THE USE OF GREEN AND BLUE INFRASTRUCTURE FOR URBAN REVITALIZATION AND TO IMPROVE MANAGEMENT OF RAINWATER: THE CASE OF THE COMPRIDO RIVER SUB-BASIN

O USO DE INFRAESTRUTURAS VERDE E AZUL NA REVITALIZAÇÃO URBANA E NA MELHORIA DO MANEJO DAS ÁGUAS PLUVIAIS: O CASO DA SUB-BACIA DO RIO COMPRIDO

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Abstract

The expansion of urban areas and the pressure on land use have changed the ecological and ecosystemic functions of the environment. Adaptive strategies such as the establishment of green and blue infrastructure can reduce the adverse effects of anthropic actions, as well as provide health and quality of life benefits to the population. These strategies are more sustainable, economical, multifunctional and flexible alternatives than traditional solutions. Among the various functions that green and blue infrastructure can assume, this work highlights the capacity for reducing the hydraulic risk allied to revitalization of the urban environment, through the establishment of urban parks, restoration of vegetation and interconnection of green areas with new leisure areas. For this analysis, interventions were proposed in the Comprido River sub-basin, in the city of Rio de Janeiro, considering the river as a structuring element of the landscape. These interventions were simulated through a mathematical model called MODCEL, which allows estimating flood heights in current and design scenarios. As a result, the authors observed that despite the limited open spaces, the multifunctionality of the green and blue infrastructure introduces several improvements for society.

Keywords: Green and blue infrastructure; Urban revitalization; Multifunctionality; Urban drainage; Comprido River.

Resumo

A expansão das áreas urbanas e a pressão sobre o uso do solo alteraram as funções ecológicas e ecossistêmicas do ambiente. Estratégias de adaptação como as infraestruturas verde e azul podem reduzir os efeitos negativos das ações antrópicas, além de proporcionarem benefícios para a saúde e qualidade de vida da população. Essas estratégias podem destacar-se como alternativas mais sustentáveis, econômicas, multifuncionais e flexíveis em comparação com as soluções tradicionais. Dentre as diversas funções que as infraestruturas verde e azul podem assumir, o trabalho pretende destacar a capacidade de diminuição do risco hidráulico aliada à promoção da revitalização do ambiente urbano, por meio da implantação de parques urbanos, recomposição da vegetação e interligação de áreas verdes às novas áreas de lazer. Para o desenvolvimento dessa análise, foram propostas intervenções na sub-bacia do Rio Comprido, no Rio de Janeiro, considerando o rio como elemento estruturador da paisagem. Essas intervenções foram simuladas através de um modelo matemático, denominado MODCEL, que permite estimar as alturas de inundação nos cenários atual e de projeto. Como resultado, observa-se que, apesar dos limitados espaços livres, a multifuncionalidade das infraestruturas verde e azul introduz diversas melhorias para a sociedade.

Palavras-chave: Infraestruturas verde e azul. Revitalização urbana. Multifuncionalidade. Drenagem urbana. Rio Comprido.

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1. Introduction

Human activities change the pattern of land use and occupation, which can alter the quality of the natural and built environment (MIGUEZ *et al.*, 2016). Urbanization is one of the anthropic actions causing the most significant environmental impacts, due to the removal of the original green cover, increased soil sealing, introduction of canalization works and occupation of riverbanks.

Cities are mainly composed of four essential systems: (1) blue infrastructure, composed of channels, rivers, lakes, lagoons and other water resources; (2) green infrastructure, with parks and natural areas; (3) grey infrastructure, corresponding to roadways and parking areas; and (4) red infrastructure, composed of buildings (POTZ, 2016 *apud* ZHANG, 2017, p. 23).

Compact cities are usually defined as mixed-use cities with relatively high urban densities and efficient public transport. Besides these features, they have dimensions that encourage walking and cycling, and are ideal to increase sustainability and promote multiple uses (BURTON, 2000). Cities can be more compact and provide a higher quality of life with easy access to well-planned multifunctional public green spaces (AHERN, 2009), such as parks and large preserved areas. Green spaces and other public areas are fundamental to achieve a better quality of life and sustainability in compact cities (RAMASWAMI *et al.*, 2016), and can also have the benefit of controlling urban floods.

The concept of drainage, whose focus was on public health during the phase known as hygienist, has evolved into the current stage with the objective of providing ecological benefits and developing new technologies, aiming at sustainable development (MIGUEZ and DE MAGALHÃES, 2010). This evolution can be observed through the substitution of structures mainly for the conduction of water with others which seek to recuperate the environmental degradation caused by urbanization. (FLETCHER *et al.,* 2015). Initially, infiltration and deposition measures were taken with the aim of imitating natural hydrology. More recently, this idea has expanded, seeking to integrate drainage with the city in a concept known as Water Sensitive Urban Design (WSUD), which adds value to the town and creates opportunities to increase biodiversity.

A high potential for solution arises when observing open spaces as multifunctional systems capable of working for the management of rainwater. These spaces can provide storage volume for the drainage system besides leisure and recreation for the population. This way, detention reservoirs can be designed to decrease peak flows in extreme events. Retention reservoirs can also be implemented as permanent lakes, offering the possibility of improving water quality, increasing infiltration, removing some of the water from the superficial system and returning it to underground reservoirs.

Green infrastructure can be defined as an interconnected network of green spaces that preserves the values and functions of natural ecosystems and provide benefits to the local population (BENEDICT and MCMAHON, 2002). This concept is on the rise and is based on principles that favor the use of multifunctional landscapes and the connectivity of systems (HERZOG, 2016). Multifunctionality is fundamental for the development of green areas in the limited spaces of cities because it considers that structures can provide multiple benefits at the same time (HANSEN *et al.,* 2017), integrating various functions like landscaping, leisure, environmental improvement and flood control.

Green infrastructure can be a key factor for the resilience of urban environments, with the aim of ameliorating the impacts of climate change (HERZOG, 2016). Besides this, green areas are essential for biodiversity and natural processes, not only for their ecological advantages but also for their educational, emotional and recreational benefits (BEATLEY, 2017; MULLER and WERNER, 2010).

Blue infrastructure consists of the urban water system, which can be integrated into the green areas of the city with the aim of recreating a natural water cycle. The city of Paris is a river metropolis, with the use of the blue infrastructure. It is an example of urbanization based on the river system (IKEDA, 2016). Through the structuring of water bodies, it was possible to reconcile the natural demands of the hydrological cycle as well as social needs. The River Seine, the main axis of the city's blue infrastructure, formerly caused catastrophic floods and was the recipient of much of domestic and industrial effluents, but today it is one of the city's main assets.

According to Perini and Sabbion (2017), the term "blue-green infrastructure" is used to denote all strategies that aim to increase urban resilience to climate change, by improving the ability to adapt and mitigate anomalies in cities. Voskamp and Van de Ven (2015) point out that some of the benefits of green-blue infrastructure are the improvement of the water balance regime and the smoothing of the peak flow of rainwater, which reduces soil erosion and increases water quality. Zhang (2017) highlights that controlling the amount of runoff water reduces flood risk because it helps maintain and protect the natural water cycle, besides replenishing aquifers.

