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A NEW VELOCITY AND TOTAL SUSPENDED SOLIDS MEASUREMENT DEVICE

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Abstract: The quality of field measurements in sewer systems relies on the spatial representativeness of the measurements. This study aims at field measurements of both velocity and total suspended solids (TSS) using a two dimensional sampler called Hydre. The device was implemented, tested and used in a sewer system for a range of hydraulic situations. This paper presents the principles of development and conception of the instrument. Analyses of the results demonstrate the ability of the device to provide robust TSS and velocity profiles in sewers for a range of flow conditions.

Résumé: L’évaluation des flux de polluants transitant dans les réseaux d’assainissement dépend notamment de la représentativité spatiale des mesures de vitesses et de concentrations en matières en suspension. Cette problématique a été étudiée expérimentalement par des mesures dans des réseaux urbains. Un échantillonneur bidimensionnel, appelé Hydre, a été développé et installé dans un collecteur. Il a permis d’étudier la répartition spatiale des vitesses et des concentrations pour une large gamme de contextes hydrauliques. Cet article présente la conception de cet échantillonneur. Les résultats sont présentés et discutés. Ils montrent la bonne homogénéité des concentrations dans la section mouillée.

Keywords: velocity profiles, total suspended solids, instrumentation, sewer.

1. INTRODUCTION

Two phase particle-laden flows have a wide range of applications related to water although the quantification of the solid mass remains a important question. For example, Pont et al. (2002) and Leecaster et al. (2002) discussed the spatial and temporal sampling representativity and strategy. In Europe, the May 1991 and October 2000 EC Directives and the national regulation define the total suspended solids (TSS) as a major source of pollution. A good management of sewer networks requires the minimisation of pollutant loads discharged to receiving waters, and this requires robust and accurate sensors to assess flow rates and TSS concentrations. Larrarte (2006,2008) described two devices developed and used in a man-entry sewer. The instruments gave a first series of data sets in a combined sewer without sedimentation. The practical experiences showed a number of problems with both samplers including the deployment difficulties, the corrosion, and the lack of data on top of the bank. This paper presents the principles of development and application of a third sampler. Results are presented and discussed.

2. MATERIAL DEVELOPMENT

The samplers Cerbère and Orphée showed their usefulness for investigating dry and wet weather velocity and total suspended solid within sewers (Larrarte 2006,2008) but both systems had some disadvantages. For example, it was not possible to make measurements on top of the bank, in an area with a compound cross section. Further the system Cerbère experienced some corrosion troubles and it was not possible to adapt it to another experimental area. Also both systems worked in an area with mean velocities larger than 0.5 m.s^{-1}. Based on these experiences, a new 2D sampler device, called "Hydre" was designed and built to investigate in a minimum of time both velocities and total suspended solid concentrations for a wide range of hydraulic conditions (Fig. 1).

