On site validation of a new CSO monitoring methodology by means of a CFD-based approach.

Validation in situ d'une nouvelle méthode de mesure des débits rejetés par les déversoirs d'orage à l'aide d'une approche basée sur la mécanique des fluides numérique.

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RÉSUMÉ

Disposer de données fiables et qualifiées en termes d'incertitudes concernant la quantité et la qualité des rejets des déversoirs d'orage (DOs) est indispensable pour des raisons environnementales, techniques et réglementaires. Le Dispositif pour la Surveillance et la Maîtrise des flux de polluants (DSM-flux) est un canal de mesure original pré-étalonné et conçu pour quantifier et qualifier les rejets des DOs. La méthode de mesure des débits repose sur l'utilisation d'une seule hauteur d'eau et de la relation hauteur d'eau-débit obtenue expérimentalement. La méthode de mesure s'est avérée robuste pour les essais effectués sur un modèle physique à petite échelle. Afin de valider la méthode dans des conditions de fonctionnement in situ et d'évaluer simultanément les possibles effets liés au changement d'échelles, un prototype de DSM-flux installé à Sathonay-Camp (France) a été suivi pendant 4 mois et les débits mesurés ont été comparés aux valeurs obtenues par une méthode de mesure indépendante établie à l'aide de la modélisation CFD. Les résultats de comparaison montrent la pertinence du DSM-flux pour mesurer les débits déversés dans l'espace de décharge des DOs complexes. Les écarts entre les débits mesurés in situ à l'aide des deux méthodes indépendantes augmentent avec le débit déversé. Ces écarts sont discutés et des pistes de reformulation de la loi hauteur d'eau-débit sont proposées.

ABSTRACT

Reliable and quality data in terms of uncertainties regarding the quantity and the quality of combined sewer overflows (CSOs) is essential for environmental, technical and regulatory reasons. The Device for Stormwater and combined sewer flows Monitoring and the control of pollutant fluxes (DSM-flux) is an original pre-calibrated measurement channel designed to quantify and qualify the CSOs discharges. The measurement method is based on the use of a single water level gauge computed into a stage-discharge relationship obtained experimentally. The measurement method proved to be robust for the tests carried out in a small-scale physical model. In order to validate the method under on site operating conditions and simultaneously evaluate the possible scale effects on a larger scale, a prototype of the DSM-flux installed at Sathonay-Camp (France) was monitored for 4 months and the measured flow rate values were compared to the values obtained by an independent measurement method based on CFD modelling. The results of the comparison show the relevance of the DSM-flux for measuring the CSO discharges in the domain of complex CSOs structures. The differences between the flow rates measured on site using the two independent methods increase with the flow discharged. These differences are discussed and ways of reformulating the stage-discharge relationship are proposed.

MOTS CLÉS

CFD, CSO, DSM-flux, monitoring, on site validation

1 INTRODUCTION

Several studies have highlighted the significant role of Combined Sewer Overflows (CSOs) as pathways to reach urban receiving waters for various contaminants, such as organic micropollutants (Becouze-Lareure *et al.*, 2016; Launay *et al.*, 2016), especially those highly removed by WWTP (Phillips *et al.*, 2012; Weyrauch *et al.*, 2010), inorganic micropollutants (Becouze-Lareure *et al.*, 2016; Weyrauch *et al.*, 2010), nutrients (Becouze-Lareure *et al.*, 2016; Viviano *et al.*, 2017), hormones (Phillips *et al.*, 2012) or bacteria (Passerat *et al.*, 2011; Weyrauch *et al.*, 2010) among others. These reported studies show the importance of CSOs contribution to both, the annual pollutant loads on the receiving waters and their peak pollutant concentrations during storm events, as well as their impacts on the receiving water bodies. Recovery of receiving water bodies' quality requires strategies to mitigate CSO impacts. In order to apply these strategies and assess their performance, a better understanding of flow dynamics in the related drainage systems is needed, as well as continuous control and reliable monitoring of CSO volumes and pollutant loads.

Since 2006, European Regulation No. 166/2006 (EUPC, 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. This Regulation obliges the urban drainage managers to implement reliable monitoring methodologies to obtain accurate data of CSO releases, at least for the most important cases.

Hence, reliable and accurate CSO quantity and quality data is needed for environmental, technical and regulatory reasons. The main challenge on the monitoring of CSOs is that overflow structures were not originally built for monitoring purposes. As a result, they often exhibit complex hydrodynamics where traditional measurement methods are difficult to apply and the uncertainties associated to these data, if estimated, are usually considerably high.

The Device for Stormwater and combined sewer flows Monitoring and the control of pollutant fluxes (DSM-flux), for which the design concept was proposed by Volte *et al.* (2013), represents a new pre-calibrated and pre-designed device to monitor and control the quantity and the quality of CSOs. The DSM-flux has been designed for the purpose of measuring overflow discharges and volumes as well as pollutant concentrations and mass loads. Additionally, thanks to its design, this device also reduces particulate pollutants by sedimentation and mitigates the erosion impacts on the receiving waters by dissipating the flow kinetic energy through turbulence.