The concepts of green and blue infrastructure, multifunctional landscapes and open space have gained space in the literature. Bacchin *et al.* (2014) present a tool that uses the ArcGIS and EPA SWMM platforms to analyze the spatial configuration and composition of the urban environment, designing integrated networks of green, blue and gray spaces which aim to improve ecosystem services and sustainable rainwater management practices. Perini and Sabbion (2017) analyze rainwater management practices in urban areas focusing specifically on integrating green and blue infrastructure for river restoration, and the impact of this infrastructure on urban revitalization, through case studies applied in different contexts. Silva and Costa (2016) identify and systematize a wide range of flood adaptation measures relevant to the design of urban public spaces. Also, they present a conceptual framework which organizes the actions identified according to the type of infrastructure strategy, which h can be used in the initial phases of a project. Herzog (2016) presents a proposal for multifunctional green infrastructure planning to protect and regenerate the native biodiversity of a basin in Rio de Janeiro. Additionally, the proposed plan aims to broaden the debate on the role of green areas and native ecosystems in cities, the need for active public participation in the construction of resilient and sustainable cities, and the importance of improving the quality of life. Hansen *et al.* (2017) examine the application of the concept of multifunctionality in urban planning based on a semiquantitative study including interviews with managers and analysis of planning documents in 20 European cities, and conduct a qualitative study of good practices observed in three cases. From the results, the authors propose five recommendations for the promotion of multifunctional urban green infrastructure in densely urbanized areas. Brody *et al.* (2017) examine open spaces in approximately 2,600 watersheds along the Gulf of Mexico for incorporation into the solution of flood problems, and through statistical models prove a direct relationship between natural open spaces and flood mitigation.

Several cities have developed green and blue infrastructure with benefits in terms of water quality, climate, pollution, recreation and health. Examples such as the Madrid Río project along Manzanares River in Spain and the revitalization of the Cheonggyecheon River in South Korea are an inspiration for transforming low-quality urban environments into human habitats that are more pleasant, friendly, sustainable and resilient.

According to Bacchin *et al.* (2014), projects that integrate the city and nature with the goal of improving hydraulic performance play a vital and multifunctional role. Gardens can mitigate flooding by intercepting heavy rainfall, acting for short-term water storage. Besides this, according to Paula (2004), vegetation influences the amount of solar radiation received, the wind pattern, precipitation, humidity, and temperature. Sattler (*apud* de Paula, 2004, p. 33) affirms that areas without vegetation have lower thermal indexes at night and higher ones during the day, presenting greater thermal amplitude than vegetated areas. Plant cover acts to attenuate local temperatures, improving the quality of life and mitigating climatic anomalies. Through simulations, the study of Cameron *et al.* (2012) conclude that a 10% increase in urban vegetation could reduce the average temperature by 4 °C in Manchester in the next 80 years. In addition to these data, the researchers report that relaxing in a vegetated space can alleviate pain, help regulate blood pressure, improve cognitive function and reduce the incidence of diseases. The study also points out that the trees are better suited to obtain thermal benefits, and the result varies according to the size, species, maturity, and shape of the trees.

This paper proposes the use of green and blue infrastructure for the revitalization of the Comprido River (literally "Long River") sub-basin of the city of Rio de Janeiro. To establish balance in the area, multisectoral logic should be employed, in which the sustainability of the urban agglomeration depends on the density of connections between green and blue spaces. As an integrated system, green and blue infrastructure can reduce runoff, increase biodiversity and offer cultural, health and leisure benefits through public access to valuable natural resources (BACCHIN *et al.,* 2014), as well as providing the necessary connections to unify fragmented natural spaces.

To evaluate the effect of the proposed green and blue infrastructure on urban stormwater management in the Comprido River sub-basin, this paper used a hydrodynamic computational tool, the Urban Flood Cell Model, or MODCEL (MIGUEZ, 2001). MODCEL assists both in diagnosing the current urban drainage situation in the basin and in quantifying the potential benefits of the proposed infrastructure improvements.

2. Case Study

2.1 Comprido River sub-basin

The Comprido River sub-basin is located in Planning Area 1 of the city of Rio de Janeiro and it belongs to the Mangue Canal basin, which covers an area of about 45 km^2. Traditional districts that suffer from frequent floods are located in this area, such as São Cristóvão, Estácio, Rio Comprido, Maracanã, Vila Isabel, Andaraí, Tijuca and Grajaú

The Comprido River arises in an area of native forest located in the Serra do Sumaré (Sumaré Range) at an elevation 590 m, whose main geographical feature is Morro do Sumaré (Mount Sumaré). The river stretches 4.5 km until emptying into the Mangue Canal.

In the region, several flood events typically occur each year, and it was one of the area most impacted by the iconic event of extreme rain in the summer of 2010. The event of March 7th, with rainfall intensity of 1,272 mm in 24 hours, injured 22 people in the city of Rio de Janeiro and flooded many of the city's main streets, especially in the Rio Comprido district.

Due to the criticality of its floods, the Comprido River sub-basin has been the target of several studies and projects to manage floods. Among them, the authors highlight the *Execução de concepção e de projetos de obras civis e ações de controle das enchentes na Bacia Hidrográfica do Canal do Mangue* (Project to conceive and design civil works and actions for flood control in the Mangue Canal Basin) (COPPETEC, 2000) and the *Plano Diretor de Manejo de Águas Pluviais do Rio de Janeiro* (Master Plan for Management of Rainwater in Rio de Janeiro) (CONSORCIO HIDROSTUDIO - FCTH, 2014). The most critical spot in this sub-basin regarding flood risk is on Rua do Matoso (PCRJ, 2015). Figure 1 shows the flood spots for the current situation of the Comprido River sub-basin for a 25-year event, simulated by MODCEL (MIGUEZ, 2001; MIGUEZ *et al.*, 2017). These floods cause damages to the local community and can be considered, along with other factors, responsible for degradation of the urban environment.

2.2 Rio Comprido district

The Rio Comprido district covers about 334.20 ha and is characterized by intense occupation, with more than 60% urban area. The district also comprises part of the Tijuca Massif, and besides the Comprido, it is also drained by the Bananal River (MARTINS, 2015).

The district is part of the initial urban center of the city and was first occupied by the upper classes, military officers and members of the higher clergy, making Rio Comprido a noble district of Brazil's then capital (LACERDA *et al.,* 2017). In the 1850s, the infrastructure works of Barão de Mauá buried several watercourses, creating underground canals, allowing further urban settlement. However, this transformed the newly constructed Mangue Canal and its tributaries into sewer streams, without any treatment. Furthermore, with the increasing occupation and waterproofing of the soil, floods became frequent and persist to today.

According to Lacerda *et al.* (2017) and Martins (2015), in 1919 the engineer Paulo de Frontin was elected mayor of the Federal District (Rio de Janeiro) and began a program of urban improvements that affected the district, including the construction of Rio Comprido Avenue (currently Paulo de Frontin Avenue), and the district went through a valorization period. After the opening of the Rebouças Tunnel in 1967, the importance of Paulo de Frontin Avenue increased and it became an important connection between the northern and southern zones of the city. In 1969, the construction of the raised Engenheiro Freyssinet Highway, also known as *Elevado Paulo de Frontin*, began. In 1971, when it was still being built, a part of the viaduct collapsed. After the tragedy, it was rebuilt and expanded for two more kilometers and finally opened in 1974.