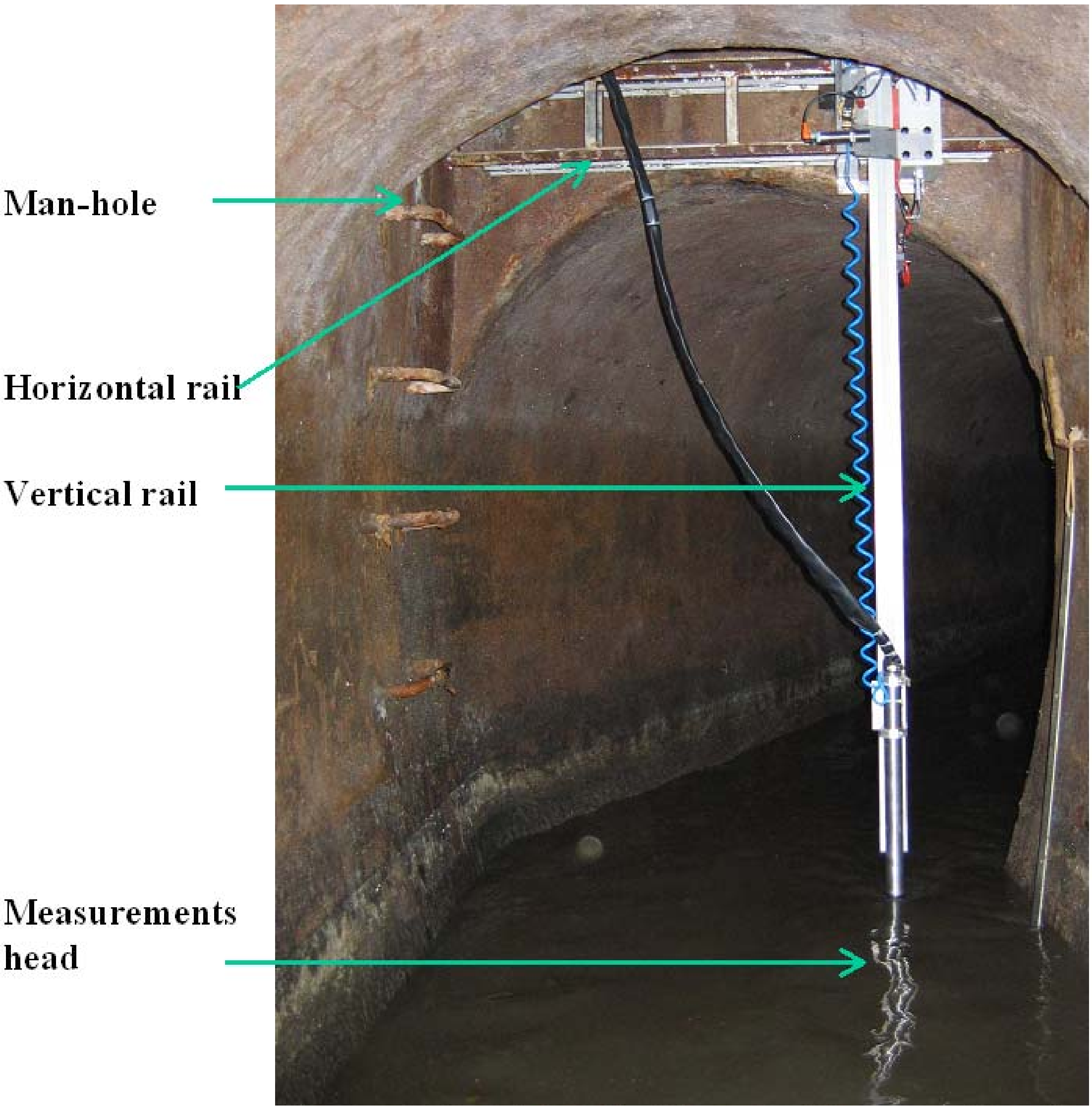

Figure 1 - Two-dimensional sampler Hydre in the combined sewer, view from upstream

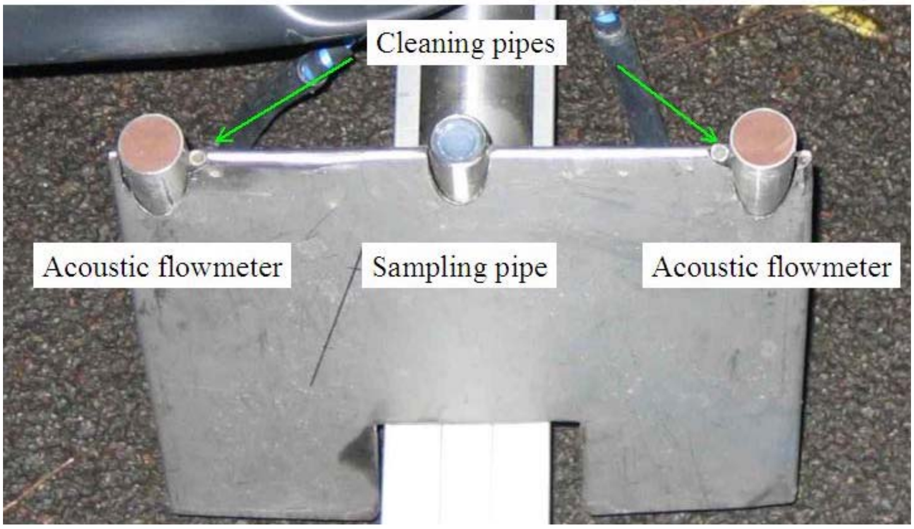

Figure 2 - Measurement head of the two-dimensional sampler Hydre

The measuring head was equipped with two flow meters Nivus PVM-PD and a sampling pipe (Fig. 2). Validation tests showed that the flowmeters Nivus PVM-PD operated within a rather small sampling volume (0.03 m long and 0.015 m diameter) positioned at 0.1 m in front of the transducer (see Appendix). In practice, a basic problem arose from drifting materials coming in contact with the transducers and clogging the sensors. Since the sensors were not visible, clogging proved difficult to detect and two pipes were devised to clean the velocity sensors with compressed air prior to each reading. The sampling pipe was also cleaned with compressed air before each sampling. At a sampling location, the data set included the mean value of two replicates, with each replicate being the mean value of the instantaneous velocity gauged over a 10-second period. This procedure complied with the NF EN ISO 748 Standard. Once velocities were simultaneously measured at both transducers, the vacuum sampling was triggered.

The device Hydre was installed in a combined sewer located in a public park of Nantes (France). The site was selected to investigate the influence of the velocity field on TSS concentrations because an intermittent deposit was previously observed. The sewer had an egg-shaped section with a bank (Fig. 3). The mean velocity V_m ranged from 0.3 to 0.5 $m.s^{-1}$ for water levels of respectively 0.53 to 1.01 m. Dry weather conditions corresponded to water levels below 0.85 m with velocities below 0.60 $m.s^{-1}$.

Hydre was implemented before each measurement campaign (Fig. 4). The transverse movement is based on displacement along a horizontal rail. The position is controlled with an ultrasonic sensor (Fig. 5). The sensor movements were remotely controlled from above the ground level with a computer system (Fig. 6). In a sewer, the wetted area could be sampled from the bottom to a maximum elevation of 1.5 m which encompassed roughly 90% of the situations encountered during a given year.

