doi: https://doi.org/10.4995/WDSA-CCWI2022.2022.14186

AN APPROACH TO IMPROVE DRAINAGE NETWORKS BASED ON THE STUDY OF FLOOD RISK

Leonardo Bayas-Jiménez[1], F. Javier Martínez-Solano[2], Pedro L. Iglesias-Rey[3] and Fulvio Boano[4]

[1,2,3] Department of Hydraulic Engineering and Environment, Universitat Politècnica de València, Valencia, Valencia, (Spain)
[1,4] Department of Hydraulics and Civil Infrastructures, Politecnico di Torino, Turin, Piedmont, (Italy)

[1] *leobaji@posgrado.upv.es*, [2] *jmsolano@upv.es*, [3] *piglesia@upv.es*, [4] *fulvio.boano@polito.it*

Abstract

In recent years, the number of pluvial floods in cities has increased. There are different reasons for this increase, but certainly the most important are the increase in the intensity of the rain and the growth of cities, which increases the impervious surface, decreases the concentration time, and consequently increases runoff. To determine the costs of flood damage, land use is very important in the estimation of the cost of flood damage because it defines the type, value, and vulnerability of the structures. On this wise, an approach of great interest to managers of drainage networks is the estimation of annual damages in the area under study, because by knowing these costs, corrective measures can be taken, and the investment needed to reduce flooding can be determined. This work aims to present a methodology to improve drainage networks with lack of capacity due to increased runoff with a focus on the study of the vulnerability to the risk of flooding. To improve the operation of the networks, the method considers the possibility of changing the existing pipes for others with greater capacity, the construction of storm tanks and the implementation of hydraulic controls. To find the best solutions, an optimization model was developed that uses a Pseudo Genetic Algorithm and the SWMM model to perform hydraulic simulations. To reduce calculation times, a search space reduction procedure is applied to identify the regions containing the best solutions. These actions are intended to improve the efficiency of the model. For the economic assessment of flood risks, the cost of flood damage is related to its probability of occurrence for different return periods. With these data, a curve with a log-linear relationship is constructed. The cost of the flood risk is obtained by integrating the area under the curve obtained. The methodology is applied in a drainage network with flooding problems called Balloon, located in located in northern Italy. The results are useful to demonstrate the benefit of risk cost analysis to make decisions and underline the relevance of including optimization models to prevent future damage in cities.

Keywords
Flood, Risk, Water, Drainage Networks, Optimization, Genetic Algorithms.

1 INTRODUCTION

Urban flooding is a phenomenon of growing importance, with the potential to affect the future of many cities around the world. There are two widely agreed reasons for the increase in the frequency of floods and the magnitude of flood damage. The first is urbanization that increases impervious surface and is often poorly planned, especially in developing countries. The second reason is climate change, which causes an increase in the frequency and intensity of precipitation events. Consequently, the risk of flooding has increased in recent years and is expected to worsen in subsequent years [1]. Urban floods occur as a result of the insufficiency of the urban drainage system to transport the runoff flows that are generated during episodes of high intensity rain. These floods can cause serious damage to people, infrastructure, and property, in addition to disrupting traffic and economic activity.

To face this problem, a frequently used tool is the optimization of drainage networks considering these new scenarios. Mathematical optimization is part of applied mathematics aimed at finding the best solutions to mathematically defined problems. The basic optimization problem consists of an objective function that will be minimized or maximized [2]. In this way, it can be mentioned the work carried out by Iglesias-Rey et al. [3] who used a Pseudo Genetic Algorithm (PGA) developed by Mora-Melia et al. [4] for the optimization of a drainage network considering the replacement of pipes, the installation of storm tanks, and the initial state of pumping units. In this work, the authors conclude that the combined use of pipe replacement and storm tank installation provides better results than the application of these actions separately. The importance of the different cost functions considered in the final optimization result was also highlighted. Continuing this line of research Ngamalieu-Nengoue et al. [5] confirm that the combined use of pipe replacement and storm tank installation provides the best results. In this work the authors warn that the increase in the number of Decision Variables (DVs) used when employing both measures together cause a significant increase in the size of the Search Space (SS). This problem in optimization with heuristic methods has been detailed by different authors [6], [7]. Mayer et al. [6] mention that this problem is called "curse of dimensionality" and not only does it make it more difficult to explore the SS, but there is also the risk that the algorithm fails to find the global solution. As a solution to this problem, Ngamalieu-Nengoue et al. [8] proposed a Search Space Reduction (SSR) method essentially based on two principles, the reduction of the resolution of the discretization of the DVs and the reduction of the number of DVs involved in the problem. In this work it was also evidenced that in the optimization process some solutions presented the reduction of pipes, with this reduction the water flow was slowed down. Based on this work Bayas-Jiménez et al. [9] consider the installation of hydraulic controls in conjunction with the installation of storm tanks and pipe replacement, conclude that the use of hydraulic controls reduces the volume of flooding, reducing the costs associated with the implementation of protection structures. In addition, the authors in their methodology implemented a convergence criterion to guarantee obtaining good solutions with a certain probability of success, adding robustness to the methodology. However, the use of this convergence criterion implies a significant increase in calculation times. To improve the performance of this optimization methodology Bayas-Jiménez et al. [10] propose a SSR method focused on the iterative reduction of DVs through three actions, the analysis of the topology of the network, the study of the discretization of the DVs and the application of a selection criterion of DVs. The authors point out that this methodology gives good results for the rain studied. However, it does not consider the effects of other rains that may occur within the design period. Although it is true that the most unfavorable situation is analyzed, rains may occur with less intensity and higher probability of occurrence that can cause flooding problems, as observed in their works by Freni, La Loggia and Notaro [11] and Olsen, et al. [12]. The main objective of this work is to study the impacts of these precipitations and identify the actions to be implemented to adapt the drainage networks to these conditions through the economic analysis of the risk of flooding.

