Smart City- Sewer System Monitoring for Better Characterization and Management

O. ABBAS*, Y. ABOU RJEILY*, and I. SHAHROUR*

* Lille 1 University of Science and Technology, LGCgE, France (E-mail: *oras.abbas@yahoo.fr, yves.abourjeily@hotmail.com, isam.shahrour@univ-lille1.fr)*

Abstract
Given the very high cost of construction and rehabilitation of sanitary infrastructures as well as the risks of its dysfunction on public health and environment, this work aims to incorporate the new technologies innovations into the management of these utilities. Real time monitoring allows to optimize the operation of these infrastructures and improve their security, sustainability and durability. Although the concept of smart sewage has recently been used, the experiences feedbacks are still few in this area. Therefore, we carried out a research in the framework of the international project SunRise Smart City, in order to implement the concept of smart sewage on the sanitation network of the Lille1 University Campus, representing the experimental field of SunRise project. In this objective, all system's information were digitized on a Geographic Information System (GIS). In parallel, the network was instrumented by smart sensors, which allow to monitor quantitative and qualitative parameters. This real time monitoring system enabled the detection of various malfunctions in the studied sanitary system. Using the data of potable water consummation in every building on the campus, a hydraulic model was built using (EPA-SWMM) code to evaluate the operation of the sewerage system under different scenarios. The results of modelled and measured wastewater flow, confirm the reliability and utility of the installed monitoring system.

Keywords
Sewage network, GIS, Hydraulic modelling, Real time monitoring, Case study

INTRUDUCTION

The growing population, aging infrastructure and costs reduction are the major challenges of urbanization in the cities. Today nearly 50% of the world population lives in cities (Dirks *et al.*, 2010; Dirks et Keeling, 2009; Dirks *et al.*, 2009). Migration from rural areas is expected to increase in the future, which will amplify the difficulties to properly deliver basic urban services (water, energy, transport, waste, etc.) and air quality in the urbanized cities. To face these problems, the concept of smart city was found as a relevant solution (Marceau, 2008; Mitchell, 2007).

Over recent years, the concept of "Smart City" has interested many economical researchers and managers in various fields of urban development. These fields have been classified into two main categories. The first category includes: Fields of energy, public lighting, waste management, water resource management and public transportation (Di Nardo *et al.*, 2013; Neirotti *et al.*, 2014; Seghairi *et al.*, 2013); while the second one includes: Education, culture, public administration, e-government and economy (Chourabi *et al.*, 2012; Rudolf; *et al.*, 2007). The smart concept consists in collaborating the eco-system, to optimize resources, with the quality of life standards aiming to continuously develop the region's attractiveness. (Chourabi *et al.*, 2012) proposed a framework for understanding the concept of smart city. They identified eight critical factors for the integration of the concept in local governments.

The information and communications technology (ICT) play an important role in the smart cities applications. It opens the way for new functionalities and approaches in managing and governing the utilities in the city (Granlund et Brännström, 2012). This can be done by three steps: collecting data (by sensors), communicating data (by wireless) and analyzing data to understand what is happening now and what is likely to happen. GIS is widely used at every stage of planning, constructing and developing a Smart City. It is used for storage and analysis of geo-localized information. Due to its analysis potential, GIS allows to perform spatial analysis and correlations and to visualize results in a friendly and representative manner.

The spread epidemics cases as a result of problems in the sewer systems, led to think for a continuous monitoring systems, that ensures the real time control of the network. The objectives of a real time control are mainly focusing on proactively preventing and avoiding the occurrence of pollution incidents (Granlund et Brännström, 2012). The monitored and controlled systems fall under the concept of smart sewer systems. The system is based on sensors technology and wireless communication. Many Recent researches focused on real time monitoring and its benefits in optimizing the wastewater network operation (Pons et Vernette, 2010; Schütze *et al.*, 2003; Stinson, 2005).

The SunRise Smart Water project is part of a larger project (Smart City SunRise) which started in 2010 and aims to build a large-scale demonstrator of smart urban networks. Given the difficulties to access and instrument urban networks in the cities, the choice focused to build the demonstrator on the Lille 1 University campus (Shahrour, 2014). This paper presents the application to integrate the sewer system within the smart city concept. It focuses initially on the collection, verification and digitization of all the information concerning water and energy networks in a GIS. Later, the application involves the collection of operational data measured by the implemented monitoring system. These data were used to understand the actual operation of the networks and to propose improvements. Analysis tools have been also developed for evaluating action strategies in order to optimally operate the networks.