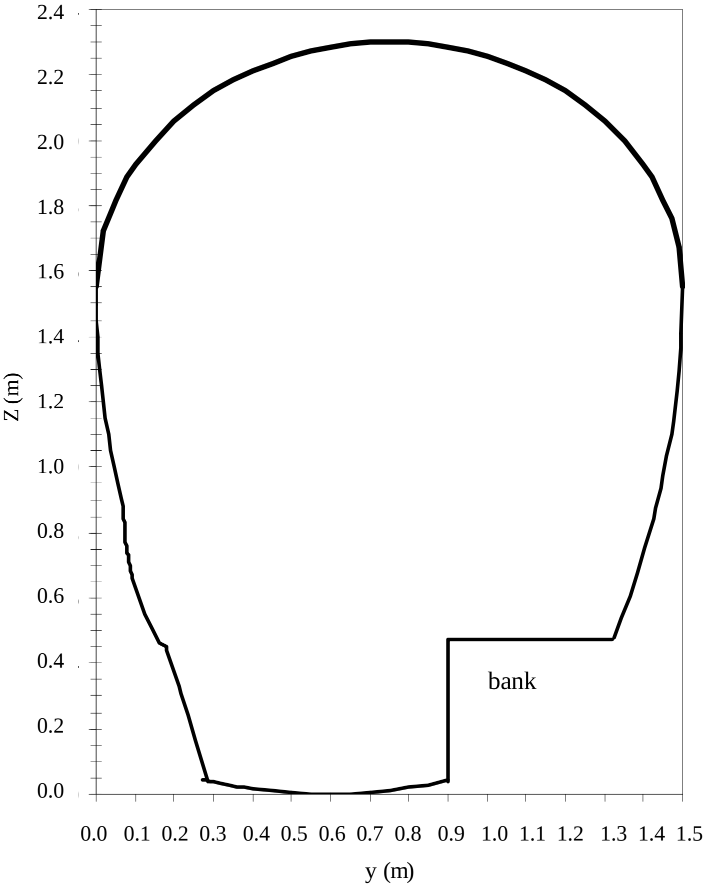

Figure 3 - Sewer cross section looking upstream

Figure 4 - Installation of the two-dimensional sampler through a manhole

Figure 5 - Two-dimensional sampler Hydre on its rail and detail of the ultrasonic sensor used to control the transverse location

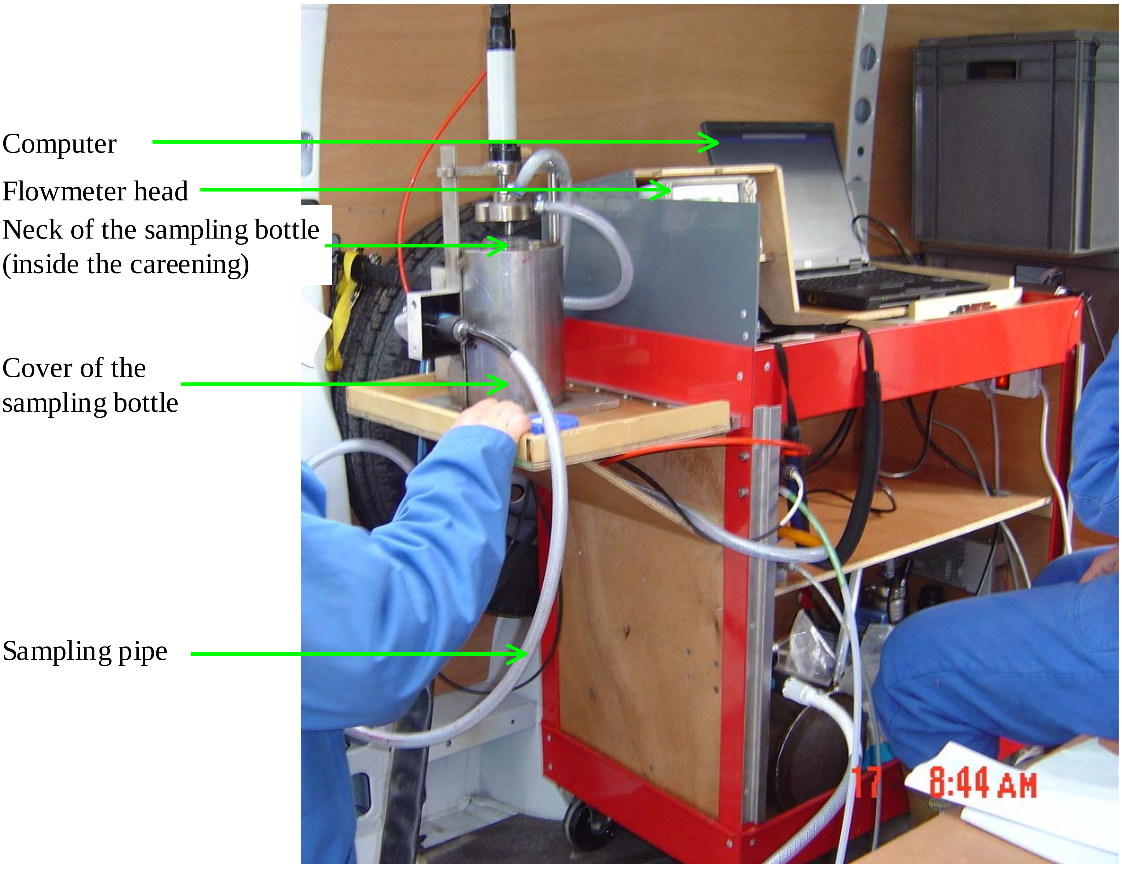

Figure 6 - Parts of the sampling device located above the ground.