Due to the urban expansion process of Rio de Janeiro, the district, previously residential, began to be a place of passage (LACERDA *et al.,* 2017). Over the years, it has undergone a degradation process of the environment, caused by the traffic noise, pollution and reduction of natural light. Even with the impact of the

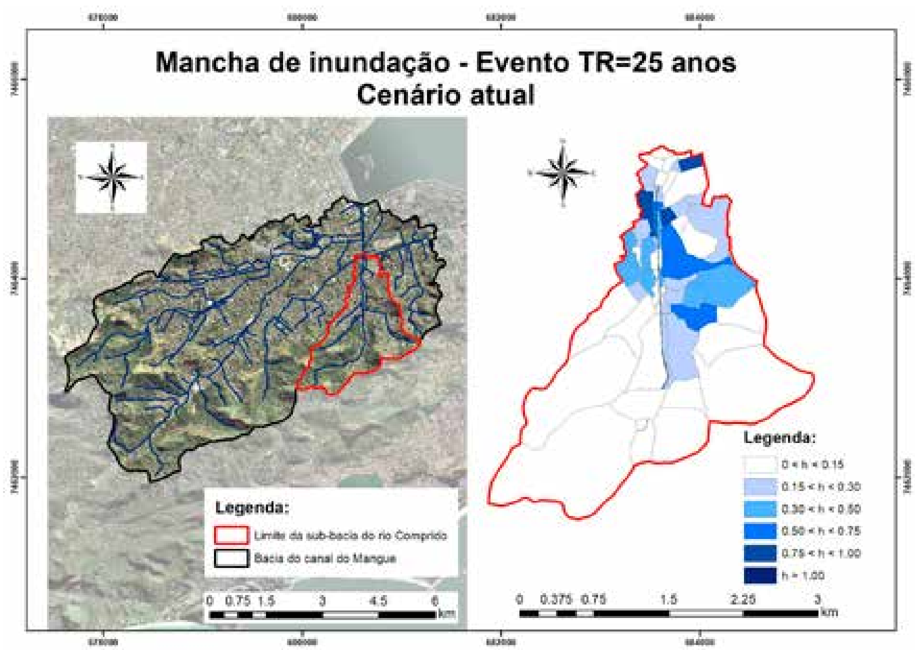

Figure 1 – Flood spots in Comprido River sub-basin for a 25-year event.

urbanization process, traditional institutions are still located in the district, such as the Fire Brigade Hospital, Union of Domestic Workers Estácio de Sá University, Osório Foundation, Inmetro, Futura Channel (television), Cesgranrio Foundation, Unicarioca University and the CAP High School (associated with Rio de Janeiro State University). Although the district is located in the historical core and in the main economic and cultural center of Rio de Janeiro, it has no recreation and commerce infrastructure for the local community (MARTINS, 2015).

3. Materials and Methods

3.1 Urban Flood Cell Model

The Comprido River sub-basin is partly composed of approximately flat urban areas, with high potential for flooding. When overflowing the drainage network, the water path is dictated by urbanization patterns. This brings complexity to the definition of flows since water can flow through both drainage networks and streets and sidewalks.

In this context, there are indications for the use of a model that can simulate flooding in the basin in a spatial and integrated way, allowing the evaluation of the various interactions between the drainage system and the urban surface. To achieve this objective, the Urban Flood Cell Model (MODCEL), developed at UFRJ, is a modeling tool that represents urban spaces through homogeneous compartments that cover the whole surface of the basin and interact according to the flow that occurs in the watershed.

The fundamental concepts of MODCEL are associated with the division of the modeled region into cells (homogeneous compartments that characterize a portion of the basin) and the interconnection of these cells through hydraulic relations capable of representing the exchange of flows between them (allowing to set up a flow network in a loop, in several directions of the two-dimensional plane). Flow cells, alone or in groups, represent either hydraulic structures or natural and urban landscapes, in an arrangement that seeks to simulate diverse flow patterns within or outside the channel network based on the interactions between modeled cells. Despite working with one-dimensional hydraulic relations, this hydrodynamic model can represent the flow in two-dimensional space. Figure 2 shows the defined and discretized modeling domain of flow cells for the Mangue Canal basin, in which the Comprido River sub-basin (highlighted) is inserted.

3.2 Identification of intervention areas – Current diagnosis

The main intervention areas were chosen along Paulo de Frontin Avenue, to structure the avenue from the open space system and its connectivity with the Comprido River. All points were selected based on underutilized plots that have potential public use, and are identified in Figure 3.

Intervention "A"

The intervention area "A" is located on the corner of Paulo de Frontin Avenue and João Paulo I Street. This space is free of buildings, is vegetated in all its extension, has private use and is walled. The neighboring buildings have institutional and residential use. Because of its current unused status even though located on a corner where there is large movement of pedestrians and vehicles, it has excellent potential to become a space for public use, to meet the needs of residents.

Intervention "B"

The intervention point "B", where a small gas station operates, is located on the opposite corner of area "A". The buildings that border this area are of mixed use, residential and commercial, as is characteristic of the buildings along Paulo de Frontin Avenue. This space's ground is impermeable and elevated with respect to the level of the sidewalk, generating superficial flows.

Intervention "C"

Area "C" is a vacant lot with the presence of some vegetation. Due to its abandoned characteristics, it has been appropriated by street dwellers, becoming a space avoided by pedestrians. It is located at an important intersection (Paulo de Frontin Avenue and Haddock Lobo Street) and can be used as a meeting space.

Intervention "D"

Located opposite area "C", intervention area "D" corresponds to a building with commerce on the ground floor (currently closed) and apartments on the upper floors. It is in a situation of abandonment, becoming a target of vandalism, with graffiti and broken windows. This area was chosen to reconnect the riverbanks, since it is also on a corner of great interest between Paulo de Frontin Avenue and Haddock Lobo Street.

Haddock Lobo Street / Paulo de Frontin Avenue

This intervention takes place throughout a triangular block, where service stations occupy more than 50% of the area. The block accompanies the riverbank, and one of its sides corresponds of Haddock Lobo Street, serving as a point of interest to join areas "C" and "D".

Condessa Paulo de Frontin Plaza

Condessa Paulo de Frontin Plaza presents, during daytime period, strong movement of pedestrians due to commercial

