CENTAUR: Cost Effective Neural Technique for Alleviation of Urban flood Risk

Deliverable 3.1 – Report on the CENTAUR installed in Coimbra

Lead Partner: University of Coimbra

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Acronyms

AC	AC Aguas De Coimbra EM
DDCA	Data Driven Control Algorithm
EAWAG	Eidgenoessische Anstalt fuer Wasserversorgung Abwasserreinigung und Gewaesserschutz
EMS	Environmental Monitoring Solutions
FCD	Flow Control Device
LMCS	Local Monitoring and Control System
UoC	Universidade de Coimbra
USFD	University of Sheffield

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Executive Summary

This report is a deliverable from the Cost Effective Neural Technique for Alleviation of Urban Flood Risk (CENTAUR) project, funded by H2020 under grant agreement number 641931. It corresponds to Deliverable 3.1 - Report on the CENTAUR installed in Coimbra.

CENTAUR is a flood risk reduction system that aims to reduce local flood risk using a dynamically controlled Flow Control Device (FCD) to utilise the unused storage in sewer networks and piped drainage systems during rainfall events. It can be installed within manholes with minimal new infrastructure and the FCD is regulated using a data-driven control system. The control system is informed by a local water level sensing system that is an integral part of a CENTAUR system. The first phase of the project involved the development and integration of the hardware systems (Flow Control Device and Local Monitoring and Control System) and the development and integration of the software (communication and control algorithms) needed for this local real time control flood risk reduction system. In the second phase of the project a complete pilot CENTAUR system has been manufactured based on the hardware and software developed in the first phase and has been installed in the Av. Júlio Henriques in Coimbra, Portugal in order to conduct a field testing program.

This report presents the activities carried out in Coimbra associated with the installation of the FCD and the local monitoring and control system (LMCS). These activities complete Task 3.1. This task had the participation of the following project partners: University of Coimbra (UoC), AC Águas de Coimbra, EM (AC), Environmental Monitoring Solutions (EMS), Steinhardt GmbH Wassertechnik (Steinhardt) and University of Sheffield (USFD).

Firstly, the report contains a brief description of the site selected to install the CENTAUR FCD on Av. Júlio Henriques. This site was selected earlier in the project, as reported in Deliverable 2.5 (https://www.sheffield.ac.uk/centaur/outputs).

The report then describes the activities carried out for the installation of the CENTAUR system: the procurement of an electricity supply, installation of a kiosk and civil engineering works, installation of the LMCS, and the installation of the FCD. The report summarises some technical issues faced during the installation and administrative difficulties with authorisations associated with the electrical supply required for the FCD.

The planned monitoring activities designed to test whether the system is operating as expected are discussed in this report. These activities will gather data to demonstrate the effect of the CENTAUR system.

Finally, a summary of key lessons learned is included which will be taken forward into Task 3.3 that will focus on re-engineering and making improvements on the pilot CENTAUR system to maximise performance whilst ensuring installation requires minimum disruption.

The installation of the CENTAUR system in the Coimbra pilot site has been achieved therefore completing Task 3.1.

CONTENTS

1 Introduction

The project CENTAUR (Cost Effective Neural Technique for Alleviation of Urban Flood Risk) is funded by H2020 under grant agreement number 641931. CENTAUR is a flood risk reduction system that aims to reduce local flood risk using a dynamically controlled Flow Control Device (FCD) to utilise the unused storage in sewer networks and piped drainage systems during rainfall events. It can be installed within manholes with minimal new infrastructure and the FCD is regulated using a data-driven control system. The control system is informed by a local water level sensing system that is an integral part of a CENTAUR system. The first phase of the project involved the development and integration of the hardware systems (Flow Control Device and Local Monitoring and Control System) and the development and integration of the software (communication and control algorithms) needed for a local real time control flood risk reduction system.

The technology development activities in the project are organised into three technical work packages: WP1 Device Integration and Manufacture; WP2 System Control and Software Development; WP3 Demonstration and Implementation. This report describes the activities carried out to complete Task 3.1, the first task in WP3. The key target for this task is to install all elements of the prototype CENTAUR system, which have been developed and tested in the earlier Work Packages 1 and 2, as a pilot system into the Coimbra catchment. The elements of the CENTAUR system are (1) the Local Monitoring and Control System (LMCS, developed in Task 1.1); (2) the flow control device (FCD, developed in Task 1.2), (3) the Fuzzy Logic control algorithm (developed in Tasks 2.1 and 2.3) which were then integrated in Task 1.3 and then tested in Task 1.4. The Coimbra drainage system has been modelled in detail (Task 2.2) and this model has been used to support the selection of the pilot site and also to carry out ‘virtual’ testing of the CENTAUR system using computer models (Task 2.3). Titles of these prior tasks are listed in Table 1. Task 3.1 involved modifications to the manhole, installation of a roadside kiosk; installation of the LMCS installation of an electricity supply; installation of the FCD and the associated control hardware. This report also details the monitoring and modelling activities to assess the performance of the prototype CENTAUR system and gives an overview of knowledge gained which was implemented in the modified and reengineered CENTAUR system to maximise performance whilst ensuring installation requires minimum disruption.