2 THE RISK

The risk can be expressed as the product of the probability of danger and the consequences that are generated. The magnitude of the consequences will depend on the exposure and vulnerability of the affected area [13]. Flood risk management has become a central part of flood control policies throughout Europe [14]. This risk management approach is also increasingly adopted in the planning of urban drainage networks, so it is no longer only the probability of a storm event that is considered, but also the impact of these events [15]. If it is considered that the probability of flooding is usually expressed in years^{-1} and that the consequences of flooding can be expressed in monetary units, the cost of the risk of flooding can be expressed in euros/year. This cost is obtained by measuring the area under the curve drawn for rainfall with several return periods. [16]. As shown in Figure 1. It is important to keep in mind that flood risk assessment is not an easy task because it is a probabilistic variable that depends on stochastic rainfall events. It is impossible to predict exactly what the consequences of flooding will be in a specific area and time. But estimates can be made that are close to the expected scenarios.

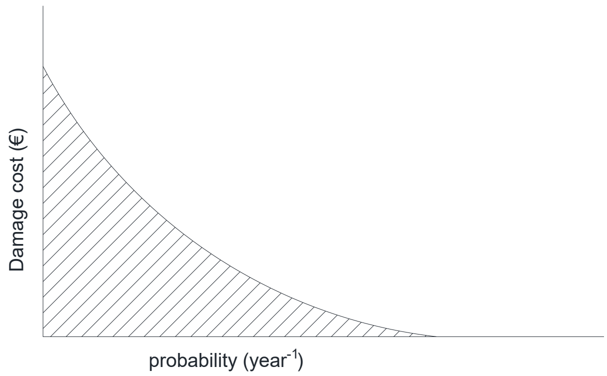

Figure 1. Annual cost of flood risk as the area under the curve.

3 OPTIMIZATION OF DRAINAGE NETWORKS

The optimization of the drainage networks is carried out considering the traditional method of substituting pipes for others with a larger diameter, the construction of storm tanks in the nodes that require it, and the installation of hydraulic control elements in the drainage network. In short, it is intended to rehabilitate drainage networks by finding the best solution to combine the installation of these infrastructures to reduce flooding. To find the best solutions, an optimization model is developed that uses the SWMM model and a Pseudo Genetic Algorithm connected by a toolkit. To compare the solutions found, an objective function is defined composed of the costs of these infrastructures and the cost implied by the risk of flooding. Thus, the model aims to minimize the objective function and find the best solutions to the analyzed problem. It is then necessary to define the DVs that the model must analyze. Specifically, there are three groups of DVs. The first group of decision variables are the diameters of the pipes in the network. The second group of DVs is the area of the storm tanks, the storm tank area is assumed as the DV because the depth of the existing manholes is set as the depth of the tank. The third group of DVs are the degrees of opening of the hydraulic control elements. When using a PGA as a search engine, it is understood that the values adopted by the DVs must be discretized. Pipe diameters are discrete while in the case of storm tanks and hydraulic controls, lists of options should be specified both for the areas of the tanks and for the degrees of opening of the hydraulic controls as proposed Bayas-Jiménez et al. [10].

Once the DVs and the values they can take have been defined, the SS that the model must explore to find the best solutions can be specified. The magnitude of the SS is calculated using equation (1).

