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Investigation into the Potential for Creating Functional Landscapes in the Expansion Area of Belém

Investigação de Potenciais de Constituição de Paisagens Funcionais na Área de Expansão de Belém

Investigación del Potencial de Constitución de Paisajes Funcionales en el Área de Expansión de Belém

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Resumo

A estruturação do espaço da cidade capitalista negligencia a condição das cidades de ecossistemas complexos. Esta foi a lógica seguida na formação da Região Metropolitana de Belém, em todos os momentos que o investimento em infraestrutura omitiu os processos ambientais, aspectos climáticos e a diversidade social da Amazônia, priorizando o adensamento construtivo e a redução da cobertura vegetal no centro e na área de expansão da cidade. Esta pesquisa propôs-se identificar os potenciais para criação de uma paisagem funcional na área de expansão de Belém, tomando a Bacia hidrográfica do Mata-Fome como um piloto para a realidade da periferia metropolitana (RMB). Geoprocessamento, cálculos matemáticos e modelagem 3D foram os recursos usados para demonstrar a viabilidade de associação de soluções baseadas na natureza (infraestrutura verde) à infraestrutura convencional, de modo a preservar usos e características culturais da paisagem, já adaptada aos alagamentos sazonais, e reduzir custos e impactos ecológicos. Conclui-se que é possível manter áreas vegetadas e permeáveis, com potencial socioambiental, paisagístico e econômico, e também contribuir para o enfrentamento das mudanças climáticas nas cidades amazônicas.

Palavras-Chave: Meio Ambiente Urbano; Mudança Climática; Infraestrutura Urbana; Geometria e Modelagem Computacional; Planejamento Territorial Urbano; Drenagem Urbana.

Abstract

The structuring of space in the capitalist city neglects the condition of cities as complex ecosystems. This was the logic followed by the formation of the Metropolitan Region of Belém (MRB), when all the investments in infrastructure consistently omitted environmental processes, climatic aspects and the social diversity of the Amazon, and prioritized constructive densification and a reduction of the vegetation cover both in the center and in the expansion area of the city. This research has aimed to identify the potential for creating a functional landscape in the expansion area of Belém, taking the Mata-Fome watershed as a pilot for the reality of the metropolitan periphery. Geoprocessing, mathematical calculations and 3D modeling were the resources used to demonstrate the feasibility of associating nature-based solutions (green infrastructures) with conventional infrastructure, in order to preserve the uses and cultural characteristics of the landscape, already adapted to seasonal flooding, and to reduce costs and ecological impacts. The conclusion is that it is possible to maintain vegetation and permeable areas, with socio-environmental, landscaping and economic potential, and also to help confront climate change in Amazonian cities.

Key-Words: *Urban environment; Climate change; Urban Infrastructure; Geometry and Computational Modeling; Urban Territorial Planning; Urban Drainage.*

Resumen

La estructuración del espacio urbano capitalista descuida la condición de las ciudades como ecosistemas complejos. Esta fue la lógica seguida en la formación de la Región Metropolitana de Belém siempre que la inversión en infraestructura omitiera los procesos ambientales, los aspectos climáticos y la diversidad social de la Amazonia, priorizando la densificación de la construcción y la reducción de la cobertura vegetal en el centro y en el área de expansión de la ciudad. Esta investigación se propuso identificar las potencialidades para la creación de un paisaje funcional en el área de expansión de Belém, tomando la cuenca hidrográfica de Mata-Fome como piloto para la realidad de la periferia metropolitana (RMB). El geoprocesamiento, los cálculos matemáticos y la modelización en 3D fueron los recursos utilizados para demostrar la viabilidad de asociar soluciones basadas en la naturaleza (infraestructuras verdes) a las infraestructuras convencionales, a fin de preservar los usos culturales y las características del paisaje, ya adaptado a las inundaciones estacionales, y reducir los costes y los impactos ecológicos. Se concluye que es posible mantener áreas vegetadas y permeables, con potencial socioambiental, paisajístico y económico, y también contribuir a enfrentar el cambio climático en las ciudades amazónicas.

Palabras clave: *Medio Ambiente Urbano; Cambio Climático; Infraestructuras Urbanas; Geometría y Modelización Computacional; Ordenación del Territorio Urbano; Drenaje Urbano.*

1. Introdução

The capitalist city is guided by the various pressures and the correlations of forces created by the agents that produce urban space (CORREA, 1995), and is modeled according to the values and priorities of the dominant classes. It is not by chance that the investment of public and private agents in urban management and infrastructure follows the demands of these groups. Under the capitalist aegis, technical interferences in the natural landscapes inserted in cities have also become more intense, while little attention has been given to socio-environmental relations. This directly interferes with social relations involving marginalized groups in cities, causing them to become less environmentally equitable (DIEP, 2022).

