Evaluation of new flow and water quality monitoring equipment in sewers under realistic flow conditions

S. Peña-Haro[1], M. Burckbuchler[2], J.T. García[3], J. Naves[4], A. Kuhn[2], D. Carreres-Prieto[5], S. Fischer[2] & J. Anta[4]*

[1] Photrack AG: Flow Measurements, Ankerstrasse 16a, 8004 Zürich, Switzerland
[2] Ubertone SAS, 67300 Schiltigheim, France
[3] Mining and Civil Engineering Department, Universidad Politécnica de Cartagena, Cartagena, 30203, Spain
[4] Universidade da Coruña, Water and Environmental Engineering Research Team (GEAMA), Center for Technological Innovation in Construction and Civil Engineering (CITEEC), Campus de Elviña, 15071 A Coruña, Spain
[5] Department of Engineering and Applied Techniques. Centro Universitario de la Defensa - General Air Academy 30720 Santiago de la Ribera (Murcia), Spain

**Corresponding author email: pena@photrack.ch*

Highlights

- Image-based, non-contact flow monitoring equipment was tested on sewer pipe flows.
- A new acoustic velocity profiler was assessed using real wastewater.
- A novel spectrophotometer for wastewater quality monitoring was tested on a flume.

Introduction

Operation and planning of sewer networks and wastewater treatment plants, as well as the fulfilment of legal obligations require knowing the volumetric flow and pollutant loads. Free surface flow measurement is a challenging task, which is commonly done by systems based on ultrasonic and electromagnetic sensors or by using weirs and flumes which affect the flow and require special installations. Wastewater creates a hard environment for sensors which need to be in contact with the fluid, moreover, some sensors have limitations measuring under low flow conditions, and sedimentation can affect the reliability of the measurements. We present preliminary results of a project within Co-UDlabs Transnational Access Programme which aimed to assess and improve the performance of several monitoring devices (a non-contact camera-based flow measurement, an acoustic doppler velocity profiling and a spectrophotometer). A comprehensive experimental and data collection campaign was performed in a 10 meters flume test facility using real wastewater under control conditions.

Methodology

Experimental setup

The BENS flume test facility consists of a 10 m long and 0.9 m wide bench for studying sewer processes using real wastewater from the pre-treatment system at A Coruña waste-water treatment plant (WWTP) (Regueiro-Picallo et al., 2018). A conventional circular PVC pipe (inner diameter of 300 mm) and an egg-shaped cross section pipe (385 mm heigh, top radius of 110 mm and a bottom radius of 55 mm) were installed parallel to each other and were operated at the same time. Wastewater was pumped with a submergible sludge pump from the post-sieving system of the WWTP (3 mm aperture) towards a head tank placed before the entrance into the pipes. The inflow is regulated by a set of valves. Wastewater was incorporated into both pipes through two equal triangular weirs. The slope of the metallic bench and thus of the pipes can be set from 0 to 2%. Two top apertures of 0.9 m and two holes were opened on each pipe to allow the installation of equipment and monitoring of water depths. Both pipes drain the wastewater into a common reception chamber equipped with an automatic tailgate used to set different downstream boundary depth conditions during the experiments (Figure 1).
Eight ultrasound distance sensors (UB500-18GM75-I-V15, Pepperl and Fuchs, Germany) were installed in the facility for water height measurement and flow rate estimation. One sensor was placed at the inlet chamber to register the height of the water over the triangular weirs, which let the same amount of water flow into the two pipes. Three sensors were then installed along each pipe to characterize water depths in

the positions shown in Figure 1. Finally, a depth sensor was placed at the downstream chamber to register the downstream boundary condition imposed by the gate. The flow discharge and depths were estimated from sensor signal through a preliminary calibration. Turbidity (SOLITAX, Hach, USA) and conductivity (LANGE 3798-S, Hach, USA) probes were installed in the inlet chamber for continuous inflow measurements. Additionally, the total, fix and volatile suspended and dissolved Solids (TSS, FSS, VSS, TDS, FDS, VDS), conductivity, turbidity and Chemical Oxygen Demand (COD) concentrations were analysed from samples taken with an autosampler (SIGMA900, Hach, USA), the nozzle was placed near the probes in the inlet chamber.

