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

Deliverable 2.5 – Report on initial strategy for CENTAUR system deployment in Coimbra

Lead Partner: University of Coimbra

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Acronyms

AC	AC Águas De Coimbra EM
EAWAG	*Eidgenoessische Anstalt fuer Wasserversorgung Abwasserreinigung und Gewaesserschutz*
EMS	Environmental Monitoring Solutions
UoC	Universidade de Coimbra
USFD	University of Sheffield

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Executive Summary

This deliverable reports on the development of the initial strategy for deployment of the CENTAUR system deployment in Coimbra. The objective of the deployment strategy is to identify a suitable site for deployment and ensure that sufficient data and knowledge is acquired to permit the design, manufacture and installation of the pilot CENTAUR system.

This report describes the studies that were taken to first identify a number of potential sites for pilot deployment and then how these sites were investigated. These investigations led to the sites being ranked both on their potential to lower downstream flood risk, the risk to properties should the system fail and other practical measures, such as access and the availability of power.

As this was a pilot study, the local water company wanted strong reassurance that if a failure did occur that flooding would be highly unlikely to occur.

The existing calibrated hydrodynamic network model produced in Task 2.2 was used to first examine the whole of the Zona Central in Coimbra for potential CENTAUR pilot sites. The modelling work identified the area upstream of Praça da República as being the most suitable with two potential installation locations. The modelling work now focussed on this area. Flow and depth monitors were moved to locations within in this area so that data was collected to improve the calibration, and thus the accuracy of the existing hydrodynamic network model in this area. New more detailed simulations were conducted with analysis focussed on this smaller catchment. It was decided to select the Av. Julio Henriques site. This was the preferred location due to its greater storage volume potential, the fewer house connections nearby and easier access to install the necessary kiosk. Once the site had been selected the geometry of the manhole was carefully measure and the upstream and downstream pipes inspected using CCTV.

The geometrical data was first used to amend the hydrodynamic model at the field site to predict its performance at a 1:100 year flood as this was the level of protection required by Agaus de Coimbra. The results of this modelling and the geometrical information were sent to Steinhardt to inform their gate design and manufacture. Once Steinhardt had finalised their design, the hydraulic design curves of the geometry of the weir and emergency control devices were input into the hydrodynamic model and it verified that at the 1:100 year flow that even if the CENTAUR system failed it would not cause flooding so meeting the key requirement of Aguas de Coimbra.

Thus a modelling framework was developed that first identified the optimum site, then upgraded the accuracy of that model at that location and then used the model to demonstrate that the safety requirements of the local water utility could be met. The data from this model was used to inform the design of the CENTAUR system for this location. Once the design for the system had been confirmed by the manufacturer Steinhardt, the hydraulic design curves of the gate design were used to check that the safety requirements in the event of failure were met. Once this requirement had been confirmed the gate manufacture was started by Steinhardt.

CONTENTS

1. Introduction

This report is part of Cost Effective Neural Technique for Alleviation of Urban Flood Risk (CENTAUR) project, funded by H2020 under grant agreement number 641931. It corresponds to Deliverable 2.5 - Report on initial strategy for CENTAUR system deployment in Coimbra.

This report describes the activities undertaken and the issues considered when investigating sites in Coimbra for field testing of the CENTAUR system. It explains how the pilot study site was identified and selected and presents details of the pilot study site and the better calibrated hydraulic model of the pilot study site and how this better calibrated model was used to inform the design of the flow control system at the pilot study site. The report also describes how hydraulic design data supplied by Steinhardt was used in the hydraulic network model to demonstrate that if the system failed it would not cause flooding for a 1:100 year event. This was a requirement of Aguas de Coimbra as this was the first test site of the system.

1.1 Partners Involved in Deliverable

University of Coimbra – Dual drainage model setup, monitoring and field campaign, data analysis, modelling, re-calibration after area identification, simulation of scenarios with the gate installed, verification of safe performance of selected design.

AC Águas de Coimbra, EM – Provision of data and field campaign support.

EMS Environmental Monitoring Solutions – Field campaign support

Steinhardt GmbH Wassertechnik – Design and manufacturing of the gate

USFD- University of Sheffield – Technical support and management

1.2 Deliverable Objectives

To report on the initial strategy that was developed for the CENTAUR system deployment in Coimbra.

2. Case study and modelling

2.1 Case study

Coimbra is a medium size city in the centre of Portugal that has suffered several urban floods in recent years. The most affected zone is the downtown area, where important services and touristic attractions are located. This zone is covered by the “Zona Central” catchment, which has a total area of approximately 1.5 km^2. The catchment is predominantly urban. The sewer system is 34.8 km long divided in 29 km of combined conduits, 4.6 km of foul and 1.2 km of stormwater. The time of concentration of the catchment is estimated to be around 45 minutes.

2.2 Model building

As described in Deliverable 2.2, the hydraulic model was based on the set up of a 1D2D urban drainage model for the case study Zona Central catchment. The 1D2D model concept is based on coupling a 1D module to represent the sewer system with a 2D module that represents the overland surface. These two modules cover most of the urban areas where stormwater flows and were connected with an innovative model set-up. In addition, 1D2D models include a rainfall-runoff module to generate runoff from rainfall inputs. The model was implemented in InfoWorks ICM v 6.5 (Innovyze, 2016).

The 1D sewer flow module was built with network and operational data, provided by the water utility company AC Águas de Coimbra E.M. The 2D overland flow module was created based on an available Digital Terrain Model (DTM – a LiDAR with 1 m horizontal resolution). Buildings polygons and land use data were used to characterize the model (e.g. roughness) and define the surface mesh (e.g. mesh resolution, break lines, voids, and boundaries). The rainfall-runoff module considered was based on sub-catchment units. These sub-catchment units were defined for all manholes, based on Thiessen Polygons within major sub-catchments that were physically-based delineated for the main conduits of the system.

The Horton method was chosen to model the infiltration of pervious areas, with parameters based on Butler & Davies (2011). Moreover, fixed runoff coefficients were adopted for impervious surfaces. The SWMM hydrological model was applied for the surface runoff routing (single non-linear reservoir) with routing dependent on surface roughness, surface area, ground slope and catchment width (Rossman, 2010).

3. Monitoring

3.1 Introduction

A flow survey started on 3rd December 2015 in order to monitor rainfall and sewage flows in the drainage system of Zona Central catchment. Two rain gauges, eight level gauges and three flowmeters were installed. Preliminary investigations, which included visits to potential locations to install level and flow gauges, were conducted to get an initial insight into the system characteristics in terms of hydraulic conditions, and also to detect potential problems installing rainfall and level gauges. The chosen locations covered all the main branches of the network and are presented in Figure 1.

