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An original methodology to instrument non-standard sewer works using water level measurements

Instrumentation innovante des ouvrages d'assainissement non standardisés – Application à la station Branly à Colmar (Haut-Rhin)

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RÉSUMÉ

Cet article traite d'une méthode générale de détermination du débit en réseau d'assainissement et particulièrement dans les ouvrages non-standardisés à conditions aux limites variables et/ou complexes. Cette méthodologie basée sur un modèle numérique en trois dimensions et utilisant la mesure de hauteur d'eau dans l'ouvrage, a déjà fait l'objet d'un précédent article pour son application aux déversoirs d'orage. Ainsi, la présente étude s'attache à généraliser cette méthode à tout ouvrage d'assainissement non-standard notamment aux rétrécissements de section impliquant un effet Venturi. Cette technique est particulièrement intéressante car elle s'affranchit des contraintes de maintenance associées aux capteurs submergés. De plus, elle permet d'évaluer l'incertitude associée à la relation hauteur / débit identifiée en tenant compte à la fois de l'incertitude sur le modèle numérique, de la précision du capteur mais également de la variabilité des conditions aux limites. Cette approche a été illustrée à travers l'exemple sur site de Branly à Colmar (FRANCE).

ABSTRACT

This article focuses on a general method to assess the flow rate in sewage networks and especially in non-standard works with variable or complex boundary hydraulic conditions. This computational fluid dynamics based methodology, using measurements of the water depth in the work, has already been described for CSOs and validated in previous articles. Therefore, this study focuses on the generalization of the methodology to other non-standard works (flumes,...). This technique is particularly interesting as it limits the maintenance required by a submerged sensor. Moreover, the chosen height - discharge relationship is related to its uncertainties (uncertainty of the CFD-model, of the sensor accuracy, but also of the unknown boundary conditions). This approach is illustrated through an example of the "Branly" work of Colmar, FRANCE, which will also highlight the growing importance of securing the measurements.

KEYWORDS

CFD-modelling, Metrology, Self-monitoring, Sewer network, Uncertainties

1 INTRODUCTION

Sanitation network instrumentation is currently a major concern because of the Water Law [MEDAD (2007)] which transposes the Directive of the Council of the European Communities of May 21st 1991 on urban wastewater treatment into French national law. This legislation makes it necessary to assess the discharge impacting the receptor environment at key points of the network. This constraint of self-monitoring requires reliable techniques to measure the flow rate.

However, this monitoring constraint is quite new compared to the construction of the sewer networks therefore, most of the works in the sewer network were not built to fit the topical instrumentation standards; their geometry and hydraulic conditions are not included in the ISO standards (ISO 4359, [1983], ISO 1438 [1980],...) [Bertrand-Krajewski (2000)].

Moreover, different discharge measurement techniques can be used, such as the association between a velocity measurement (given with a Doppler Effect sensor for example), and a water height measurement [Bertrand-Krajewski (2000)]. In some cases, this technique leads to non-negligible measurement and operating problems [Joannis (2001)] (deposit on the sensor leading to the need for regular maintenance, position in the sewer etc.).

This article focuses on another discharge assessment technique based on measurements of one or several water levels in those non-standard sewer works. This method using a numerical model to define a suitable height-discharge relationship has already been investigated and validated by several researchers in laboratory and on site [Vazquez et al. (2006), Zug et al. (2002)]. It is particularly interesting as it takes the uncertainties into account while defining the more suitable depth-discharge relationship. Thus, three main uncertainties have been studied: the uncertainty due to the numerical model, the uncertainty due to the unknown / variable boundary conditions and finally the uncertainty due to the sensors accuracy.

2 METHODOLOGY OF INSTRUMENTATION OF NON-STANDARD WORKS

2.1 Objectives

This originality of the proposed methodology is located in its objectives. Indeed, it aims at assessing the discharge in non-standard sewer works (CSOs, flumes,...) using just and only water level measurements. Two techniques can be used:

- A. Only one water level sensor is needed: when the water goes through the critical depth (which depends of the geometric proprieties).
- B. Two water level sensors are required. This applies when there is a possible downstream influence of the flow.

2.2 Methodology

The general methodology developed in this article is based on a hydraulic analysis of the site and on a computational fluid dynamics model. The main steps have been summarized in the following diagram (cf Figure 1). However the model conception process as well as the validation has already been dealt with in previous articles and particularly through the application to non-standard combined sewer overflows (CSOs) (Isel et al [2012] (submitted), Lipeme Kouyi et al. [2005]).

