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Research article

DSM-flux: A new technology for reliable Combined Sewer Overflow discharge monitoring with low uncertainties

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ABSTRACT

In the past ten years, governments from the European Union have been encouraged to collect volume and quality data for all the effluent overflows from separated stormwater and combined sewer systems that result in a significant environmental impact on receiving water bodies. Methods to monitor and control these flows require improvements, particularly for complex Combined Sewer Overflow (CSO) structures. The DSM-flux (**D**evice for **S**tormwater and combined sewer flows **M**onitoring and the control of pollutant **flux**es) is a new pre-designed and pre-calibrated channel that provides appropriate hydraulic conditions suitable for measurement of overflow rates and volumes by means of one water level gauge. In this paper, a stage-discharge relation for the DSM-flux is obtained experimentally and validated for multiple inflow hydraulic configurations. Uncertainties in CSO discharges and volumes are estimated within the Guide to the expression of Uncertainty in Measurement (GUM) framework. Whatever the upstream hydraulic conditions are, relative uncertainties are lower than 15% and 2% for the investigated discharges and volumes, respectively.

1. Introduction

Combined Sewer Overflows (CSOs) represent a major source of pollution for receiving water bodies and their impacts on aquatic ecosystems are well recognized. Several studies have highlighted the significant role of CSOs as pathways to reach urban receiving waters for various contaminants, such as organic micropollutants (Launay et al., 2016), especially those highly removed by wastewater treatment plants (WWTPs) (Phillips et al., 2012; Viviano et al., 2017; Weyrauch et al., 2010), inorganic micropollutants (Weyrauch et al., 2010), nutrients (Viviano et al., 2017), hormones (Phillips et al., 2012) or bacteria (Passerat et al., 2011; Weyrauch et al., 2010) among others. These studies show the importance of CSO contribution to both, the annual pollutant loads on the receiving waters and their peak pollutant concentrations during storm events. For example, Launay et al. (2016) showed that despite the relatively low contribution of CSOs to the total annual water discharge (18%), CSO discharges contributed between 30% and 95% of the annual load for 26 pollutants (caffeine, ibuprofen, 16 polycyclic aromatic hydrocarbons (PAHs), phenolic xenoestrogens, and urban pesticides). Phillips et al. (2012) also found similar results in their study: composing 10% of the total annual water discharge, CSO discharges contributed between 40% and 90% of the annual load for hormones and organic micropollutants with high wastewater treatment removal efficiency. Phillips et al. (2012) also showed that peak concentrations of most of the analyzed pollutants during storm events could reach values up to 10 times higher in CSOs than in WWTP effluents. Weyrauch et al. (2010) and Passerat et al. (2011) also obtained similar results in the receiving urban rivers they monitored. Viviano et al. (2017) used caffeine as a marker to identify the CSO contribution of phosphorous to the receiving river during four rain events. For a CSO contribution of around 6.6% of the total river water discharge, 56.5% of the total phosphorous and up to 77% of the total caffeine loads came from CSOs.

Truchot et al. (1994) and House et al. (1993) explain the different types of impacts due to urban discharges on the receiving waters and many studies have focused on CSO impacts during recent years (*e.g.*, Becouze-Lareure et al. (2016); Passerat et al. (2011); Riechel et al. (2016)). Recovery of receiving water body quality requires strategies to mitigate these impacts. Some of the strategies involve

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(i) reducing the number of overflows (for example, by increasing the urban catchment permeability and thereby reducing stormwater runoff volume), (ii) increasing the sewer capacity (increase of the WWTP capacity, construction of retention basins), (iii) improving the sewer system management (integrated modeling, real-time control techniques) and (iv) better managing CSO quantity and quality (construction of CSO retention basins, wetlands or biofilters downstream of the overflow points). All these strategies require a better understanding of flow dynamics in the related sanitation systems as well as continuous control and reliable monitoring of CSO volumes and pollutant loads.

In recent decades, several environmental authorities and governments have encouraged worldwide urban drainage managers to increase the control of CSOs (MJC, 2015; MDDELCC, 2014; OME, 1994; US-EPA, 1994). Since 2006, European Regulation No. 166/2006 (EU, 2006) concerning the establishment of a European Pollutant Release and Transfer Register, obliges European Union member states to report annually the releases to water of any pollutant specified in Annex II of the Regulation for which the applicable threshold value specified in this annex is exceeded. Hence, CSO pollutant loads must be, at least, estimated as well as the corresponding flow rates. The main challenge focuses on the monitoring of CSOs as overflow structures were not originally built for monitoring purposes. As a result, they often exhibit complex hydrodynamics and uncertainties associated with traditional measurement processes, if estimated, usually are considerably high.

