Qualifying measurement sites in sewer systems: methodology and operational tool

Qualification de sites de mesure en réseau d'assainissement : méthodologie et outils opérationnels


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RÉSUMÉ
Le projet MENTOR a pour objectifs de proposer une méthodologie permettant d’analyser, de qualifier et de mettre en place des points de mesures pertinents pour une gestion efficace des eaux urbaines dans le but de mieux quantifier et mieux qualifier les rejets aux milieux aquatiques récepteurs. Ce projet permettra la mise au point d’outils opérationnels destinés aux gestionnaires et aux responsables de métrologie des réseaux d’assainissement urbains. Il fournira également des recommandations sur le plan organisationnel au niveau des services et équipes en charge de la gestion des eaux urbaines. Cet article présente la démarche du projet et quelques exemples de résultats.

ABSTRACT
The MENTOR project aims at proposing a methodology to qualify the ability of measuring site to give representative information for an efficient management of urban waters. This will contribute to a better knowledge of the pollutants poured into receiving waters. The project will provide operational tools for technical and management staff in charge of metrology as well as recommendations both technical and managerial. This paper presents the main lines of the project as well as some results.

KEYWORDS
Metrology, Sewer networks, Social practices, Technical devices
1 INTRODUCTION

With more than 70% of the French national population living in urban areas, the anthropisation of the urban water cycle is obvious and requires a holistic approach. Reaching the EWFD (European Water Framework Directive) objective prescribing a good ecological status of water bodies will not be possible without an adequate operation of sewer systems. However, their functioning is rather unknown even if they represent a huge asset. According to the data provided by IFEN (French Environment Institute), 24.8 millions of flats and houses in France in 2004 were connected to sewer systems whose total length was above 280000 km. These figures reveal the economical significance of the operation and the management of sewer systems. From an environmental point of view, it is known since many years that pollutant loads discharged by urban water systems during storm weather significantly contribute to the degradation of the quality of water bodies. It is thus necessary to estimate these pollutant loads at both event and annual scales in order to better evaluate the functioning and to improve the operation of urban sewer systems, and to contribute to a better chemical and ecological quality of water bodies.

The concepts of permanent diagnosis and self-monitoring of sewer systems was introduced more than 15 years ago in order to improve the operation of sewer infrastructures, the planning of works and the regulatory and financial issues (e.g. to allocate investment costs within inter-municipal structures). Consequently, in situ measurements shall be carried out in order to evaluate, and then to improve, the real functioning of sewer systems. Measurement networks are a key instrument for monitoring and operation, with an increased interest in case of continuous on line measurements. Various papers exist (Bertrand-Krajewski et al., 2000 and 2001), (Joannis, 2001) to help implementing those permanent diagnosis and self-monitoring of sewer systems. However, as in all technical systems, this implementation meets many technical, economical, political but also organizational and managerial constraints. It generates also a lot of questions of practitioners (Laplace et Deshons, 1998 ; Leclerc et Battaglia, 2001 ; Gandouin et al, 2006). Quite a large number of French sewer networks are equipped of flowmetering devices as those devices are necessary to know the driving flow-rate which will transport the pollutant loads. Most of those devices measure both the water level and the flow velocity locally. Then a first question arises: are those sensors able to catch the mean velocity? Part of the answer can be deduced from other questions: which part of the spatial distributions are they able to estimate? Can this part of the flow be properly related to the mean velocity? Some researchers (Bardiaux et al, 2007), (Lassabatere et al., 2013) have worked on such questions and proposed laws to describe the vertical distribution of the streamwise velocity.

Many European teams have also developed computational fluid dynamics (CFD) skills and then researches to understand the hydraulics of sewers or to manage combined sewer overflows (Fach et al., 2008 et 2009) ; (Jarman et al., 2008) or to improve the implementation of sensors (Lipeme Kouyi et al., 2005 ; Vazquez et al., 2005). (Lipeme Kouyi, 2004). Those numerical tools have also been used for flowmeters calibration by Pryl et al. (1998). Some teams are also working on the representativeness and the validation of measurements of flow rates (Hugues et al, 1976), or water quality (Mourad et al., 2005). In the same time, real time control through modeling of the whole system is a tool aiming at protecting the receiving waters (Schutze, 1999; Butler et Schutze, 2005; Vanrolleghem et al., 2005). (Ostrowski et al., 2002) have briefly drawn the main lines of a methodology aiming at improving the implementation of sensors in real sewers. More recently some of the current project partners have presented more deeply a methodology and even some test cases (Bonakdari, 2006 ; Larrarte et al., 2004 & 2010).

However, an efficient operation of sewer systems also depends on the ability of both sewer systems and measurement networks to be resources for their operating organizations: how do they contribute to create economic and usage value? Such difficulties can be related to the capacity of these technical devices to ensure:

- Values for organizations responsible for these devices (local authorities, technical engineering design offices, management firms, etc.)
- Services and Uses to publics (i.e residents, users, inhabitants, etc.)