The separate wastewater network on the University campus is characterized by small pipes, which can confront some failures during operation, such as sanitary overflow due to inflow or infiltration (Machado *et al.*, 2007). Consequently, an effective sewage monitoring system becomes a necessity to detect any abnormal changes and take the appropriate action before problem aggravation. This paper describes also the application of monitoring system applied on the sanitary sewer network of campus.

The proposed concept for making the sewer system smarter was based on coupling three different axes. The first one is based on creating a GIS database, which allows to back up patrimonial information, reporting useful situation and supporting managers' decisions. The second axe consists in implementing a real time monitoring system by instrumenting the network with smart sensors. The third axe is conducted by using the sensors data to simulate the hydraulic operation and to evaluate the system capacity during different scenarios. This approach helps detecting abnormal operations of the network and enables the operators to be more effective in analyzing the situation and proactive in planning the interventions

MATERIAL AND METHODS

I. CASE STUDY AND EXPERIMENTAL SITE

The Lille1 University Campus represents a small town of about 25 000 users, including 4 000 resident students on the campus. It is located in Villeneuve d'Ascq in the southwest of Lille in northern France (Figure 1). It was built in 1960 on 110 hectares with nearly 140 buildings and a total area of about 320 000 m^2. These buildings are used for various purposes like teaching, research, student residence, administration, catering, sport, cultural activities and recreation. The campus is organized into major academic areas: chemistry, physics, biology, social sciences, mathematics and engineering schools. It is served by different urban networks: drinking water, sewage, district heating, gas, electricity and public lighting.

Figure 1: Satellite image of the Lille1 University Campus

The urban drainage system on the campus is a separate system, where wastewater and storm water are evacuated in separated pipes. The wastewater network consists of 12 km of secondary branches, (shown in green, Figure 2) which discharge their effluents in a primary network of 4 km long. The main network is composed of two collectors (shown in red, Figure 2). The first one collects wastewater from the south part of the campus and directs it to an outlet situated in the East. The second collects the wastewater from the north part of the campus and evacuates it towards an outlet located in the North. Both of principal collectors after exiting the campus area join the combined sewer system of the community before reaching the treatment plant.

Figure 2: Wastewater network on the Lille1 University Campus

I. Construction of GIS database

The GIS is widely used for storage and analysis of geo-localized information in various fields such as geography, geology, transport, ecology, water and energy. Recently it is increasingly used for urban data. It allows to store and visualize data on urban systems and their attributes, and thus, to achieve an important step in the SunRise project. In this context, we identified and collect the information regarding the studied area and sanitation network. Later, all the information were verified and digitalized into a GIS software (ArcGIS 10.2.2). The GIS database includes different layers, which helps to visualize and manage the information easily. For example, (Figure 3) shows the classification of the buildings by their types of activity, where 30% of teaching buildings are for engineering sector and 18% are for physique sector, etc.

Concerning the sewer network, a layer representing the architecture of the network (manholes, pipes, diameters, lengths, material type, ground elevation…), was constructed. This layer allows to visualize the actual system components. For example, Figure 4 quantifies the pipes by their diameters where 65% of pipes have a diameter equal to 200mm. In addition, existing equipment were digitized in a separate layer (Pumps, dates of installation, type, characteristics, etc.) as shown on (Figure 5). Furthermore, water quality measurements were conducted frequently on the studied campus, and results were introduced in a layer on the GIS database (Date, concentration of all quality parameters, etc.)., Figure 6 presents 9 sampling points on the campus.