Therefore, this article will focus on the validation / calibration stage and finally the end users step through the example of a real site called Branly and located in Colmar, France. Indeed, once the model has been conceived and the methodology applied, the more suitable h/Q relationship is defined with its related uncertainties and domain of applicability. Depending on the stakes of the site and the expected uncertainty from the sewer manager, the uncertainty is considered as acceptable (if any case, then the calibration of the sensors' zeros is required) or not. If the related uncertainties are not acceptable, then a small modification of the sewer work can be done, such as uprising the crest in the CSO, settling of baffles in the flow, etc.; the dedicated methodology will be detailed in following article. If the uncertainties of the relationship are considered to be acceptable, then a calibration of the sensor zero has to be done by inspecting the site and checking the measurements manually. Once the sensor has been calibrated a first time, any drift can be identified by redundancy, that is to compare of the results with other instrumentation leading usually to the same results. Moreover, by comparing the measurement data with its historical background in dry weather conditions, the quantity of deposit can be identified nearly in real time; the offset of the sensors can therefore be adjusted depending on this value.

This seventh step leads to calibrated measurement data which are integrated as inlets in the sensor transmitter. Once the chosen h/Q relationship and the domain of applicability put in this transmitter, the user is directly given the flow rate and/or the total discharge volume with the related uncertainty of the method.