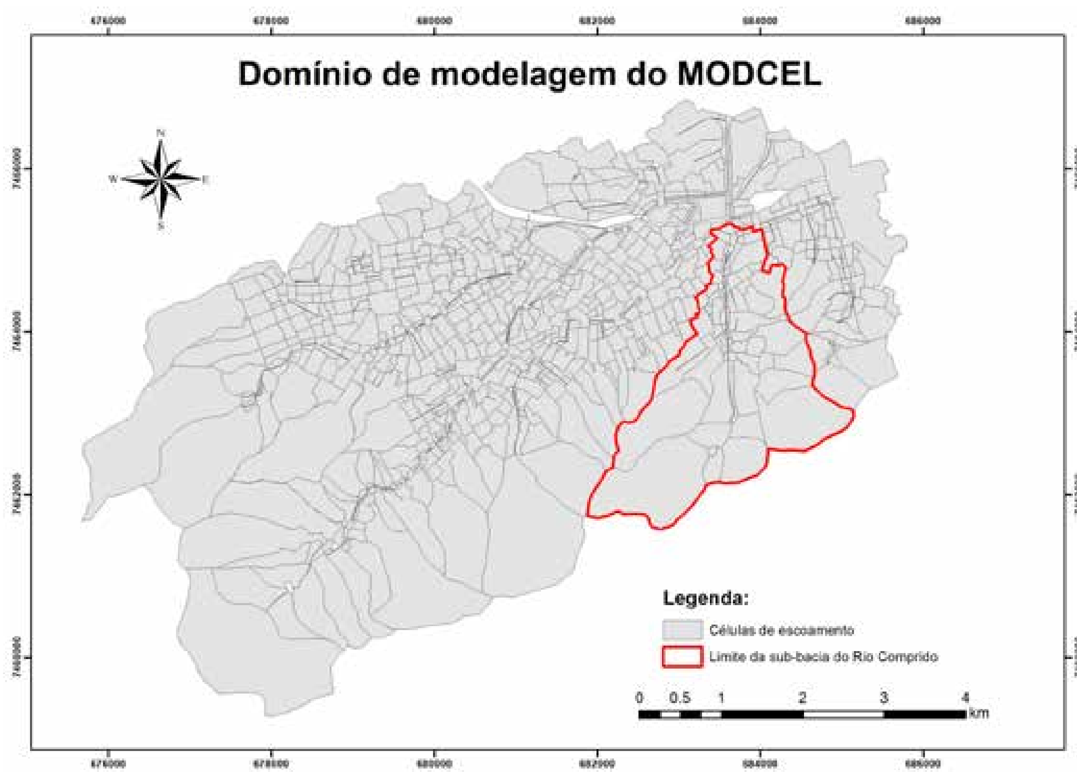

Figure 2 – Modeling domain and discretization of flow cells using MODCEL.

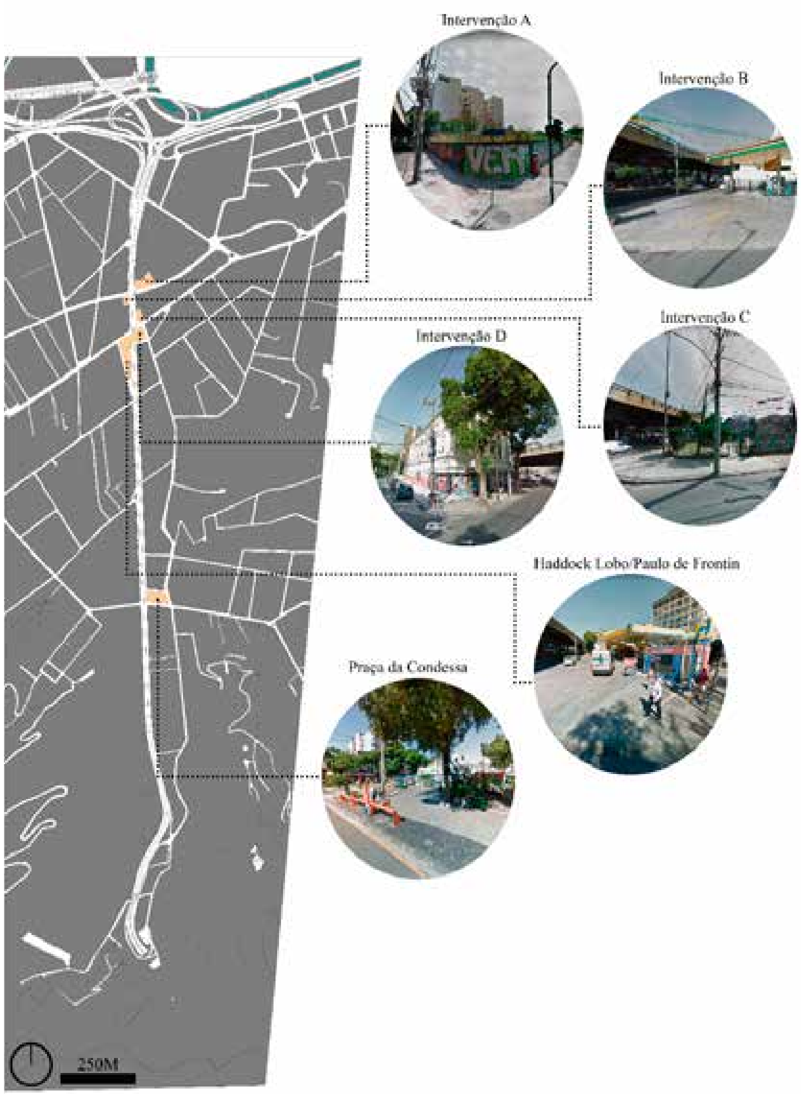

Figure 3 – Identification of the intervention sites along Paulo de Frontin Avenue.

establishments in its surroundings, besides proximity to Pereira Passos Municipal School and Salles Neto Municipal Health Center. Another relevant factor for the place's movement is the bus lines that connect the neighborhood with the South Zone (Copacabana, Ipanema and Leblon) and downtown region.

This square has a significant number of trees compared with the surroundings, and a fountain. The place also has spaces for rest and contemplation, food kiosks, game tables, gymnastics equipment for the elderly and playground equipment for children. Additionally, the site contains a bicycle rental station, which through daily or monthly rental plans, encourages people's movement in the city via alternative transportation. There is intense pedestrian movement and the use of the square by the residents reinforces the importance of making the space resilient to floods.

Comprido River canal

The Comprido River is channeled and presents random variations in its hydraulic sections, having parts that are open and other that are closed. At some points, the change of the section causes bottlenecks in the canal and impairs the hydraulic capacity of the watercourse, causing overflow during heavy rainstorms. This proposal for intervention starts from the need to resize the Comprido River canal so that it can drain the rainwater from the macro drainage system without failures for a given return period (RP).

3.3 Interventions in design scenario

Proposals for multifunctional infrastructure

The road system would be resized along the banks of the Comprido River. A cycle path was designed to connect all points of intervention and enable the most efficient and sustainable movement of the population across the area. In addition, with increased flow of people, the sense of security would increase, as well as the number of potential customers of the surrounding commercial establishments. Another benefit would be stimulation of physical activity through the use of bicycles, helping to combat a sedentary lifestyle. Figure 4 shows the proposed cycle path to interconnect with other intervention areas along the Comprido River.

Pedestrians become the priority in this design by increasing the sidewalks and creating a path with a long green corridor parallel to the Comprido River. This green corridor has aesthetic and landscape function, creating a landscape unit through the composition and spatial relationship of the river and its banks, and the road system. The planning of the green-blue infrastructure also has the purpose of improving the response of the urban drainage system to the occurrence of floods. In order to obtain the improvements in the surrounding areas, the urban interventions would be carried out in the places previously studied, as described in the following paragraphs.

In intervention area “A”, a Community Garden is proposed, composed of an urban garden with space for activities of elderly people. The garden beds would be arranged so as to be raised relative to the level of the sidewalk, to avoid contamination of the species planted during the occurrence of floods. This square aims to provide residents with a venue for interaction, through the cultivation of healthy foods, besides the regular practice of physical activities. Engagement and appropriation of space by residents would be encouraged, by the possibility of obtaining free produce from the garden, fruit of the collective effort.

From the observation of the movement of pedestrians in the surroundings, the authors detected intense movement of residents walking their dogs. In this way, intervention area “B” was chosen to be a public space of commerce and contemplation for the residents, besides a space of leisure for their pets. Considering its main attraction, this space was denominated Pets Plaza.

Besides the Community Garden, the Pets Plaza was also provided with places of permeable soil to enable infiltration of runoff and decrease the chance of flooding. In order to shade the areas for walking, relaxation and exercise, we chose to plant *Bauhinia Fortificata*, a species adapted to rainforests (PINHEIRO, 2017), which has landscape characteristics.