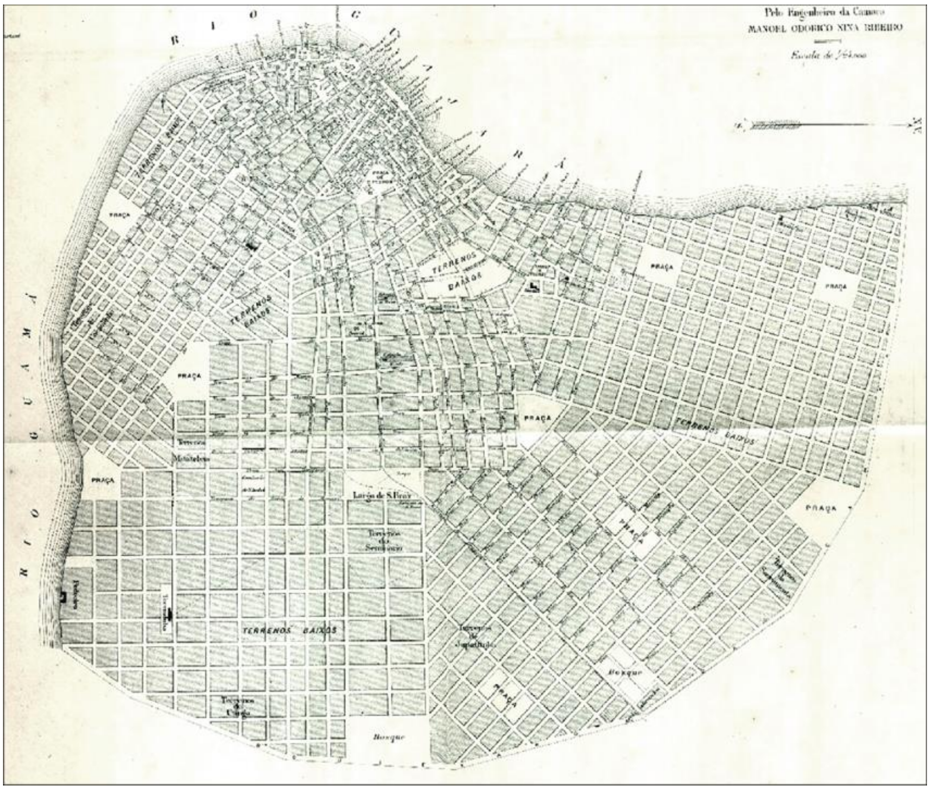
Since the second half of the twentieth century, the contents of urban ecology have been identified as being essential in order to understand the complexity of the urban ecosystem and its cause and effect relationships (SPIRN, 1995; MCHARG, 1971). However, the most common aspect is that industrial infrastructure and sanitation solutions and the process involved in providing this infrastructure in cities have neglected resources, natural landscapes and social demands (BONZI, 2015), because they cause intense soil sealing, a massive land occupation of the watersheds and the deforestation of green areas (CARNEIRO & MIGUEZ, 2011), thereby reducing the infiltration and storage capacity of rainwater, increasing surface runoff and making cities vulnerable to climate change (BONZI, 2015).

In the way that the social production of space occurs in peripheral capitalism, the natural landscape is usually inserted into traditional management and infrastructure either as a good or a service, which meet the immediacies of urban agents without considering social and cultural aspects. Management is based on the hypothesis that negative damage to this natural environment is reversible, but in fact this increases the conditions of risk and vulnerability of a large section of the population (SOUZA, 2016; MIRANDA, 2020).

In the city of Belém, the impact of this type of management may be better understood from the historical and socio-spatial background of the city. The expansion of the city was modulated by economic cycles and migratory flows (BECKER, 2018). During the rubber boom period (1850-1920), investment took place in urban planning interventions guided by the Belém Expansion Plan by Nina Ribeiro (see Figure 1), influenced by Eurocentric, hygienist visions that met the demands of the rubber elite. This plan promoted urban infrastructure only in the highest parts of the first patrimonial league of the city, avoiding the structuring of areas with low elevations, common in the Amazon floodplain, identified as lowlands (MOREIRA, 1989). Thus, the plan neglected the watercourses and the Amazonian specificities of the site, following the concept that nature may be dominated through projects that enable the control or elimination of landscape elements (MIRANDA, 2020).