3. RESULTS

The flow is considered as fully turbulent and subcritical when the Reynolds number $R_e = V_m D_h /(4\nu)$ is greater than 10^5, where V_m is the flow velocity, D_h the hydraulic diameter and

ν is the water kinematic viscosity with $\nu = 10^{-6}$ m^2.s^{-1}.

3.1 Velocity fields

The channel was narrow and shallow. The aspect ratio $\mathrm{Ar} = \mathrm{b}/\mathrm{h}_{\max}$ was between 1.4 and 2.1, where b is the free surface width and h_{max} the maximum water level in the main channel during the measurements. In such narrow channels, the maximum velocity was clearly located below the free surface during dry weather conditions (Fig. 7). The results were consistent with the earlier velocity measurements of Larrarte (2006) in another egg-shaped sewer. On top of the bank, a local dip phenomenon could also be seen, that means that the maximum velocity is located below the free surface. Bonakdari et al. (2008) showed numerically that this velocity dip phenomenon was related to strong secondary currents of the second kind of Prandtl, and the flow was fully three dimensional. Figure 8 shows an example of velocity profiles measured during a storm event when a combined sewer overflow was active about 1 km upstream of the measurement area.

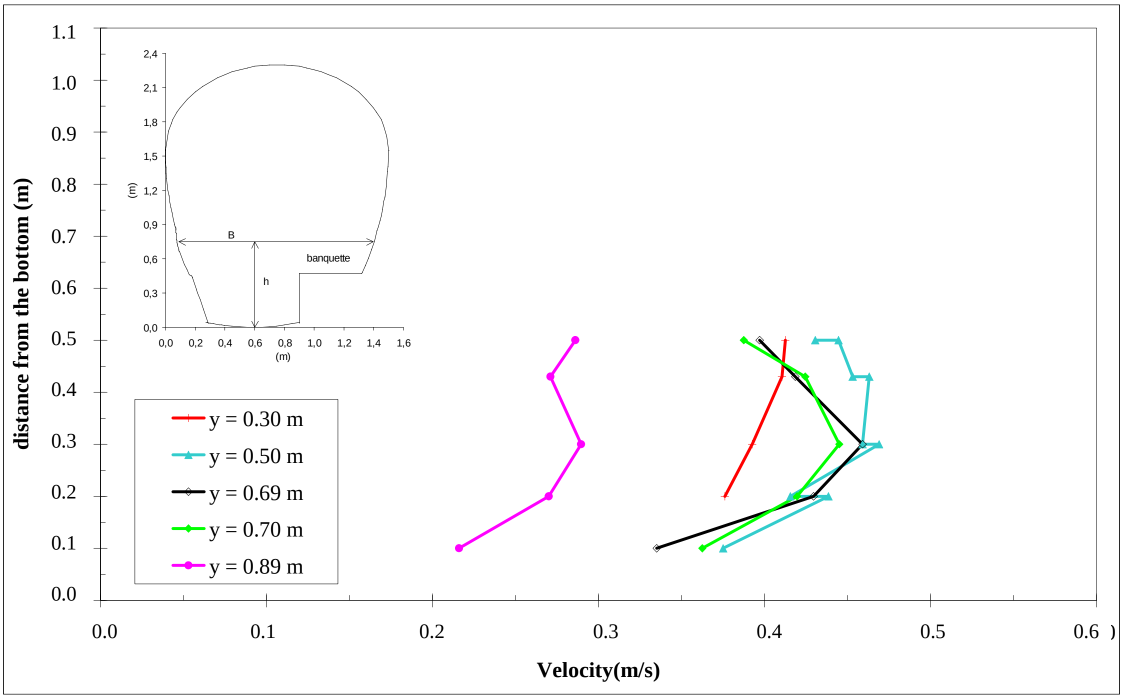

Figure 7 - Field measurements of vertical distributions of velocity for dry weather conditions