The proposals for intervention in these places are presented in Figure 5.

In intervention area “C”, a Children’s Square is projected, a space with playground equipment and structures for children. Its surface takes advantage of the existing plant cover, allowing permeability.

In intervention area “D”, the Culture Square is projected, which gains cultural use from its reservoir in an amphitheater format, serving for music and other artistic manifestations, with a retention capacity of 968.80 m^3. In addition, the square is 0.20 m lower compared to its surroundings, which adds in 305.60 m^3 to its storage capacity. Its perimeter also has vegetation cover to increase soil permeability.

At the junction of Haddock Lobo Street and Paulo de Frontin Avenue, in front of the Culture Square, the Triangle Plaza was proposed, which is named after the shape of the block, unlike other plazas, whose names refer to their main attractions. Because of the larger area, there are two large retention basins that, when empty, have different uses, but both are aimed at young people. The first place corresponds to a multi-sport court with three large steps of 55 cm of bleachers, with storage capacity of 1,977.80 m^3. The second corresponds to a plane with obstacles for skateboarders, with storage capacity of 887.20 m^3. In the perimeter of both basins a recessed garden covers the ground, highlighting two spaces: a garden near Haddock Lobo Street, creating a place for relaxation, with trees to provide shade and act as an acoustic barrier of the noises caused by the traffic; and another garden along its opposite sidewalk, where there are several residences. This generates an increase of 210.00 m^3 of storage in Triangle Plaza. At its end, a point for kiosks is formed, to create a triangulation of activities (LYNCH, 2011).

Just like in the Community Garden and Pets Plaza, *Bauhinia Fortificata* was chosen for planting in the Children’s and Culture

Figure 4 – Proposed cycle path.

Squares and Triangle Plaza, because it is a species that adapts easily to the recurrence of rainfall (PINHEIRO, 2017). The Culture Square and the Triangle Plaza are joined by footbridges that cross the canal, making sure that there is no segregation between the banks of the Comprido River, strengthening the occupation of open space systems.

Figure 6 presents a construction design for the Children's and Culture Squares and Triangle Plaza and Figure 7 a section in Triangle Plaza.

Condessa Paulo de Frontin Plaza has large movement of pedestrians and it is possible to observe the acceptance of its functions by the residents, characterizing their strong appropriation of the area. Due to its importance for the vitality of the neighborhood, this paper proposes, in addition to the existing functions, the incorporation of a multisport court with a capacity of 511.50 m^3 to function as a temporary reservoir of water during the occurrence of extreme rainfall events. The objective is for the area be resilient to the occurrence of floods by manipulating the multifunctionality of the public space, so that flooding affects as little as possible the residents and people who need to pass through the neighborhood, in addition to minimizing the damages caused for these events. As arboreal elements, *Licania tomentosa* and *Cassia spectabilis* were proposed, species found in the region until the 1960s (DECOURT, 2018), which can recover the landscape of the Rio Comprido district. Figures 8 and 9 present the intervention proposals in Condessa Plaza.

As for the hydraulic operation of the reservoirs proposed in the Culture Square, Triangle and Condessa Plazas, the water inflow occurs from the Comprido River through spillway structures and also surface flows from the river banks and part of the drainage lines of the surroundings. The reservoirs mitigate the flood events to their maximum capacity. When this capacity is exceeded, the water returns to the Comprido River and adjacent streets. After the flooding event, with the emptying of the river, the depletion of the reservoirs occurs through unidirectional floodgates ("flap"

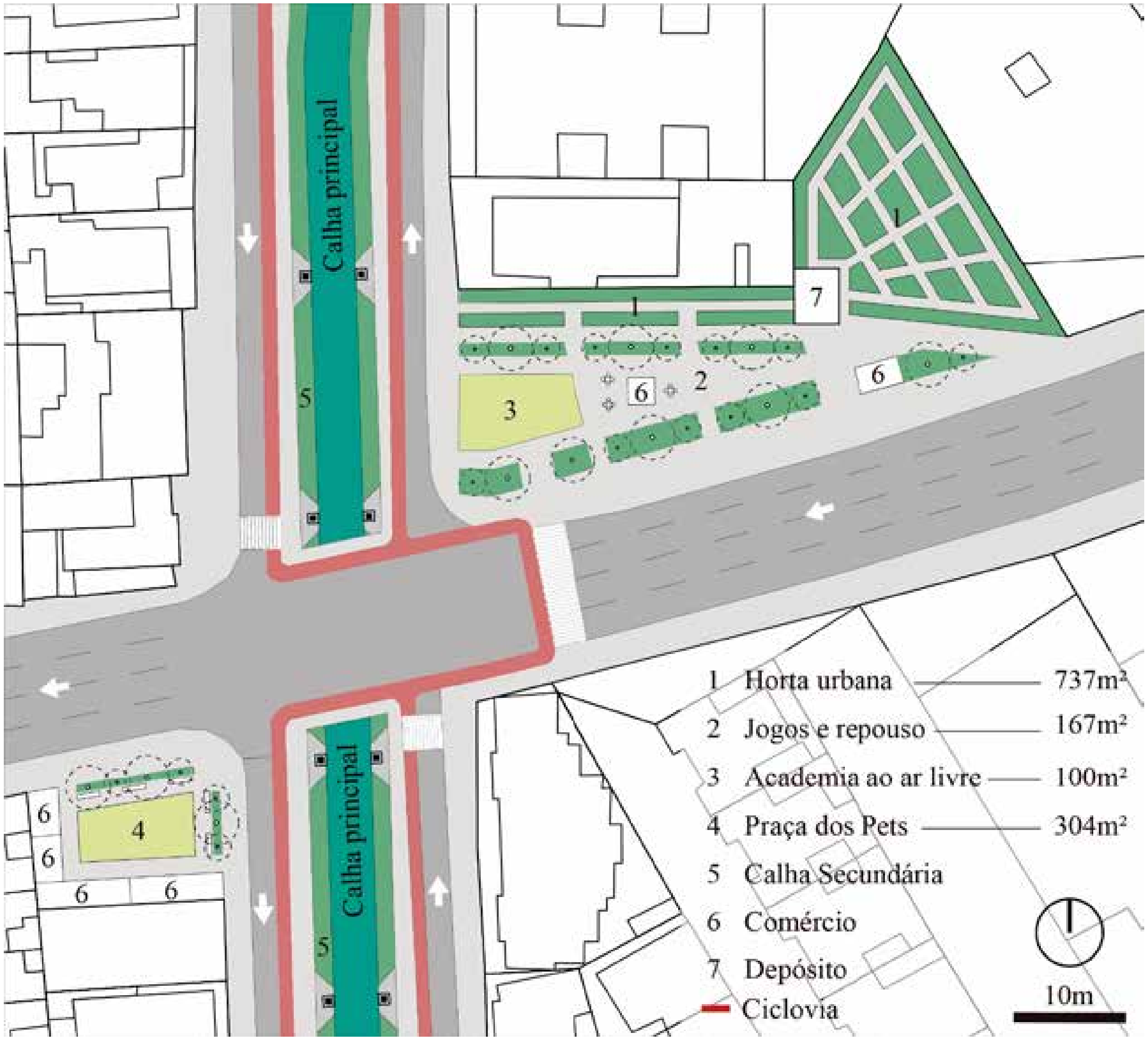

Figure 5 - Community Garden and Pets Plaza.

floodgates), which allow the flow only out of the plazas towards the Comprido River.