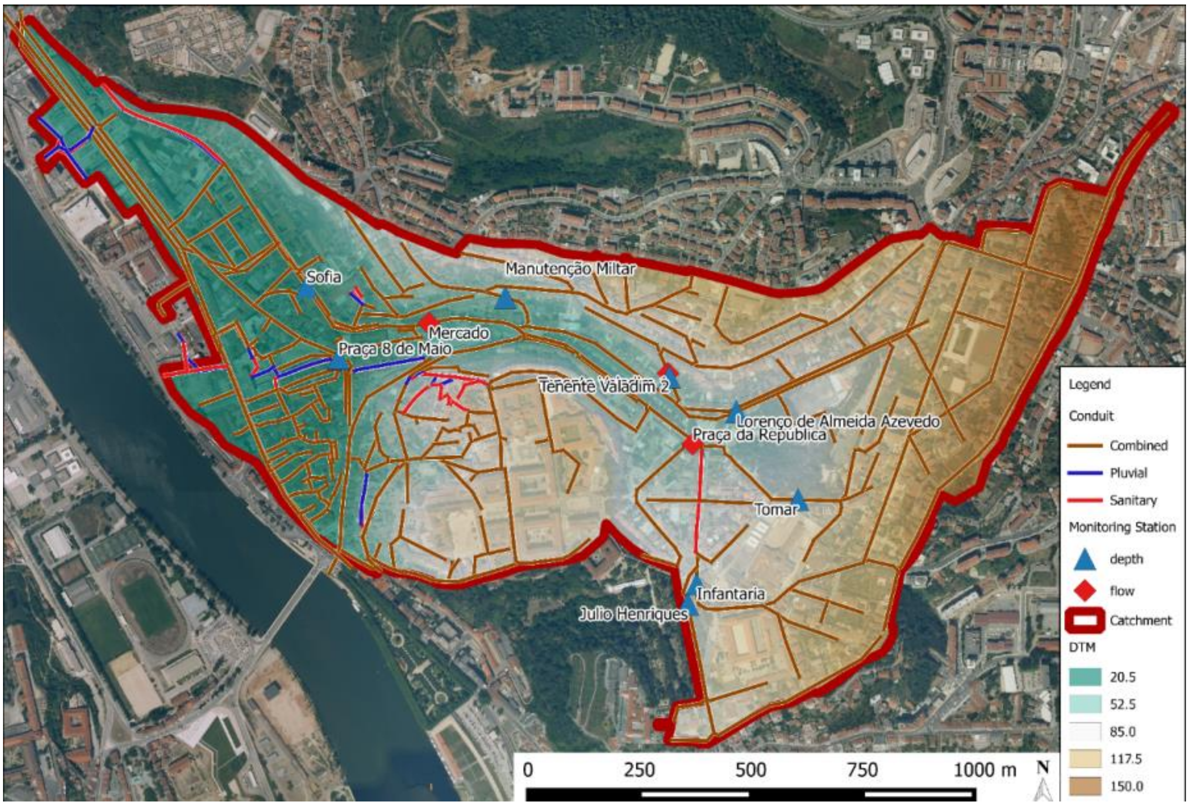


Figure 1 Zona Central catchment with location of level and flow sensors

3.2 Calibration process

The first step for the calibration of this model was to adjust the hydrological parameters to get a better fit of the simulated data with the hydraulic data retrieved from the sensors from the sewer. For this purpose, the values of the fixed runoff coefficient and the Horton parameters were modified.

The runoff coefficient indicates the portion of water from the precipitation to be considered runoff. It is a function of the ground cover and can vary according to each subcatchment and land use.

The Horton infiltration was considered for the pervious surfaces. This model controls the infiltration capacity of the pervious surface, meaning that, when the soil reaches its capacity of infiltration the infiltration rate starts to decrease. The combined adjustment of these parameters has led to a good approximation with the control points in the sewer. Most of the control points in the system were within the convergence criteria adapted from Code of Practice for Hydraulic Modelling of Sewer Systems (WaPUG, 2002).

- Visual comparison
- Storm flow verification (adapted from WaPUG, 2002)
    - Flow rate in a range of 15% to 25%
    - The unsurcharged depth has a tolerance range of 100mm
    - Timing of the peak and duration

In order to properly represent flooding events, it was necessary to control the amount of water entering the sewer system. In this model, the inlets were represented by orifices in the network. The inlet capacity was then adjusted by changing the limiting discharge coefficient to a value that could represent floodplains (flood extents) recorded on historical flooding events. The limit of water entering the sewer network was the main parameter used to calibrate the flooding levels on the surface of the 2D model. This calibrated model was used to identify general areas in the catchment in which a CENTAUR system may be beneficial.

3.3 New locations of the sensors

During the General Assembly meeting in March 2016, project partners visited several potential locations for the installation of a CENTAUR flow control, identified using the calibrated Zona Central model (Deliverable 2.2). Following discussion at the meeting, the area upstream of Praça da República was identified as being the most suitable with two potential installation locations. On 27th April 2016, sensors were moved to improve calibration in this small part of the Zona Central catchment where it was decided the CENTAUR may be installed. This part of the catchment was divided in 3 subcatchments: Julio Henriques, Infantaria 23 and Praça da República, where Praça da República is the subcatchment that drains the water from the 3 subcatchments. Av. Julio Henriques was the preferred location to install the gate due to greater storage volume potential, the fewer house connections nearby and easier access to install the necessary kiosk. Praça da República zone will contain the downstream control point. There is also the option of installing a second CENTAUR device in Infantaria 23 for further testing and validation. For this phase 2 flow survey, two flow meters and five level sensors were installed (Figure 2). Since this date the rainfall events recorded have smaller intensities than the ones recorded previously.