The DSM-flux is a rectangular open channel with an original geometry and consists of four main areas whose main purpose is to allow the device to operate properly under various flow regimes at different locations. A detailed description of the functioning of the device and the methodology to monitor CSO discharges are pointed out in Maté Marín *et al.* (2018). This methodology mainly consists in a stage-discharge relationship (HQR) obtained experimentally that allows measuring CSOs discharges from a single water level gauge. It was proven that the measuring method was robust for multiple inflow conditions concerning different flow regimes and velocity fields with different flow symmetry characteristics at the entry of the device. Uncertainties were estimated to 15% for the highest flow rates and to 2% for the volumes of some characteristic CSO events reproduced in the small-scale physical model.

In order to validate the DSM-flux measuring method under field and unsteady operating flow conditions and to simultaneously evaluate the possible scale effects from a small to a larger scale, a field prototype installed at Sathonay-Camp (France) was monitored for 4 months and the measured flow rates were compared to the values obtained by an independent measurement method based on CFD modelling. This paper presents the results of this comparison.

2 MATERIALS AND METHODS

2.1 The Sathonay-Camp experimental site

The DSM-flux field prototype is installed in the combined sewer system of Sathonay-Camp (France), downstream a CSO structure that overflows to the Ravin stream through a 1 m diameter (∅1 m) concrete conduit of 70 m length and slope 3% (Figure 1A). In order to avoid modifying the existing overflow discharge pipe and other conduits next to it, it was decided to install the DSM-flux prototype in a smaller conduit, parallel to the existing CSO discharge pipe. For that purpose, a distribution chamber was built 25 m downstream from the CSO structure (Figure 1B). This chamber is divided in two sections separated by a 0.69 m height frontal weir. The water entering the chamber firstly fulfils the upstream section and the flow is mainly conveyed to the DSM-flux through a ∅0.4 m PVC pipe of 10 m length and slope 1%. Part of the flow also conveys through a ∅0.2 m drainage gate, located at the invert level of the frontal weir, which allows the complete drainage of the upstream part of the chamber after an event. When the entry of the outflow pipe is completely submerged, water starts flowing over the frontal weir, passing through the downstream section of the chamber and reaching the Ravin stream through the existing ∅1 m CSO discharge pipe. In order to avoid the downstream influence from the Ravin stream, the ∅0.4 m outflow conduit connecting the distribution chamber with the DSM-flux was raised 0.29 m from the chamber invert. For security reasons, the conduit inlet section was temporarily reduced to a half with a sluice gate. The water passing through the DSM-flux overflows to a drainage basin which is connected to an outflow conduit made of two sections: a ∅0.4 m PVC pipe of 15 m length and slope 1% and a stainless steel extension conduit of equivalent cross-section, that is attached to the interior of the Ravin's pipe, adopting the same slope, and that overflows directly into a downstream chamber, where the Ravin converges with the ∅1 m CSO discharge pipe.