In relation to the Comprido River, changes would be made to the cross section and the bottom, from Condessa Plaza to its mouth at Mangue Canal, in order to improve its hydraulic capacity. As the river is inserted in an urban area, the authors decided to keep the banks in concrete to guarantee their stability. However, unlike the current configuration, a secondary level is proposed for the flows, with a temporary storage function, located in the sections between the viaduct pillars, as shown in Figures 5, 7 and 8. The suggested elevation for the secondary level corresponds to the elevation of the maximum simulated depth of flooding for the one-year recurrence time. In this storage area, plant species adapted to floodplains, such as *Allamanda cathartica* and *Typha latifolia* (Pinheiro, 2017) are foreseen. In this way, the secondary level, besides reducing the risk of flooding, would have aesthetic function, improving the microclimate and water quality.

Other interventions in the design scenario

Besides the multifunctional infrastructure mentioned above, some interventions proposed by the *Plano Diretor de Enchentes da Bacia do Canal do Mangue*, PBCM (Flood Master Plan for Mangue Canal Basin) were also incorporated into the design scenario, with the objective of complementing the actions to reduce flood risks in the region. This plan, which includes, among other interventions, the construction of several reservoirs at the foot of the mountains, was complemented by a series of studies carried out at the Computational Hydraulics Laboratory of COPPE/UFRJ (REZENDE, 2018). It is important to highlight that these interventions have not been implemented, and therefore are exclusively part of the project scenario.

The mountain foot reservoirs, conceived by COPPETEC (2000), are damping structures for slope drainage flows, which were dimensioned for a 10-year return period. Two reservoirs, called *Alto Comprido*, with a useful volume of 3,669.00 m^3, and *Bananas*, with a useful volume of 4,286.00 m^3, were incorporated in this work, since they are interventions in the Comprido River

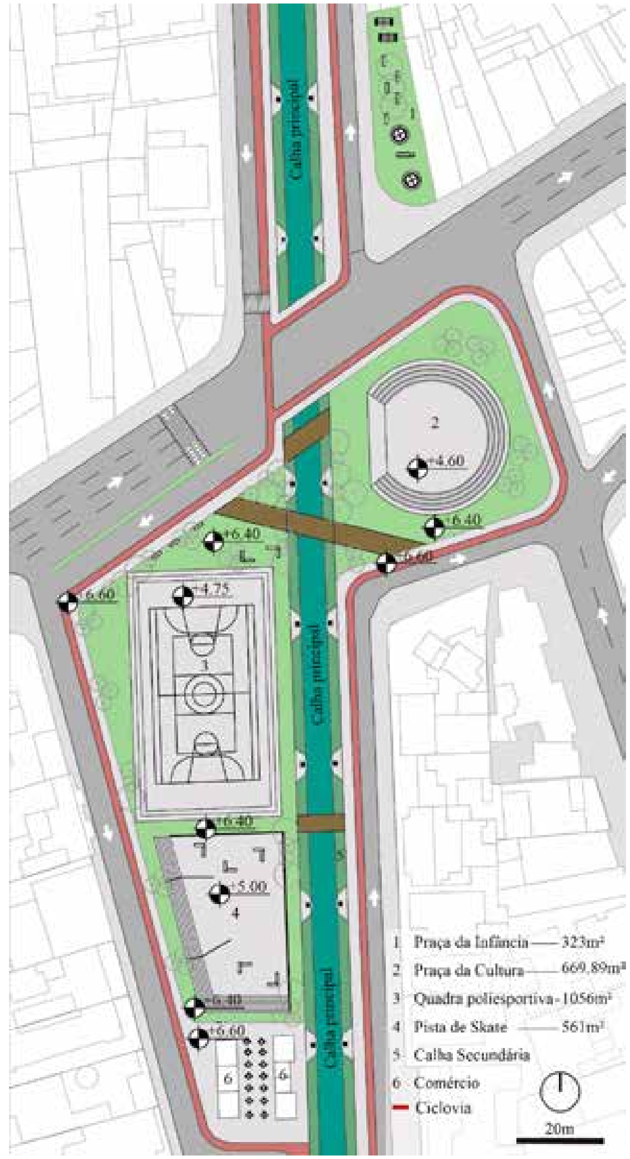

Figure 6 – Children's and Culture Squares and Triangle Plaza.

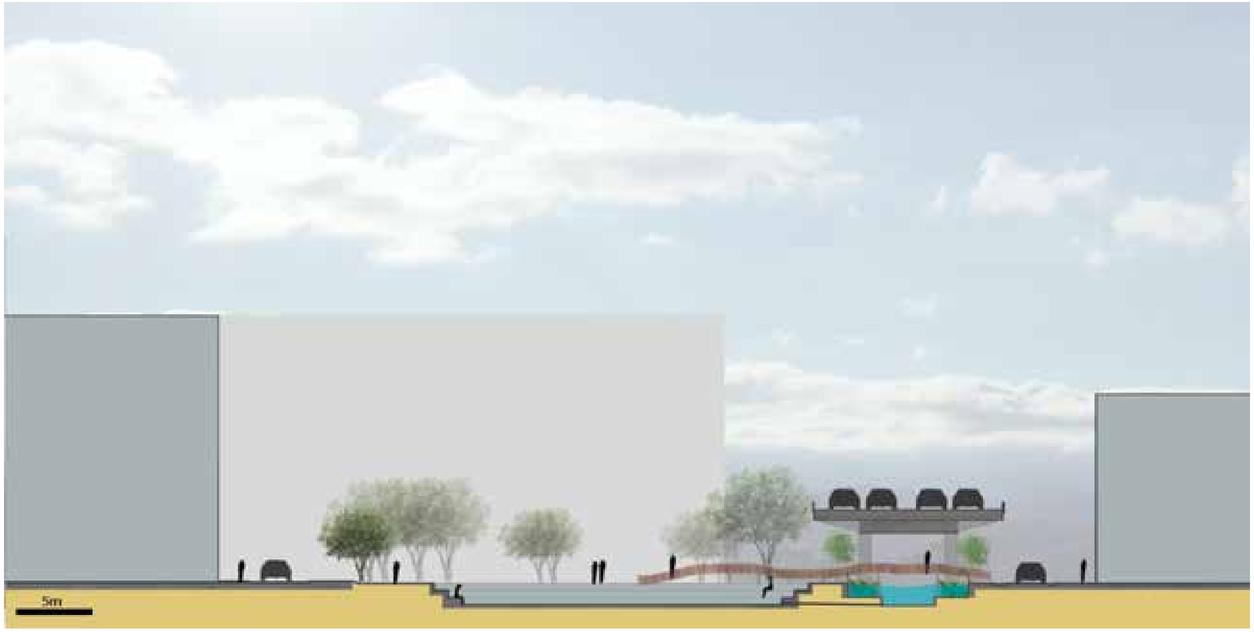

Figure 7 – Section of Triangle Plaza.

sub-basin. For a 10-year return period, the damping capacity of these reservoirs is 15% and 50%, respectively.

In addition to the mountain foot reservoirs, Rezende (2018) identifies Del Vecchio Square with potential storage area in the form of a detention reservoir associated with an urban square. This intervention, with a useful volume of 1,660.00 m^3, was also incorporated in the proposals to reduce the risk of flooding in the Comprido River sub-basin.