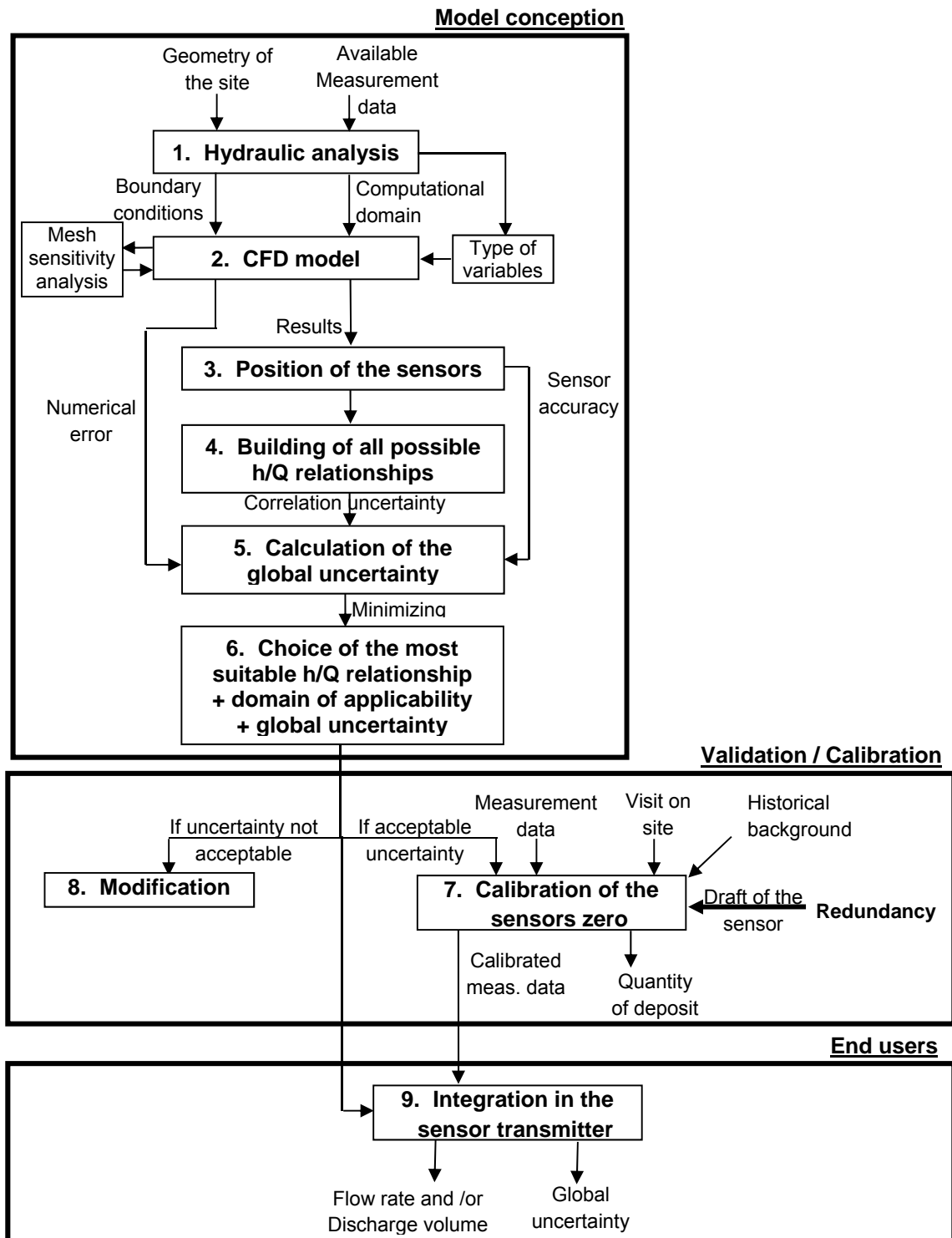


Figure 1. Diagram summarizing the main steps of the methodology

3 APPLICATION ON SITE

3.1 Description of the "Branly" site

The Branly site is a key point of the sewer network of Colmar (FRANCE) and represents around 80 % of the total discharge volume of the city. This site is made of several discharge elements (cf Figure 2) that can be studied individually:

- Two Archimedes' screws (nominal flow rate of 2 m³/s). The flow rate led by the screws goes through a discharge chamber before reaching a hanging channel and falling in the mixing area. A Venturi effect occurs between the discharge chamber and the hanging channel because of a section constriction.
- Three submerged non-clogging impeller pumps with a nominal discharge of 0.5 m³/s. Every pump is linked to a 1m-diameter riser in which the water is pumped before falling into the mixing area using a horizontal 0.5m-diameter pipe.
- A gate (3.13m*2m) located upstream of the mixing area and discharging the flow in case of a extreme rainy event.
- The Branly site is also characterized by:
 - A mixing chamber located downstream of the mixing area. It is supplied by two mild slope circular pipes with a diameter of 2.14m. This chamber precedes the discharge of the flow in the natural environment.