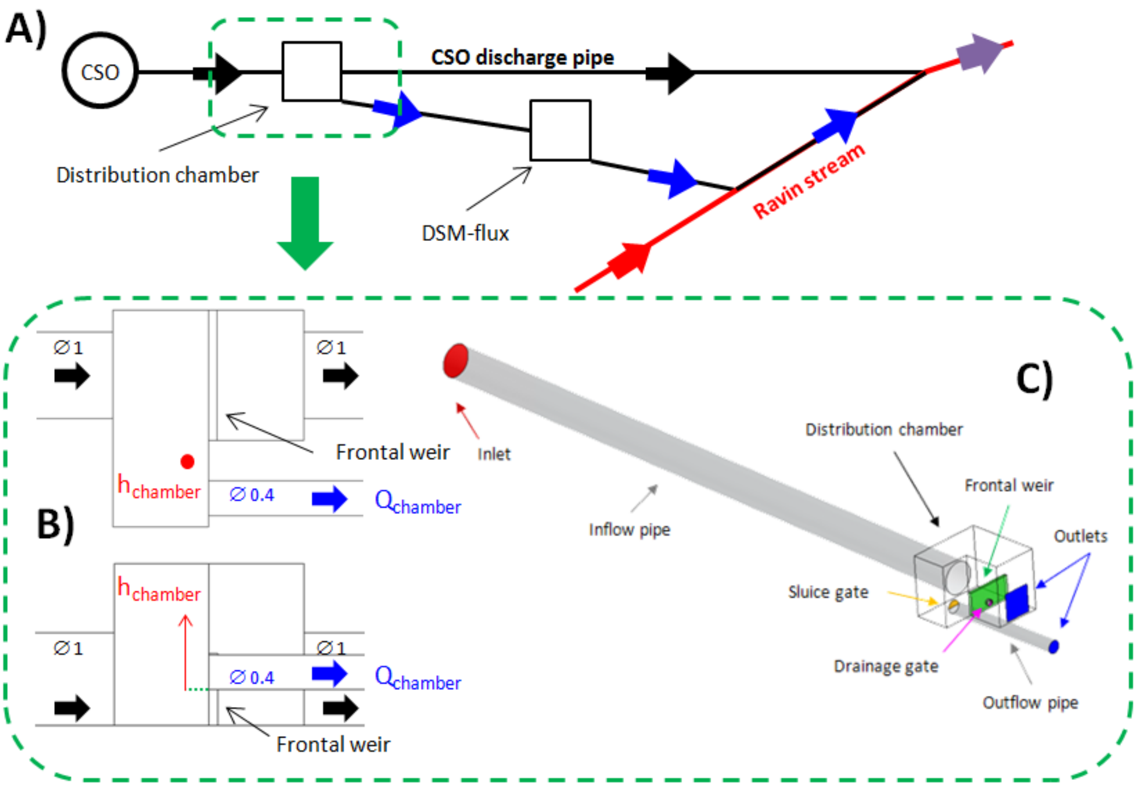

Figure 1.- A) General schematic of the DSM-flux experimental site; B) Horizontal (top) and profile (bottom) views of the distribution chamber; C) 3D view of the distribution chamber numerical model.

2.2 The measuring methods

2.2.1 The DSM-flux measuring method

As presented in Mate Marin *et al.* (2018), the DSM-flux HQR is defined as:

$$Q_{dsm} = 0.4639 \cdot \left(\frac{h_{dsm}}{w}\right)^{-0.135} \cdot L \cdot \sqrt{2g} \cdot h_{dsm}^{3/2}$$

where Q_{dsm} is the flow rate conveyed through the DSM-flux, w is the DSM-flux weirs height, L is the DSM-flux weirs total length, g is the gravitational acceleration and h_{dsm} is the water level above the weirs crests measured at the DSM-flux overflow area. At the experimental site, this water level is measured with a radar installed above the DSM-flux prototype. Further details about the process followed to determine this relationship are found in Mate Marin *et al.* (2018).

2.2.2 The distribution chamber measuring method

In order to validate the DSM-flux HQR, a second flow rate measurement method was needed. As there was a radar installed at the distribution chamber to measure the flow over the frontal weir, it was decided to determine another HQR between that water level gauge and the flow rate conveyed to the DSM-flux through the ∅0.4 m outflow pipe of the chamber (Figure 1B). This relationship was established numerically with a Computational Fluid Dynamics (CFD) model of the distribution chamber (Figure 1C) implemented in the commercial software ANSYS Fluent. RANS equations were solved considering the RNG k-ε turbulence model, a scalable wall function, second order upwind discretization schemes, the PISO velocity-pressure coupling algorithm and two convergence criteria: a minimum value of 10^{-3} for the scaled residuals and a mass balance between the inlet and the outlets lower than 3%. The distribution chamber HQR is defined as:

$$Q_{chamber} = \begin{cases} 0.5229 \cdot h_{chamber}^2 + 0.0653 \cdot h_{chamber} + 0.001, & 0 \leq h_{chamber} < 0.285 \\ -0.1365 \cdot h_{chamber}^2 + 0.2973 \cdot h_{chamber} - 0.0115, & 0.285 \leq h_{chamber} < 1 \end{cases}$$

where $Q_{chamber}$ is the flow rate conveyed to the DSM-flux through the ∅0.4 m outflow pipe of the chamber and $h_{chamber}$ is the water level in the distribution chamber above the conduit invert (Figure 1B), which is also measured with a radar at the experimental site.

3 RESULTS AND DISCUSSION

The Sathonay-Camp experimental site was monitored for 4 months and water level data of the distribution chamber ($h_{chamber}$) and the DSM-flux (h_{dsm}) radars were recorded every minute. A total of 41 CSO events were registered during these 4 months. Discharges measured by means of both monitoring methodologies are similar for flow rates up to 60 l/s. Differences increase along the increasing of overflow rates higher than 60 l/s, the DSM-flux discharges being greater than the ones obtained at the distribution chamber. Deviations (for both CSO volumes and discharges) are significant particularly for events with discharge peaks higher than 0.15 m^3/s. Despite the differences for the higher flow rate values, evaluation coefficients for most of the registered events are satisfactory, with Nash-Sutcliffe coefficient values higher than 0.5 for 71% of the events. CSO volumes have also been estimated with both monitoring methodologies and compared, showing noticeable relative differences due to the mismatch of the higher flow rates (only 15% of the events have differences in volumes under 10%). Either installation mistakes at the distribution chamber (increasing of the opening of the sluice gate, inflows from streets) or inaccuracies in the monitoring methodologies for higher flow rates (scale effects for the DSM-flux measuring method), may explain these deviations.

4 CONCLUSIONS

The DSM-flux method for measuring CSOs discharges is validated on site for flow rates lower than 60 l/s, but shows non-negligible deviations for the higher flow rates. Measures are being taken to fix technical issues in order to obtain a robust second flow rate measurement method and assess the performances of the DSM-flux HQR at the field scale.

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