After these reservoirs' incorporation in the model, the authors identified that the drainage line from Aristídes Lôbo Street, approximately 800 meters long, works as a flood generator in a large area of the basin. This is because it captures a large volume of rainwater and directs it to the Comprido River, but for certain events it is not able to direct this flow without generating floods. Floodwaters reach almost one meter of depth and are not directly related to drainage failures by overflow from the Comprido River's main bed, but to lack of capacity of box culverts. Thus, an overflow canal is proposed for the drainage line of Aristídes Lôbo Street, which intercepts the rainwater from the first 300 meters (upstream) and directs it through a new line, located along Antônio Pedro Galiazzi Lane, towards the Comprido River, relieving the final section of the undersized drainage line.

4. Results and Discussion

Green and blue infrastructure can play the role of leisure space and provide a more pleasant aesthetic setting for passersby to contemplate the landscape. Green corridors also assist in flood control and improve water quality and microclimate. It can even be said that they allow improved flow of people through bike

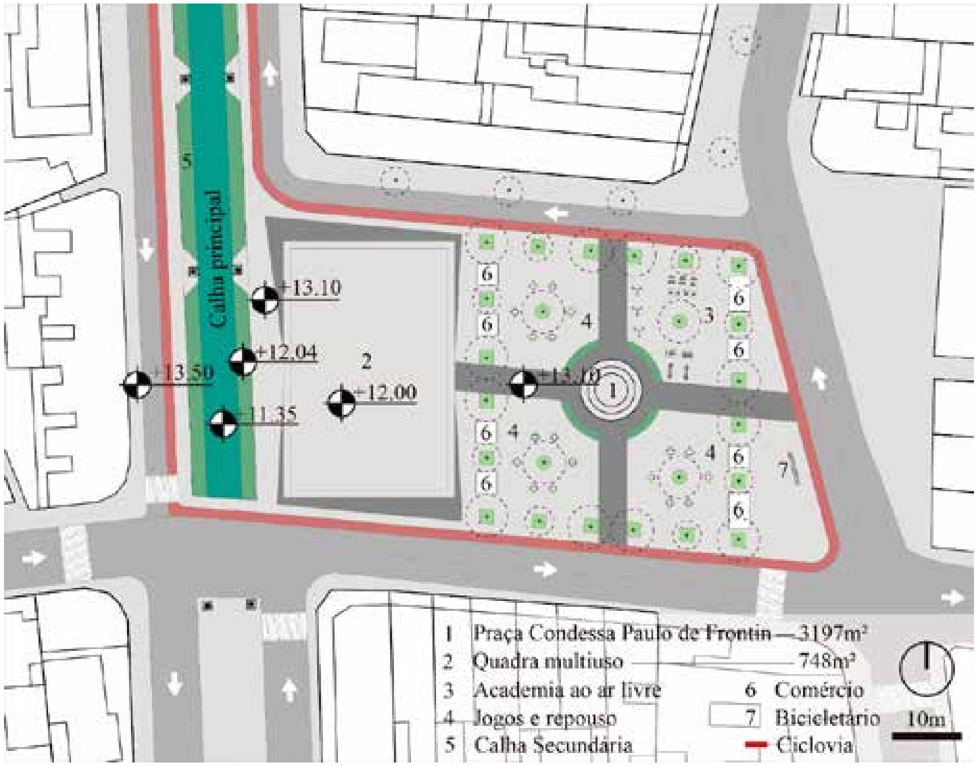

Figure 8 – Condessa Plaza.

and walking paths, which establish a pleasant space for walking and cycling, according to Figure 10. In addition to these benefits, they provide areas for the practice of physical activities and can encourage economic activities in the region.

With respect to the hydrodynamic simulation of the interventions, Figure 11 shows the variation of maximum water levels along the Comprido River, between Condessa Plaza and its mouth in Mangue Canal, for current and design scenarios. The figure also highlights the most critical section of the river regarding the overflow of canal and the part in which the flow occurs in an underground culvert. The proposed multifunctional design is able to mitigate floods of the Comprido River sub-basin for a 25-year return period, maintaining practically all flood volumes of the macro drainage system within the river's canal.

Figure 12 shows the flood heights before and after the implementation of the proposed interventions in the watershed, for the 25-year return period. Significant improvement in the floods observed at the diagnostic stage is noticeable.

Figura 9 –Section of Condessa Plaza.

In addition to the results for a 25-year design rainfall, other return periods were also simulated. Table 1 presents the stored volume per reservoir for these simulations and Figure 13 illustrates a cross-section of the river, near Condessa Plaza, with the new configuration of the canal, indicating, besides the base flow height, the water levels for return periods of 1, 25, 100 and 500 years. Although the modifications of the Comprido River canal and the implementation of upstream reservoirs are the principal elements responsible for flood mitigation, other interventions are essential to alleviate local flooding and to offer a series of services that traditional hydraulic works cannot.

5. Conclusions

Green and blue infrastructure has a strong potential to integrate hydraulic and landscape functions in the urban environment, making it more resilient. The case study of the Comprido River sub-basin represents an opportunity to incorporate scientific knowledge in the revitalization of metropolitan regions that suffer from frequent flooding. Regarding the benefits in the macro drainage system, the proposed interventions could reduce the flood levels in several areas of the basin, in addition to maintaining the 25-year recurrence time flow in the river canal. These interventions also would provide improvements in the quality of life and leisure for the population and help increase urban resilience.

Although the proposals are focused on the case study of the Comprido River sub-basin, these strategies can be adapted to other urban areas, promoting the reduction of the hydraulic risk combined with the improvement of river ecosystems.

The drainage system can be a catalyst for changes when flood mitigation is needed. The demand for relief, in turn, leads to a search for storage spaces and possibilities of infiltration, to recover hydrological functions lost during the urban expansion. This adds further evidence of the need to incorporate the logic of green-blue infrastructure in urban space planning.


Figure 10 – Green and blue corridor in perspective.

Table 1 – Stored volumes in the reservoirs for different simulated return periods (RP).

Reservoir	Stored volumes in each intervention (m²)							
	RP=1	RP=2	RP=5	RP=10	RP=25	RP=50	RP=100	RP=500
Culture Square	1,274.40	1,274.40	1,274.40	1,274.40	1,274.40	1,274.40	1,274.40	1,274.40
Triangle Plaza	2,803,44	2,844.48	2,970.00	3,075.00	3,075.00	3,075.00	3,075.00	3,075.00
Condessa Plaza	333.00	363.60	399.30	424.80	470.70	511.50	511.50	511.50
Del Vecchio Square	830.00	962.80	1,162.00	1,344.60	1,626.80	1,660.00	1,660.00	1,660.00
Bananas	526.60	862.69	1,427.20	2,012.12	3,087.50	3,989.88	4,286.00	4,286.00
Alto Comprido	1,379.27	1,827.22	2,626.75	3,403.72	3,669.00	3,669,00	3,669.00	3,669.00

