Simulation of hydraulic performance of urban drainage infrastructures. Study case of Almirante Reis drainage basin, in Lisbon.

Marco António Ferreira Pereira*

*IST – UL (University of Lisbon), Lisbon, Portugal. Corresponding author, e-mail marco.pereira@tecnico.ulisboa.pt

Abstract:

In recent decades there has been a large growth of cities, both in terms of buildings and the population. However, urban drainage systems are often undersized or in poor condition due to age or lack of maintenance. Additionally, the increase of the population leads to increase of the impervious areas in the urban centres, reducing the infiltration of the rainwater into the soil, forcing that the drainage of this water is made by surface runoff, resulting, many times, in floods.

This master thesis aims to resort to mathematical modelling to evaluate the hydraulic performance of urban drainage systems in scenarios with aggravated of impermeabilization with consequence on storm flows conditions, in a basin of Lisbon, the L basin, or the basin of Almirante Reis Avenue.

The aim is generally to assess the problems resulting from the drainage basin and to propose measures to help their integration, assessing its effectiveness, with special focus on implementing solutions that promoted the reservation and / or infiltration of flows rain, dampening the flow.

Thus, using the SWMM model were made three types of scenarios, each of which based on a different approach to the source control of storm water runoff, using the creation of storage units, the implementation of green roofs, and the creation of a solution combined the previous two scenarios.

Keywords: urban basin, mathematical modulation, flooding, surface runoff, origin controller solution.

Introduction

Over time, the urban drainage has become increasingly important in the development of societies. In the last two centuries has been observing an increase in the population of urban centre, which together with the lack of land use planning, created strong pressure on these areas, resulting in increased construction and consequently of impermeable areas, reducing infiltration areas, which resulted in an overload of the drainage system.

This occurred in the city of Lisbon, so that the objectives of this dissertation to go through resort to mathematical models in order to test and evaluate some solutions that can be implemented in the system settings. For this, a city's drainage basin was chosen, the L basin or Almirante Reis avenue basin, who has a habit of be subject to floods in the area of the squares of Martim Moniz and Figueira, to model and test solutions based on water storage and the infiltration of rainwater, with the help of SWMM model.

Urban drainage in Portugal. Challenges and perspectives

In Portugal, in the late fifteenth century, there are the first records of street cleaning actions and plumbing of Lisbon, which were intended primarily to collect rainwater. However, from the mid-eighteenth century, due to the 1755 earthquake, with the reconstruction of the city, it is the construction of a careful and structured drainage system. Over the years, with the lack of improvements in the drainage network, there was a degradation of this resulting in a cholera outbreak in the mid-nineteenth century in Lisbon (Matos, 2003).

It is in the early twentieth century, in the United Kingdom, which is disclosed the principle of separative network, and in 1930 the city of Porto became the first in Portugal to apply this type of system. In the following decades, it was the turn of other areas of Portugal in particular Barreiro, Estoril, Cascais, Beja, Setubal, Viseu, Tomar and Elvas, improve their drainage systems or build one. In places like Almada, Feijó, Costa da Caparica and Espinho, it is built entirely separative system from scratch. In Lisbon, remained the unitary system from Campolide areas to downtown and from Santa Apolonia to Ajuda and separative system in Algés Zone, Belém, Olivais and Benfica (Matos, 2003).

In the late twentieth century, came into force the 1994-1999 Regional Development Plan with the aim of bringing Portugal close to European average in sanitation issues, carrying out the construction of various infrastructures throughout the country in order to raise the percentage the population served, and also have been published on August 23, 1995 the Regulatory Decree 23/95 which aimed to approve a regulation for the sanitation systems that guarantee good operating condition, security and public health of drainage systems (Soares and Antão, 2008).

In 2000, is the approval of PEAASAR I (Strategic Plan for Water Supply and Waste Water Sanitation 2000-2006), and the publication of the Water Framework Directive (Directive 2000/60/EC of the European Parliament and of the Council, 23 October 2000). This policy brought together a wide range of measures and strategies in order to regularize the decisions and patterns of action in order to protect the water sector, and was applied to all Member States of the European Union, in order to ensure good ecological quality of European water bodies by 2015. Relatively to PEAASAR I, this intends to intervene in environmental improvement, creating integrated solutions and ensure high quality and sustainability of the service. One of the goals of this plan was to ensure that 95% of the population had drinking water at home and 90% of the population with sanitation of urban wastewater.