$$S = n_i\ (\log NS) + m_i\ (\log ND) + p_i\ (\log N\theta) \tag{1}$$

In the equation S represents the magnitude of the SS, n_i the nodes analyzed of the network, m_i the pipes analyzed of the network, ND represents the range of commercial diameters adopted, NS the list of areas defined, p_i the pipes analyzed of the network with the possibility to install hydraulic controls and Nθ represents the opening options defined. It can be inferred that the SS is quite large and that it potentially increases as the number of elements analyzed increases. The time and computational effort that the exploration of the total space would require would be very important, for this reason it is necessary to implement a SSR process. In the space reduction process as a first step, a first mapping of the entire SS of the algorithm is performed, each DV is analyzed by the algorithm using a list of options with a coarse discretization. Using a thick option list allows one to quickly identify DVs that can be included in the most promising region of the algorithm's exploration space. After performing a certain number of evaluations, the fifth percentile (P_5) of these evaluations is analyzed, selecting the candidate DVs for the new search region through a selection criterion based on repeatability. The process is repeated in the new defined region, eliminating the DVs that do not meet the selection criteria. In each iteration of the process, the convergence of the results towards certain DVs that increase the repeatability in the sampling, defining each time the region with the best solutions. The process ends when all DVs meet the selection criteria and the SS cannot be reduced any further. Once the final search region is defined, the final optimization is performed on this new scenario. This new optimization uses the refined option list. In order to perform a much more detailed exploration of the SS to identify the global optimum of the problem.

4 ANALYSIS OF THE COST OF RISK

To analyze the cost of the risk of flooding, it begins with the definition of the cost functions of both the infrastructure to be installed and the cost of the risk of flooding. The first infrastructure investment cost function is the cost of pipe renovation, for the case under study a second-degree polynomial equation is determined as shown in equation (2).

$$C_p(D_i) = (179.71\, D_i{}^2 + 281.32\, D_i - 14.139)\, L_i \tag{2}$$

In the equation $C_p(D_i)$ represents the cost of renewing the pipe in euros, D_i is the diameter of the pipe and Li represents the length of the pipe.

The second infrastructure investment cost function is the cost of storm tanks. To define this function, the cost of building tanks of different sizes has been analyzed. With these data, a cost function composed of two terms is determined and is shown in equation (3)

$$C_T(V_i) = 21220 + 9483.43 V_i{}^{0.65} \tag{3}$$

Where C_T (V_i) represents the cost in euros of the construction of a storm tank. and V_i is the flood volume that the tank must store.

The third structure investment cost function that has been determined for this project is the cost of hydraulic control. To define this function, the cost of acquiring and installing valves of different diameters has been analyzed. This analysis determines a second-degree polynomial function that is shown in equation (4).

$$C_v(D_i) = -271.53\, D_i{}^2 + 4401.70\, D_i + 148.32 \tag{4}$$

Where C_v (D_i) Is the cost of the hydraulic control, Di is the diameter of the pipe where the hydraulic control would be installed.

On the other hand, to account for the reduction in the initial investment in infrastructure, an annual amortization factor Λ is required that affects each cost function. In this work, the expression shown by Steiner (2007) and shown in equation (5) is used.

$$\Lambda = \frac{i}{1 - (1+i)^{-n}} \tag{5}$$

In the equation i is the annual interest and n is the time in years in which it is proposed to recover the investment.

To obtain the annual cost of the flood risk, the cost of the flood damage must be calculated. One of the most used techniques to carry out the analysis of the damage of the flood is to use as a reference the depth or level of the flood. The analysis based on the flood level allows to reduce the flood and the cost of the flood depending on the flood zone. An expression that calculates the cost of flood damage as a function of flood depth and land use are the so-called damage-depth curves. In this sense, an expression that allows this calculation to be carried out is the one presented in equation (6).

$$C_y(y_i) = C_{max}\, A_i\, \left(1 - e^{-\lambda \frac{y_i}{y_{max}}}\right)^r \tag{6}$$

In equation, y_{max} is the maximum depth at which the flood reaches maximum damage. C_{max} is the maximum cost of flood damage obtained when y_{max} is reached A_i is the area of the analyzed sub catchment and y_i is the depth reached of the analyzed node. Once the cost of floods has been defined, in order to proceed to study the cost of the risk of flooding, the cost of the flood must be related to the return period of the analyzed scenario. For the different return periods, the respective calculations must be made to establish the corresponding cost of flooding. To obtain the curve, the cost obtained is related to the probability of exceedance of the event. In this sense, Olsen et al. (2015) [12] mention that these values can be represented as a linear-logarithmic relationship to extrapolate the cost of flood damage for intermediate return periods. Figure 2 shows this relationship, the area under the curve represents the annual cost of flood risk.

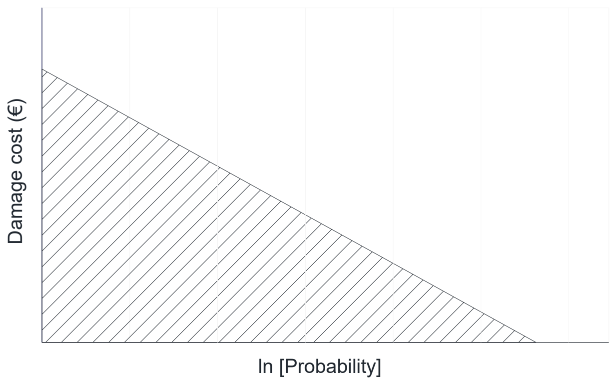

Figure 2. Annual cost of flood risk as the area under the curve in a log-linear relationship.