Table 1: Tasks undertaken prior to CENTAUR system deployment in Coimbra.

Task Number	Title
1.1	Deliver a local water level monitoring communication and control system
1.2	Design and fabricate flow control device
1.3	Integrate LMCS and data driven control algorithms
1.4	Integrate wireless communication and monitoring system with the flow control device and test data driven control software
2.1	Develop new software system architecture based on existing DDCA
2.2	Characterise, monitor and model the Coimbra urban drainage system for deriving virtual training datasets for development of data driven control software
2.3	Virtual testing of CENTAUR system

1.1 Partners involved in the deliverable

UoC – Coordination of the task, monitoring and organization of field campaign, data analysis, and hydrodynamic modelling.

AC – Provision of catchment and sewer system data and field campaign support.

EMS – Design manufacture and installation of LMCS and field campaign support.

Steinhardt – Design, manufacturing and installation of the FCD.

USFD – Technical support and co-ordination with other project activities.

1.2 Deliverable objectives

The objective of this deliverable is to report on the installation of a pilot CENTAUR system in a sewer in Coimbra. The report describes the completion of Task 3.1: *Installation of CENTAUR system within pilot catchment*.

2 The pilot site

The pilot site for the first field testing of the FCD was selected earlier in the project, the full details of the selection process and outcome are described in Deliverable 2.5 (D2.5) which is available on the CENTAUR website (https://www.sheffield.ac.uk/centaur/outputs). In this section, the selected site is briefly presented.

The site selected for the installation of the CENTAUR system is on Av. Júlio Henriques, this site has a length of large diameter pipe which provides a suitable potential storage volume. Installation of the FCD on Av. Júlio Henriques will reduce flows in the downstream part of the system, with the target point in Praça Républica. Figure 1 shows the location of the storage on Av. Júlio Henriques and an aerial image of the location with the sewer network superimposed and the storage length being shaded in blue. Figure 2 shows the geometry of the manhole into which the FCD was installed.