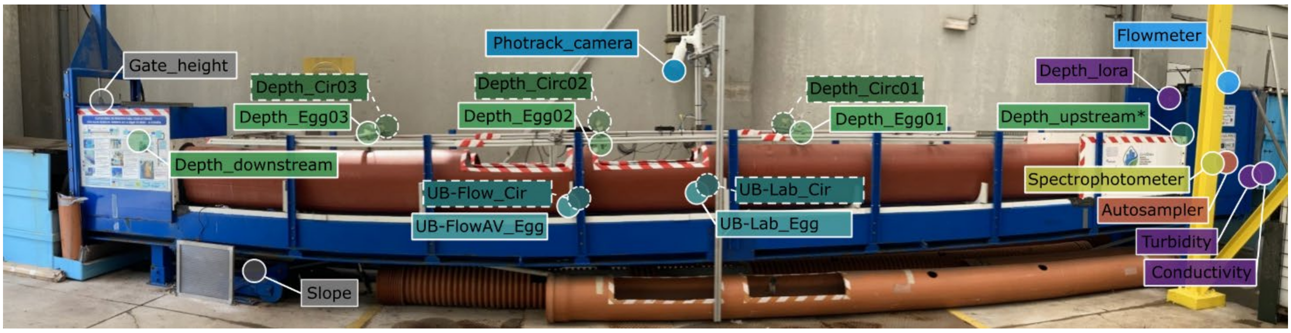

Figure 1: BENS flumes and scheme of the sensors installed in the facility during the experimental campaign. *Depth_upstream i*ncludes flow measurement from the level over the triangular weirs.

Sensors tested

Using the above instrumentation as reference, the new devices considered in this work were installed in the facility to monitor water quantity and quality and to assess and improve their performance in sewers. First, an image-based system for volumetric flow monitoring named as DischargeKeeper was installed. The system mainly consists of an IP camera, a processing unit and data transition unit. The camera was mounted on top of the pipes (Figure 2b) to estimate the discharge of both pipes from the same recorded video. The DischargeKeeper is capable of optically measuring the water height, and the surface velocities using a cross-correlation technique. From the surface velocities, the wetted area and assuming a vertical velocity distribution the volumetric flow is calculated (Peña-Haro et al., 2021).

One velocity profiler and one average velocity sensor developed by Ubertone (France) were assessed to measure vertical central profiles and average velocity. The UB-Flow prototype and UB-Flow AV are hydrodynamic probes equipped with one transducer, both connected to a splash-proof logger with embedded user interface. The UB-Flow measures velocity profiles along the acoustic beam with a spatial resolution down to 1 mm using proprietary technology based on coded pulsed coherent Doppler. The device also gives access to acoustic backscattered echo amplitude which gives information about suspended sediment loads (Pallarès et al., 2014) and interface detection. The UB-Flow AV aims to monitor average velocity in sewer networks (between -1 and 4m/s) from 30mm water depth with a high autonomy. Quality indicators are also registered. UB-Flow and UB-Flow AV sensors were installed in the bottom of the circular and egg-shaped pipes (1MHz), respectively (Figure 2c and Figure 2d). As a complement, a few measurements were also performed with two laboratory profilers: UB-Lab X2 and UB-Lab P with 3 MHz transducers, at the end of certain experiments measuring velocity and echo profiles from the water surface (Burckbuchler et al., 2019).

Finally, a novel broad-spectrum spectrophotometric analysis equipment based on LED technology was tested for continuous characterization of the pollutant load of urban wastewater, without the need for chemical reagents or water handling (Carreres-Prieto et al., 2023). The equipment, whose nozzle was placed near the probes in the inlet chamber, takes wastewater samples at regular time intervals and performs a spectrophotometric analysis within a range between 380-700 nm. From this analysis, the equipment determines, with the help of correlation models, various water quality parameters, such as Chemical Oxygen Demand (COD) or Total Suspended Solids (TSS) among others. Likewise, to analyse the size of the solids present in the sample, the equipment performs multiple analyses spaced in time on each sample, to obtain the spectral response associated with the sedimentation process.