The curve can be expressed as shown in equation (7).

$$C_y = a \ln[p] + b \tag{7}$$

The limits of the integral are established as follows: a lower limit 0 that represents the probability of exceedance associated with an event with an infinite return period and an upper limit p_0 that represents the probability of exceedance for which the cost of flood damage. equation (8) shows the expression resulting from this integration and which is the equation used to calculate the cost of the annual risk of flooding.

$$C_F(p) = a\,(p_0 \ln[p_0] - p_0) + b\, p_0 \tag{8}$$

With these concepts defined, the Objective Function (Equation (9)) to be minimized by the model is obtained.

$$OF = \Lambda\,[C_p(D_i) + C_T(V_i) + C_v(D_i)\,] + C_F(p) \tag{9}$$

5 MODEL APPLICATION

The methodology is applied in the network called Balloon located in the north of Italy. The network is made up of 71 pipes and 70 nodes. 75 basins covering an area of 40.88 hectares are connected to the network. The network has a total length of 1848.60 meters. The elevation of the highest point is 229 meters above sea level and at the lowest point the elevation is 221 meters above sea level. These topographical characteristics make the area prone to flooding. The network works entirely in gravity. For its operation, the network has depths of up to 10 meters. Figure 3 shows the Balloon network and the sub catchments that make it up.

Figure 3. Balloon drainage network.

As for the area studied, it is characterized by being a large area with different land uses that are detailed in Table 1.

Table 1. Land uses of the studied area.

Land uses	Percentage
Streets and roads	28.97%
General trading	18.93%
Parks and playgrounds	10.10%
Education	7.87%
Restaurants	7.56%
Hotels	7.50%
Offices	6.71%
Car parks	3.47%

Churches	2.27%
Museums	1.75%
Health	1.70%
Warehouses	1.68%
Dwellings	1.51%

For the analysis of the risk in economic terms, the IDF curves are used for return periods of 2, 5, 10, 20, 50 and 100 years (Figure 4). With these curves storms of 1 hour duration with 5-minute intervals have been calculated. For the study of the risk of flooding, the 6 storms have been considered.

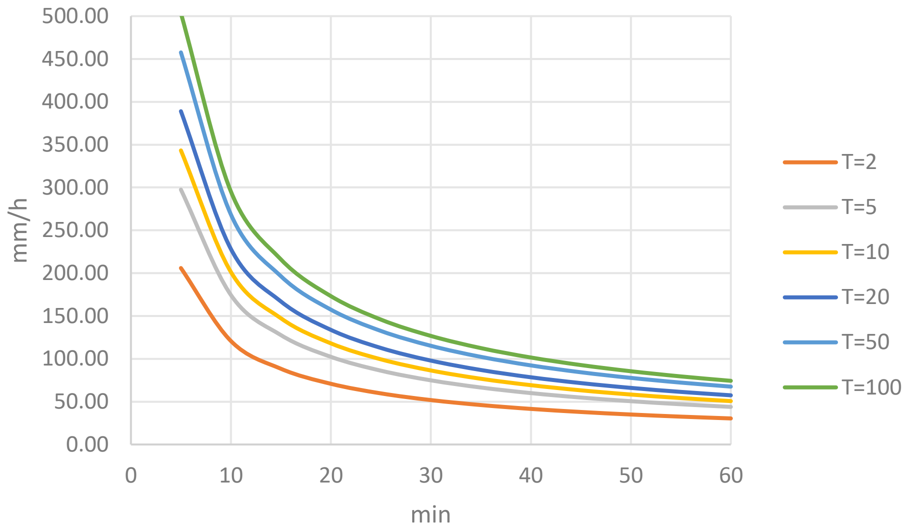

Figure 4. IDF curves for the study area.

In the analyzed scenario, the network in its current state generates economic losses related to flood damage of approximately €170,436.37 per year.

6 RESULTS

6.1 Application of the SSR method

The SSR method is applied in each secondary Branch of the network, three Branches that discharge the water in the main network were defined. Figure 5 shows the different branches that make up the Balloon network. When applying the method in each branch DVs that would not be part of the SS that contains the best solutions to the problem are eliminated. As a result, it is obtained that the elements of Branch L1 and Branch L3 are not part of the SS while only node N63 of Branch L2 is part of the final SS.