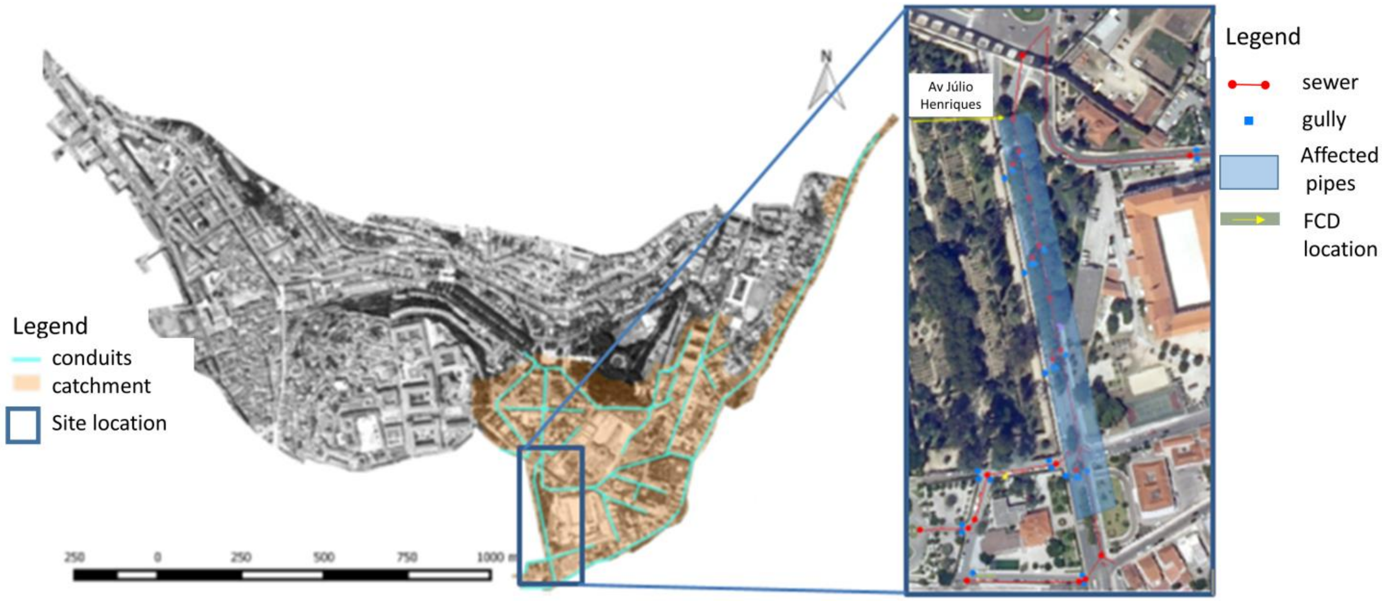

Figure 1 Location of Av. Júlio Henriques storage and aerial Image of FCD location and affected pipes.

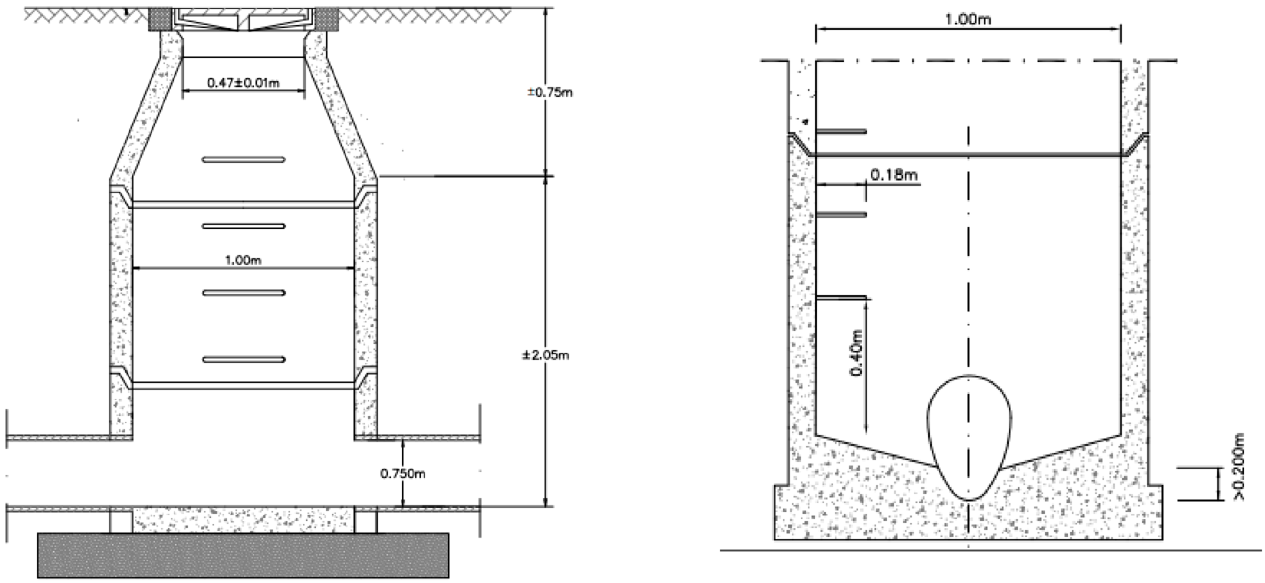

Figure 1: Geometry of selected manhole for installation of the FCD

The available storage volume for different return period rainfall events was estimated using the sewer network hydraulic model which has been developed and calibrated earlier in the project (Task 2.2). The design rainfall events are based on the Portuguese standard design rainfall curves (IDF curves) with the 1 year event extrapolated from that series. To obtain a rainfall hyetograph, the alternating block method was used. The advantage of this method is that the return period is constant and independent of the event duration. The design rainfall events were 45 minutes long, this is equal to the time of concentration for the catchment. The available volume of storage is calculated based on the maximum depth of water modelled in the pipes for each design rainfall event. Table 2 summarises the storage volumes calculated, where the Wetted Volume represents the part of the sewer system that is filled with water at the peak of the rainfall event and the Available Storage Volume represents the part of the sewer system that is empty and available for additional storage during the rainfall event. Figure 3 illustrates the longitudinal profile of the sewer network including the FCD location and the upstream conduits and manholes identified to act as storage. The storage volume is calculated based on the capacity of the conduits and manholes that are upstream the FCD and bellow the maximum water level behind the FCD (Figure 3).