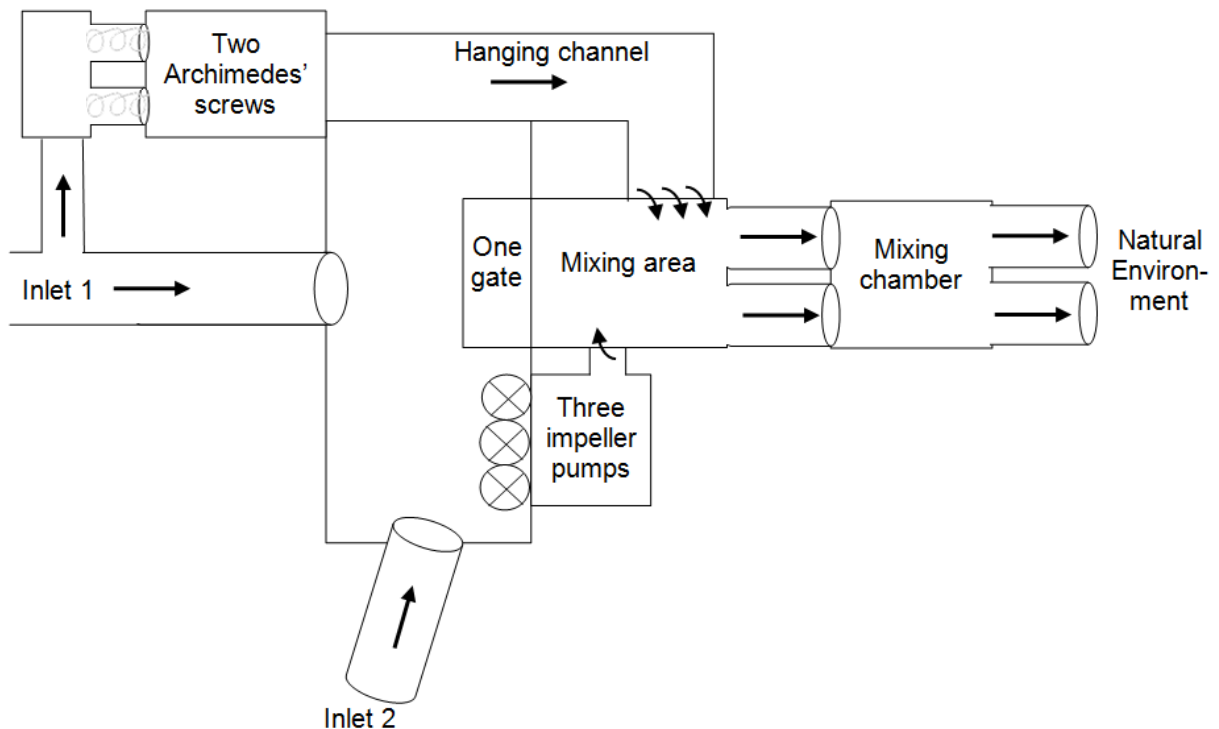


Figure 2: The Branly site with different independent discharge elements (screws, gate, pumps)

Those different elements will be individually instrumented. The total discharge volume will therefore be calculated with two different techniques in order to secure the measurements by redundancy:

- Sum of the discharge volume of the different elements (pumps, screw pumps and gate)
- Instrumentation of the mixing chamber downstream of the discharge elements

3.2 Instrumentation of the different discharge elements

3.2.1 Instrumentation of the pumps

The flow is pumped up through a riser before falling into the mixing area using a horizontal pipe (cf. Figure 3).



Figure 3: Photo of the three risers (left) - Model of one of the three pumps (right)

Therefore, the water goes through the critical depth which means that the pumps discharge can be measured using only one water level sensor for each riser (measurement technique A). This instrumentation is necessary in order to take the years of service of the pump into account in real time as it can lead to a possible decrease of the discharge; the total dynamic head of the pump can therefore be updated. Moreover, the energy loss induced by the horizontal junction is not common as it is sometimes submerged but not all the time.

Therefore the previous CFD-based methodology has been applied leading to a relationship between the water level and the corresponding discharge for each pump.

Figure 4: Height / discharge relationships depending on the functioning of the endless screws

For each pump	$h > 0.10 \text{ m}$	$Q_{pump} = 1,234 \cdot h^2 - 0.643 \cdot h^3 - \frac{1.647 \cdot 10^{-5}}{h^2 + 10^{-6}}$
	$h \leq 0.10 \text{ m}$	$Q_{pump} = 0.314 \cdot h^{1.5}$

With h the water level at the center of each riser in m and Q_{pump} the flow rate in m^3/s

The related global uncertainty of this relationship is maximum of 10 % for $Q_{pump} > 0.10 \text{ m}^3/\text{s}$. Indeed, the evolution of this uncertainty is inversely proportional to the evolution of the flow rate; the more the flow rate increases the less the uncertainty. Likewise, for small flow rates ($Q_{pump} \leq 0.10 \text{ m}^3/\text{s}$), the related uncertainty can be quite high (up to 50%).

3.2.2 Instrumentation of the endless screws

To instrument the endless screws, the choice has been made to take advantage of the natural Venturi effect that takes place in the section restriction between the discharge chamber and the hanging channel (cf Figure 5).

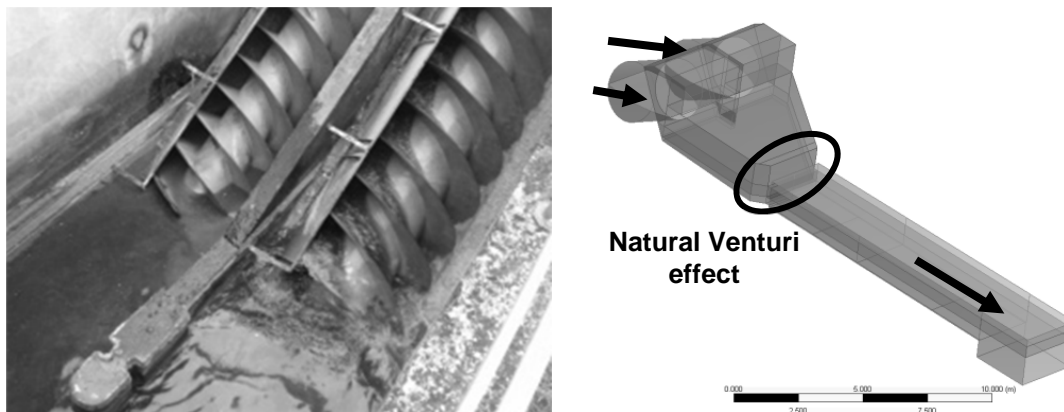


Figure 5: Photo of the Archimedes screws (left) - Natural Venturi effect in the Archimedes screws discharge chamber (right)

However, because this Venturi effect was not significant enough, it has been increased by building a

site-specific flume using stainless steel walls (cf Figure 6).