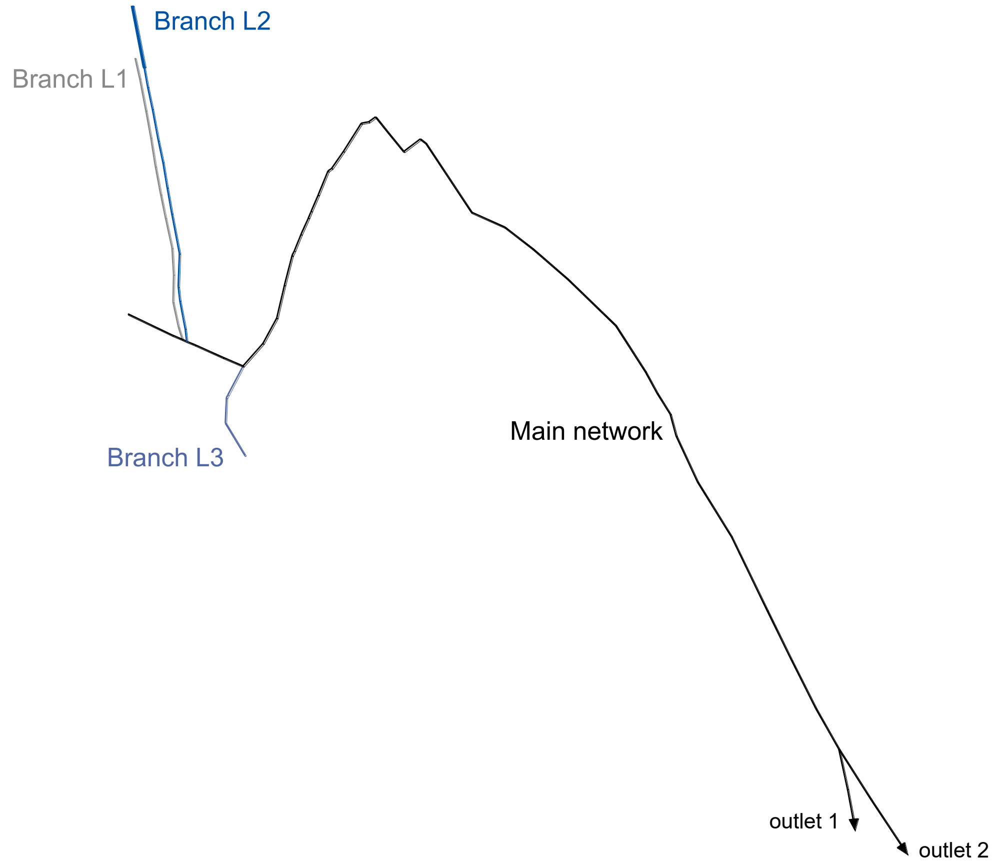

Figure 6. Branches of the Balloon network

Completed the reduction of the SS in each branch, the SSR method is applied in the total Balloon network, eliminating from the analysis the DVs discarded in the analysis of the branches. Applying the method in different iterations reduces the SS by limiting the search to the optimal region. The Table 2, Table 3 and Table 4 show the reduction in each interaction of the SSR method. Table 5 shows a summary of the SS reduction obtained by applying the SSR method compared to the total network without any previous reduction.

Table 2. Results of the first iteration

Pipes	~~C1~~	~~C2~~	~~C3~~	~~C4~~	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19
	C21	C22	C23	C24	C25	C26	C27	C28	C29	C30	C31	C32	C33	C34	C35	C36	C37	C38	C39
	C41	C42	C45	C46	~~C58~~	~~C59~~	~~C60~~	~~C61~~	~~C62~~	~~C63~~	~~C64~~	~~C65~~	~~C66~~	~~C67~~	~~C68~~	~~C69~~	~~C70~~	~~C71~~	~~C72~~
	~~C73~~	~~C74~~	~~C75~~	~~C76~~	~~C77~~	~~C78~~	~~C79~~	~~C80~~	C81	C82	C83	C84	C85	C86					
Nodes	~~N1~~	~~N2~~	~~N3~~	~~N4~~	N5	N6	N7	N8	N9	N10	N11	N12	N13	N14	N15	N16	N17	N18	N19
	N20	N21	N22	N23	N24	N25	N26	N27	N28	N29	N30	N31	N32	N33	N34	N35	N36	N37	N38
	N39	N41	N43	~~N45~~	~~N46~~	~~N47~~	~~N48~~	~~N49~~	~~N50~~	~~N51~~	~~N52~~	~~N53~~	~~N54~~	~~N55~~	~~N56~~	N57	~~N58~~	~~N59~~	~~N60~~
	~~N61~~	~~N62~~	N63	~~N64~~	~~N65~~	~~N66~~	~~N67~~	~~N68~~	N69	N70	N71	N72	N73						