From the 1960s onwards, capitalist interest imposed itself on the social order of the city through the implementation of federal projects for roadway connections, the opening of the region to the national and global market, and the establishment of competition between local and national dynamics (CARDOSO et al., 2015). Subsequently, the National Integration Program (known as PIN) expanded the process of industrialization in the Central-South region of Brazil, and integrated the Amazon into the national market. The region received migrants from other parts of the country, attracted by land reform and the exploitation of natural resources, and in 1973, the Metropolitan Region of Belém (MRB) was created to reproduce the national project of conurbation, and break with the economy of the forest, which, until then, had sustained it as a regional metropolis (or primate city) (BECKER, 2018; CARDOSO et al., 2015).

Figure 01: Plan of Belém with Nina Ribeiro's expansion plan for the city's First Patrimonial League.



Source: Muniz (1904).

The Brazilian pattern of urban expansion, induced by industrial activities following experiences in the Central-South region of the country (TONUCCI FILHO et al., 2015), also guided metropolitan urban expansion in the case of the Amazon. This process was linked to economic growth and the exploitation of the natural landscape since the natural resources were considered to be infinite (BECKER, 2007). In the 1980s, the productive restructuring process of the countryside and the expansion of agrarian conflicts intensified an exodus toward the peripheral regions and lowlands of the city (CARDOSO et al., 2015).

Alongside this, from the end of the 1960s onwards, social and physical modeling of the occupation of the expansion area of Belém (Second Patrimonial League) became intensified (SOUZA, 2016; CORREA, 2016), after the conversion of idle rural land outside the city limits of the First Patrimonial League into institutional areas. From the 1980s however, there was an alternation between public and private agents in the production of housing typologies (the housing complexes were surrounded by informal subdivisions, and condominiums and private subdivisions occupied the reserved spaces on the axis of Avenida Augusto Montenegro) (CARDOSO et al., 2016). This process was combined with the free implementation of medium and large commercial and service enterprises, in addition to large institutional uses along the same avenue, which exposed the fragility of management in controlling land use and occupation (SOUZA, 2016).

The rapid, intense occupation of the expansion area of Belém brought together different socioeconomic profiles, which produced different patterns and spatial typologies, characterized by the rapid conversion of land use and an improvised densification of the urban area. However, public spaces, the mobility system and urban infrastructure remained deficient and incompatible with the local demand (CARDOSO et al., 2016). Despite this, the area still presented occurrences of urban agriculture and a significantly greater amount of vegetation cover than that of the central area - the First Patrimonial League - as well as a relatively less dense urban area (MIRANDA, 2020), in addition to a greater occurrence of living rivers (non-channeled and that maintained life in the waters) and relief movement. However, the improper land occupation of river basins and urban drainage projects, which maintained the same logic as Nina Ribeiro's plan, placed pressure onto these elements.

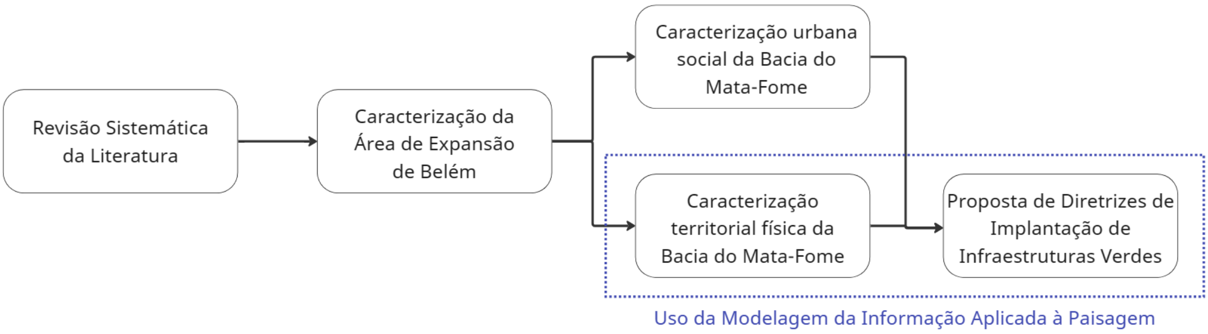
As a result of this pattern of expansion, it is possible to observe: a reduction in the vegetation area, soil sealing and the suppression of urban voids, the channelization and choking of watercourses and a modification of water patterns, a complete disregard of the characteristics of the climate and Amazonian rainfall and a displacement of the population to marginalized, densely populated areas, with no access to urban infrastructure or adequate basic sanitation. The occupation and expansion of the city failed to incorporate knowledge from the field of urban ecology, and thus, environmental risks were socially and politically constructed in the lowlands and marginalized areas of Belém (MIRANDA, 2020).