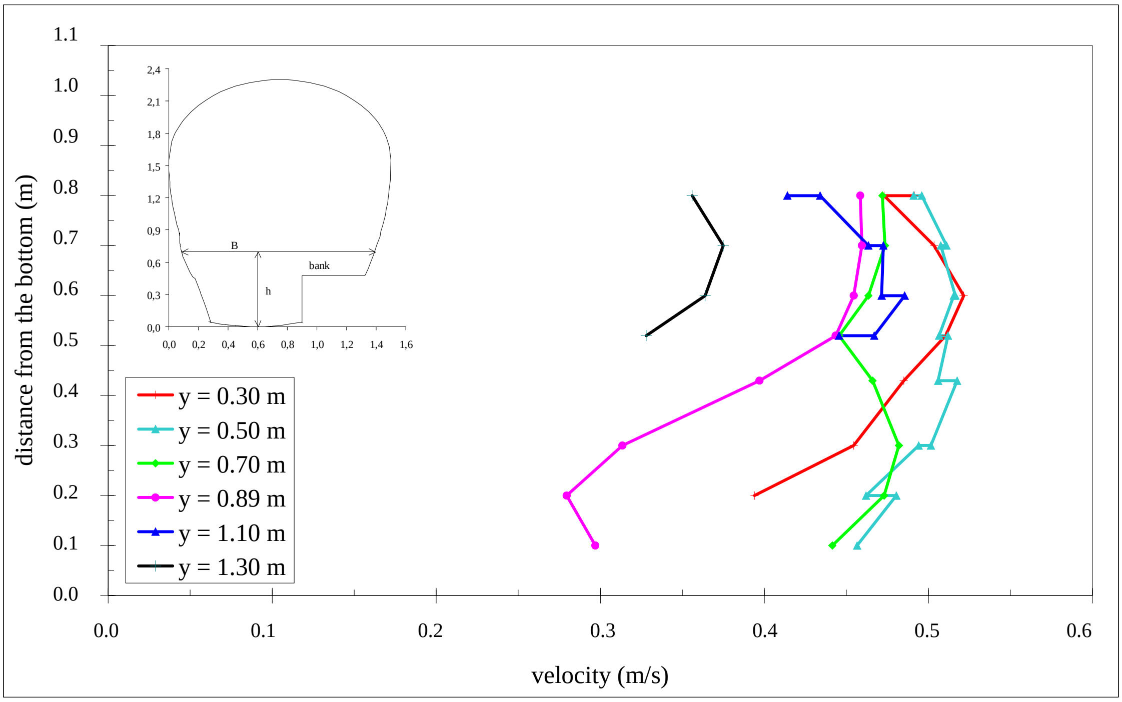

Figure 8 - Field measurements of vertical distributions of velocity during storm event conditions

3.2 TSS concentrations

The water samples were sieved at 2 mm and analyzed to get the TSS and volatile matter concentrations (in g.m^{-3}) with respect to the French and European standard NF EN 872. In most cases, the samples were analyzed twice to evaluate the uncertainty associated to the analysis process. The precision of TSS and volatile matters measurements was about 10 g.m^{-3}. The amount of particles greater than 2 mm was less than 5% in mass. The flowmeters measured also the temperature, which varied from 11 to 22°C. About 12 dry weather and 4 rainfall campaigns were conducted between March 2006 and November 2007. They gave respectively 500 dry weather and 200 rainfall event concentrations.

Figure 9 shows that the TSS concentrations were between 100 and 350 g.m^{-3}. For dry weather days, the result was close to the earlier observations of Larrarte (2008), 5 km downstream. During rainfall events, including storm events, the concentrations remained also lower than 350 g.m^{-3}. No influence of storms was noticed, and this differed from the observations made downstream by Larrarte (2008).

Figure 10 shows the ratio of volatile to total suspended solids concentrations. A high ratio of volatile matters to TSS indicates a large component of organic matter. More than 70% of particles of that urban area showed a large organic component and the meteorological context had no influence on the results.

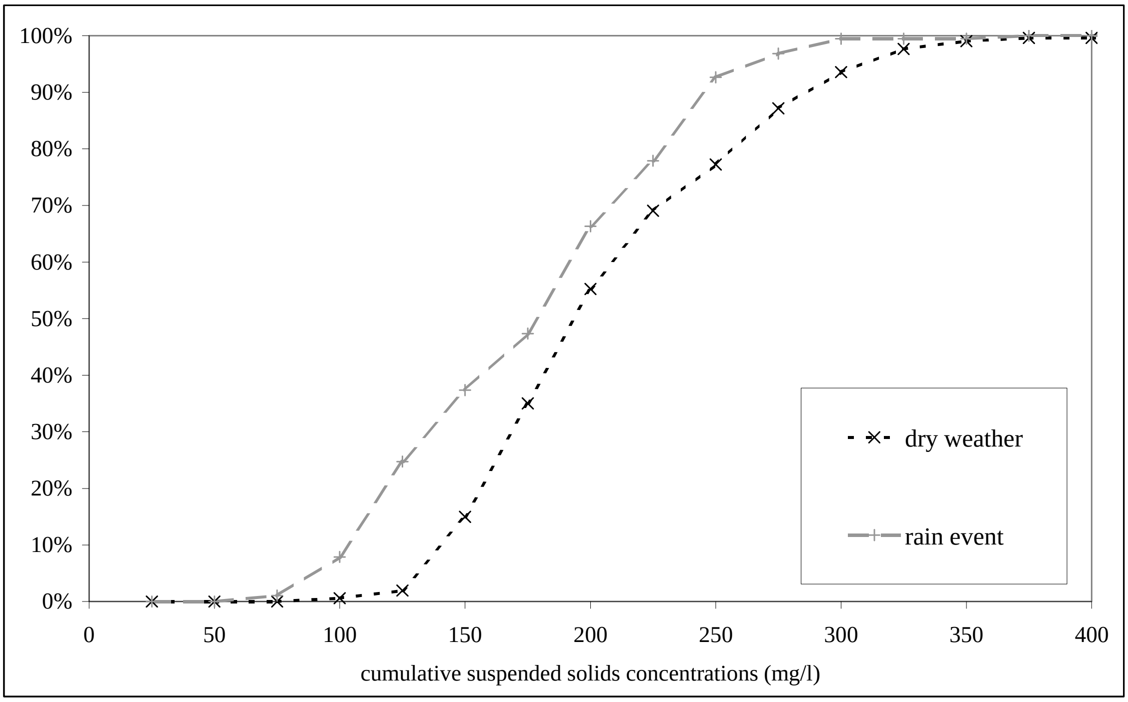

Figure 9 - Cumulative total suspended solid concentrations.