	Subcatchment
1	PRAÇA DA REPÚBLICA
2	INFANTARIA
3	JULIO HENRIQUES

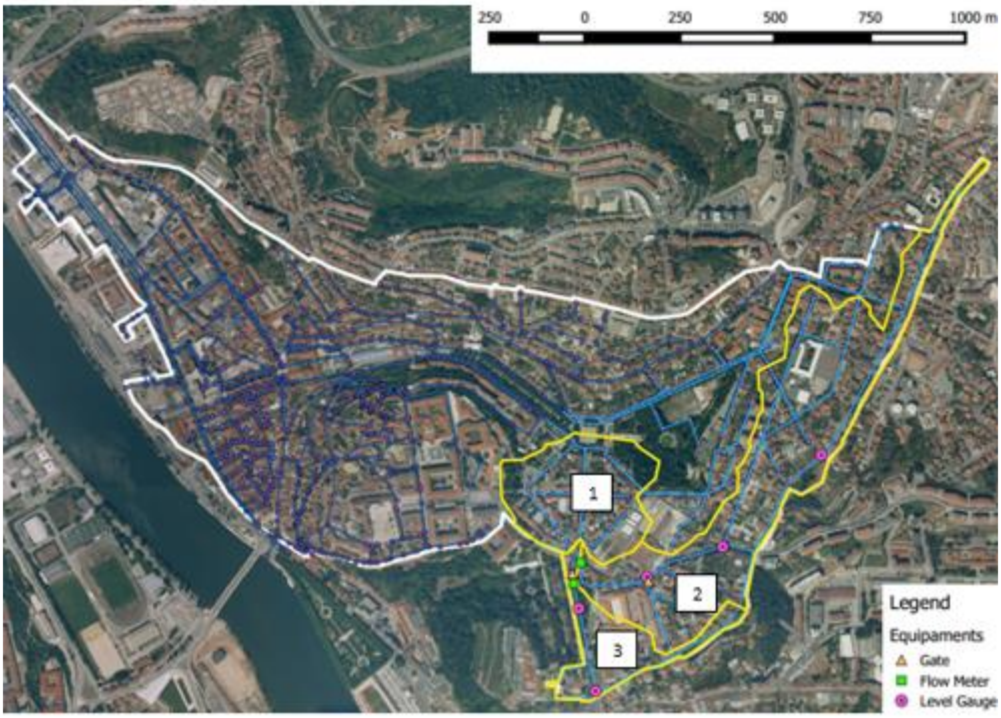


Figure 2 Zona Central catchment with the new location of level and flow sensors and possible gate locations.

3.4 Re-calibration summary

The improved calibration was completed mainly by adjusting the runoff coefficient for the different sub catchments according to land use and flow response. Although the previous calibration was already inside the range of acceptance it was possible to notice some improvement using the new hydrological parameter values at the potential gate locations.

Two events were used for calibration (5 and 8 May 2016) and one for validation (11 May 2016).Figure 3 shows results of flow and water depth in Av Julio Henriques, as an example.

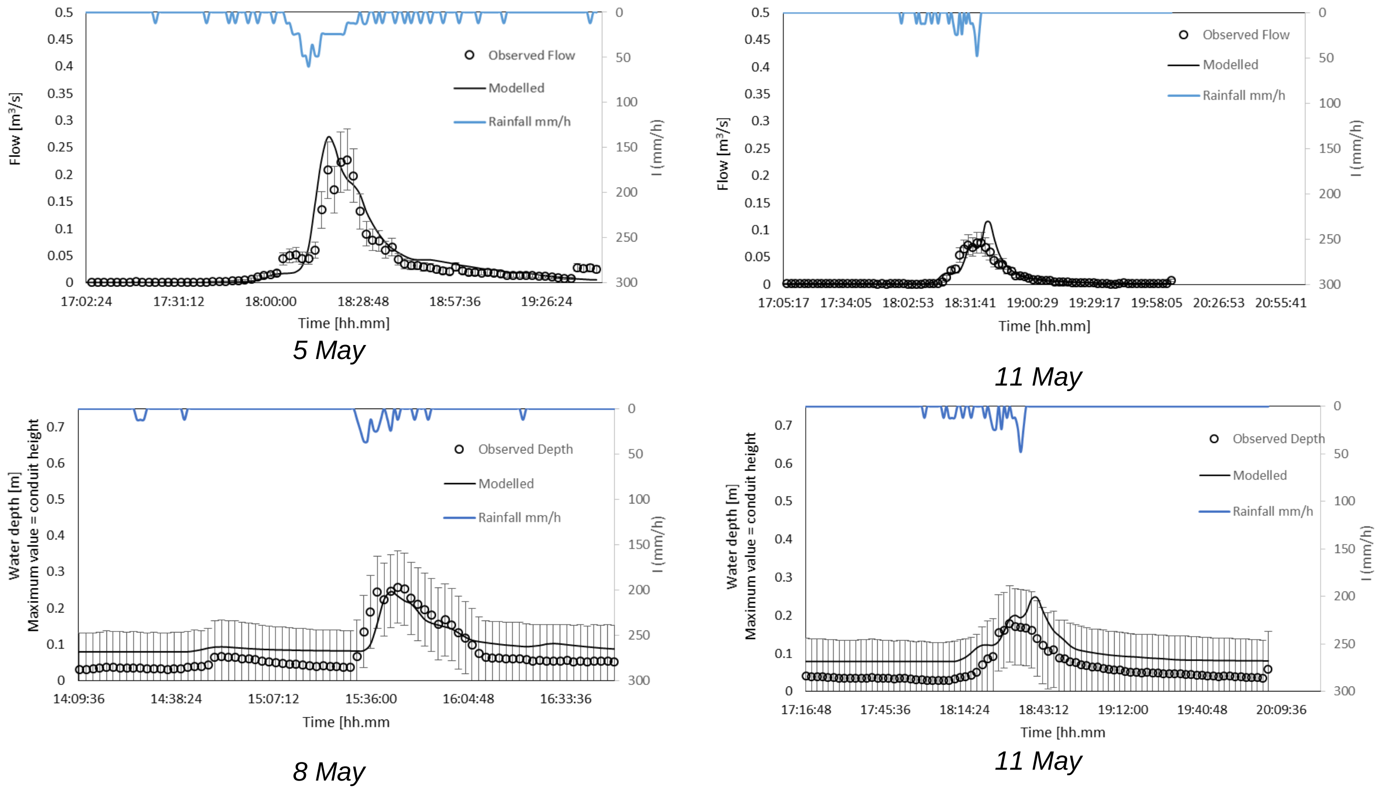


Figure 3 Example of Calibration and validation of data in Av Julio Henriques flowmeter.

The re-calibrated model was then used to provide information about the storage volume available upstream of the potential gate locations and to simulate what would happen in the catchment once a gate was placed in either site.

4. Initial strategy for system deployment

4.1 Gate location

After carefully discussion among all partners Av. Júlio Henriques and Rua da Infantaria 23 (Largo de Santana) were chosen as possible locations to receive the first installation of the CENTAUR system. Av. Julio Henriques has proven to be the most suitable location due to its higher storage volume capacity. Figure 4 shows the Orto image of both the locations. The proposed manholes are similar to the majority of the manholes in Coimbra and are circular with an internal diameter of 1.0 m. The top part of the manhole shaft is a cone shape with approximated diameter of 0.6 m on the top followed by a narrow throat with diameter of around 0.48 m. Figure 5 and Figure 6 show details about the manhole dimensions.