Thus, difficulties are depending on the capacity of technical devices to secure social urban activities.
both of the public and organizations (ability to be enlisted). We are basing our approach on concepts developed by instrument theory, which define technical devices like a set of technical objects and organizations. So we refer to works devoted to sociology of innovation (Akrich and al., 2006; Midler, 1998); theory of social action, user representation and practices (Lefevbre, 1972; Raymond, 1984; Pinson 1993; Begout 2005). We are also interested in instrumental genesis (Heidegger, 1995; Arendt, 1972; Simondon, 1989; Habermas, 1987; Dewey, 2003; kapp, 2007; Cosandey, 2008) through these assumptions:

- All social activities require mobilization of technical devices.
- There is no technical device without organizations in charge of its maintainance in operation (design, construction, management, etc.)
- Technical device raises a dual process: instrumentation means how organizations endow the public/users with technical devices and also instrumentalization as how users mobilize those technical devices to achieve their daily social activities.

Therefore, integrated instrumentation needs to be reflected with studying social and technical environment in which this instrumentation will be realized.

The main objective of the MENTOR (for MEasurement sites conception method for sewer NeTwORks) project consists to propose a methodology for the design and the audit of discharges and particulate pollutant loads measurement sites in sewer systems. MENTOR will also provide operational tools for data processing and use. The steps of the methodology are the following ones:

1. defining the characteristic parameters of the flow,
2. modeling the hydrodynamics of an existing or planned measurement site,
3. simulating various sensors configurations for this site,
4. qualifying or not the site,
5. defining appropriate methods for interpretation of measured data,
6. establishing organisational recommendations ensuring the implementation of best metrological practices.

The 42 months MENTOR project (from April 2012 to September 2015) is organized in 8 working packages that aim at crossing the capabilities of laboratory experiments, Computational Fluid Dynamics (CFD) and in sewer experiments to achieve those steps. In this paper, steps 1 up to 5 are performed highlighting i) how open channel junction may disturb discharge measurements and ii) how CFD modeling enables to improve the quality and the understanding of field data.

2 SOME APPLICATIONS OF THE METHODOLOGY

2.1 Influence of a junction on the discharge estimation

Junction flows are common features of typical sewer networks. They are composed of two (or more) upstream free-surface flows merging into one downstream flow. Flowmeters in sewers are often located in the vicinity of such junctions, either in the upstream or the downstream branches, for practical reasons, especially easy access from manholes. The objectives of this work is thus twofold: i) to verify and quantify the capacities of a 3D numerical model to compute the flow pattern in an open-channel junction configuration and ii) to simulate the introduction of a common used commercial flowmeter such as Doppler devices close to the junction and quantify the error made when estimating the corresponding discharge.

The experimental set-up of open-channel junction flow located in LMFA is used with the upstream discharges $Q_x=Q_y=2L/s$ and a water depth $h=12cm$. The velocity field is measured at 6 elevations along the 7 verticals within the 11 sections shown in figure 1 using a commercial micro-ADV from Nortek. On the other hand, calculations are performed at LGCIE using the 3D numerical code Fluent which solves the RANS equations with the RNG- k-epsilon as closure model and using rigid lid to model the free surface at the 12cm water level (as the free-surface evolution remains negligible in this experiment). Figure 1 shows locations of the measurement cross sections and the key flow pattern.
obtained by Weber et al. (2001) which confirms the 3D aspect of the flow across open channel junctions.

Regarding the second objective, we simulate the introduction of a commercial flow-meter in the upstream and downstream branch of the junction and compute the discharge that would be estimated by the flow-meter. To do so, we average over the vertical axis the measured or computed streamwise velocities at the centre of each available section and multiply this averaged-velocity by the wet-section (12cmx30cm). The discharge estimated using this approach is plotted in Fig. 2 using the measured $Q_m$ and computed $Q_c$ data along with the real discharge $Q_r$ controlled by electromagnetic flow-meters on the experimental set-up (plain lines). The corresponding error is computed as $E=(Q_m-Q_r)/Q_r$ for the measurements and $E=(Q_c-Q_r)/Q_r$ for the calculations. It appears that while the error that would be made by the commercial flow-meter in the upstream branch is lower than 14%, this error in the downstream branch could reach up to 52% of overestimation if the flow-meter was located at a distance of one channel width downstream from the entrance of the downstream branch. This error then rapidly decreases towards downstream. Additional calculations showed that the distribution of this error strongly varies regarding the upstream discharge combinations ($Q_{xi}$ and $Q_{yi}$).