Table 2: Available volume for different return period design rainfall events.

	Full pipe and full manhole	**1 year ***	**2 year**	**5 year**	**10 year**	**20 year**
Wetted Volume (m^3)	87.242	34.783	42.551	51.138	55.339	58.436
Available Storage Volume (m^3)	0	52.459	44.691	36.103	31.903	28.806

*75% of a 2 year return period rainfall

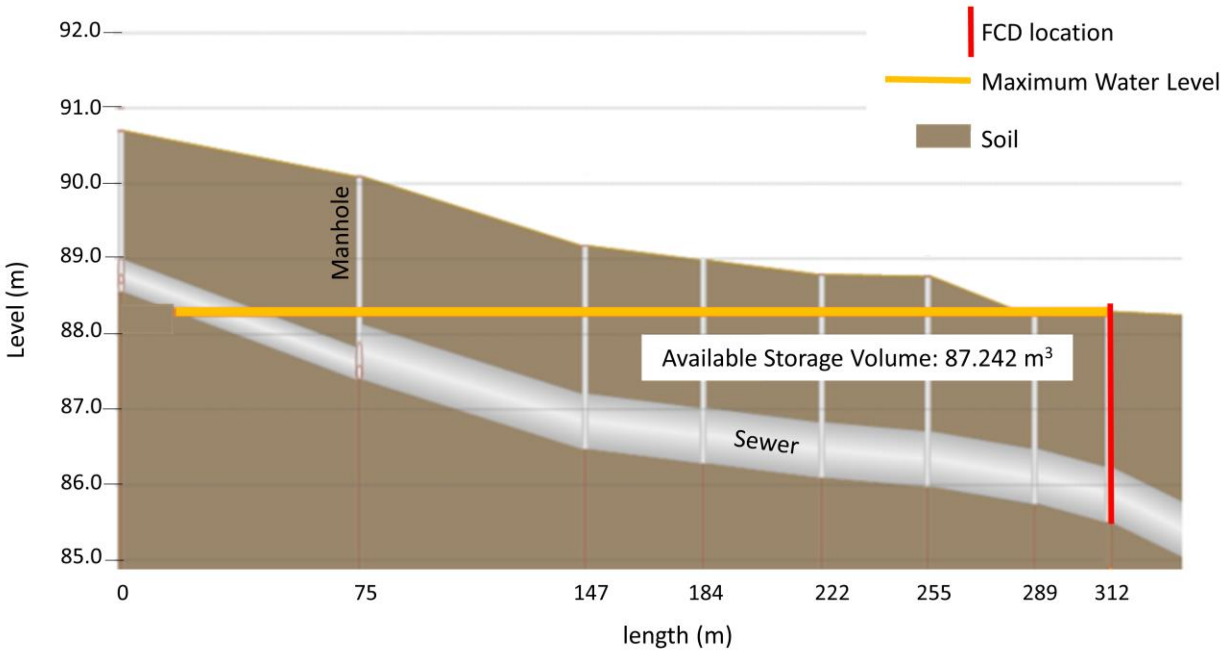

Figure 2 Longitudinal profile perspective showing the pipes available for storage (maximum water level is just below the ground surface)

Av. Julio Henriques was selected to install the FCD because there was a high storage volume capacity (relative to alternate options) and it was important for AC that the number of upstream house connections was small. However, in this location the manhole cover was required to be replaced and a new power connection was needed. (The FCD installed at the pilot site required a larger manhole cover to be fitted and the manhole shaft to be modified to 1.0 m diameter to the ground surface - see section 3.1)

Praça da Républica was selected as the downstream water level measurement point (flood location) because it is a downstream location with good conditions for monitoring the water level (a shallow gradient and reasonable depth range). In between the FCD location and Praça da Républica there is a relatively long distance of 350 m and also an elevation change of over 20 m. In this length there was no suitable monitoring location due to the steep gradient and a bifurcation where the drainage network flows in two parallel pipes, both of these conditions would make monitoring inaccurate. Moreover, Praça da Républica is also a practical place to access and divert traffic to install and maintain the monitoring equipment.

3 Installation of the CENTAUR system

The CENTAUR system installation can be broken down into a number of elements. The key components are the FCD which is the physical device controlling flows and the LMCS which monitors water levels and issues commands to the FCD. Additionally, there are required enabling works: the FCD requires a power supply; a roadside kiosk is needed to house the FCD control panel and LMCS control module; the manhole cover may need to be enlarged; ducts to run power and control cables from the control panel, in the roadside cabinet, to the FCD located in the manhole need to be installed.