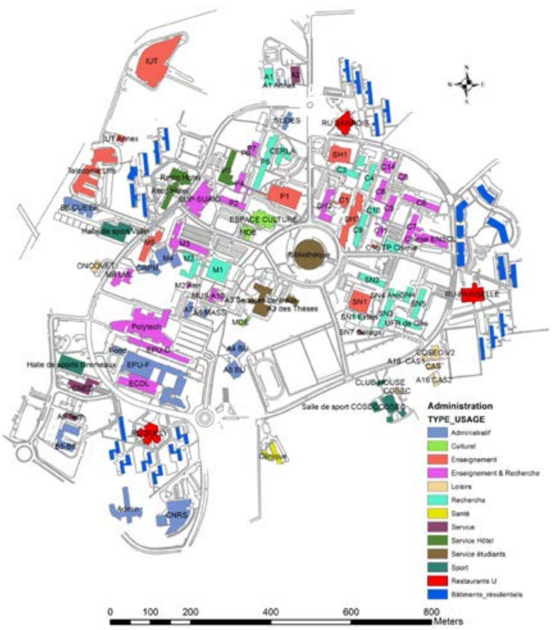

Figure 3: Distribution of the campus buildings by type of use

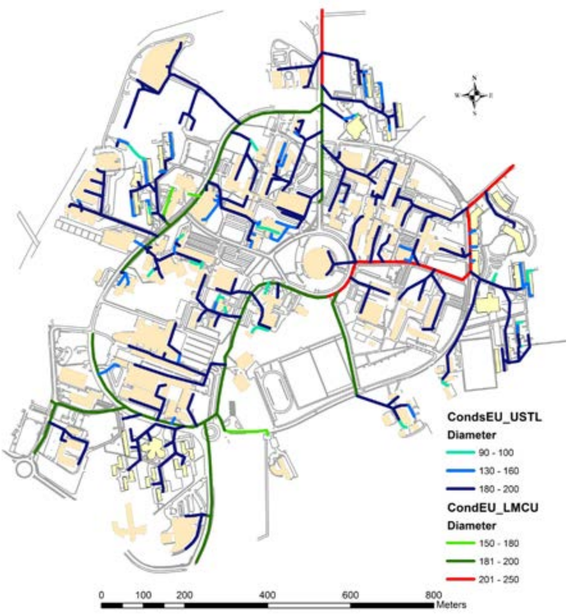

Figure 4: Diameters distribution of wastewater pipes

Figure 5: Existed equipment on wastewater network

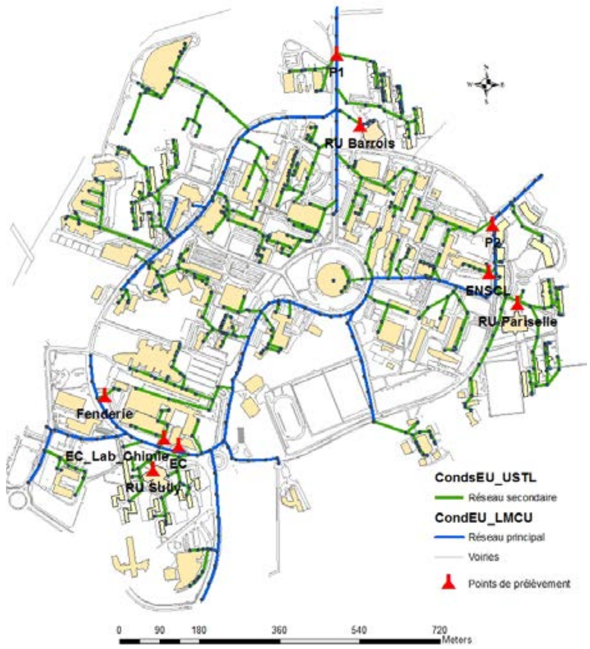

Figure 6: Sampling point for water quality analyses

The GIS database includes also an inspection layer. All interventions and anomalies observed since 1980 till now, with all video inspections and physical failures of pipes (breaks, cracks, root penetration…) are introduced within this layer. The inspection layer includes photos, the description of observed damage (defects and malfunctions in plumbing), the degree of nuisance, the number of performed intervention and the date (Figure 7). Thus, the resulted GIS database incorporates all data of the studied site as well as all the information concerning sewer system. It provides access to networks data at different scales, performs analysis with spatial and time correlations and offers data visualization. This enables the use of the data for optimal management of the system in an intelligent way. The inspection layer helps to have a GIS database of historical deficiencies detected on the sewer network during successive inspections. This information, geographically and timely defined, helps to locate the vulnerable areas and to operate the maintenance and renovation operations in a more rational manner. In addition, it allows to evaluate the evolution of the sewer system. Figure 7 shows in red all inspected pipes with an example of detected failures.