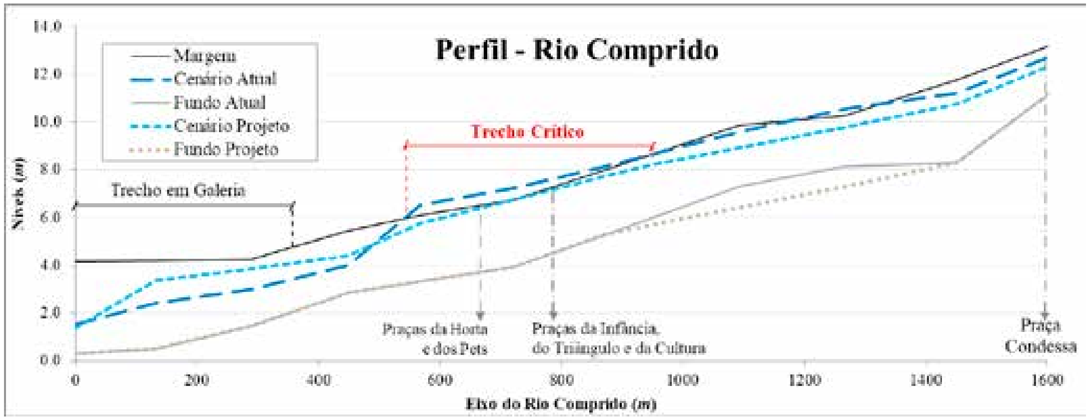

Figure 11 – Comprido River water levels for the 25-year return period.

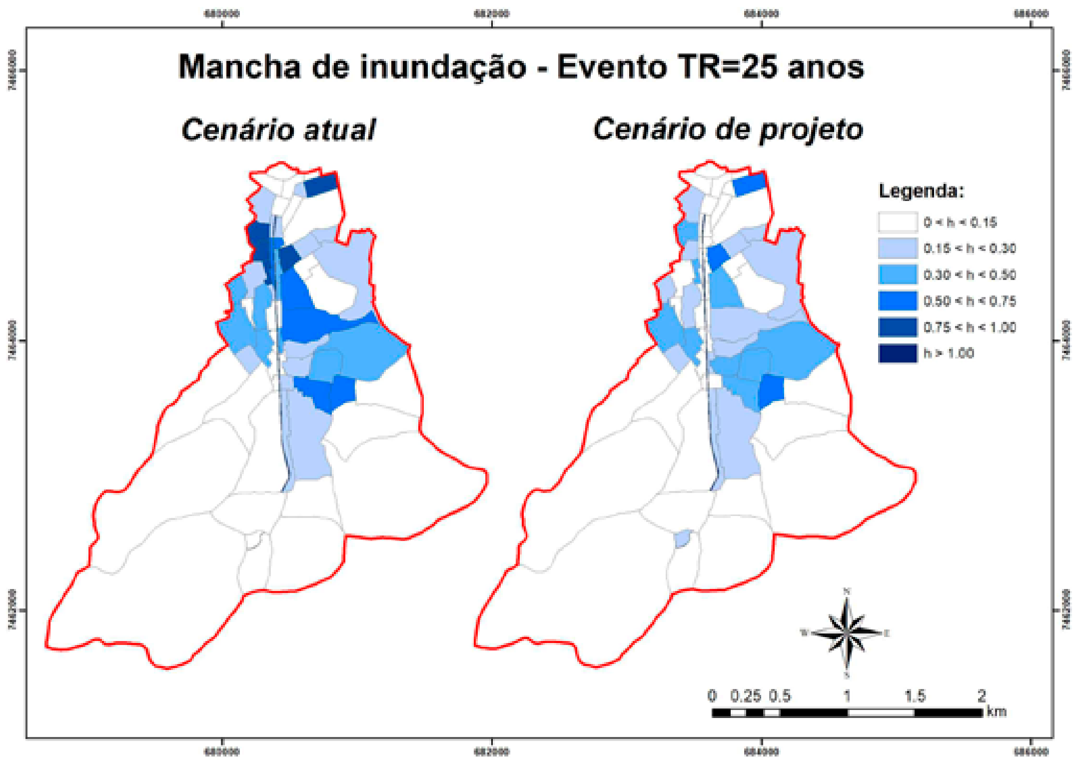

Figure 12 – Flood heights from the current and design scenarios for a 25-year event.

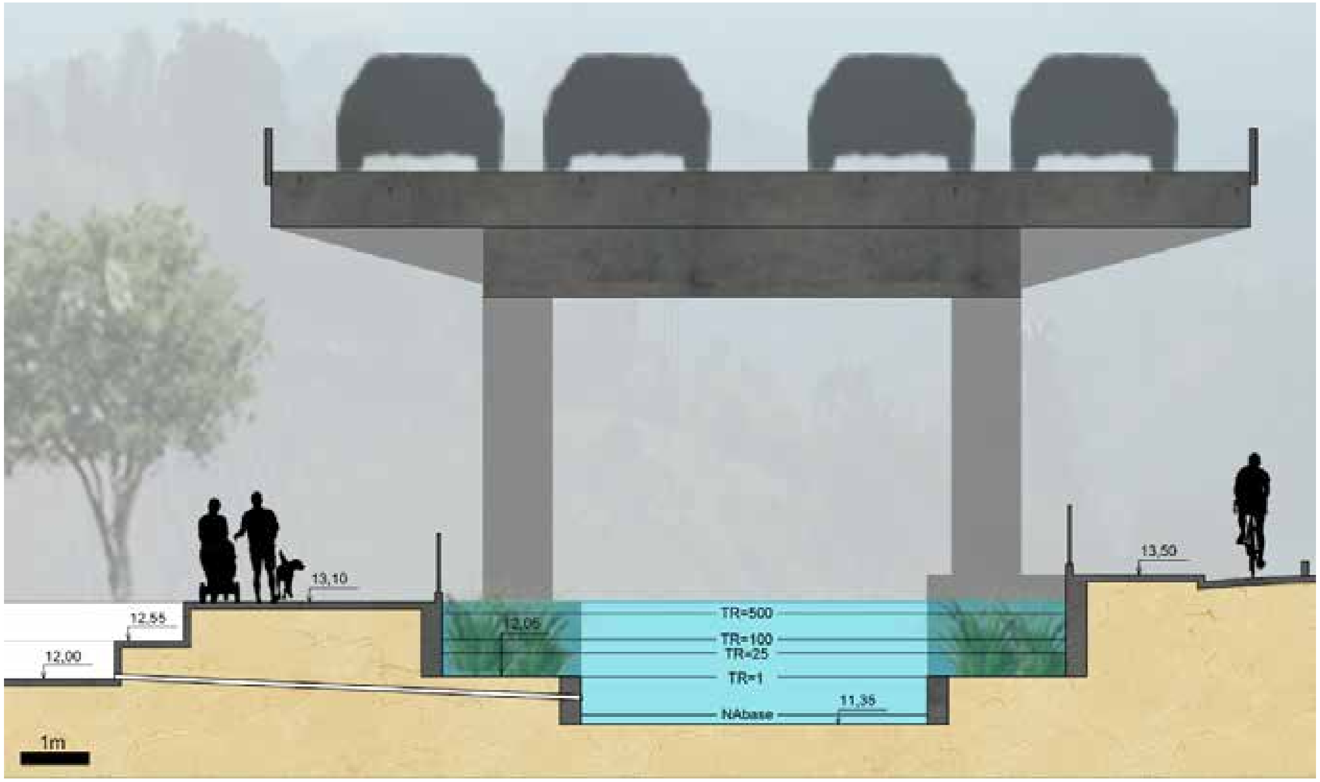

Figure 13 – Section of the Comprido River.

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