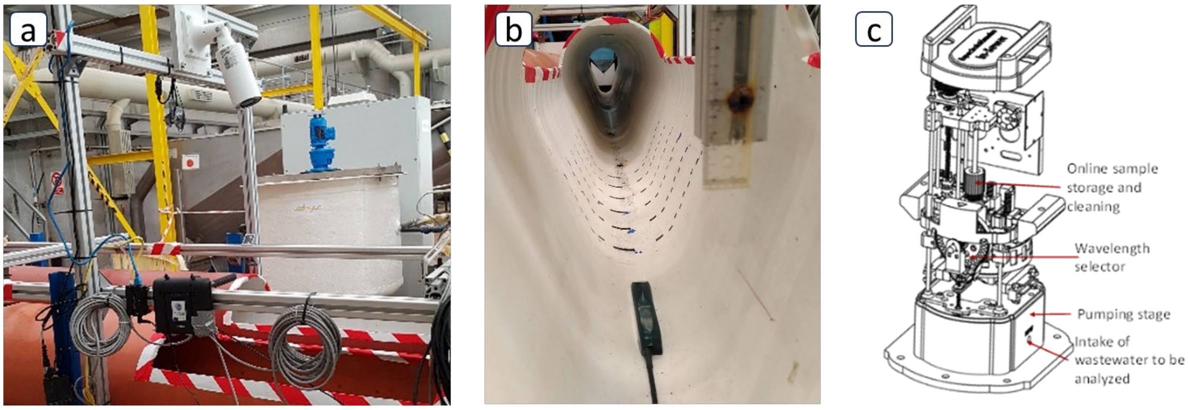

Figure 2. a) DischargeKeeper equipment installed in the middle section of the flume; b) UB-Flow and UB-Flow AV installed on the bottom of the circular and egg-shaped pipe, respectively; and c) and online LED Spectrophotometer scheme.

Test procedure

A total of 53 short tests (ST) of less than 30 mins were carried out where the input flow rate, the downstream boundary condition and the slope were set for different conditions covering the full range of the facility with slopes between 0.2 and 1.5 %, flows between 1 and 6 L/s and water depths between 15 and 180 mm. 16 long tests (LT) were performed, during these tests a ST condition was left for more than 12 h. On three of those long tests sediments accumulated at the bottom of the pipes. They will be used to understand the effects of sediment bed load on the different sensors. 4 turbidity tests (TT) varying suspended solids concentration (SSC) and 3 tests varying flow rate or boundary condition (BC) completed the experimental campaign. Water quality and hydraulic variables were measuring during the full experimental campaign duration.

Results and discussion

Preliminary results are focused on analysing data collected by the different devices and assessing their performance on estimating depths, velocities, flow rates and water quality for some elected short tests covering the full range of the facility. Depths and velocities obtained in the circular pipe from the different instrumentation for the test ST25 are presented as an example in Figure 3. During this test the flow varied while the slope and the downstream boundary condition were kept constant. A direct comparison between devices beyond water depth is not possible due to the different nature of the variables measured (mean surface velocity, mean velocity of the central profile and bulk velocity from flow measurement and depth), so results of velocities are not expected to fit and results plotted in Figure 3b show just the ability of the velocity profilers and DischargeKeeper to monitor depths and velocities in a transient sewer flow in a consistent way.