In 2007 it is published the Lisbon Drainage Master Plan in order to assess system performance in order to identify and characterize their drainage system and their main weaknesses. This plan had as goals consider alternative solutions to solving the detected problems and create a plan for the management of the Lisbon drainage network (CHIRON, ENGIDRO and HYDRA, 2007). This year was also prepared PEAASAR II (Strategic Plan for Water Supply and Sanitation Wastewater 2007-2013), who came to continue the PEAASAR I, being one of the concerns the clarification of a fair price for water in order to ensure a conscious use of water resources and the environment, as well as ensure the quality and continuity of the system (MAOTDR, 2007).

The Regulatory Authority for Water and Waste Services (ERSAR), was created in this period and had as main objective the regulation and organization of the sectors of water and waste for sustainability, both social and environmental, in these sectors (MAOTDR, 2007).

In 2011, it was reached the level of water supply 95% of its population. However, for wastewater services, collecting such reached 81% and 78% the treatment, being further away from the objective to be 90% of the population served by the wastewater drainage system.

In 2015, it is approved the new Drainage Master Plan of Lisbon, with the main objectives, control at the source, strengthening and rehabilitation of collectors, disconnection of links between collectors of the primary and secondary network, separation and control flow rates, creating storage reservoirs and tunnels to divert the flow of low-lying areas (Assembleia Municipal de Lisboa, 2015)

The PENSAAR 2020, presented in 2014, is divided into four distinct phases, the first which analyses the current situation and made a balance PEAASAR II; the second, which takes place more emphasis on the strategic framework with a strong focus on the goals, objectives and scenarios; the third, with an action plan of measures, existing investments and resources, and the fourth phase, which includes a management plan, monitoring, updating, and evaluation of performance.

Currently, the challenges facing the country pass through the resilience and safety of water and sanitation services, support for green growth, and the provision of quality service professionalized and social sustainable, economically and financially.

Simulation models in urban drainage

In the 70s, appeared the computer modelling. This new instrument was integrated into the planning, design and analysis of systems, facilitating the study and analysis of the flow in collector networks in variable regime and do sensitivity analysis to systems. Thus, various models have been developed to simulate different types of systems, not only WWTP drainage or network, but also transport of sediment and the behaviour of the discharge and the effect of these on the quality of the receiver (Ferreira, 2006).

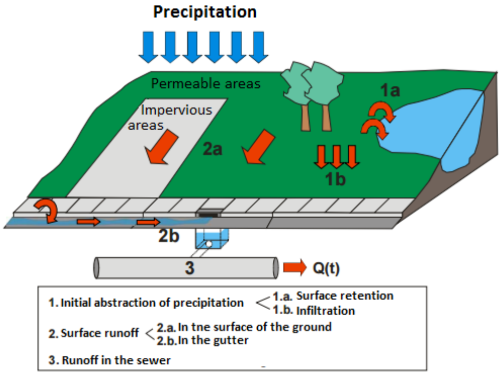

Figure 1 - Processes an existing drainage system (adapted Meller, 2004).

In the case of simulation of wastewater and storm water system is necessary to meet the functional requirements of the system, the hydraulic characteristics of the flow, and the hydrology of urban areas where the system is, the methods used to collect variables of interest as well as to its accuracy, assumptions and specific conditions for the model in question, and possible solutions that can be applied.

The models may be statistical or dynamical relation to time, aggregated or distributed in terms of space linear or non-linear with respect to equations deterministic or probabilistic in the field of variability of variables or processes, and can even be discrete or continuous (APESB, 2015) .There are also models of black box model, grey box model and glass box / white box model, which vary from each other in the growing complexity of the equations that using (Ferreira, 2006).

To model an urban drainage system, it is important to consider two models, the propagation model of runoff and the flow model in collectors (Meller, 2004).

The propagation model of surface runoff, it is important to consider the events occurring in the basin, such as infiltration in the ground storage in depressions, evaporation and evapotranspiration. Thus, the effective precipitation is estimated from the actual rainfall is attenuated by these phenomena.

The surface runoff in a basin spreads according to one of four models, the unitary hydrogram, the linear reservoir, kinematic and the curve time / area.