Based on the above, this article aims to identify the potential for creating a functional landscape in a peripheral area subject to flooding, with a view to confronting climate change in the expansion area of Belém. This was a case study for the Mata-Fome watershed, supported by mathematical resources and 3D modeling. It set out to demonstrate the viability of providing green infrastructure solutions associated with conventional infrastructure, in order to consolidate occupation and to preserve the uses and cultural characteristics of the landscape, already accustomed to seasonal flooding, thereby reducing the costs and ecological impacts.

2. Methodology

To meet these objectives, the research adopted the following methodological pathway: a) a literature review, searching for a repertoire in order to implement green infrastructure; b) a multiscale characterization of the natural cycles and of the physical, biotic and cultural processes in the expansion area; c) the urban characterization of the Mata-Fome watershed of the predominant patterns of the urban fabric and socio-cultural profiles (production by the market, informal production, spaces of resistance); d) a territorial characterization of the Mata-Fome watershed with the support of Google Earth satellite images, census data and thematic maps generated via Rhinoceros 3D and QGIS software modeling; e) implementing guidelines for green infrastructure in urban voids (green routes, backyards, gardens, squares, parks, floodplains and riparian forests) with the aid of parametric analyzes generated in Rhinoceros 3D (Figure 2).

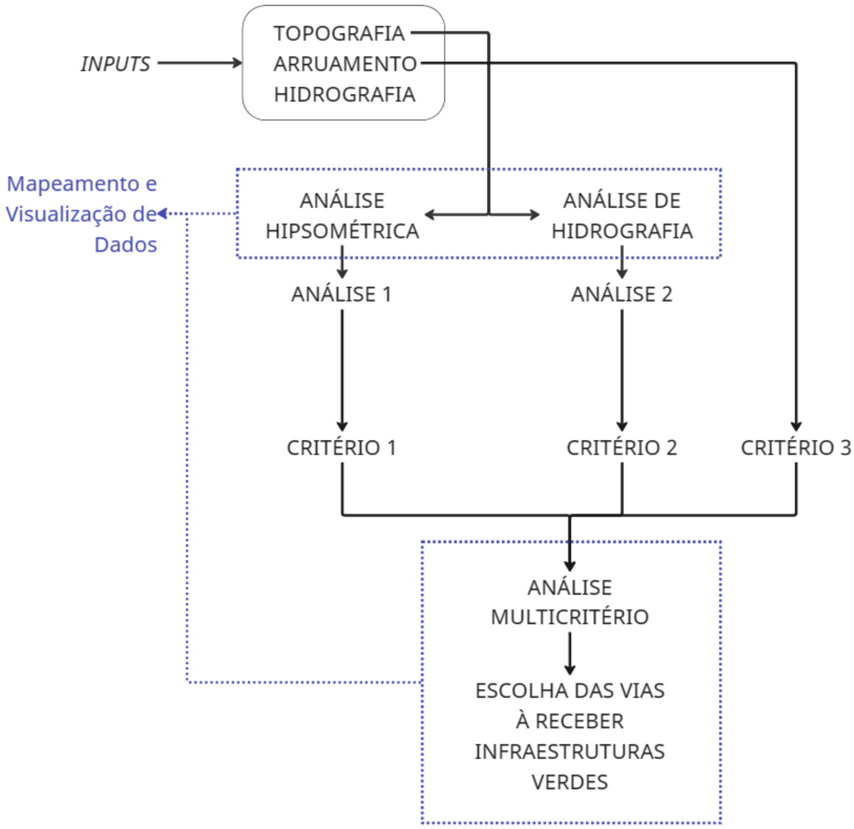
Figure 02: Illustration of the research methodology.



Source: Own elaboration (2023).

The modeling used an informational design algorithm (Figure 3): Applied Landscape Information Modeling (LIM), an intelligent design tool that aims to bring automation to landscape modeling and urban planning (AHAMAD et al., 2012; CARVALHO, 2020), through the interoperability between the Rhinoceros program, a complete 3D modeler, and its plugin, Grasshopper, which produces the visual programming interface and facilitates an understanding of the results (SOUSA, 2018).

Figure 03: Algorithm Structure.



Source: Own elaboration (2023).

3. Urban Ecology and Green Infrastructure as a Strategy to Combat Climate Change: scenarios and challenges for Belém

The conventional urban drainage system focuses on reducing the risk of flooding and reducing the risks and losses caused by flooding (TUCCI, 2012; PORTO et al., 2012), and also applies structural measures that modify the precipitation and flow of water sheds or indeed the rivers themselves (TUCCI, 2012). Such modifications provide for quickly directing the volume of rainwater toward the river mouth, focusing on the problem of local runoff, acting only as a transfer of adversity and impacting the downstream areas, without treating the watershed as a system (CARNEIRO & MIGUEZ, 2011). These measures, in addition to being expensive, are rigid and predispose to the conversion of the natural landscape, contributing to the urbanization process. As the vegetation cover is removed, soil sealing and the channelization of the floodplains increase, a greater volume of rainwater runs off faster, carrying sediments, which thereby accumulate in the lower areas (CARNEIRO & MIGUEZ, 2011).