Figure 7: The inspection layer and an example of a detected system structural failure

II. IMPLEMENTATION OF MONITORING SYSTEM

In order to understand the hydraulic operation of the sewer system and to detect any abnormal phenomena, we have instrumented the network with quantity and quality sensors. We decided to begin this step by implementing the monitoring system on a sector, shown in blue in (Figure 8). The instrumented point is located on the main collector that receives sewage discharges from buildings in the south area of the campus. The instrumentation included a water level and velocity sensor equipped with a recorder and a GMS/GPRS communication system. We also equipped the network by a turbidity sensor.

Figure 8: Instrumented sector

The sensors used are manufactured by IJINUS, and equipped by a recorder IJILOG, which stores data up to 15 devices in its radio field and sends them via GSM/GPRS to a database. These sensors are powered by a battery pack with a large capacity IP67 10.8V / 102Ah IAVL. This pack comes in a suitcase that contains lithium batteries 3.6V/34Ah. The flow meter has been fixed on a plate, which has been positioned in the downstream side of the pipe ID 52 (GIS reference), having a diameter of 200 mm (Figure 9).

Figure 9: Flow meter installation (a) flowmeter, battery and data logger (b) installation step,(c) installed senor in the manhole

III. RESULTS AND DISCUSSION

The installed sensors provide information about the flow rate (velocity, level) and turbidity. Figure 10 shows the measurements recorded from 3 to 10 September 2015 and 24 September to 1 October 2015. By superimposing the measurements of these two weeks, we notice the daily and weekly similarity of the flow measurements. This similarity can be used to detect malfunctions in the system. It is noted that the flow variations are much larger on working days than on weekend. This result is predictable, because the activity on the campus is much higher during the weekdays. Figure 11, which presents a comparison between the flow rate on weekend and working days, confirm these results. Mean flow during weekend is equivalent to 2.7m3/h, while 6.3 m3/h is the mean flow during the weekdays.

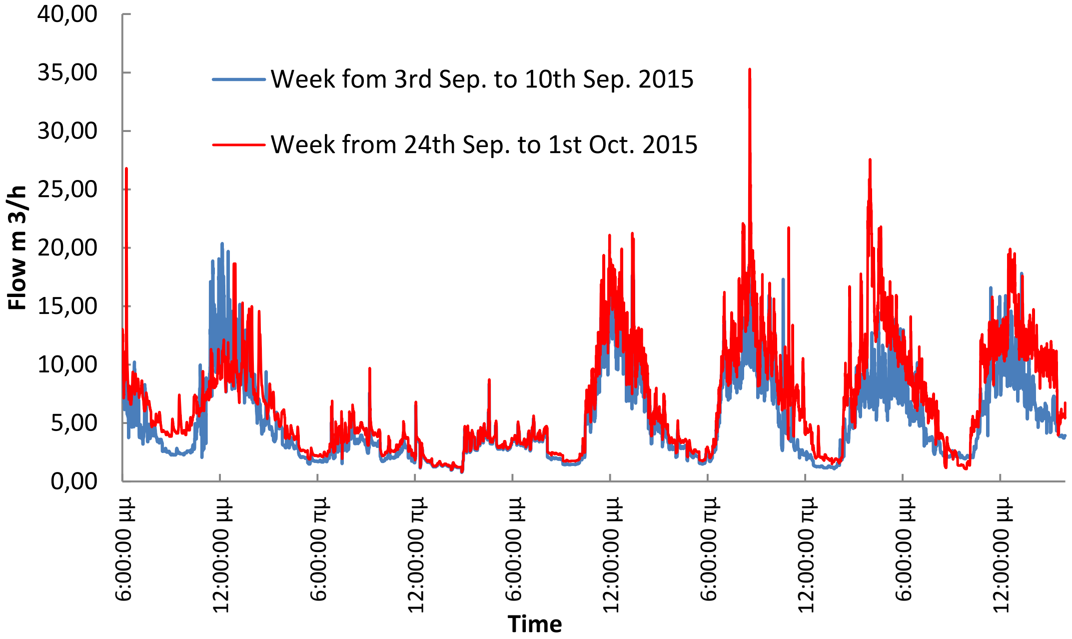

Figure 10: Comparison of measured flow between September 3th to 10th, 2015 and September 24th to October 1st, 2015