The flow propagation model for collectors describes the spread of the flow in the collectors, which is based on the continuity equation and the equation of conservation of quantity of movement.

As the surface runoff model has four types of models in the manner of propagation in the basin, also the flow network model collectors has four types of preferred designs according to which it can model the diffusion model, the reservoir , the kinematic and dynamic complete (Ferreira, 2006; Rossman, 2010).

Of these, the most relevant for this work is the full dynamic model since this model takes into account all the basic effects of hydrodynamics, as the effect of propagation of dynamic wave downstream and upstream, the effect of damping, delay and deformation variations in the flow rate and flow time through the collectors, and the effects of backwater (Ferreira, 2006). It is also for this reason that this model provides the most accurate results. So in this model are taken into account storage phenomena and pressure drops in and out of conduits, and allows the simultaneous calculation of the amounts of water levels at the nodes and flow in conduits, and you can apply it to any urban drainage network, including meshed networks (Rossman, 2010, Ferreira, et.al., 2011).

The Storm Water Management Model - SWMM is a dynamic model that simulates the quantity and quality of runoff, especially in urban areas, created in 1971 by EPA, United States Environmental Protection Agency. This model simulates the flow either to the surface or the network of collectors. For these reasons, it is often used as a tool in drainage system projects rainwater and wastewater drainage systems, and these systems unit, separative or mixed. It is also worth to note that this program has undergone several updates, the latest being the SWMM version 5.1.007 (Rossman, 2010).

The SWMM model allows us to analyse a drainage system through an interaction between four representative modules of the environment, atmospheric module, the soil surface, groundwater and transport (Rosman, 2010).

The SWMM allows verifying the evolution of the flow within the network, and the height of each conduit in a given simulation period, which may be a single event or precipitation comprises a long-term continuous simulation. The modelling results can be presented in various formats, and the charts, time series tables and profile diagrams, the most common (Rosman, 2010).

The SWMM model, uses several mock objects to simulate the wastewater drainage system and represented on the map of the study area, which are represented by rain gages, responsible for providing rainfall data entering the system, and subcatchments (urban basins), and on the propagation of flow in the system through the transport elements, we have objects as conduits (collectors), the junctions (manholes), the dividers, the outfalls, the outlets, the storage units and pumps.

Description of the study case

The case study is about one of the basins of Lisbon, L basin of Almirante Reis Avenue. The city of Lisbon is composed of 24 parishes, an area of 83.84 km² and a population of 547 733 (2011), and has remained relatively stable in recent years, with 564 657 inhabitants in 2001 (CML, 2015b).

In the area of Terreiro do Paço, flow, in times, into the Tagus river two streams, the stream of Arroios and the stream of Valverde or St. António, corresponding respectively to the valleys of the avenues Almirante Reis and Liberdade, which are no longer possible to observe since they are piped under the streets. These two areas are two of the basins are included in the set of sub-basins that drain the wastewater to the treatment plant of Alcântara, with the city divided in two zones, high and low, and several sub-basins (Figure 2).

It should also be noted that, due to the amount of impervious areas, the city's relief and the occurrence of heavy precipitation, coinciding with the period of high tide, the risk of flooding in the city is high, especially in the downtown area. It should be noted that floods occur especially in the fall period, due to lack of regular cleaning of collectors, ditches or drains. This factor to be attached to that tide levels have an influence not only on the effect of flooding, but also on the flow as they may prevent it from being discharged into the estuary, or even reverse its direction.

The basin under study was divided into smaller sub-basins, each relating to each section of collectors. The conduits introduced into the model correspond to those in the register had a diameter equal or higher than 800 mm, resulting in a network of collectors with a total length of 47 879.6 m.

L Basin intersects the area of five parishes Lisbon, the parish of Areeiro, Arroios, Penha de França, St.ª Maria Maior and S. Vincente de Fora, which was calculated the area of each parish in the basin and fixed and floating population of the basin .

The fixed population of L Basin makes a total of 45 304 inhabitants (about 8.5% of the city population), which joins the floating population, which according to the 2011 census, is 17 636 people, resulting in a population total in the L basin of 62 940 people.

It was attributed to a catchment population of 175 l/hab.dia, according INSAAR data from 2010 and a surging factor to the 0.9 system. With these data, we calculated the average daily flow for sub-basin, based on domestic flow and infiltration flow and applied to a time series of hourly system requests.