Since the 1970s, there have been widespread debates and studies on the impacts of anthropic action on environments, resulting in environmental regulations such as the Best Management Practices (BMP, from “Best Management Practices for Rainwater”) of 1973. From this, management techniques based on nature were proposed as alternatives to conventional drainage systems. However, it was only in 1987 that the concept of "sustainability" gained strength in the Brundtland Report, entitled *Our Common Future*, promoting discussion and consolidating the concepts of sustainability and sustainable development in environmental guidelines.

Currently, the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (AR6 - IPCC, 2022) has recognized that anthropic activities are potentiating the negative effects of climate change and triggering not only extreme weather events, but also significant changes in the structure of global ecosystems. The report indicates that the global temperature increase of 1.5°C is irreversible, and that there is an urgent need to change the way of production in several sectors, to mitigate the risks caused by climate change. It also notes that, in different regions, the most vulnerable populations and systems are disproportionately affected by climate change, and more subject to water and food insecurity that result from it.

The negative effects of extreme changes in climate and the occurrence of intense weather events have already been indicated since the second half of the twentieth century (IPCC AR6, 2022), a period that consolidated the urban way of life in the rationalist and industrial city (CAPEL, 2002). This was also a time when, in the Amazon, the National Integration Plan provoked definitive changes in land use and in the genesis and expansion of urban stains, especially in the state of Pará, and which, added to agricultural expansion and farming and deforestation, were already causing changes in the regional climate (MORAES et al., 2022).

If such climate changes have caused impacts on human health, livelihoods and urban infrastructure (IPCC, 2022), in the current climatic emergency scenario, they also include the loss of biodiversity in ecosystems, a determining factor of resilience. Artaxo (2020) recalled that the loss of natural resources affects entire regions, as well as the local climate and microclimate, and that this must be taken into account when confronting the effects of the climate crisis.

An analysis of the evolution of climate data over a period of 35 years for the Metropolitan Region of Belém, a period in which more than 551.73 km² were anthropized, revealed that changes in land use had changed the microclimate of the metropolitan area (MORAES et al., 2022). In Belém, between the years 1985 and 2020, there were variations in the annual precipitation and in the thermal amplitude of around 10°C, and an increase in the maximum temperature of 1°C (MORAES et al., 2022). This has generated a trend toward an intensification of threats from meteorological events in the environmental scenario of the MRB, with particular emphasis in the intensification of precipitation between 2011-2020 (MORAES et al., 2022).

If the risks associated with climate change affect the population unequally, given that the poor population, who live on the periphery and lowlands, have less resources and infrastructure than the ruling class to face climate events, this process constitutes oppression and environmental injustice, given the unequal distribution of the power to use land and nature resources (ACSELRAD, 2002). Thus, it is essential to understand how the MRB has been affected by climate change, and then identify the possible scenarios for reducing these impacts on the different experiences of the population in the city.

Phenomena such as changes in the hydrologic cycle, which include increased rainfall and droughts and thermal variations and microclimate warming (MARENGO & SOUZA, 2018), are the tendency for the Amazon city. Nevertheless, the AR6 indicates that climatic and non-climatic events (such as changes in temperature and land use) in the Amazon will result in severe, irreversible losses of biodiversity and ecosystem services, if there is a global temperature increase of 2°C. This is a probable scenario if the temperature increase is not limited to 1.5°C within the next 10 years (IPCC 2022), and if greenhouse gas (GHG) emissions are not reduced and the rate of carbon sequestration is not increased (AR6 IPCC 2022).

An increase in global temperature not only interferes with the meteorological dynamics, but also with the dynamics of the tides, with a forecasted average rise in sea level by 2050 of 15 to 30 centimeters, which may cause an increase in inundations and flooding in cities, which will potentialize risks due to a lack of vegetation cover and an increase in impermeable surfaces. Thus, the effects of climate change on urban space demand more than the existing conventional infrastructure is able to offer, either because of the high cost or due to the lack of flexibility in the face of socio-environmental requirements. The situation becomes worse in marginalized areas, where urban infrastructure is either minimal or nonexistent, and its implementation tends to neglect social and environmental characteristics, since this population has no control over the process of providing infrastructure that is typical of urbanization (VILLAÇA, 1998; HARVEY, 2014).