Figure 4 Júlio Henriques and Rua da Infantaria 23 Orto Image

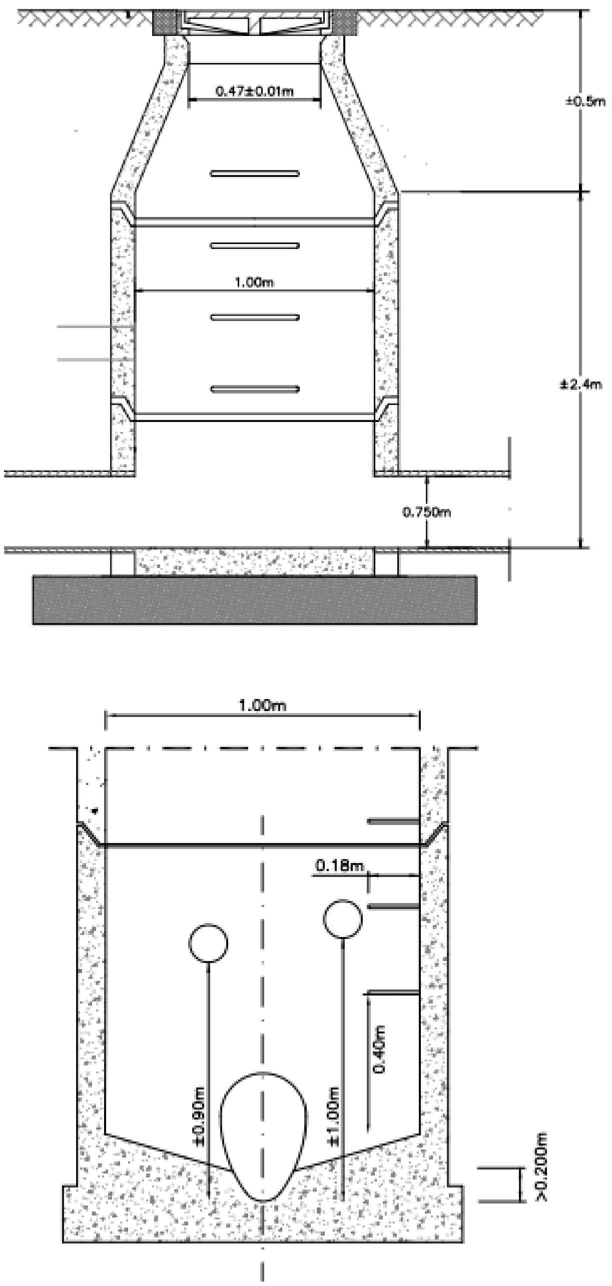


Figure 5 Drawings of manhole on Infantaria 23

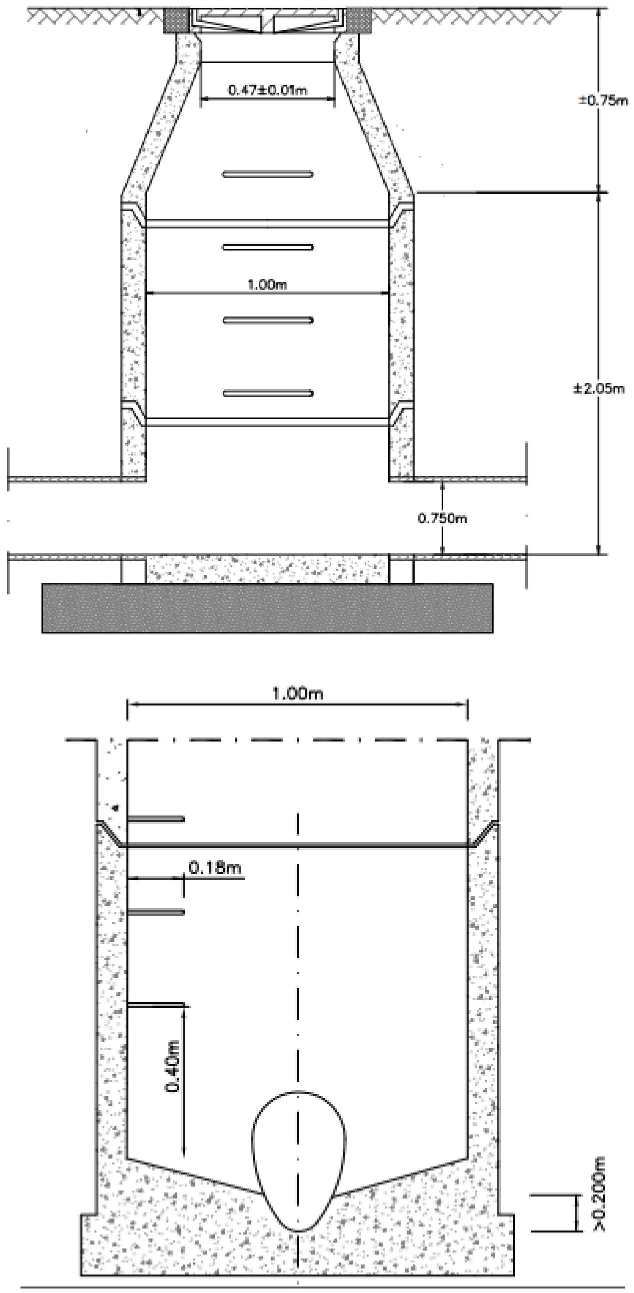
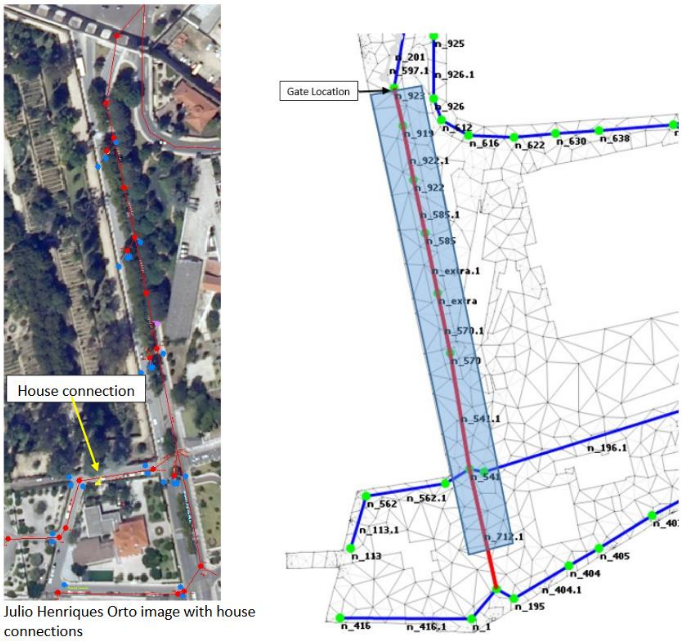


Figure 6 Drawings of manhole on Av. Julio Henriques.

Figure 7 shows images for the proposed gate location in Av. Júlio Henriques (Orto image and InfoWorks image).Figure 8 to Figure 10 are photos from this site location during the survey visit in spring 2016.