Figure 2 - Basins belonging to the System of Alcântara (adapted from PGDL, 2008).

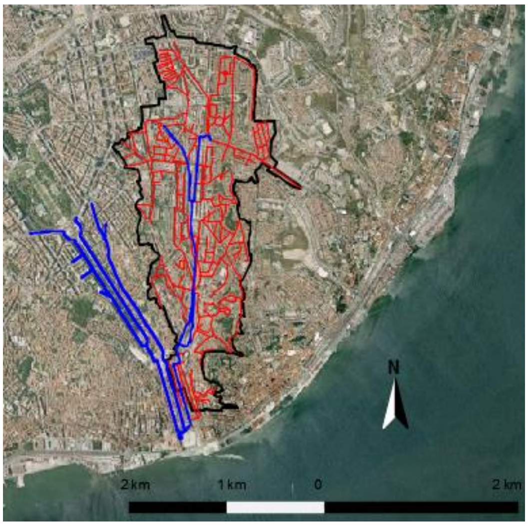

Figure 3 - Collectors with more than 800 mm od diameter (adapted from Google Earth, 2015).

Model application, presentation and discussion of the results

Given that flooding is a problem in the city of Lisbon, the aim of this work involves resort to SWMM model to study the hydraulic behaviour of the basin and test solutions to this problem. The infiltration in the model basins is given in the form of Horton having a maximum and minimum rate of 75 mm/h 0.25 mm/hr, with a decay constant of 7 h^{-1} and the time required for the soil to dry completely saturated, it takes 7 days.

Regarding the collectors, its roughness varies depending on the material of the conduits, and concrete or PVC materials are listed in the register, although this information is given only for some sections. Thus, it gave a value of 0012 for PVC and 0.013 for concrete. The value of 0.013 was adopted for all conduits without information on the material used, the amount Rossio, and 0.02 to downstream, since from this point there sediments which settle in the system, from the estuary, leading to have a coefficient Mannig higher. These values were estimated based on studies conducted by Lancaster A. (1996), to upstream collectors, and downstream based on criteria proposed by Ashley (2004), which relates to deposition of sediments with the flow behaviour in the collectors (Salgado, 2013).

Have been introduced, in system, two time series, "Flodar _Tempo_Seco" for hourly requests of the population, and a series of tidal height for inserting in the outfalls. For the series of precipitation introduced to the wet time, was used a hyetograph, with a return time of 10 years, specifically developed for performing modelling studies. Is to mention that these series have been adapted to the peaks coincide in the same time period in order to create the worst case scenario.

Two collectors were chosen to analyse the flow rate, the water level and the flow rate of the flow full section, one in the middle of the basin, on Francisco Ribeiro Street, the T65, and the other at the end of the basin, in the Prata Street, the T119.

To observe how the system behaves in dry weather, a simulation was made where we got a peak flow of 0.214 m^3/s in conduit T119, wherein the heights of the flow do not exceed 5% of the diameter of either of the conduits, which also occurs with the full flow section not exceeding 4%, since the flow is only contributory of domestic origin.

In the wet weather simulation, it is to repair the higher flow rates occur in the period of 6 hours and 30 minutes to 12 hours. In this simulation we observe a peak flow of 22.74 m^3/s in the conduit T119, and 14.45 m^3/s in conduit T65. It should be noted that domestic flow has no great impact on the flow behaviour, in the system, when it joins this the flow from the precipitation. Another point to note is the fact that the conduit T119, since it is the final L basin conduit, the flow reaches the height of this, since here all arrive flow produced in the basin. Already the full flow section at the end collector is 1, this is, the conduit enters into charge, such as with some collectors upstream thereof. As shown in the profile of the final section of the conduits between nodes LN140b the LN170.

As you can see in the Figure 4, in some nodes the height of water reached the surface, which means that leakage may occur and thus floods in these points.