On this point, proposals for the mitigation, adaptation and urban resilience for cities place Nature-based Solutions (NbS) and Green Infrastructures as alternatives for recovering the natural landscape and rivers in cities. The composition of multifunctional landscapes corroborates with the absorption of floods or the confrontation of extreme climatic events, therefore, although the AR6 has classified the impact of climate change on the structure of terrestrial, aquatic or floodplain ecosystems in Latin America as being high or very high, it is recommended that cities in the region invest in green infrastructure systems, ecosystem services and sustainable land use, allied to urban planning and the sustainable management of urban waters, in turn focused on adaptation and responses to climate change.

3.1 The formation (and provision of urban infrastructure) of the Expansion Area in Belém

Until the 1960s, the continental area of the municipality of Belém, which goes beyond the First Patrimonial League, was used for rural activities and occupied by spatial typologies intended for food production, second homes, and social and leisure activities (SANTOS & CARDOSO, 2015). However, the national strategy for expanding the frontiers established by PIN in the 1970s resulted in a migratory flow that, on the one hand, led to a swelling of the population in the First Patrimonial League of Belém, and on the other, to urban expansion through housing programs financed by the National Housing Bank (BNH) and executed by the Housing Company of Pará (COHAB). The expansion of the city beyond the institutional belt, towards the Second Patrimonial League, was justified by the need to reduce the housing deficit (SOUZA, 2016). The real estate occupation of this space was guided by a branch of the former Belém - Bragança railway, which was replaced by the current Avenida Augusto Montenegro, in a road formation with a “fishbone” structure (CARDOSO et al., 2016).

The provision of infrastructure for the first housing complexes promoted the valorization of reserved land, with a great stimulus for civil construction together with the spread of informal land occupations and clandestine subdivisions, also attracted by the new dynamics (SOUZA, 2016). Informal settlements emerged close to housing complexes in order to take advantage of the infrastructure built for the latter (SOUZA, 2016; LIMA, 2002), and the limited provision of technical networks released effluents into existing bodies of water (CARDOSO, MIRANDA, 2018). From the 1990s, gated communities began to appear along the sides of Avenida Augusto Montenegro to meet the demands of the upper-middle class. These were presented to the population as an alternative to the verticalization of the Center of Belém (SOUZA, 2016), and maintained the same practices as the housing complexes of releasing effluents into watercourses (CARDOSO, MIRANDA, 2018).

Land occupations with different socioeconomic standards were superimposed onto this space. It was not only the real estate market that took advantage of the changes, but also the trade and services sector, in order to meet the new needs of the ruling class located outside the city center. As of 2010, the creation of a new metropolitan centrality motivated a movement called “Nova Belém”, which consisted of planning the implementation of horizontal and vertical condominiums, shopping malls, medium and large commercial towers, medium and large supermarkets, etc., together with a strong advertising discourse (CARDOSO et al., 2016).

However, the production of the expansion area relied on the action of three agents: the State, Capital and the excluded population, with their own strategies of land occupation (SOUZA, 2016). Even after all this transformation, there was no provision of public spaces, investments in urban infrastructure nor a consolidated, more efficient roadway structure (CARDOSO et al., 2016). There existed a disarticulation between the human scale and the typologies adopted by the new uses, while the urban quality depended on the socioeconomic standards of the population, and resulted in different spatial arrangements and forms of accessibility (SANTOS & CARDOSO, 2015).

An interview held with municipal administration technicians revealed that actions to provide infrastructure and sanitation, in addition to being fragmented, depend on the decisions of the government body with more political power and financial resources available at that particular time. Due to the lack of a clear action agenda, requirements are met with no systemic planning. In everyday life, interventions are designed in a sectoral manner, with no attention being paid to the ecological, environmental, social and urban impact.