Julio Henriques Orto image with house connections

Julio Henriques model

Figure 7 Av. Júlio Henriques: Orto image with house connections and Julio Henriques network from the hydraulic model in InfoWorks

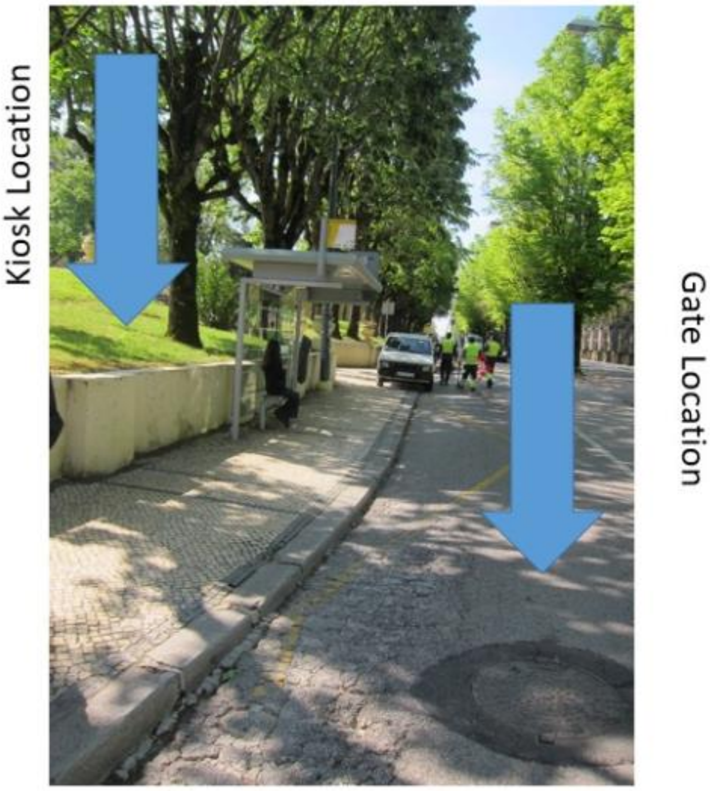


Figure 8 Av. Julio Henriques gate location

Figure 9 Street view of the gate location in Av. Júlio Henriques

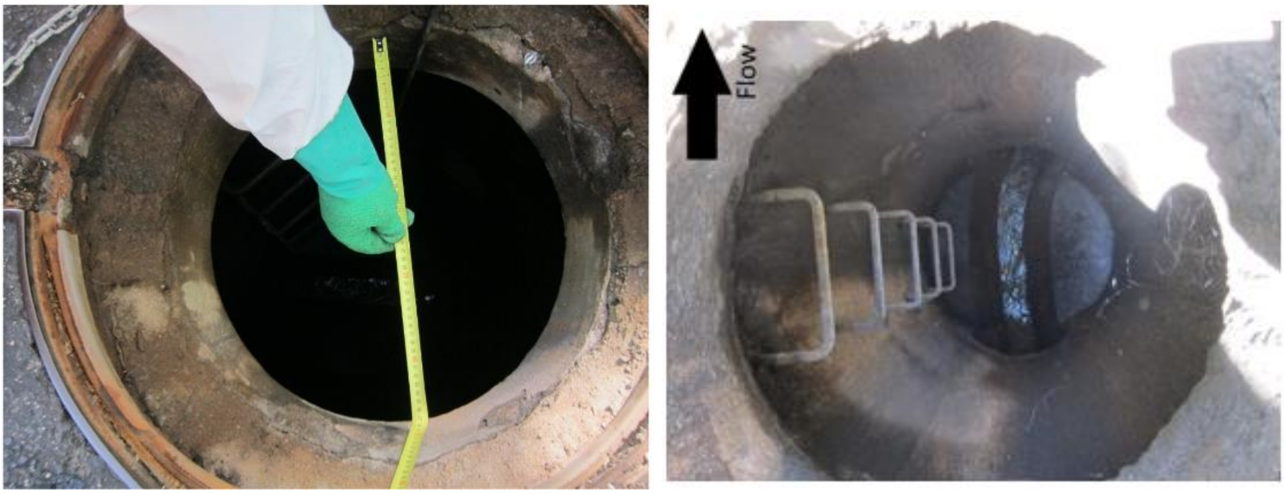


Figure 10 Av. Júlio Henriques manhole opening and internal view from top.

Figure 11 shows images from the gate location in Infantaria 23 (Orto image and InfoWorks image).Figure 12 to Figure 14 are photos from site location during the survey visit.

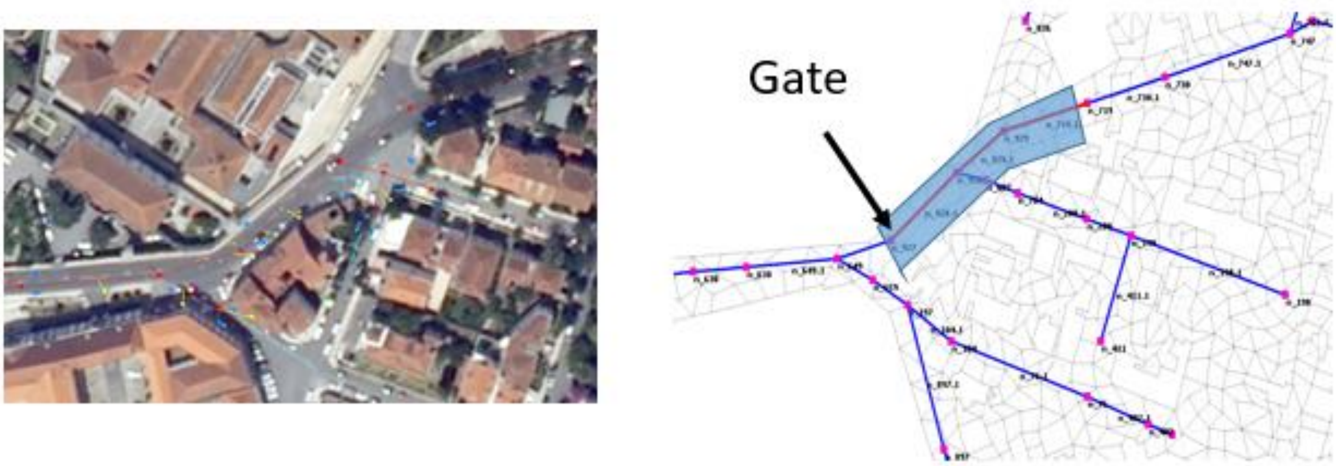


Figure 11 Rua da Infantaria 23 Orto image with house connections and network from the hydraulic model in InfoWorks

Figure 12 Overview of the gate 1 location in Rua da Infantaria 23

Figure 13 Potential kiosks location at Rua da Infantaria 23

Figure 14 Manhole inside view in Infantaria

4.2 Geometry

Detailed geometry information upstream of the proposed manhole for the gate installation in Av. Júlio Henriques and Rua da Infantaria 23 are presented in Table 1 and Table 2.