3.1 Power supply

During the early stages of designing the FCD for the Coimbra pilot the power supply was discussed. The selected site on Av. Júlio Henriques did not have a power supply available so AC worked with the power distribution utility, EDP (Energias de Portugal), on the viability of the necessary 3 phase power and this was confirmed in October 2016. After the viability was confirmed, the price for its provision was agreed with the EDP and paid for in December 2016.

In January 2017, EDP planned the connection works and informed AC that they needed additional authorisation from the city council to carry out the necessary excavations. This was an unexpectedly lengthy process, which was only completed in July 2017.

The electrical connection was then installed in July 2017, and the safety certification was obtained from Certiel in the same month. The contract between AC and power supply company Endesa was then completed and the electricity meter was installed in August 2017 providing power to the system.

3.2 Civil engineering works

A kiosk to house the control panel for the FCD and also the electricity supply meter was required. This was specified by Steinhardt (size 1250 x 1000 x 420) and AC arranged the necessary permissions for the installation with the city council. The kiosk was installed on the footpath adjacent to the FCD manhole entry in December 2016 as shown in Figure 4.

The FCD installed at the pilot site required a larger manhole cover to be fitted and the manhole shaft to be modified to 1.0 m diameter to the ground surface. This was to allow safe, easy and quick installation and removal of the FCD. A conduit for the power and control cables was also needed between the kiosk and FCD. These works were organised by Steinhardt and AC and were completed in December 2016.

Figure 4 Kiosk installed on Av. Júlio Henriques in Coimbra

3.3 LMCS

The CENTAUR Local Monitoring and Control System (LMCS) monitors water levels and issues commands to the FCD. The system requires a high level of reliability in terms of communication links, power and sensor data. The technology uses a Fuzzy Logic based algorithm to control flows in the drainage network, storing excess flows in the upstream sections of the network to minimise flooding at a downstream location.

EMS installed the prototype LMCS in October 2016 (Figures 5 and 6). Although not necessary for the autonomous operation of the system, an online dashboard connects to the LMCS and gives operational visibility (Figure 7).

The prototyping platform was based on Libelium's "Waspmote" and "Meshlium" products. A number of issues, largely associated with this prototyping platform, were encountered during the field trials of the prototype LMCS in Coimbra and via a post-trial evaluation:

i. The central module of the LMCS (the HUB) was based on Meshlium. During field trials, this was superseded by the "Meshlium Xtreme". The Meshlium Xtreme operated on radio frequencies that require licenses to operate in each country; this would be impractical for the market product.
ii. These obsolescence issues could eventually extend to other components.
iii. It was clear from field trails that the prototyping platform would be difficult to optimise toward the very low power consumption required by the market product.
iv. Because the components provided by the prototyping were generalised rather than designed toward the specific purpose of the CENTAUR elements, they were over-specified, with redundant parts, and would be high cost.
v. The communication protocols used by Meshlium and Waspmote were not fit-for-purpose and could not give guaranteed signal. This compromised the overall CENTAUR system.
vi. Certification of the in-manhole CENTAUR module based on Waspmote componentry was highly unlikely.

Hence the decision was made to migrate to specifically designed hardware for the beta version. The beta version was trialled on the University of Sheffield laboratory facility in the summer of 2017 before being installed in Coimbra in October 2017. The beta version overcame the issues encountered with the prototype system.

Figure 5 CENTAUR prototype module installed in Av. Júlio Henriques, Coimbra.

Figure 6 CENTAUR prototype module installed in Coimbra drainage network.