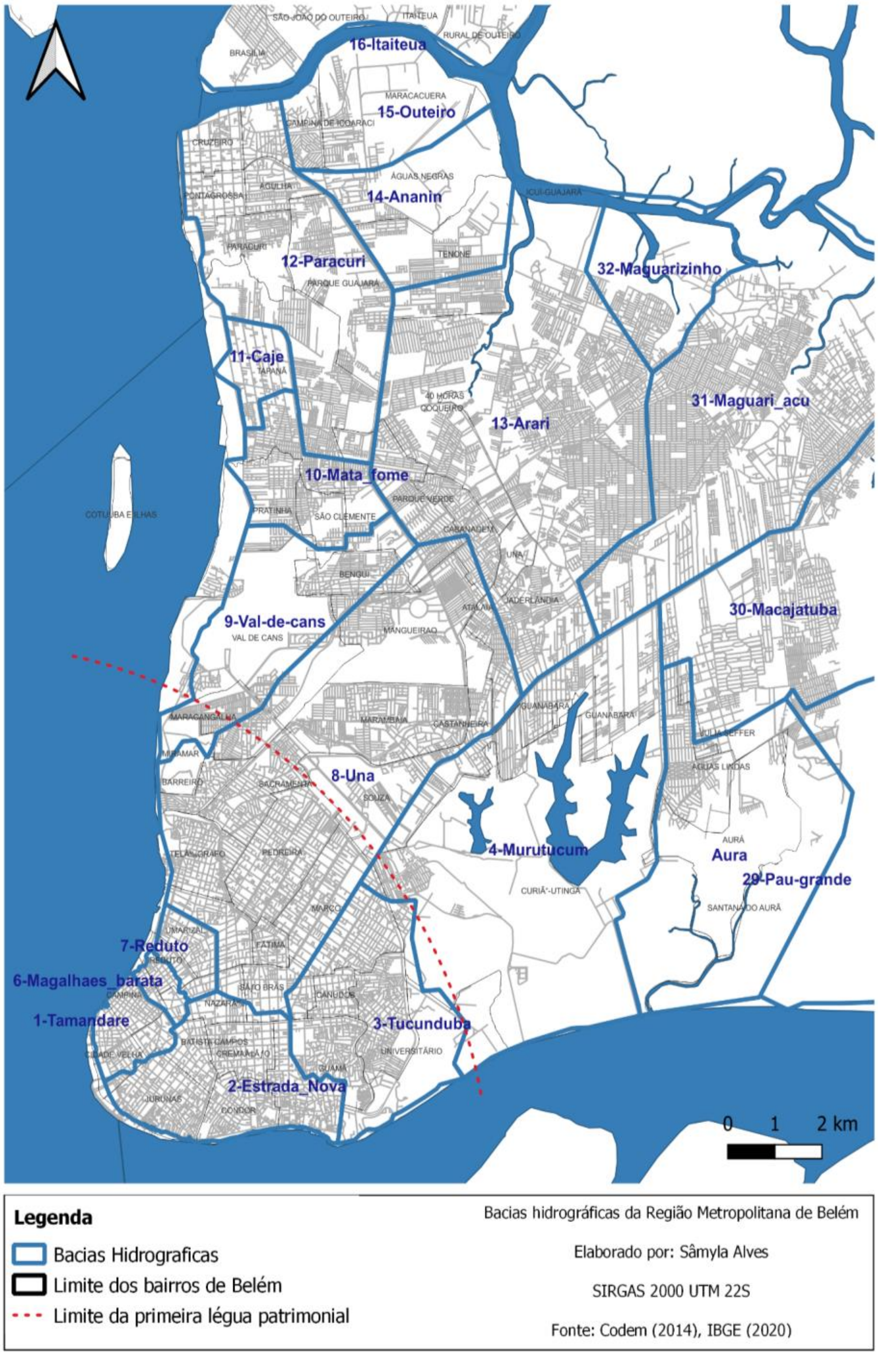
Within this context, the expansion area received insufficient and inadequate drainage infrastructure, rainwater management and protection of natural areas, thereby increasing the impact of the reduction in vegetation cover. Miranda (2020) detected a tendency to repeat the suppression of vegetation and soil sealing that occurred in the center of Belém — with a loss of 16.7% of the vegetation areas between 1999 and 2018. The reduction in soil permeability increased the occurrence of inundations and floods in several neighborhoods. Building densification and the extension of the roadways network outweighed the management of existing green areas, and no priority was given for the population's access to rivers and vegetation areas, even when these have some protection (CARDOSO et al., 2016). This fact is counterintuitive in a region such as the Amazon, where people have historically depended on biodiversity for their livelihood.

The literature recommends that planning land occupation in the city takes the watershed as a unit to promote urban and environmental convergence (ARAÚJO et al., 2007; CARNEIRO & MIGUEZ, 2011; MAGALHÃES, 2013; PESSOA & FAÇANHA, 2015). Therefore, there is a need to delimit subwatersheds, within the formally recognized watersheds located in the expansion area (see Figure 4), which are: the Una watershed, Val-de-Cães watershed, Mata-Fome watershed, Cajé watershed, Ariri watershed, Paracuri watershed and Anani watershed.

The urbanization of the watersheds of the Second Patrimonial League was incremental and disjointed, given the complexity of its natural environment, which is why there was an emphasis on traditional micro-drainage practices, defined by the primary network of pipelines (CARNEIRO & MIGUEZ, 2011). Despite the provision of infrastructure for the housing complexes and private subdivisions, the implementation of micro-drainage and adjacent road paving was limited, and the interstices between the complexes were informally occupied, with neither public support nor compliance with legislation.