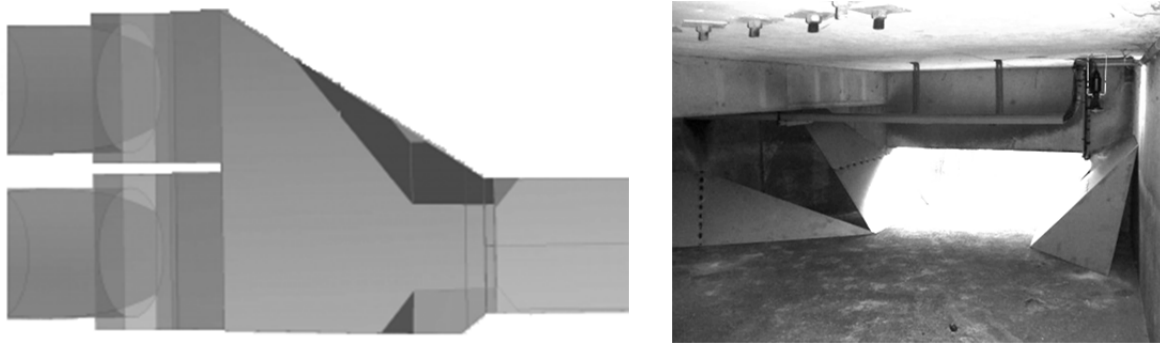
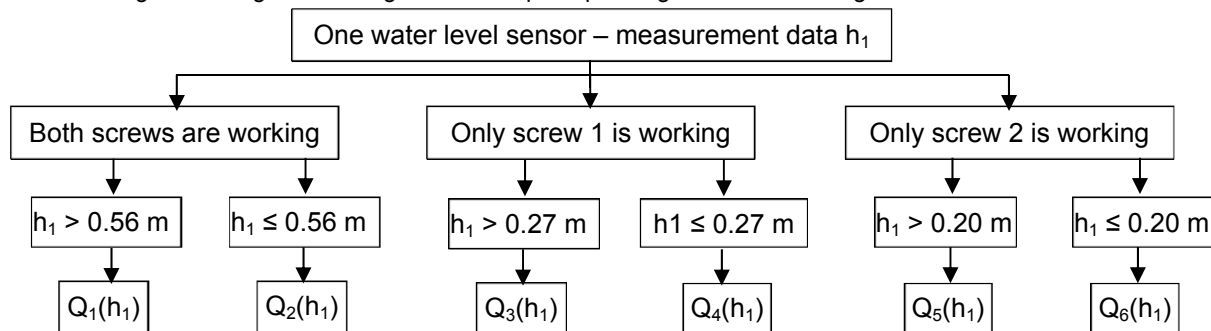


Figure 6: Model of the new flume (left) – Photo of the building of a site-specific flume (right)

Of course, this flume does not fit the ISO-standards [ISO 1438 (1980)]. However, using the previous methodology based on a CFD-model, a relationship between the water level and the discharge can be found when one screw or the other is working and when both of them are functioning (see figure 4). Moreover, because there is not downstream influence and that the flow is falling into the mixing area at the end of the hanging channel, only one water level measurement is required (measurement technique A).

Figure 7: Height / discharge relationships depending on the functioning of the endless screws

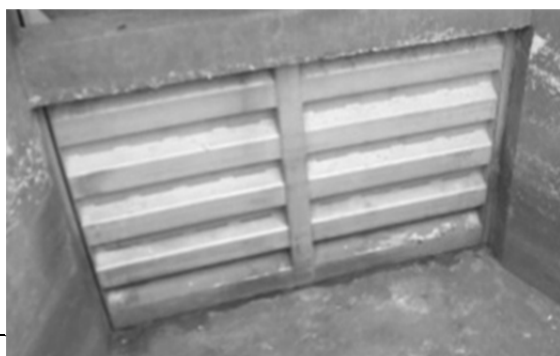


With h_1 the water level at the sensor position in m and Q_i the flow rate in m^3/s

When both screws are working, the flow rate is quite important therefore the related uncertainty is low (maximum 11 % for $Q_{screws} > 2.1 m^3/s$). When only one screw is working the related uncertainty is higher (maximum 20 % for $Q_{screws} > 0.3 m^3/s$). Moreover, as it has been said before, this uncertainty increases while the flow rate decreases, therefore for smaller discharges ($Q_{screws} \leq 0.3 m^3/s$), the related uncertainty can go up to 50%.