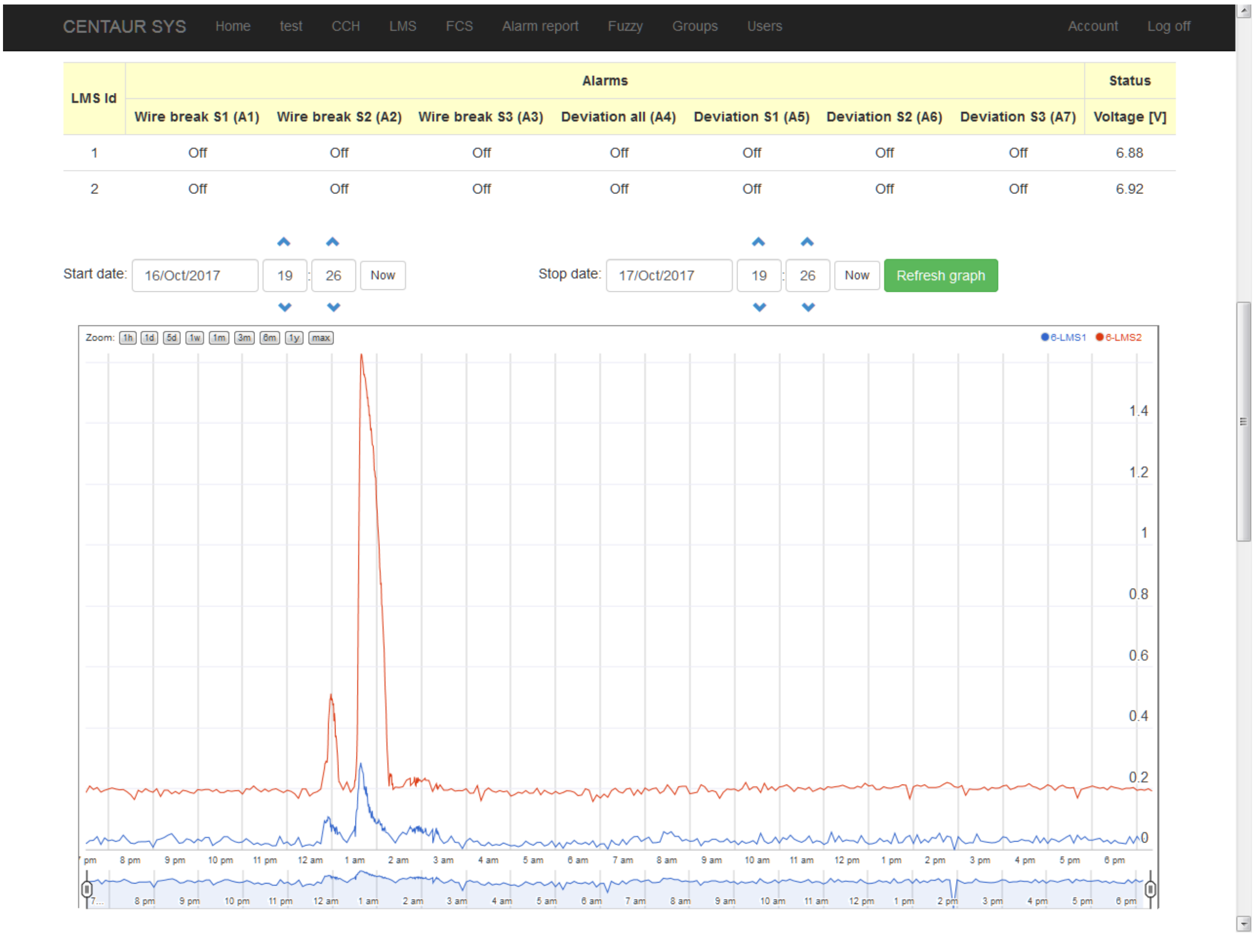

Figure 7 Coimbra water level data showing in LMCS online dashboard.

3.4 FCD

Following discussion with all project partners, the final design of the FCD was confirmed by Steinhardt in October 2016, and the manufacture of the FCD started. The FCD was shipped to Portugal and installed during February 2017 (Figure 8).

It was not possible to complete the final commissioning and FCD tests until the electricity supply had been connected. Steinhardt finished the commissioning process in September 2017, this final commissioning involved turning on the power to the FCD and verifying manually that the FCD moved over the full range and that the control panel was functioning correctly. EMS and USFD then conducted additional commissioning tests with the help of UoC and AC to confirm that the LMCS was communicating with the FCD and that the control algorithm was performing as expected. The system was fully operational in October 2017.

Figure 8 Steinhardt control panel and EMS LMCS hardware installed in kiosk.

4 Activities for monitoring the CENTAUR system

During the pilot testing the performance of the system was monitored closely to ensure that it was functioning correctly, to understand if the performance could be improved by adjusting the control algorithm and to quantify the benefit of the installed system. This activity was the basis of the Deliverable 3.2 ‘Report on the performance of the pilot CENTAUR and recommendations’.