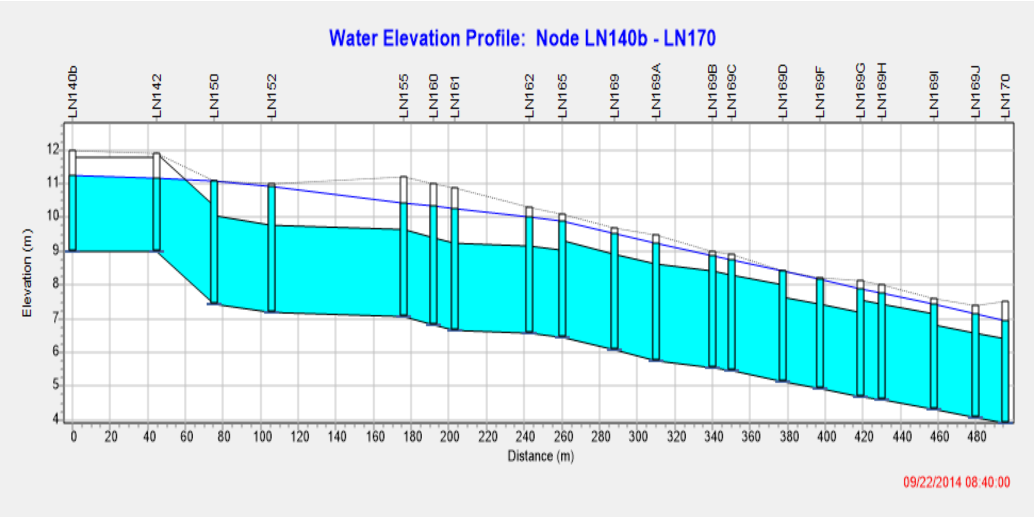

Figure 4 - Profile flow between nodes LN140b and LN170, in wet weather.

To resolve this problem have been put into hypothesis three possible solutions, one of them involving three scenarios of reserve to produce a damping in flow, other using green roofs to increase the permeable area in the basin, increasing infiltration and reducing runoff that reaches the system, and a third solution, which combines the best of the reserve scenarios, with green roofs.

In the first reserve scenario, it is considered that the first two levels of the car park of Martim Moniz Square are intended to reserve of rainwater, having this a capacity of 40 250 m^3 and having a valve in the conduit downstream of the reservoir with a discharge coefficient of 0.4, to control the discharge flow.

For values of Q/QSC, these indicate that T119 collector doesn't enter into overload as is possible to see the profile between the nodes LN140b and LN170 (Figure 5**Erro! A origem da referência não foi encontrada.**). In the Table 1 is possible see the peak flow of this scenario and the damping of this measure in the basin.

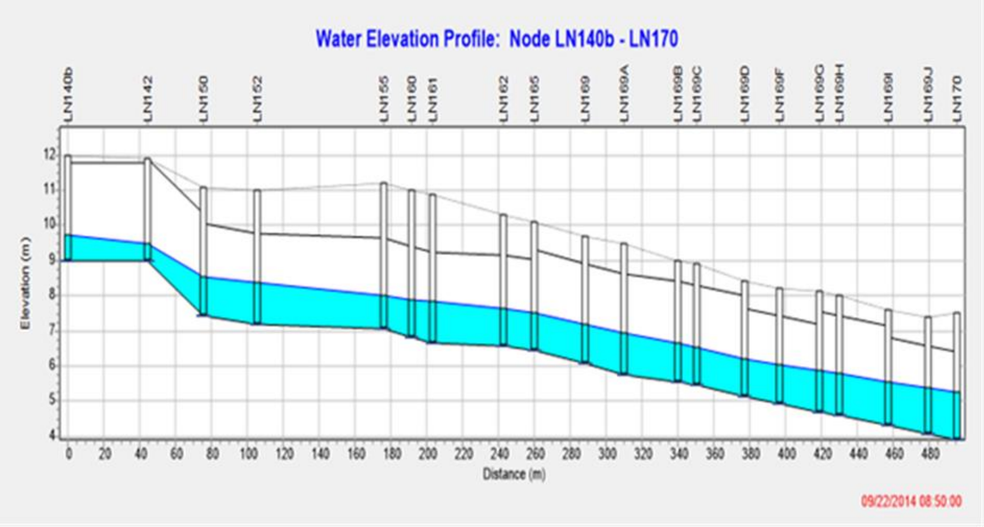

Figure 5 - Profile flow between nodes LN140b and LN170, in scenario 1.

For the reservoir, it is noted that this produces a 90% damping at peak flow rates of the tributaries to this, as shown in Figure 6.