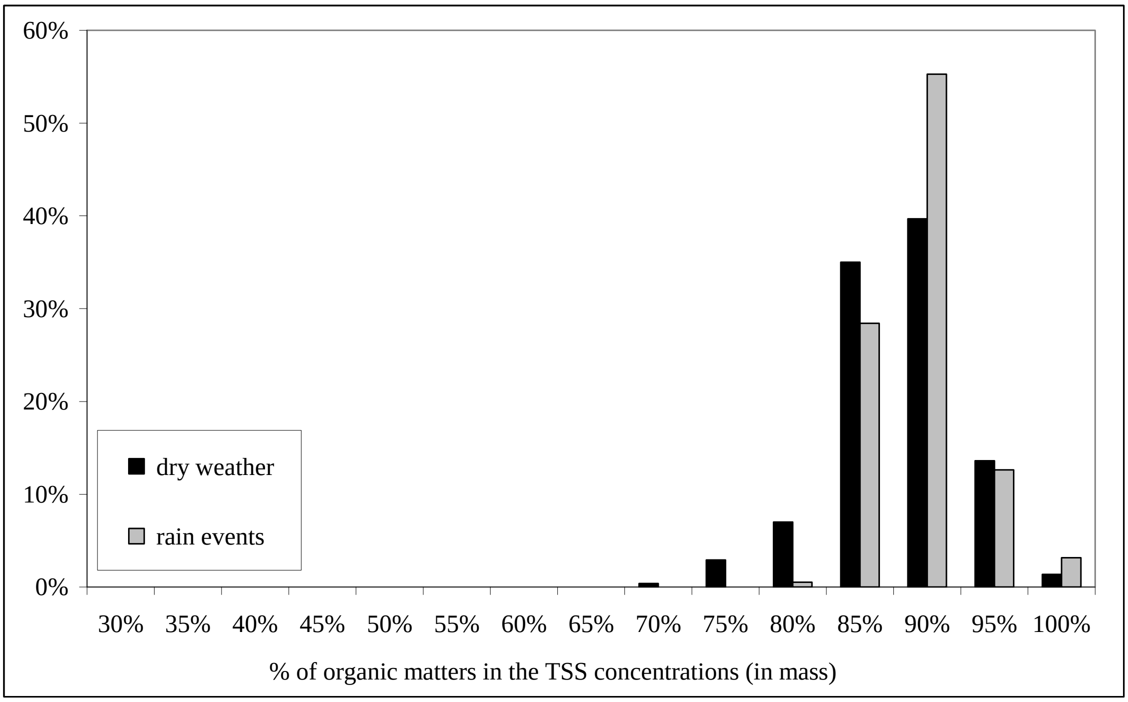

Figure 10 - Percentage of organic matter in the TSS concentrations (in mass).

Figure 11 shows the ratio of particles smaller than 125 microns to total suspended solids. The data ranged between 55% and 85% for most samples. The ratio tended to be larger during rainfall conditions than dry weather days. But the rainfall conditions corresponded to only 3 rain events and the result needs to be confirmed.