3.2.3 Instrumentation of the gate

On this site, the gate is working as a last resort before flooding, that is in case of an extreme rainy event. The way the gate works depends on the water level downstream of it. Indeed, a downstream influence can occur, resulting in the gate been submerged. Therefore, two water level sensors have to be put into place (measurement technique B), one upstream of the gate and the other one downstream of it (cf Figure 8).



Water level sensors

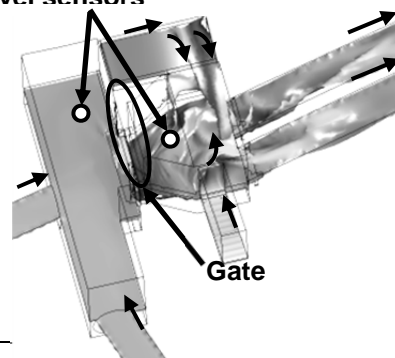


Figure 8: Photo of the closed gate (left) - Simulation of the flow with an open gate and localisation of the water level sensors (right)

The aim of this instrumentation is to recalibrate the coefficients in the typical height / discharge relationships for submerged underflow gates and free underflow gates [DHI Software (2004)]

$$Q_{submerged,underflow} = \frac{\alpha}{\sqrt{1 - \left(\frac{\alpha \cdot a}{y_1}\right)^2}} \cdot a \cdot b \cdot \sqrt{2g(y_1 - y_2)} \quad (4)$$

$$Q_{free,underflow} = \frac{C_c}{\sqrt{1 + \frac{C_c \cdot a}{y_1}}} \cdot a \cdot b \cdot \sqrt{2gy_1} \quad (5)$$

with α , C_c a calibration coefficient, a the vertical gate opening in m, b the width of the gate in m, y_1 the upstream water level in m and y_2 the downstream water level in m and g the gravity $g = 9.81\text{m/s}^2$

The previous methodology has been applied using two different models, one with the submerged gate, that is with a downstream influence, and one without. The related results compared with the first set of data highlighted that this particular gate usually works under submerged conditions. This has to do with the gate being the last discharge elements to open up and also with the mild slope of the discharging pipes whose total length is about 135 m.

Therefore, the α coefficient has been linked with the vertical gate opening following the relationship:

$$\alpha_{calibrated} = -0.180 a^2 + 0.257 a + 0.457 \quad (6)$$

Of course, this calibration is only valid on the particular Branly site and with the present control system.

3.3 Instrumentation of the mixing chamber

In order to secure the measurements, a redundant instrumentation has been put in place on the Branly site. Therefore, the mixing chamber downstream of the discharge elements has been instrumented, with the intend to compare the results with the sum of the three individual instrumentations previously described. This instrumentation has been done by taking into account the natural Venturi effect that is taking place because of the section restriction in each of the two sewer pipe downstream of the mixing chamber (cf Figure 9 - left). The position of the water level sensors as well as the more suitable height / discharge relationship (7) have been identified based on the previous methodology using a CFD-model. Moreover, because of a possible downstream influence of the natural environment, this mixing chamber has been instrumented using technique B, that is two water level measurements for each site, that is one sensor upstream of the Venturi effect and one downstream in each sewer pipe so a total of 4 water level sensors (cf Figure 9 - right).

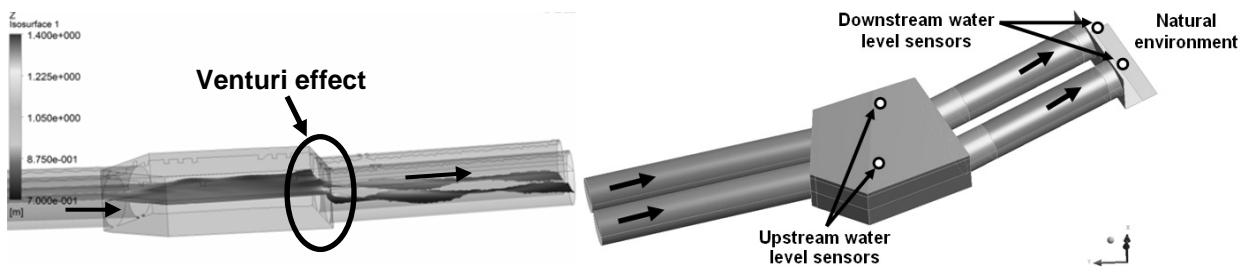


Figure 9: Lateral view of the mixing chamber (left) - Localisation of the sensors (right)