The tables columns are: **ID**, representing the name of the structure in the model; **Type**, indicating the type of structure (node or conduit); **Area**; **Chamber Roof**, the highest point in the manhole; **Chamber Floor**, representing the lowest point in the manhole; **Flood Limit**, shows the highest water level allowed before flooding upstream start; **Used length** is the total length of the conduit used in the calculations; **Used height** is the total height of the manhole used for the calculations.

This geometry was updated with a CCTV survey done by Águas de Coimbra in late May 2016.

Julio Henriques

ID	Type	Area(m^2)	Chamber Roof	Chamber Floor	Flood Limit level	Used length/height(m)
n_923	Node	1.100	88.300	85.500	88.240	2.740
n_919.1	conduit	0.287	-	-	88.240	22.300
n_919	Node	1.100	88.240	85.740	88.240	2.500
n_922.1	conduit	0.287	-	-	88.240	32.800
n_922	Node	1.100	88.770	85.970	88.240	2.270
n_585.1	conduit	0.287	-	-	88.240	32.600
n_585	Node	1.100	88.792	86.090	88.240	2.150
n_extra.1	conduit	0.287	-	-	88.240	36.500
n_extra	Node	1.100	88.950	86.228	88.240	2.012
n_570.1	conduit	0.287	-	-	88.240	36.400
n_570	Node	1.100	89.174	86.470	88.240	1.770
n_541.1	conduit	0.287	-	-	88.240	70.400
n_541	Node	1.100	90.094	87.390	88.240	0.850
n_712.1	conduit	0.159	88.550	87.390	88.240	42.174

Table 1 Network geometry upstream the gate (Julio Henriques)

Infantaria

ID	Type	Area (m2)	Chamber Roof	Chamber Floor	Flood Limit level	Used Length/height (m)
n_927	node	1.100	102.660	99.660	102.660	3.000
n_928.1	conduit	0.287	-	-	102.660	42.800
n_928	node	1.100	102.960	100.710	102.660	1.950
n_929.1	conduit	0.196	-	-	102.660	28.200
n_929	node	1.100	103.650	101.650	102.660	1.010
n_719.1	conduit	0.196			102.660	18.105

Table 2 Network geometry upstream the gate (Infantaria 23)

4.3 Available Volume

The approximated available volume storage for different return period rainfall events was calculated based on the results of the hydraulic model. Table 3 summarizes the storage volume calculations, where the **Wetted Volume** represents the part of that system that is filled with water and the **Available Storage Volume** represents the part that is empty and available for further storage. Figure 15 and Figure 16 illustrate the longitudinal profile of the used network section.

JULIO HENRIQUES**	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						
**Gate located at the middle of downstream manhole						

Table 3 Available volume in different return period (Julio Henriques)

INFANTARIA **	Full pipe and full manhole	< 1 year*	2 year	5 year	10 year	20 year
Wetted Volume (m^3)	26.286	6.528	7.657	8.816	9.652	10.350
Available Storage Volume (m^3)	0.000	19.757	18.629	17.470	16.634	15.936
*75% of a 2 year return period rainfall						
**Gate located at the middle of downstream manhole						

Table 4 Available volume in different return period (Infantaria)

Julio Henriques

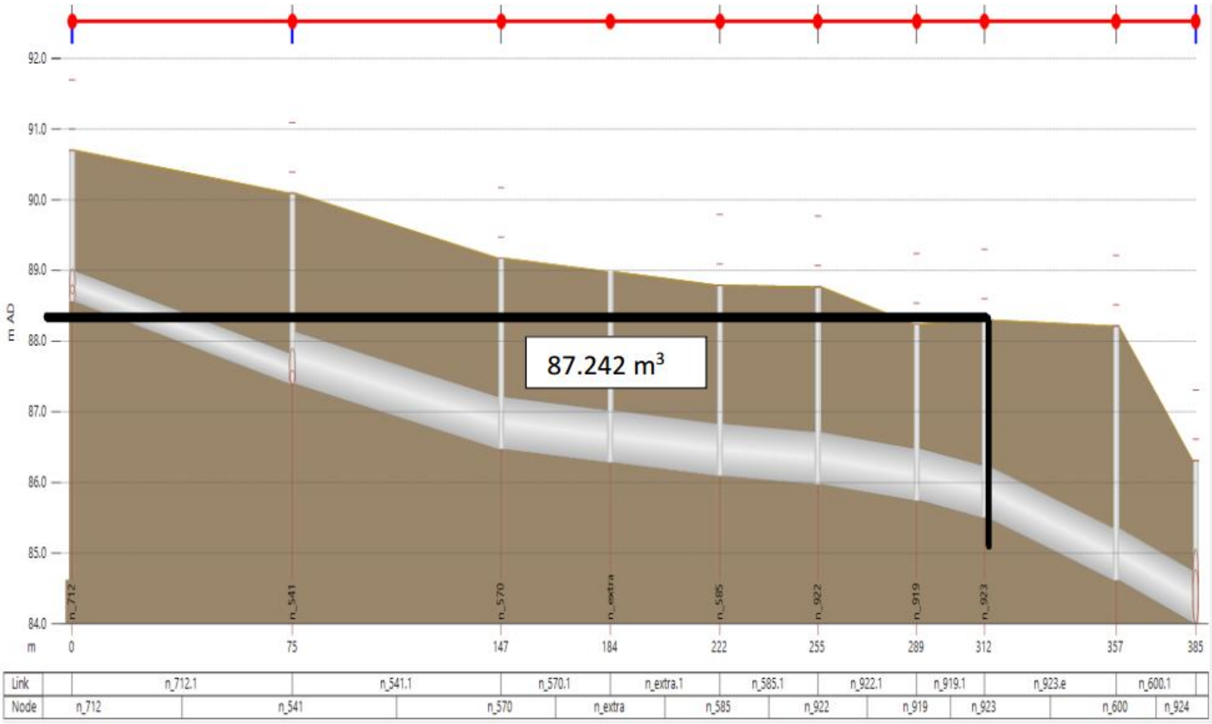


Figure 15 Longitudinal profile perspective showing the pipes available for storage volume (Julio Henriques)