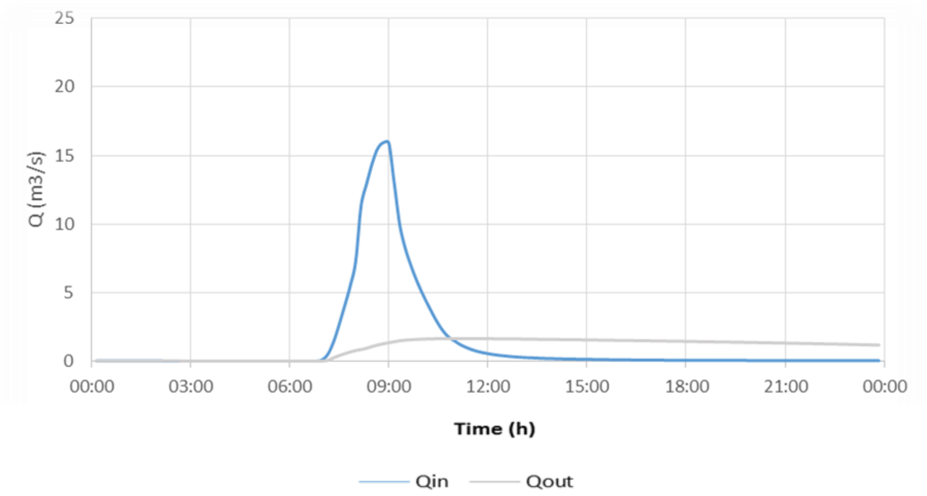

Figure 6 - Flow affluent and effluents to the reservoir of Martim Moniz Square, scenario 1.

In scenario 2, joins a reservoir of 5 415 m^3 to scenario 1, in the zone of the Intendant square, which produces a damping in the influent flow rate of 35%, with little influence in the basin, hence the damping that this scenario produces as well as the flow in the final stretch is the same as the previous scenario, given that the new reservoir has little influence on the system, results in identical values to scenario 1 (Table 1).

In scenario 3, a new reservoir is added in the basin, in the zone of Chile square with capacity of 2 920 m^3 and produce a damping of 35% in affluent flow, it being possible to observe, in Table 1, the flow at the end section of the basin and damping that this scenario produces.

In the scenario of green roofs, the option is to change the impervious area through the implementation of green roofs in 20% of the buildings in the basin.

In this scenario, although there are no fully flooded manhole, the end collectors are overloaded, and the damping that this measure has is only 5% in the basin (Table 1).

Finally, we combined the simulation scenario with reservation that showed better results, scenario 3, with the hypothesis of green roofs.

In this simulation, there is a damping in basin, relatively to wet weather simulation, of 38%, like in the scenario 1 (Table 1). In Figure 7 and Figure 8 is possible see the profile of the flow in two different, and better, scenarios.

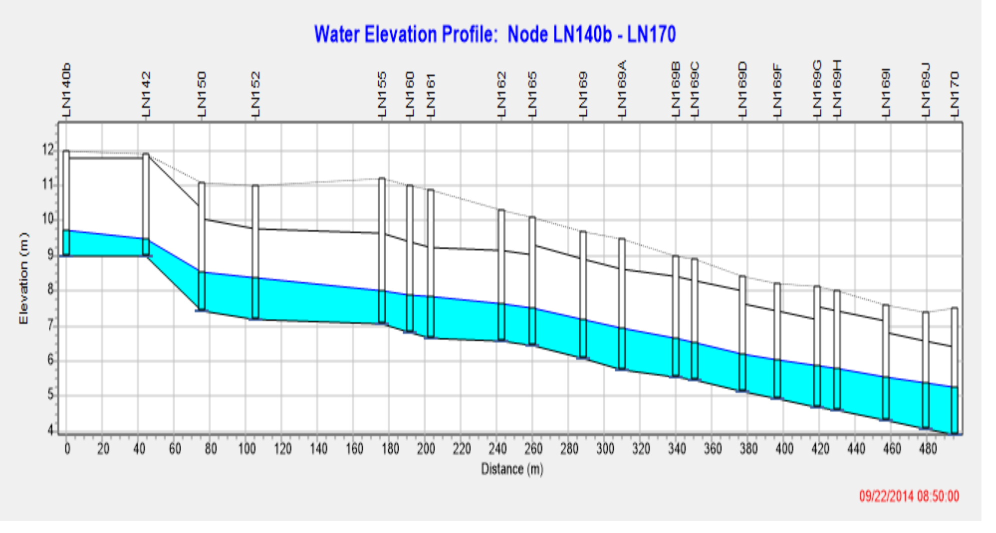

Figure 7 - Profile of flow between nodes LN140b and LN170, in the scenario 1.