Thus the parametric equation linking the discharge going through one pipe to the two corresponding water levels measurements (in the mixing chamber h_{MC} , and in the natural environment h_{NE}) has the following structure:

$$Q_{total_discharge} = Q_{left} + Q_{right} \quad (7)$$

$$= (1 - C_1) \cdot \frac{-\beta_1 + \sqrt{abs(\beta_1^2 - 4 \cdot \alpha_1 \cdot \gamma_1)}}{2 \cdot \alpha_1} + C_1 \cdot (2.503 \cdot h_{MC1}^2 + 0.283 \cdot h_{MC1})$$

$$+ (1 - C_2) \cdot \frac{-\beta_2 + \sqrt{abs(\beta_2^2 - 4 \cdot \alpha_2 \cdot \gamma_2)}}{2 \cdot \alpha_2} + C_2 \cdot (2.383 \cdot h_{MC2}^2 + 0.776 \cdot h_{MC2})$$

with h_{MC} the water level measured at the sensor position in the mixing chamber in m, and h_{NE} the one measured at the natural environment in m. The variables and coefficients with the index 1 are valid for

the calculation of the discharge in the left discharge pipe and the one with the index 2 refer to the right pipe.

Moreover, the coefficient α_i and β_i are function of h_{MCi} and γ function of h_{MCi} and h_{NEi} ($i \in [1;2]$). They have been calibrated with the previous method and are different from left to right.

The coefficient C_i is defined by the following expression.

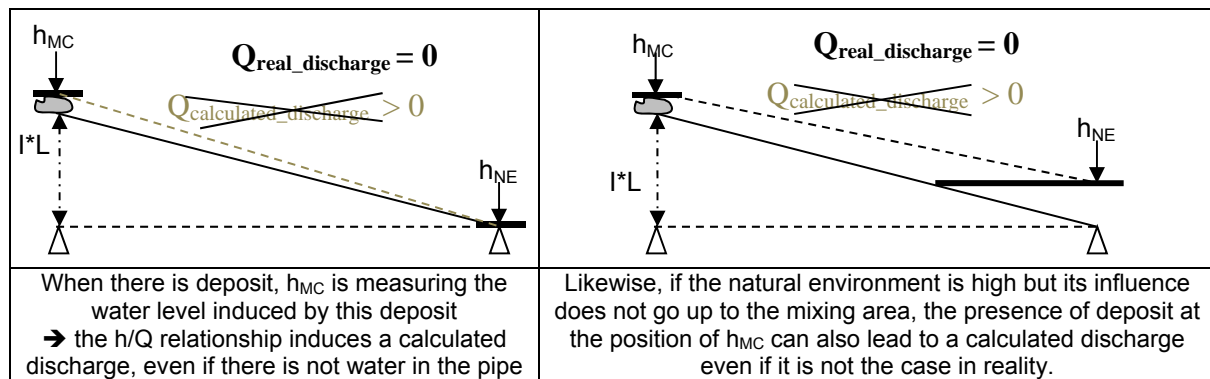
$$C_i = 1 - \frac{1}{1 + 50 \cdot \exp(-50 \cdot (h_{NEi} - 0,6773 \cdot h_{MCi}))} \tag{8}$$

The expression $(h_{NEi} - 0,6773 \cdot h_{MCi})$ represents the boundary between the submerged and unsubmerged Venturi effect downstream of the mixing chamber. Thus, the defined h/Q relationship for the mixing chamber is divided in two parts for each pipe (left or right). The first part, marked with the coefficient $(1 - C_i)$ corresponds to the h/Q relationship of the submerged Venturi effect, whereas the second part (with the coefficient C_i) corresponds to the calculation of the discharge when the Venturi effect is not submerged.