Infantaria

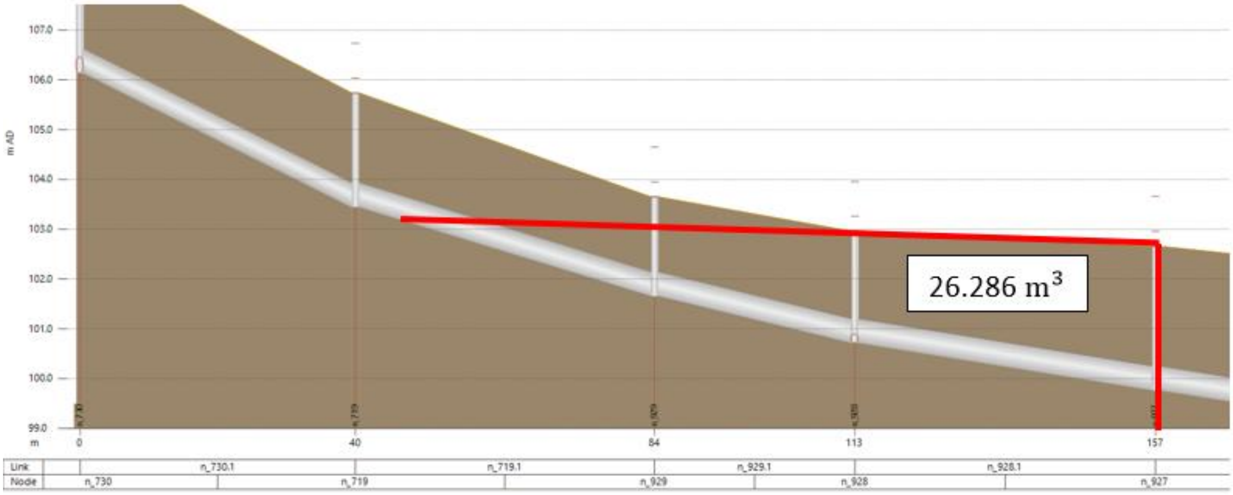


Figure 16 Longitudinal profile perspective showing the pipes available for storage volume (Infantaria)

5. Simulations of the drainage network including the CENTAUR gate

The proposed CENTAUR system comprises a computer controlled gate, two relief valves and an overflow weir. For safety reasons the system to be installed is designed to control flows in the range from 1 to 100 years rainfall return period, with maximum approximated expected flow rate of 0.76 m^3/s. At 0.76 m^3/s the upstream pipe entirely is filled. A series of simulations were performed using training data sets generated based on design storms in order to verify the flow dynamics of the sewer system after the installation of the gate and define the dimensions of the real gate, namely the weir height. The simulations demonstrate the influence that the valves and dimensions of the gate have on the upstream water depth condition of the network during different design rainfall events. Figure 17 shows the representation of the gate in InfoWorks.

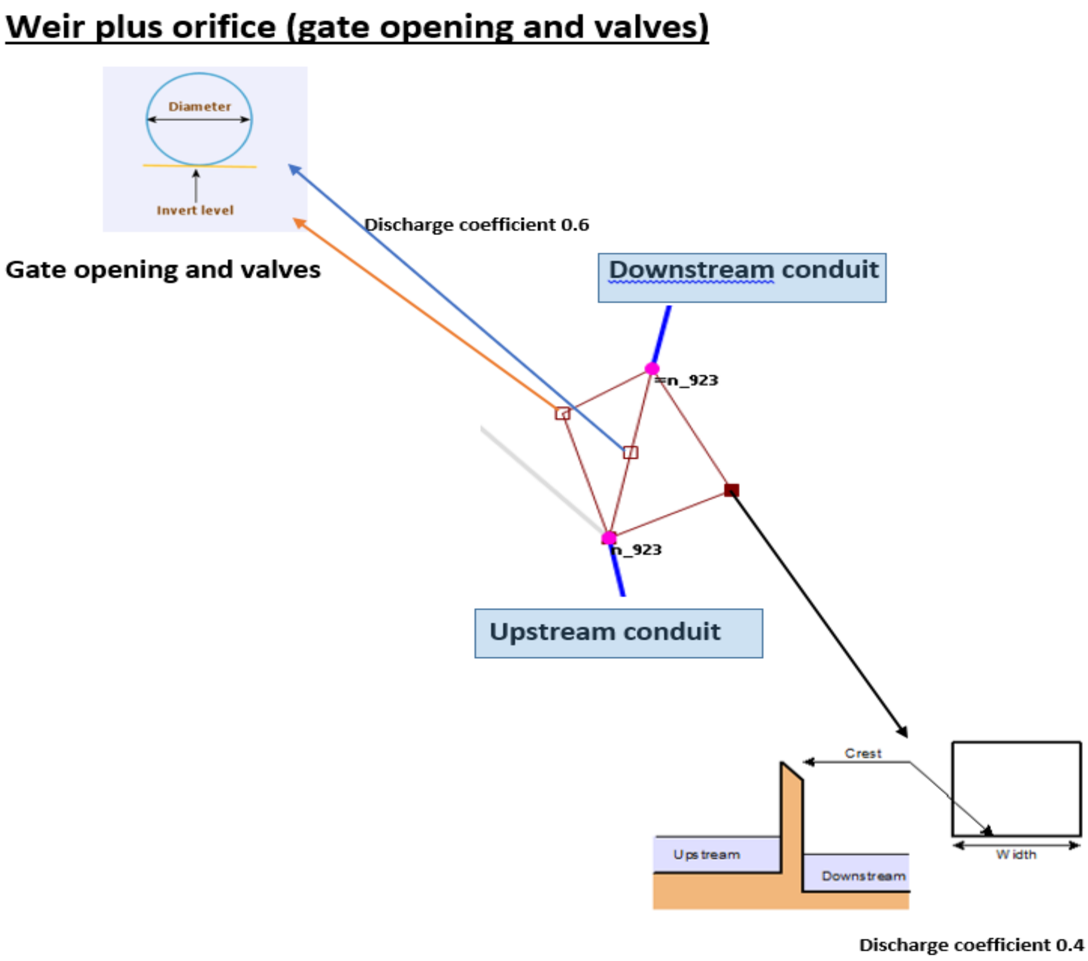


Figure 17 Representation of the gate in InfoWorks

Note: The dimension of the emergency relief valve was chosen based on the desired maximum flow through orifices (between 0.35 m^3/s to 0.4 m^3/s). Only one orifice was used to represent both valves. At this stage, conservative weir and orifice coefficients were used.*

*(According to InfoWorks user guide, the discharge theory for an orifice predicts a typical coefficient to be 1.0, which is the default value. Values typically range between 0.2 and 3.0).

Several scenarios were simulated, in order help the gate design process. The summary of the results of the simulations for 20 and 100 years return period rainfall events with a duration of 45 minutes are displayed in Table 5.