Table 3. Results of the second iteration

Pipes	~~C1~~	~~C2~~	~~C3~~	~~C4~~	C5	~~C6~~	~~C7~~	~~C8~~	~~C9~~	~~C10~~	~~C11~~	~~C12~~	C13	~~C14~~	C15	~~C16~~	~~C17~~	C18	~~C19~~
	~~C21~~	C22	~~C23~~	~~C24~~	~~C25~~	~~C26~~	~~C27~~	~~C28~~	~~C29~~	~~C30~~	~~C31~~	~~C32~~	~~C33~~	~~C34~~	~~C35~~	~~C36~~	C37	C38	C39
	C41	C42	~~C45~~	~~C46~~	~~C58~~	~~C59~~	~~C60~~	~~C61~~	~~C62~~	~~C63~~	~~C64~~	~~C65~~	~~C66~~	~~C67~~	~~C68~~	~~C69~~	~~C70~~	~~C71~~	~~C72~~
	~~C73~~	~~C74~~	~~C75~~	~~C76~~	~~C77~~	~~C78~~	~~C79~~	~~C80~~	~~C81~~	~~C82~~	~~C83~~	C84	C85	C86					
Nodes	~~N1~~	~~N2~~	~~N3~~	~~N4~~	~~N5~~	~~N6~~	~~N7~~	N8	N9	~~N10~~	~~N11~~	N12	N13	~~N14~~	N15	N16	~~N17~~	~~N18~~	~~N19~~
	N20	~~N21~~	~~N22~~	~~N23~~	~~N24~~	~~N25~~	~~N26~~	~~N27~~	~~N28~~	~~N29~~	~~N30~~	~~N31~~	~~N32~~	~~N33~~	~~N34~~	~~N35~~	~~N36~~	~~N37~~	~~N38~~
	N39	~~N41~~	~~N43~~	~~N45~~	~~N46~~	~~N47~~	~~N48~~	~~N49~~	~~N50~~	~~N51~~	~~N52~~	~~N53~~	~~N54~~	~~N55~~	~~N56~~	~~N57~~	~~N58~~	~~N59~~	~~N60~~
	~~N61~~	~~N62~~	N63	~~N64~~	~~N65~~	~~N66~~	~~N67~~	~~N68~~	~~N69~~	~~N70~~	N71	~~N72~~	~~N73~~						

Table 4. Results of the third iteration

Pipes	~~C1~~	~~C2~~	~~C3~~	~~C4~~	C5	~~C6~~	~~C7~~	~~C8~~	~~C9~~	~~C10~~	~~C11~~	~~C12~~	~~C13~~	~~C14~~	C15	~~C16~~	~~C17~~	~~C18~~	~~C19~~
	~~C21~~	~~C22~~	~~C23~~	~~C24~~	~~C25~~	~~C26~~	~~C27~~	~~C28~~	~~C29~~	~~C30~~	~~C31~~	~~C32~~	~~C33~~	~~C34~~	~~C35~~	~~C36~~	~~C37~~	~~C38~~	~~C39~~
	~~C41~~	~~C42~~	~~C45~~	~~C46~~	~~C58~~	~~C59~~	~~C60~~	~~C61~~	~~C62~~	~~C63~~	~~C64~~	~~C65~~	~~C66~~	~~C67~~	~~C68~~	~~C69~~	~~C70~~	~~C71~~	~~C72~~
	~~C73~~	~~C74~~	~~C75~~	~~C76~~	~~C77~~	~~C78~~	~~C79~~	~~C80~~	~~C81~~	~~C82~~	~~C83~~	C84	C85	C86	-				
Nodes	~~N1~~	~~N2~~	~~N3~~	~~N4~~	~~N5~~	~~N6~~	~~N7~~	N8	~~N9~~	~~N10~~	~~N11~~	~~N12~~	~~N13~~	~~N14~~	N15	N16	~~N17~~	~~N18~~	~~N19~~
	~~N20~~	~~N21~~	~~N22~~	~~N23~~	~~N24~~	~~N25~~	~~N26~~	~~N27~~	~~N28~~	~~N29~~	~~N30~~	~~N31~~	~~N32~~	~~N33~~	~~N34~~	~~N35~~	~~N36~~	~~N37~~	~~N38~~
	~~N39~~	~~N41~~	~~N43~~	~~N45~~	~~N46~~	~~N47~~	~~N48~~	~~N49~~	~~N50~~	~~N51~~	~~N52~~	~~N53~~	~~N54~~	~~N55~~	~~N56~~	~~N57~~	~~N58~~	~~N59~~	~~N60~~
	~~N61~~	~~N62~~	N63	~~N64~~	~~N65~~	~~N66~~	~~N67~~	~~N68~~	~~N69~~	~~N70~~	~~N71~~	~~N72~~	~~N73~~	-					

Table 5. Magnitude of SS and number of DVs of the network without SSR and the final search space

Scenario	n_i	m_i	p_i	ND	NS	Nθ	DVs	S
Total network	70	71	71	40	5	10	212	233
Final SS	4	5	5	40	5	10	14	15

6.2 Final Optimization

Once the final search region has been delimited, a final optimization is applied using a refined optimization criteria and including the use of hydraulic controls. This optimization demands a greater computational effort, and it is for this reason that it becomes necessary to reduce the SS as a previous step.

Applying the optimization method, a solution is obtained, this solution is assumed to be very close to the optimal one. The proposed solution contemplates the substitution of the C84, C85 and C86 pipes. The installation of storm tanks in the nodes N8, N15, N16 and N63 and a Hydraulic Control element in the C75 pipeline. Figure 7 shows the infrastructure to be installed in the Balloon network. The characteristics of the elements to be installed are shown in Table 6.