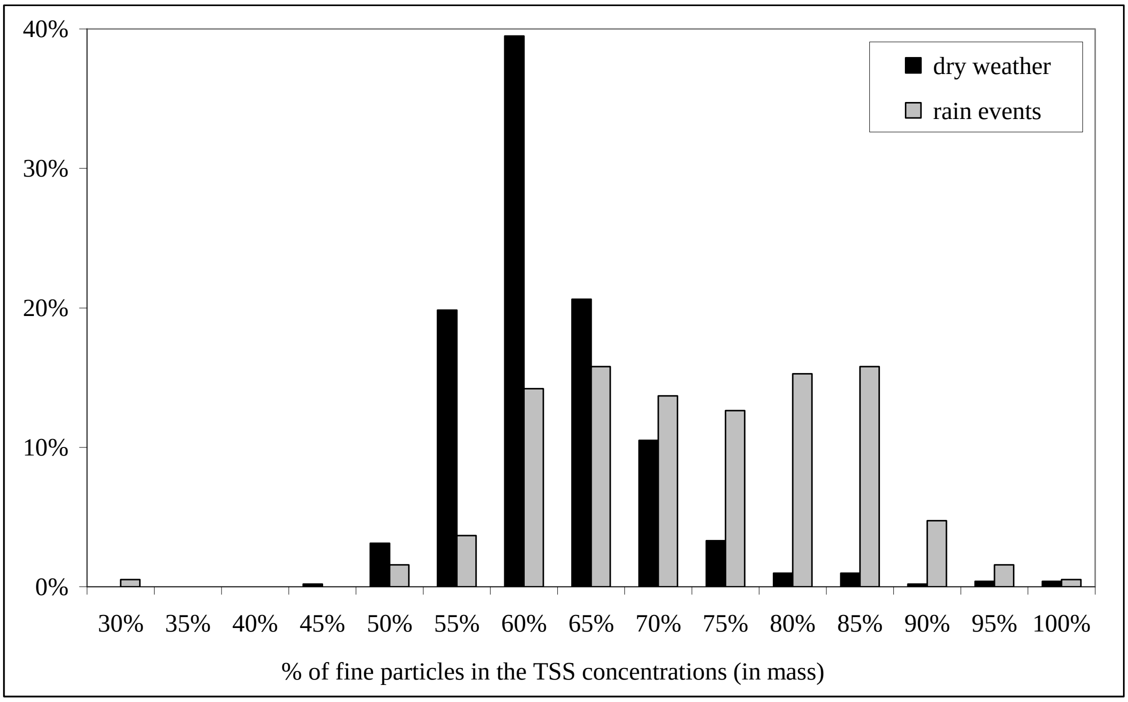

Figure 11 - Percentage of particles smaller than 125 microns in the TSS concentrations (in mass).

The spatial distribution of pollutants was investigated. Figure 12 shows the TSS concentrations measured on various verticals within the cross section. The data corresponded to a dry weather day with a water level of 0.57 m and a 0.02 m thick sediment deposit below the sampler. The mean velocity in the cross section was equal to 0.37 m.s^{-1} and this was below the commonly accepted self-cleansing velocity. There were vertical concentration fluctuations but no concentration gradient was noticed. The results presented were consistent with those of Ahyerre at al. (2001) for the suspended solid concentrations. The concentrations obtained by Ahyerre et al. (2001) in the sediment were higher than those obtained by Worhle and Brombach (1991) close to the bottom.

4. CONCLUSION

A two-dimensional sampler device was developed to improve the reliability of measurements in sewer systems. The sampler allowed the measurements of both velocity and total suspended solids within the cross section of a sewer for a wide range of hydraulic conditions.

The analysis of the results recorded by the sampler demonstrated the ability of the device to characterise both the velocity and TSS fields. The measurements showed that a dip phenomenon occurred in the narrow channel with a second maximum over the bank, there was no concentration gradient even though a deposit existed at the time of the sampling, and the particles were mainly organic and fine whatever the meteorological conditions.

Field experiments must be extended to include other rainy days and storm event measurements and to investigate the relation between sediment deposit and hydraulic conditions.

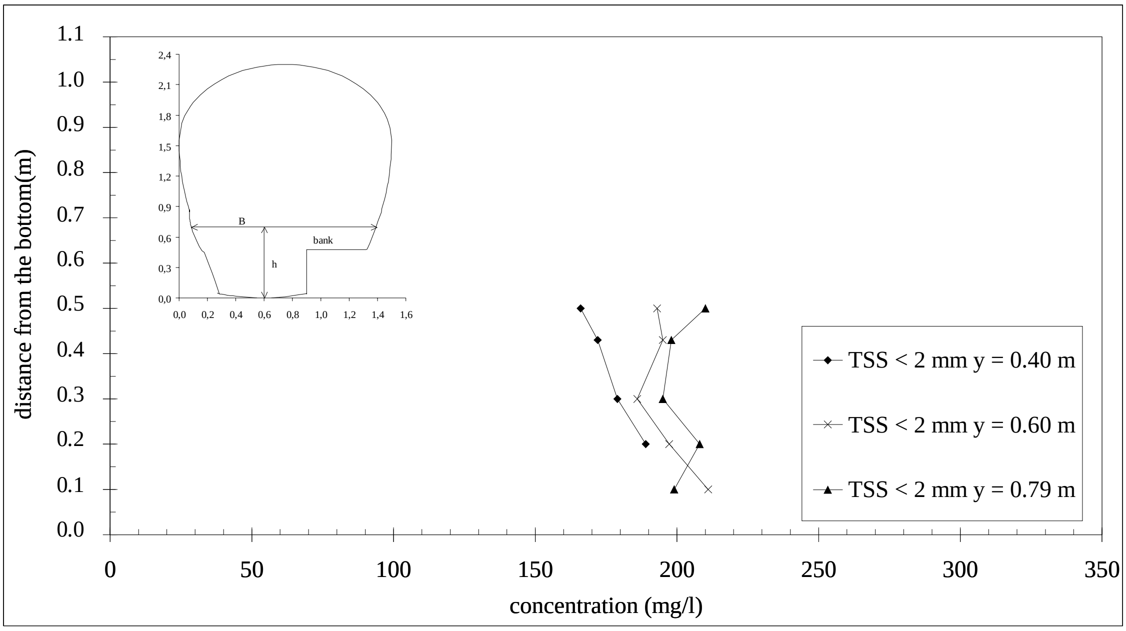

Figure 12 - Vertical distributions of the TSS concentrations for a dry weather day