4.1 Regular checks

In order to ensure that the system was performing as expected, UoC, USFD, AC and EMS checked the online dashboard at least once per day to determine that the recorded water levels were reasonable and that any changes in the FCD position were as expected. An online spreadsheet was used to record these checks and also to record any changes made to the operating parameters of the LMCS. The initial parameters on the LMCS were based on recorded level data and experience gained from running the algorithm in hydro-dynamic models and in the laboratory test facility at USFD. The parameters were initially set to ensure the CENTAUR system was activated in small rainfall events (i.e. with a return period of several times per month) to ensure that initial performance data could be obtained in a short period of time. These parameters were periodically reviewed during the testing period to allow testing of the CENTAUR system under a range of operating conditions. UoC worked with AC to agree a procedure to manually re-open the FCD in the event of the CENTAUR system causing any unexpected network problems. AC has a team working 24 hours per day, 5 days per week and 16 hours per day during weekends.

4.2 Monitoring

Sensors were installed in the sewer network to record performance before and after the installation of the FCD in order to accurately quantify the flow dynamics and demonstrate the effectiveness of the pilot CENTAUR system. The sensors were installed into the area selected for installation of the pilot FCD in April 2016 and these remained in place during the pilot study. In addition to the two LMCS level sensors, there were eleven sensors installed and collecting data for performance analysis (Figure 9). These are:

- 6 level sensors;
- 3 flow meters;
- Rain gauges at the office of AC and at UoC (outside the area shown in Figure 9)

The data collection was done in close partnership between UoC and AC. The six level sensors and three flow meters record data every three minutes and were downloaded manually every three to four weeks. The rain gauges record data every minute and were downloaded after significant rainfall events. Data from the LMCS sensors was downloaded from the online dashboard.