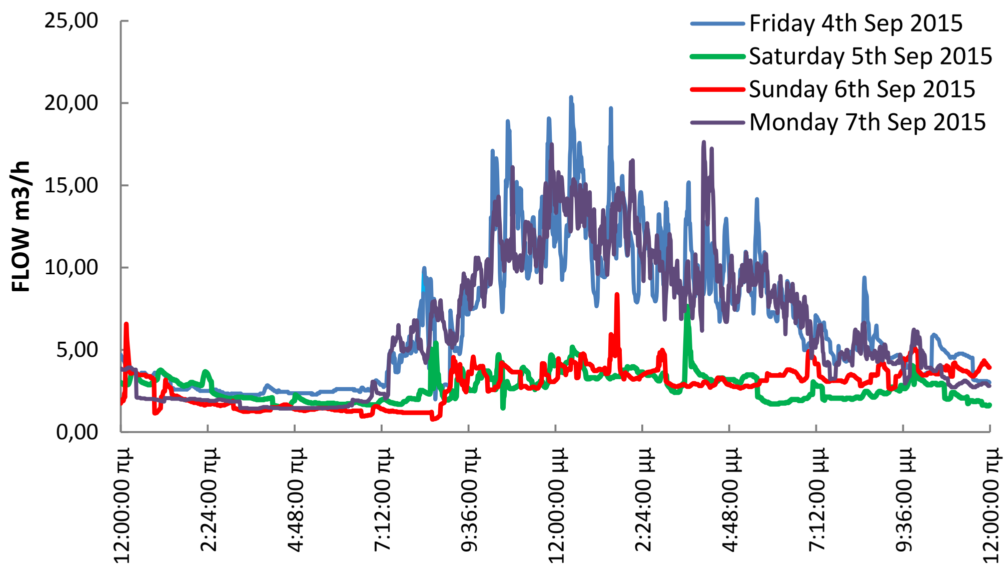

Figure 11: Measured flow rates during workdays and weekend

IV. Model EPA-SWMM

Given the complexity of sanitation and difficulties of modelling their networks, it is necessary to combine numerical modelling with advanced instrumentation to monitor the hydraulic operation and quality variation of the wastewater flowing within the networks. The instrumentation allows to calibrate the numerical models, and thereby improves the analysis of these networks. It is also interesting to monitor in real time the operation of these networks to quickly respond in case of anomalies. This is the major objective of "intelligent remediation" network.

It is important at this stage to test the network capacity during the normal operation. In this paper, EPA-SMM was used to build our simulation model, because it is a reliable model that has been used worldwide for various types of objectives in wastewater networks. To measure the flow entering the sewage system, all drinking water supply connections were equipped by water meters. These sensors record the hourly consumption of drinking water. Considering the discharged wastewater is equivalent to the drinking water consumption rate for each building, we can introduce these recordings as loads on the modeled manholes in the SWMM model. We worked over a period of 15 days (between 15th and 30th September 2015). This period is sufficient for analyzing the system operation and for comparing the modeled results with the measured values. Figure 12, shows the measured and modeled flow. There is a general similarity in the shape of the flow rate measured by our monitoring system and the flow rate modeled based on the consumption data. The peaks of the measured flow rates are higher than the modeled flow rates. This can be explained by the frequency of measurement of wastewater monitoring sensor that is set to record a measurement every minute, while loadings introduced to the model are measured every hour. Therefore the sensors measurements can detect peaks, which are smoothed by an hourly average in the model calculations. The modelling results affirm the accuracy and the reliability of the measurements taken by the monitoring sensors. Figure 13 shows the network operation under the daily normal peak, occurring on September 22, 2015 at 12:30. Flow exceeds 3l/s and circulates in the main network. The majority of this flow (more than 65%) comes from the sector containing the university restaurant. Results show the sufficient capacity of the network to discharge wastewater from buildings in normal conditions.