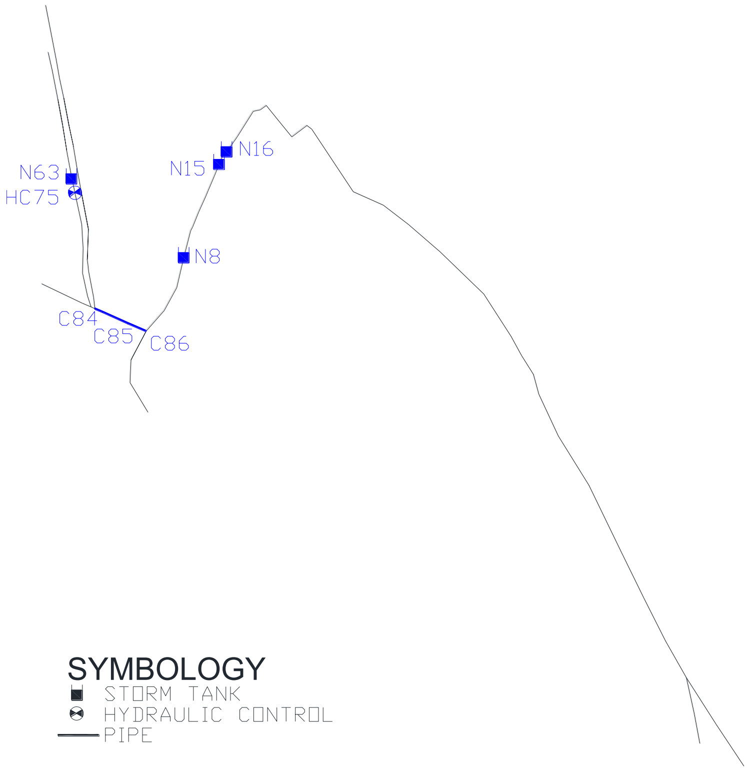

Figure 7. Elements to install in the Balloon

Table 5. Magnitude of SS and number of DVs of the network without SSR and the final search space

Characteristic	Elements								
	C5	C84	C85	C86	N8	N15	N16	N63	C75
Actual diameter (m)	0.70	0.70	0.70	0.70					
Optimized diameter (m)	1.00	1.10	1.00	1.00					
Volume (m^3)					2304	4914	4644	594	
Head-loss (m)									72.55

The costs of each term of the solution are shown in the Table 6. Finally, the Figure 8 shows the minimum value of the OF obtained in each iteration of the SSR and of the final solution.

Table 6. Term of objective function of the final solution

Terms in Objective Function (€/year)				
Flood	Storm Tank	Pipes	Hydraulic Control	Total
5,642.37 €	19,733.83	2,739.02	153.34	28,268.56

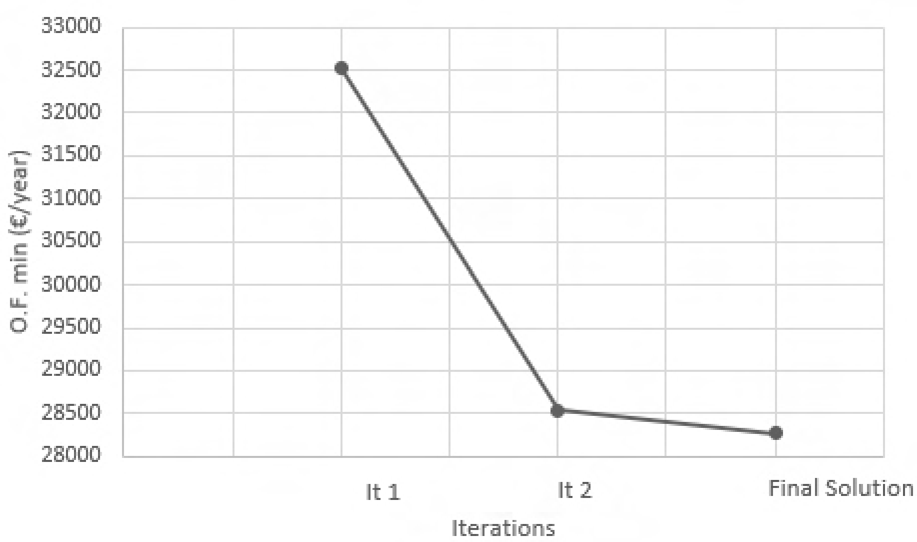

Figure 8. Minimum value objective function in each iteration

7 DISCUSSION

The result of the optimization process demonstrates the suitability of using the proposed method of changing pipes and installing tanks and hydraulic controls in the rehabilitation of the Balloon network. The cost of infrastructure also shows the suitability of the method with an annualized investment of €22,626.19, floods can be avoided that could generate very high costs of damage due to flooding. It should also be noted that the methodology allows for a certain level of flooding, so a cost associated with this damage appears in the objective function. This cost is 3.31% of the annual cost if measures were not taken to rehabilitate the drainage network. A strong point of the presented methodology is to establish the cost of flood damage according to the land uses of the cities. With the differentiation of land uses, the optimization of the network will allow more volume of flooding in areas where the flood does not cause damage or where the damage is minimal, such as in green areas and parking lots, etc. But it will greatly limit flooding in areas that, due to their activity, require greater protection (hospitals, dwelling, etc.). In this regard, it is important to point out that differentiating land uses in the studied area can be a starting point to link this methodology with the Low Impact Development technologies. These techniques can be installed in certain green areas of the study area.