						RESULTS						Invert level of the gate	85.5
Return Period Rainfall	**Weir Height (m)**	**Weir Width (m)**	**Orifice diameter (m)**	**Valve diameter (m)**	**Valve height (m)**	**orifice flow (m^3/s)**	**valve (m^3/s)**	**orifice +valves (m^3/s)**	**weir flow (m^3/s)**	**Total flow (m^3/s)**	**Flooding?**	**Water level node upstream (m AD)**	**Water depth node upstream (m)**
Open valves - no limit in discharge													
100 years	1.7	0.6	0.3	0.365	0.8	0.174	0.224	0.398	0.345	0.743	**Beginning of flood**	87.8	2.3
100 years	1.7	0.8	0.3	0.365	0.8	0.169	0.217	0.386	0.36	0.746	**No flood**	87.7	2.2
100 years	1.8	0.8	0.3	0.365	0.8	0.173	0.225	0.398	0.349	0.747	**Beginning of flood**	87.8	2.3
20 years	1.9	0.6	0.3	0.365	0.8	0.177	0.222	0.399	0.178	0.577	**No flood**	87.86	2.36
20 years	1.9	0.8	0.3	0.365	0.8	0.174	0.218	0.392	0.188	0.58	**No flood**	87.78	2.28

Table 5 Summary of the results of the drainage network containing the gate

6. Validation of the design

After the simulations described in Section 5, Steinhardt GmbH Wassertechnik confirmed the design of the gate together with the operational rating curves of the valves and weir. Using this information, a new set of simulations was performed in order to verify the influence of the gate on the upstream catchment area considering that the gate opening would be or completelly closed or completelly open. The gate opening was represented as an orifice with a 0.3 m diameter opening, the passive control valves located on the upper part of the gate would limit the head over the weir to an acceptable level, and the weir height would allow the rest of the flow to pass freelly.

The CENTAUR system controls the flow in different stages. 1) A 0.05 m^3/s flow would pass freely through the gate without any control; 2) flows between 0.05 m^3/s and 0.15 m^3/s would be controlled by the algorithm; 3) above 0.15 m^3/s flow will start filing the storage volume up to the crest of the weir until a depth of 0.45 m above the crest is reached; 4) after that the passive valves will open to provide extra flow to pass through the gate.

The representation of the gate can be seen in Figure 18 and Figure 19. When the gate is closed or blocked for something the flow crossed the gate only by the valves and above the weir, and when the gate is open the flow can also pass trough the orifice.

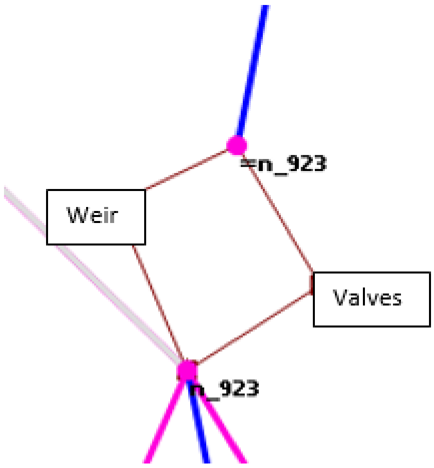


Figure 18 Closed gate

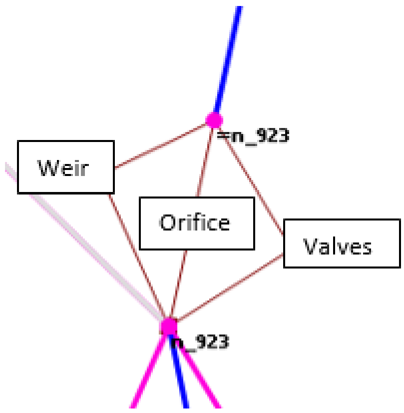


Figure 19 Open gate

A series of simulations were performed in order to verify the flow dynamics of the system using the provided gate design given by Steinhardt. The summary of the simulations are shown in Table 6, in the table it is possible to see the flow that can pass through each structure, the controlled opening is represented by the orifice, the passive control valves by a given rating curve and the flow over the weir also was input as a given rating curve.

				MAX FLOW (M^3/S)						
RAINFALL RETURN PERIOD	**WEIR (M)**	**VALVE (M)**	**ORIFICE**	**WEIR**	**VALVE**	**ORIFICE**	**TOTAL**	**FLOOD**	**WATER DEPTH IN THE GATE (M)**	**FREE SPACE AT CRITICAL NODE (M) N_570**
100 years	1.8	1.22	open/free	0.033	0.398	0.311	0.742	No	1.88	
100 years	1.8	1.22	closed	0.287	0.473	0.000	0.760	Limit	2.15	0.22

Table 6 Simulation results using the gate provided by Steinhardt

7. Next Steps

The final design of gate was confirmed by Steinhardt in October 2016 and the manufacture of the gate started. Aguas de Coimbra checked with the electricity provider on the viability of the necessary power at the gate locations and in October 2016. After the viability was confirmed, a budget for its provision was agreed and paid for in December 2016. During this period the minor civil engineering works to the manhole, including manhole cover replacement were organised by Steinhardt and completed in December 2016. Aguas de Coimbra supervised and received permission from the city council for the installation of the kiosk. This was concluded in December 2016 and the gate with all the components was in place at the start of February 2017.

In January 2017, EDP scheduled the connection works and informed Aguas de Coimbra that they needed a new authorization from the city council. After the new authorization was approved by the city council, the electrical connection was installed in July 2017. The certification was done by Certiel (end of July 2017) and then the contract with the Electrical supplier was completed (between Endesa and Aguas de Coimbra) and the electrical meter was installed (August 2017). During this period CENTAUR local monitoring and communication system (LMCS) has been installed and tested by EMS.

8. Conclusions

The hydraulic model created for the Coimbra case study, as Deliverable 2.2 represented well the observed data in the Zona Central catchment sewers. The calibration process for this model was divided in two stages. First the model was calibrated considering the whole central zone of Coimbra (Deliverable 2.2), this model was used to identify the smaller part of the catchment where the CENTAUR gate should be located. Once this area was identified the calibration was improved by moving the flow monitors to focus on the gate location. Based on the characteristics of the available locations and available storage volume, Av. Júlio Henriques was chosen as the location to receive the first installation of the CENTAUR gate.

The re-calibrated network model was then used to simulate the effect that different configurations of the CENTAUR system could have on water levels upstream of the gate. These results were used by Steinhardt to develop a suitable design for the CENTAUR gate. The designed system is able to control the flow caused by return period rainfall event up to 100 years. The gate opening is controlled by a self-learning algorithm and its rules can control the passage of the water through the gate from 0.05 m^3/s up to 0.15 m^3/s. In addition to that, the flow will be able to spill over the weir crest and also pass through two passive valves that will only work after a certain water depth over the weir crest is reached. The provided design was tested in the hydraulic model and its safe performance validated and so it was shown to be safe to be installed at the site. The simulations have shown that the dimensions and rules of the designed gate are able to control the flow in the system in events up to 100 years period return rainfall. It also shows that in case of obstruction of the gate opening the water level upstream will be able to remain in a safe level with low risk of flooding upstream.

Once the design was shown to be safe, Steinhardt started the manufacture of the gate in preparation for the installation of the CENTAUR system at the Av. Júlio Henriques site.

9. References

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