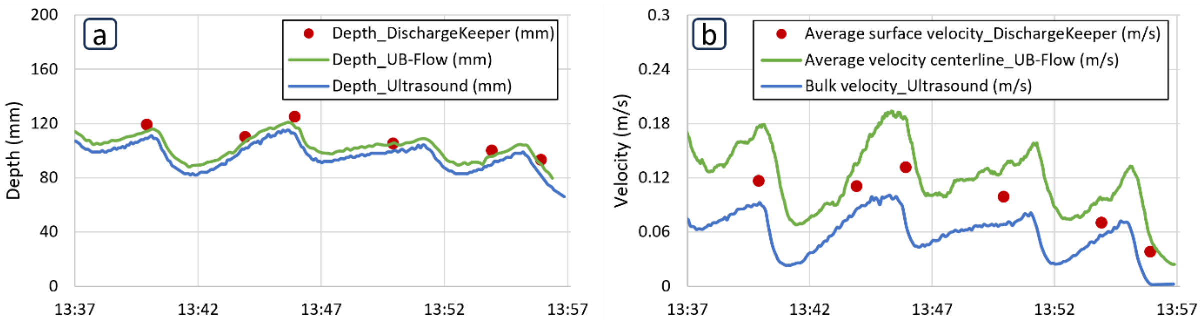

Figure 3. a) Depth and b) velocity results obtained from DischargeKeeper system, UB-Flow velocity profiler and ultrasound depth sensors for experiment ST25, where flow varies for a certain slope and downstream boundary condition. Velocity results are not expected to fit since the different nature of the variables measured (surface, central profile and bulk velocities).

Regarding the real-time characterization of the pollutant load of the wastewater, using LED spectrophotometry, Figure 4 shows a comparison between the chemical oxygen demand (COD) (Figure 4a) and total suspended solids (TSS) (Figure 4b) values measured in the laboratory and those obtained by spectral analysis, where a high correlation between the two is observed, denoting the accuracy of the system. The spectrophotometer data also showed the existence of a temporal behaviour, a crucial aspect to be able to estimate the levels of contaminants. Likewise, the sediment characterization obtained from the analysis of the samples at different times accounting for particles sedimentation roughly fit the nature of the elements present in the wastewater.

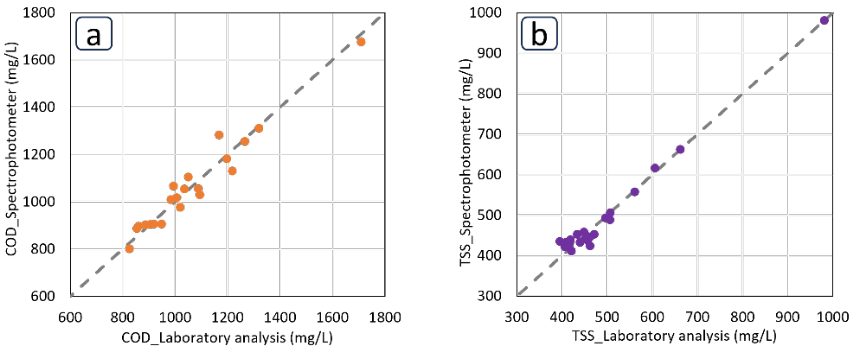

Figure 4. Comparison between the values of a) chemical oxygen demand (COD) and b) total suspended solids (TSS) reference values obtained from laboratory analysis and those obtained using correlation models developed from spectrophotometer data.

Conclusions and future work

DischargeKeeper monitored successfully surface velocities in both pipes along the 3 months of duration of the experimental campaign, generating a complete dataset that is being used for development purposes. The UB-Flow and its logger from Ubertone allowed remote real-time visualisation of velocity and backscattered echo amplitude profiles throughout the whole project duration. The recorded data includes data to assess data quality and robust surface/bottom detection. The project has also confirmed the correct operation of the LED spectrophotometry equipment with continuous analysis capability and its suitability to operate in real environments without user intervention and allowed to detect aspects to improve in future versions. Further work will be oriented to the estimation of total flows from each of the velocity measured analysing the uncertainties involved. The sensitivity of the DischargeKeeper, UB-Flow and UB-Flow AV to sediment accumulation will be also assessed, analysing also the evolution of surface velocities and vertical velocity profiles throughout sediment accumulation and evaluating the possibility to estimate the quantitative and time-resolved evolution of the sediment accumulation height. Water turbidity estimations will be also considered for DischargeKeeper through image analysis and for UB-Flow through backscattered echo amplitude profiles. Fluorometric analysis will be investigated regarding the LED spectrophotometry equipment for the estimation of more complex pollutants, such as pathogens.

Acknowledgment

The authors acknowledge financial support from the European Union under the Horizon 2020 program within a contract for Integrating Activities for Starting Communities (Ref. 101008626).

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