5. ACKNOWLEDGEMENTS

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6. NOMENCLATURE

$Ar = \frac{b}{h_{mx}}$	aspect ratio	
b	width of the free surface	(m)
C	concentration	$(g.m^{-3})$
D_h	hydraulic diameter	(m)
h_{max}	maximum water level	(m)
R_e	Reynolds number	
S_m	wetted area of the vertical cross-section	(m^2)
V_m	mean velocity	$(m.s^{-1})$
y	transverse distance (Fig. 3)	(m)
y_{max}	maximum width of sewer channel (Fig. 3)	(m)
ν	water kinematic viscosity	$(m^2.s^{-1})$

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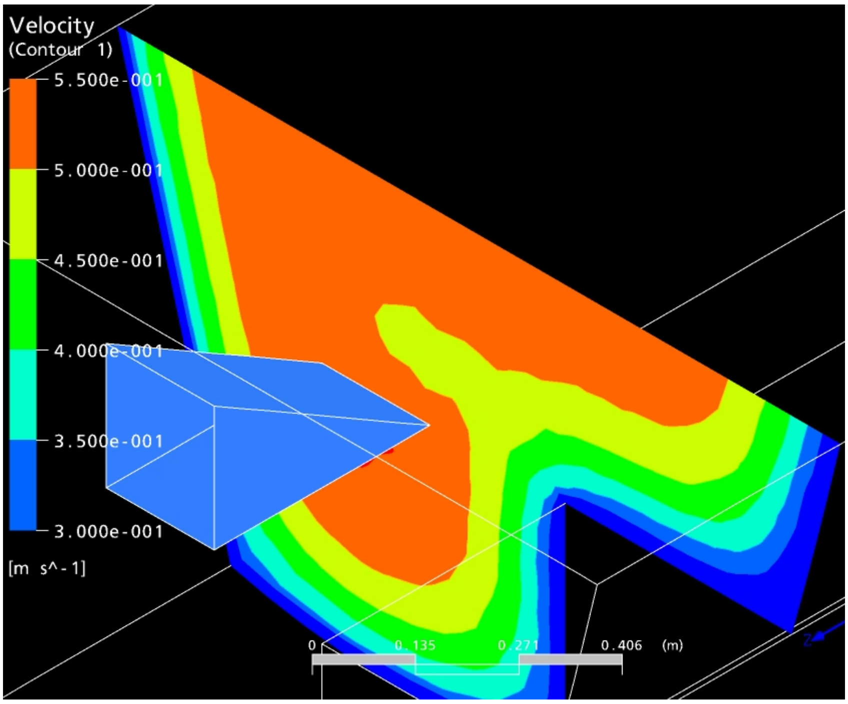
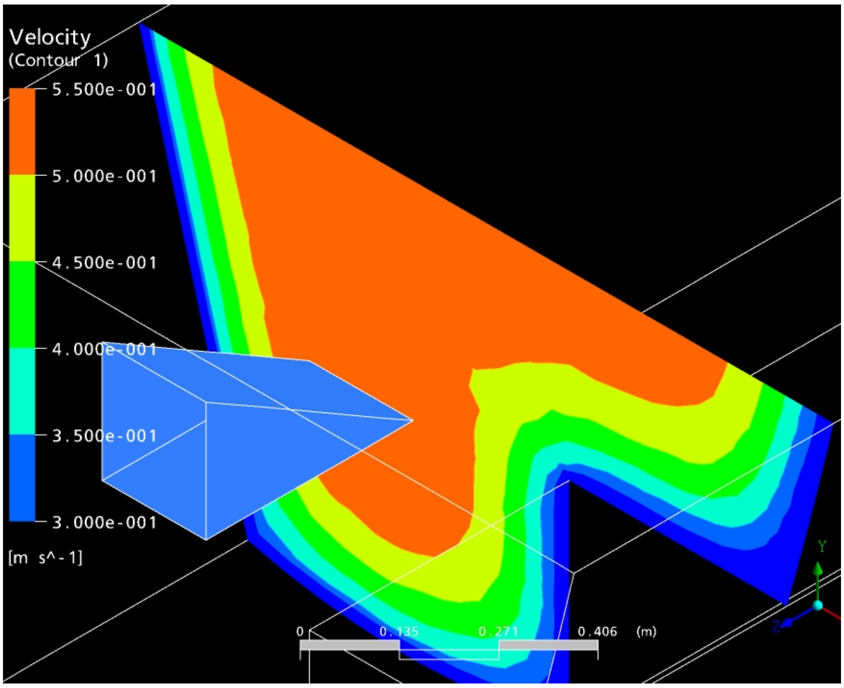
8. APPENDIX

It can be noticed on Figure 2 that the two-dimensional sampler Hydre is intrusive. The velocity field around the measurements head was computed with a three-dimensional Navier-Stokes solver. Figure A-1 shows the influence of the measurement head on the velocity field at 0.05 m upstream. This influence becomes negligible at 0.1 m upstream of the head that was the location of the ultrasonic flowmeter sampling volume.



(A) 0.05 m upstream of the head



(B) 0.10 m upstream of the head

Figure A-1 - Flow field around Hydre sampler head