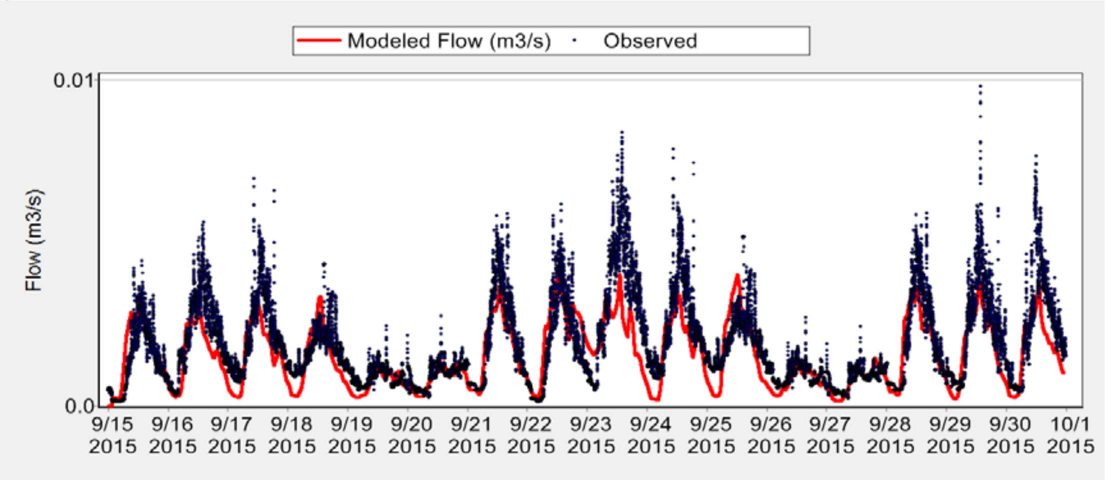

Figure 12: Measured and modeled flow for the period between 15th and 30th September 2015

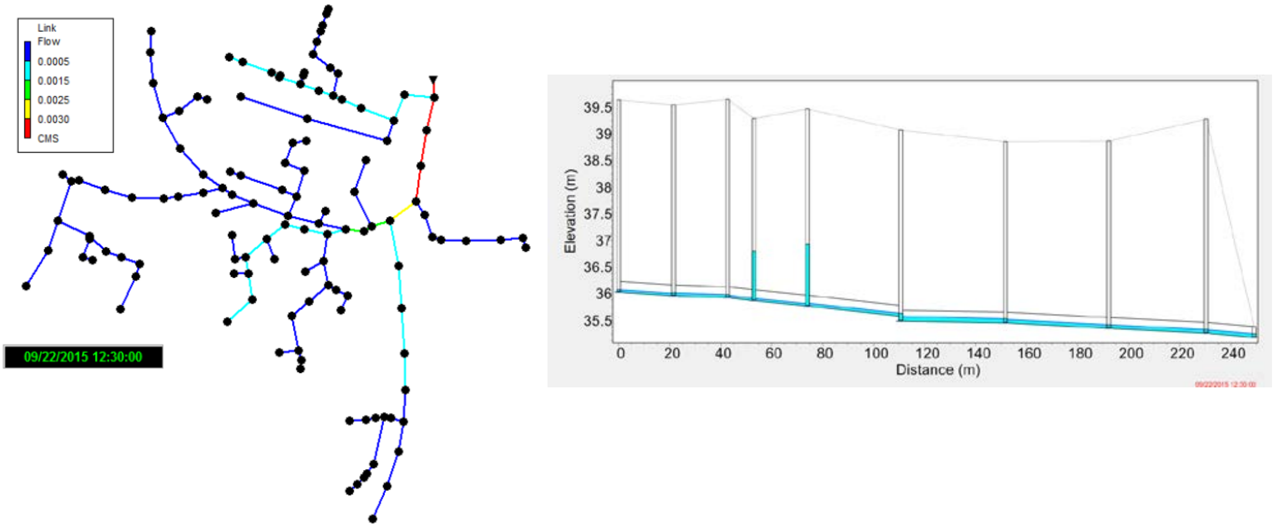

Figure 13: System operation under normal conditions during the daily peak flow on September 22 at 12h30

CONCULUSION

This article has described the importance of a real time monitoring system in the concept of smart cities. The wastewater system on the campus of Lille 1 University was chosen as a case study to apply the concept of smart city. At first step, an important work was dedicated to collect and digitize the data. A numerical database has been built on the GIS. This database is organized in different layers, which help to visualize and analyze all components of the sewerage network and information monitoring. The layers include all information about the studied site. One of the most important layers is the inspection layer, which details the historical deficiencies detected on the sewer network with their nature and severity. This helps to locate the vulnerable areas and to plan the maintenance and renovation operations in a more rational manner. In addition, through the digitization of successive inspections, this layer enables the managers to evaluate the long-term evolution of the sewer system.