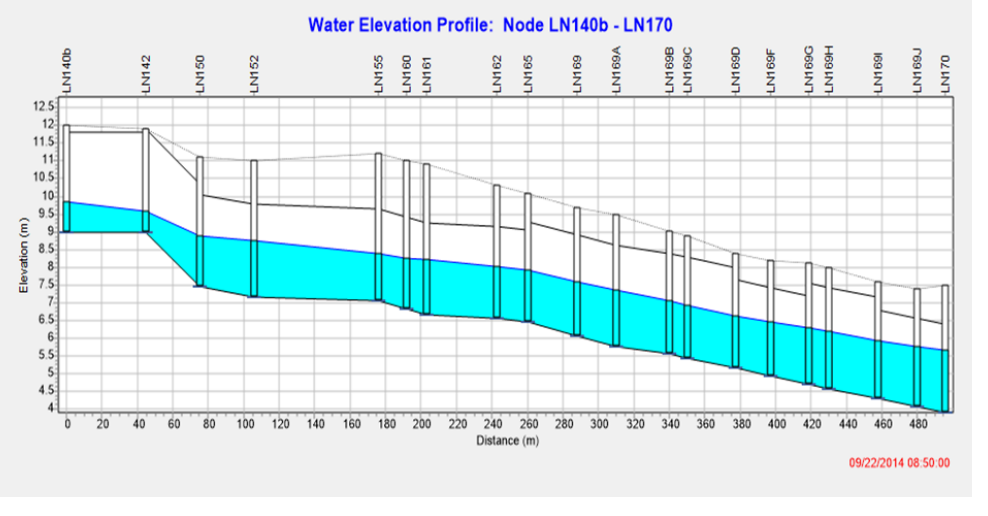

Figure 8 - Profile of flow between nodes LN140b and LN170, in the combined solution.

It should be noted that in this combined scenario, the damping that each reservoir has in affluent flow, is 97% in the reservoir of the Chile Square, 82% in the Intendente Square, as in all previous scenarios, and 84% in the reservoir of the Martin Moniz Square.

In the table (Table 1) below are the flow rates and damping of the various scenarios.

Table 1 - Flows and damping of different simulation scenarios.

	Peak Flow in final conduit (m³/s)	Damping in the basin
Dry weather	0.214	-
Wet weather	22.74	-
Scenario 1 – 1 Reservoir	15.73	31%
Scenario 2 – 2 Reservoirs	17.04	35%
Scenario 3 – 3 Reservoirs	16.84	35%
Scenario 4 – Green Roofs	21.72	5%
Scenario 5 – Combined	13.99	38%

Conclusion

It was concluded that the different simulated scenarios, the scenario of combined simulation presents better results, revealing a 38% damping in the effluent flow of the basin, due to increased reserves in the basin. In this solution, the final section of conduits of the system is no longer overloaded, reducing the risk of flooding, in the final area of the L basin. However, the Martim Moniz reservoir is the one with the greatest flow damping capacity, resulting in a better scenario, the scenario 1, because this has a minor amount of investment relativity to the combined scenario.

The scenario 1 is the best reservoir scenario, producing a dumping of 31% in basin. In another hand, the scenario of green roofs doesn’t present advantage in reducing the flow at the end of the basin, can be used as an aid to other measure, more efficient, like reserve.

Despite this work be at academic level, can conclude that the combined scenario is one of the best prevents the occurrence of floods, it is important to note that both the installation of reservoirs as the implementation of green roofs are expensive measures and require proper maintenance and management, instead of scenario 1 that has only a storage unit, that it is a better and economic measure in the basin. In the future, should be studied other scenarios that contemplate the use of other measures such as the diversion of flows or the change and improvement of conduct and completion of registration, since this is incomplete in some areas.

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