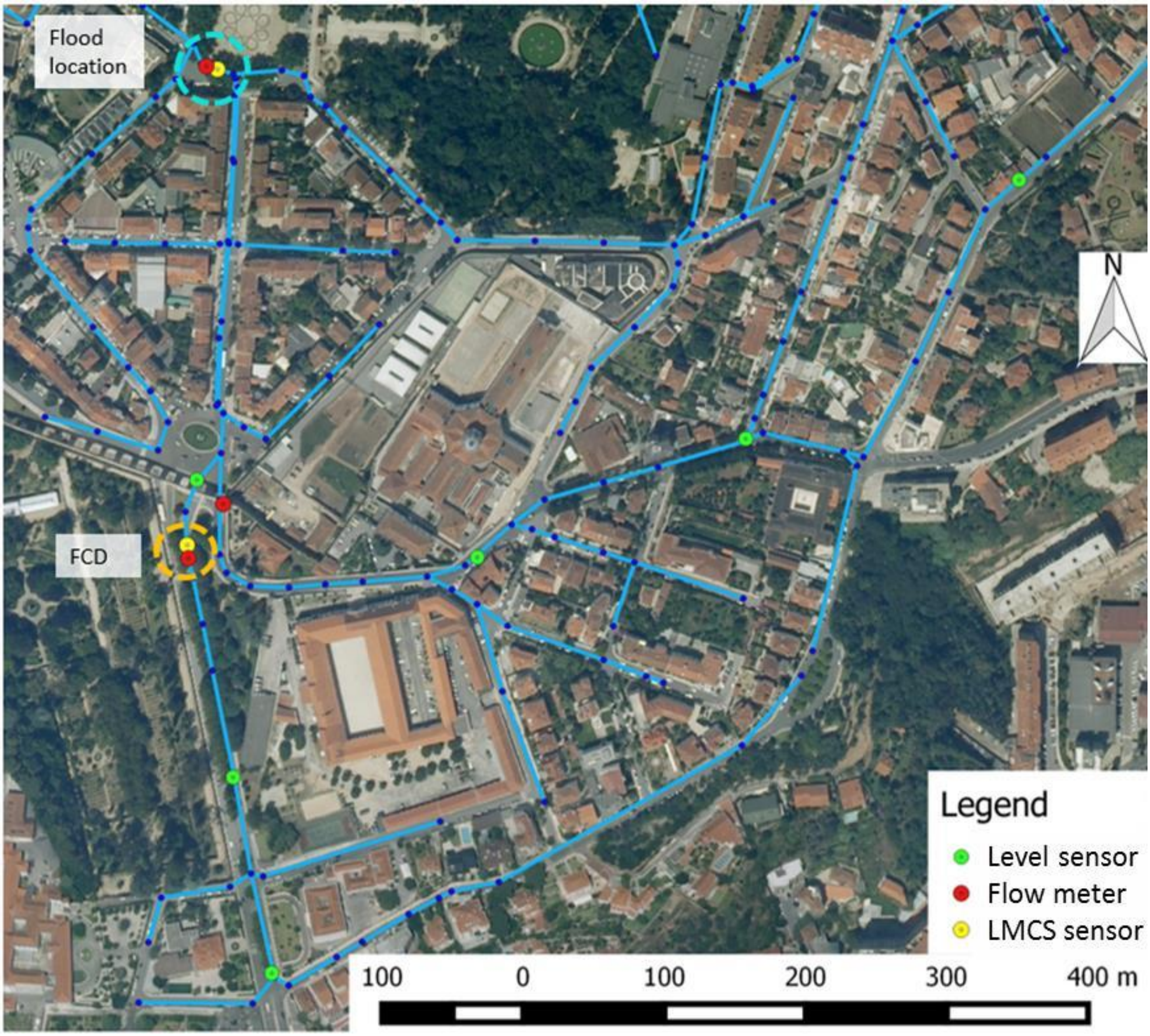

Figure 9 Location of: Monitoring sensors for testing, CENTAUR FCD, Flood Location.

4.3 Hydro-dynamic modelling

Alongside the monitoring data, a calibrated hydro-dynamic model was used so that performance of the CENTAUR system could be assessed. This was necessary because rainfall events are all different, hence those recorded before the CENTAUR system was installed were not the same as those installed after, and hence a direct comparison of measured data alone was not possible.

The hydro-dynamic modelling has two main objectives: a) to model the reference situation without any FCD and b) to adjust the FCD discharge coefficients. Comparing water depths and flows in the model against measured values enables the performance of the FCD to be evaluated by calculating the reduction of water level and flow in the control sections. With the behaviour of the FCD well adjusted, it is possible to evaluate other scenarios, namely a different location for the FCD and the installation of other FCDs within the sewer network.

5 Lessons learnt and recommended improvements

The field installation in this pilot site has been achieved successfully and valuable knowledge and experience has been gained for future installations. Based on this knowledge, there were several recommendations for modifications to the LMCS and FCD. These recommendations were taken into account for implementation at the second field testing site in Toulouse, France:

a) LMCS design

It was always envisaged that the prototype LMCS installed in Coimbra would be reviewed and re-engineered using the knowledge and experience gained from the laboratory study and pilot installation. The reengineered LMCS features a different communications protocol, which has a stronger signal and also be engineered to minimise power consumption. Due to the difficulties encountered with the prototype LMCS, the reengineered LMCS was installed in Coimbra.

b) FCD design

The partners agreed that it would be beneficial for the FCD to be re-designed, so that it would not usually require the manhole shaft and cover to be modified and also to reduce the electrical power requirement. The revised design can be inserted through a standard 600mm diameter manhole cover and is actuated hydraulically, rather than using an electric motor. This has multiple benefits that include: the device within the manhole is physically smaller and no high voltage electrical power is needed inside the manhole. Also, the hydraulic compressor has a smaller electrical power requirement and there is an additional ‘fail safe’, whereby, if electrical power is lost, the pressure reservoir is able to raise the FCD (with the hydraulic control valves being powered by a back-up battery to operate the internal control valves).

6 Conclusions

The installation of the CENTAUR system in the previously identified pilot site in Coimbra has been achieved successfully and lessons have been learnt. The following conclusions are presented according to activities or components:

1. The prototype LMCS has been installed in locations which are easily accessible with the support of AC. Some communication issues were experience between the FCD location and the flood location. Lessons were learnt and problems have been resolved by installing a reengineered LMCS.
2. The prototype FCD was manufactured by Steinhardt. For the installation, some civil engineering works were completed in order to adjust the manhole to allow the prototype FCD to be installed. Electrical works were necessary to make the power supply available at the FCD location. The installation of the power supply was delayed due to authorisations required from the local authority in Coimbra to allow the power supply company to excavate the pavement in order to lay the cables.
3. Commissioning tests: Following the installation of all components the CENTAUR system was checked to ensure correct operation. The system became fully operational in October 2017.
4. Operational procedures: The online data was checked daily during the initial period of operation. During rainfall events, careful attention was taken in order to fully open the FCD in case of unexpected problems. AC has a team running 24 hours per day, 5 days per week and 16 hours per day during weekends for any emergency situations in the network. This team was aware of the procedure to open the FCD in case of an emergency.
5. System monitoring: Additional sensors were installed in the catchment to monitor water flows, these, along with the hydro-dynamic model allowed the performance of the system to be understood.

This report signifies the completion of Task 3.1 of the CENTAUR project “Installation of CENTAUR system within pilot catchment”.