The studied sewer network is instrumented by real time monitoring system. This system consists of quality and quantity sensors of type IJINUS. The monitoring system allowed detecting changes in flow rates in normal and abnormal period. Daily and weekly discharge measurements showed that the flow is more important in working days than holidays. The numerical model built using SWMM, showed the entire operation of the studied sector in normal conditions. The results of the model simulation affirm the accuracy and the reliability of the monitoring sensors measurements.

The instrumented real time system and dynamic modeling show the advantage of the concept of smart cities in understanding the operation of wastewater network, analyzing its dysfunction, optimize its use and define intervention priorities.

Due to our installed sensors and after analyzing the recorded flow rates, abnormal increases in the flow were detected. Different anomalies are under study and analysis in order to evaluate their origins, which could be due to an infiltration of parasite water. We intend to draw on the feedback of our experience to make future improvement in wastewater system monitoring. It is also necessary to work with the sensors manufacturers to improve their performance in terms of accuracy, reliability of operation, data transmission and battery life.

REFERENCES

Chourabi H., Nam, T., Walker, S., Gil-Garcia, J. R., Mellouli, S., Nahon, K., Pardo, T., et Scholl, H. J. (2012). Understanding smart cities: An integrative framework. Paper presented at the System Science (HICSS), 2012 45th Hawaii International Conference on.

Di Nardo A., Di Natale, M., Santonastaso, G. F., et Venticinque, S. (2013). An automated tool for smart water network partitioning. Water resources management, 27(13), 4493-4508.

Dirks S., Gurdgiev, C., et Keeling, M. (2010). Smarter cities for smarter growth: How cities can optimize their systems for the talent-based economy. IBM Institute for Business Value.

Dirks S., et Keeling, M. (2009). A vision of smarter cities: How cities can lead the way into a prosperous and sustainable future. IBM Institute for Business Value. June.

Dirks S., Keeling, M., et Dencik, J. (2009). How smart is your city?: Helping cities measure progress. IBM Institute for Business Value, IBM Global Business Services, New York.

Granlund D., et Brännström, R. (2012). Smart City: The Smart Sewerage. Paper presented at the 6th IEEE Workshop on user MObility abs VEhiclar Networks.

Machado B., Carvalho, T., Do Céu Almeida, M., Cupido, C., et Cardoso, M. (2007). Minimization of inflow and infiltration in separate sanitary sewer systems. Paper presented at the NOVATECH.

Marceau J. (2008). Introduction: Innovation in the city and innovative cities. Innovation, 10(2-3), 136-145.

Mitchell W. J. (2007). Intelligent cities. UOC papers, 5, 1885-1541.

Neirotti P., De Marco, A., Cagliano, A. C., Mangano, G., et Scorrano, F. (2014). Current trends in Smart City initiatives: Some stylised facts. Cities, 38, 25-36.

Pons B., et Vernette, P. (2010). Supervision de la Télégestion Lyonnaise de l'Assainissement (STELLA). NOVATECH 2010.

Rudolf; G., Christian;, F., Hans;, K., Robert;, K., Nataša;, P.-M., et Evert;, M. (2007). Smart cities-Ranking of European medium-sized cities: Vienna University of Technology.

Schütze M., Campisano, A., Colas, H., Vanrolleghem, P., et Schilling, W. (2003). Real-time control of urban water systems Proceedings of the International Conference on Pumps, Electromechanical Devices and Systems Applied to Urban Water Management (pp. 1-19): Citeseer.

Seghairi N., Mimeche, L., Debabeche, M., et Hamzaoui, A. (2013). Elimination du cuivre present dans les eaux usees industrielles sur un filtre plante de tamarix. . Courrier du Savoir, 15.

Shahrour I. (2014). Smart City: a living laboratory. Crisis Response, 10(1).

Stinson M. K. (2005). Benefits of Sewerage System Real-Time Control. Paper presented at the Impacts of Global Climate Change.