2.2 A CFD based methodology for discharge measurement with ultrasonic paths – Applications to two gauging stations

2.2.1 Description of the gauging stations

The gauging station Milan (Mulhouse, France) (see Figure 3a) is located in a unitary horseshoe-
shaped sewer that is equipped with a middle footway. Indeed, the flow is divided into two streams in dry weather conditions. The gauging station is located about 15 meters upstream of a combined sewer overflow chamber (see Figure 3b) and about 20 meters downstream of a bend. A dissymmetric confluence is located about 650 meters upstream of the site at the beginning of the middle footway (see Figure 3c). The mean slope of this sewer is about 0.12%. Four paths are used in this gauging station.

The gauging station Quai Forst (Mulhouse, France) (see Figure 3d) is located in a unitary egg-shaped sewer, 10 meters upstream of a sharp bend, 20 meters upstream of a large manhole presenting a backward-facing step, and 80 meters downstream of a bend presenting a large radius of curvature. The mean slope of this sewer is about 0.10%. Three paths are used in this gauging station.

Figure 3. Views of the gauging stations: a) Cross-section of the station Milan, b) Photograph of the downstream CSO chamber of the station Milan, c) Photograph of the upstream dissymmetric convergence of the station, d) Cross-section of the station Quai Forst.

2.2.2 Methodology

The methodology consists in (Bardiaux et al. 2011):

- Analyze the hydraulic behavior in the environment of the gauging station using data analysis,
- Define the computational domain and the boundary conditions,
- Carry out the representative simulations,
- Analyze the results,
- Translate the results in operational discharge relationships,
- Evaluate the uncertainties.

The aim of the study was to present and apply a computational fluid dynamics based methodology to discharge determination using ultrasonic (transit-time) measurements in sewer pipes. This approach was illustrated for two gauging stations presenting particularities on which the International Standard Association warned against direct application of the international standard ISO 6416:2004. Based on a detailed hydraulic analysis (Bardiaux at al. 2011), simulations were carried in order to calibrate the weighting coefficients \( \alpha_i \) of the discharge relationship (Equation 1).

Moreover, correlations between variables were studied in order to define degraded relationships that can be used when a number of paths are not working (often the case in rough sewer conditions).
2.2.3 Results

2.2.3.1 Optimal functioning

Operational relationships (AFNOR 2005) are given in the form of Equation 1. Here, \( V_i \) are the mean velocities measured along the ultrasonic paths; \( S_i \) are the areas affected to each measured velocity; \( \alpha_i \) are weighting coefficients that must be calibrated.

\[
Q = \sum_{i=1}^{n} \alpha_i V_i S_i
\]  

(1)

Table 1 shows the weighting coefficients that have been identify. They are significantly different from 1 demonstrating a non-standard behaviour.

<table>
<thead>
<tr>
<th>Number of immersed paths</th>
<th>&quot;Milan&quot;</th>
<th>&quot;Forst&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.00</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>0.97</td>
<td>0.93</td>
</tr>
<tr>
<td>3</td>
<td>0.90</td>
<td>0.93</td>
</tr>
<tr>
<td>4</td>
<td>0.91</td>
<td>0.93</td>
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The global uncertainty on the discharge was roughly estimated based on the measurement uncertainty and the method error. This results in a global uncertainty comprising between 5% and 12% for the site “Forst”, 3% and 15% for the gauging station “Milan” (between 5% and 22% when taking into account the error due to the presence of deposits). The method uncertainty was always lower than 6%, which means that the global uncertainty is mainly due to measurement uncertainty.

2.2.3.2 Degraded relationships

Figure 4 illustrates the link that can exist between two measured variables, here \( V_1 \) and \( V_2 \) for the station Milan and \( V_2 \) and \( V_3 \) for the station Quai Forst. Even if these correlations are not perfect, they are precious information in order to evaluate, even approximately, the discharge in degraded conditions (Dufresne et al. 2012). For example, if the first path of the station Milan is not working, the degraded condition \( V_1 = 2V_2 \) can be used to estimate the discharge. The additional error can be evaluated.

![Figure 4. Velocity V1 (right channel) as a function of the velocity V2.](image)

The discharge relationships given in this study are simple and operational: they can be directly used by the manager of the sewer system to determine the discharge for these two gauging stations. Degraded relationships are approximate equations that can be used when a number of paths of the gauging station are not working.
3 CONCLUSION

The MENTOR project involves both technical and social sciences teams in order to propose a methodology which aims at improving sewer networks managements. MENTOR global methodology is based on 6 steps including technical aspects (laboratory experiments, field data, CFD modeling, etc.) and social science methods (particularly organizational choices which enable to improve metrological practices). 5 steps are performed dealing to laboratory experiments, CFD modeling and field measurements, and show how CFD approach allows i) improving the validation of field data and ii) indicating the best location of flowmeter downstream to open channel junctions in sewer systems.

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