CSO volumes are currently estimated by different techniques regarding, for example, the CSO structures and surrounding configurations (Fig. 1). If hydraulic conditions are favorable in the overflow pipe (uniform flow regime, subcritical flow), CSO flow rates can be measured directly in this conduit, downstream of the CSO structure. Two methods are commonly used: stage-discharge relations (HQRs) or velocity-based methods (VMs). HQRs may be associated with pre-calibrated weirs, pre-designed channels (such as a Venturi or Parshall flume), or any device delivering a rating curve under appropriate flow regimes only needing one water level measurement to obtain CSO measurements, which usually implies low uncertainties for the estimated discharges. However, appropriate hydraulic conditions must be guaranteed and downstream influence must be avoided. Uncertainties in discharges derived from these methodologies are rarely lower than 10% (Joannis et al., 2009). VMs consist in measuring velocities in a selected cross-section of the overflow pipe and the corresponding water level. As for previous water level-based calibrated devices, these methods require specific hydraulic conditions to assume the representativeness of the extracted mean velocities within the selected cross-section. Relative uncertainties in overflow rates obtained by VMs are usually around 20% (Bertrand-Krajewski et al., 2000) and often reach values up to 30% due to *in-situ* factors (Joannis et al., 2009). In addition, flow measurement techniques are intrinsically complicated to deal with as reminded by Melching (2006).

If it seems difficult to perform measurements in the overflow conduit, two alternatives are usually chosen: (a) a balance-based method that enables overflow rates to be obtained by means of the difference between the upstream and downstream flow rates in the main flow pipe; or (b) specific HQRs are determined using water levels measured in the CSO chamber. The difference-based method has the same limitations as direct measurements in the overflow conduit and it requires double instrumentation, which means that, apart from higher costs particularly related to maintenance and time needed for the data analysis, uncertainties also are increased because of the double measurement. The specific HQR method is usually more accurate than the balance-based method, particularly if the CSO structure has a geometry that allows the utilization of well-known classical expressions or adapted relations for frontal or lateral weirs. However, in most of the cases, CSO structures have complex geometries, due to maintenance limitations or because they evolve over the years and require a rehabilitation leading to new additional materials such as bricks combined with concrete, new connections with bends or side-walk benches. In these cases, site-specific HQRs must be established. Recent methods use online sensors to estimate overflow rates by means of site-specific HQRs derived from three-dimensional (3D) modeling. Several research groups have applied Computational Fluid Dynamics (CFD)-based methodologies to successfully obtain HQRs for complex CSO structures and have defined the optimal position of the corresponding water level sensors (Fach et al., 2009; Isel et al., 2014; Lipeme Kouyi et al., 2011, 2005). Isel et al. (2014) and Lipeme Kouyi et al. (2011) estimated relative uncertainty or mean error values around 10% for higher discharges and 30% for smaller overflows obtained by means of these CFD-based methods. Concerning overflow volumes for a CSO event, associated uncertainties are usually lower, even if Isel et al. (2014) obtained values that roughly exceed 14% for CFD-based methods.

It seems that HQR methods broadly present lower uncertainties.

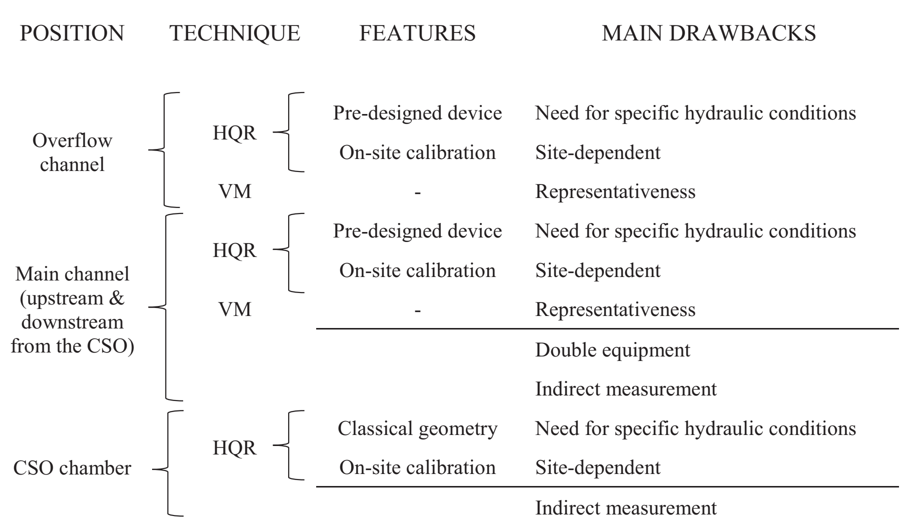

Fig. 1. Current methods to measure CSOs. Considered techniques: HQR (stage-discharge relation methods) and VM (velocity-based methods).