) incorporating depreciation periods and operational costs. This was found to be of only minor influence and reconfirmed the general conclusion that for the Kessel-Lo system RTC was by far the most cost-efficient measure. Obviously, this outcome cannot be extrapolated to any other random catchment; nevertheless it is believed to reveal an important trend in the strategic planning of CSO impact mitigation. More details are presented in (Dirckx 2010).

CONCLUSION

CSO design in Europe often is based on the UES (emission based) principle, although some countries follow the EQO/ EQS (“immission” based) principle that—in Europe—was first introduced in the UK with the Urban Pollution Manual. In order to make the follow-up of CSOs less complex, CSO performance indicators based on emission criteria are still popular. Spill frequency turns out to be a bad indicator, contrary to volume based indicators. As oxygen depletion can be related to oxygen demand (represented by BOD and COD) and CSOs discharge a significant share of these pollutants compared to treatment plants, they are likely to play a role in remediation planning in the frame of water quality based legislations like the Water Framework Directive in Europe. Given the fact that water quality modelling and monitoring are labour-intensive and/or very complex, and (up-to-date) water quantity models are not available by default, water quantity monitoring (water level) seems, for the time being, the best option to characterise CSO spill behaviour at an acceptable price. Indeed, the low battery
consumption (a pre-requisite for off-field installations) and the ability to transfer data via the GSM or GPRS network make water level measurements by far the most cost effective option to quantify CSO behaviour on a large scale. CSO spill flows and volumes can be calculated out of the level signal provided that CSO characteristics are well determined.

As for CSO spill mitigation measures, RTC seems preferential to static measures, when considering cost-benefit aspects. Both disconnection of the combined sewers and the building of storage tanks might be effective measures but at a terribly high price. On the contrary, adjustment of throttle pipes turns out to be relatively cheap, yet less effective.

REFERENCES