On the other hand, the methodology based on risk analysis analyzes different rainfall events in order to obtain the curve of flood damage - probability. This action demands important calculation times, for this reason, the inclusion of an SSR method is an essential step. The results of applying the method are promising, reducing the SS by 93.56%, this reduction is produced meticulously to define the most promising region of the total SS. This can be seen in Figure 8 where it is observed that in each solution the minimum value of the objective function is reduced.

8 REFERENCES

[1] A. Jha et al., “Five Feet High and Rising Cities and Flooding in the 21 st Century,” Policy Research Working Paper, vol. 5648, May 2011.

[2] J. A. Snyman and D. N. Wilke, Practical mathematical optimization, 2nd ed., vol. 133, Springer Science+ Business Media, Incorporated.

[3] P. L. Iglesias-Rey, F. J. Martínez-Solano, J. G. Saldarriaga, and V. R. Navarro-Planas, “Pseudo-genetic Model Optimization for Rehabilitation of Urban Storm-water Drainage Networks,” in Procedia Engineering, vol. 186, 2017, pp. 617–625.

[4] D. Mora-Melia, P. L. Iglesias-Rey, F. J. Martinez-Solano, and V. S. Fuertes-Miquel, "Design of Water Distribution Networks using a Pseudo-Genetic Algorithm and Sensitivity of Genetic Operators," Water Resour. Manag., vol. 27, no. 12, Sep. 2013, pp. 4149–4162.

[5] U. A. Ngamalieu-Nengoue, P. L. Iglesias-Rey, F. J. Martínez-Solano, D. Mora-Meliá, and J. G. S. Valderrama, "Urban drainage network rehabilitation considering storm tank installation and pipe substitution," Water (Switzerland), vol. 11 , no. 3, 2019.

[6] H. R. Maier et al., "Evolutionary algorithms and other metaheuristics in water resources: Current status, research challenges and future directions," Environ. Model. Softw., vol. 62, Dec. 2014, pp. 271–299.

[7] S. Sophocleous, D. Savić, and Z. Kapelan, "Leak Localization in a Real Water Distribution Network Based on Search-Space Reduction," J. Water Resour. Plan. Manag., vol. 145, no. 7, Jul. 2019, p. 04019024.

[8] U. A. Ngamalieu-Nengoue, P. L. Iglesias-Rey, and F. J. Martínez-Solano, "Urban drainage networks rehabilitation using multi-objective model and search space reduction methodology," Infrastructures, vol. 4, no. 2, Jun. 2019, p. 35.

[9] L. Bayas-Jiménez, F. J. Martínez-Solano, P. L. Iglesias-Rey, D. Mora-Melia, and V. S. Fuertes-Miquel, "Inclusion of Hydraulic Controls in Rehabilitation Models of Drainage Networks to Control Floods," Water, vol. 13, no. 4, Feb. 2021, p. 514.

[10] L. Bayas-Jiménez, F. J. Martínez-Solano, P. L. Iglesias-Rey, and D. Mora-Meliá, "Search space reduction for genetic algorithms applied to drainage network optimization problems," Water (Switzerland), vol. 13, no. 15, Jul. 2021, p. 2008.

[11] G. Freni, G. La Loggia, and V. Notaro, "Uncertainty in urban flood damage assessment due to urban drainage modelling and depth-damage curve estimation," Water Sci. Technol., vol. 61, no. 12, Jun. 2010, pp. 2979–2993.

[12] A. S. Olsen, Q. Zhou, J. J. Linde, and K. Arnbjerg-Nielsen, "Comparing Methods of Calculating Expected Annual Damage in Urban Pluvial Flood Risk Assessments," Water, Vol. 7, vol. 7, no. 1, Jan. 2015, pp. 255–270.

[13] P. Samuels et al., Language of Risk – Project Definitions, 2nd ed., FLOODsite, Apr 2009.

[14] B. Merz, H. Kreibich, R. Schwarze, and A. Thieken, "Review article 'assessment of economic flood damage,'" Natural Hazards and Earth System Science, vol. 10, no. 8, 2010, pp. 1697–1724.

[15] Butler and David, "Urban Drainage" , 4th ed., CRC Press, Apr. 2018.

[16] N. W. Arnell, "Expected Annual Damages and Uncertainties in Flood Frequency Estimation," J. Water Resour. Plan. Manag., vol. 115, no. 1, pp. 94–107, Jan. 1989.