Once the relationship has been identified, the sensors zeros have been calibrated manually during a on-site visit in dry weather conditions (± 1 cm for the two sensors in the natural environment). The offset of the sensors have therefore been modified depending on the quantity of deposit at that time at the sensor position. This offset is going up to +11 cm for one of the two sensors in the mixing chamber. Once this has been done, the available measurement are considered to be calibrated.

This quantity of deposit can be quite problematic while dealing with water level measurements, especially because of its time-variability. Indeed, two cases can occur that will induced a calculated discharge when there is not (cf Figure 10).

Figure 10: Situations inducing a calculated discharge even if there is none because of the deposit



However, this deposit quantity can be identified nearly in real time by comparing the calibrated measurement data with their historical background in dry weather conditions; therefore the apparent slope I_i changes through time. Moreover, in order to deal with the deposit problems, the following condition has to be taken into account while integrating the h/Q relationship in the sensor transmitter:

If ($h_{MC2} > 0.06$ m et $I_2 \cdot L_2 + h_{MC2} - h_{NE2} > 0.022$ and $I_1 \cdot L_1 + h_{MC1} - h_{NE1} > 0.022$)
 → Then $Q_{total_discharge}$ can be calculated with the previous relationship
 → Otherwise $Q_{total_discharge} = 0$

Moreover, any drift of the sensors can be easily identified by redundancy. Indeed, the mixing chamber has been instrumented to compare it with the sum of the instrumentation of the three discharge elements taking separately. Therefore, if the results of both instrumentations is completely different (more than 25%), the sensors must be checked for any drift. Moreover, because of the two pipes, the instrumentation has been doubled in the mixing chamber as well as in the natural environment. The information measured in both locations are not completely different from right to left therefore any drift of sensors for these sensors will be immediately identified.

3.4 Results and redundancy of the measurements

Once the different instrumentations have been validated on site and the sensors zeros calibrated, they have been applied to a 5-month databank (from july to novembre 2012). The total discharge volume for each month has been compared, leading to the following results:

Figure 11: Comparison of the total discharge volume with the two instrumentations of Branly

Discharge volume (in m ³)	July	August	Sept.	Oct.	Nov.	TOTAL
Sum of the three discharge element instrumentations taken individually	112830	63263	60005	96517	99316	431931
Instrumentation of the mixing chamber	131160	64417	53007	81967	108484	439035
Overestimation of this volume by the sum of the three elements	-14%	-2%	13%	18%	-8%	-2%

Thus, the two different methodologies are not exactly identical instantaneously. This can be due to a high uncertainty on the measurement of the discharge volume at the mixing chamber when the flow rate is low and the downstream influence of the natural environment quite high (particularly in July and October). Moreover, the individual instrumentation of the three pumps has not been set up yet, therefore, the discharge volume of the pump is a mere approximation based on the data analysis.

However, over time the redundancy of the instrumentation leads to the same value. Thus, the difference of total discharge volume between the two instrumentations of Branly on this 5-month databank is less than 2 %.

Finally, the part of each discharge elements can be estimated. Therefore, the Archimedes' screws represents nearly 65 % of the total volume discharge on this period, whereas the pumps represent 32 % and the gate only 3%.

4 CONCLUSIONS

A methodology based on CFD models and aiming at the exploitation of the hydraulic analysis of a particular sewer work in order to assess the discharge using just and only water level measurements has been developed. This measurement technique allows maintenance problems linked to the sensors submersion to be overcome. Moreover, it does not require any calibration.

This methodology is applicable to every complex sewer work with or without a downstream influence. Two measurement techniques are therefore possible: the first one (technique A) only requires one water level sensor (with a passage of the flow through the critical depth) where the other one (technique B) is based on two water level measurements (upstream and downstream of the work).

This methodology has been applied to the complex site of Branly (Colmar, France). This specific work is a merging of three different discharge elements which have been instrumented individually according to the following table:

Discharge element	Measurement technique	Downstream influence
Three pumps	Technique A	No
Two endless screws	Technique A	No
One gate	Technique B	Yes

Moreover, because of the sensitivity of this key point of the Colmar network, a redundancy of the discharge measurement has been carried out. Thus, the mixing chamber downstream of the previous discharge elements has been instrumented using technique B. The results of this instrumentation has therefore been compared to the sum of the measurements in the three discharge elements, leading to a difference of the total volume over the past 7 months of less than 2%.

ACKNOWLEDGEMENTS

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