The watersheds in the Belém expansion area also have a high population density. The Paracuri and Mata-Fome watersheds are the most densely populated, from among those fully located in the expansion area, and are mostly occupied by precarious settlements in terms of access to infrastructure (PEREIRA, 2008).

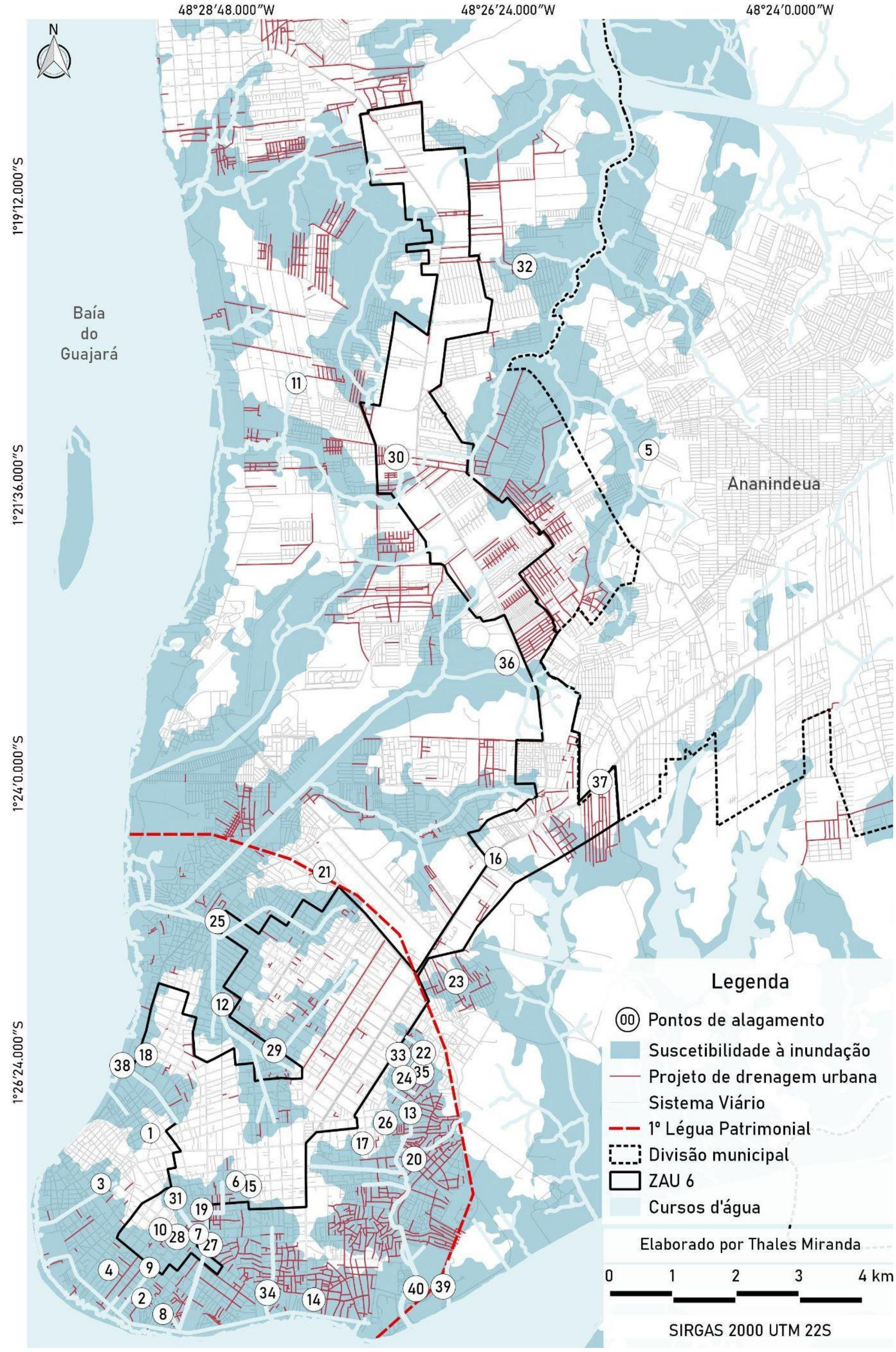
Figure 04: Location map of the watersheds in the municipality of Belém.



Fonte: Codem (2014), IBGE (2020).

It may be observed that, in Belém, flooding is aggravated by the tidal regime, and the flooding is a consequence of a deficient, insufficient and inadequate drainage network unable to support the volume of water to be drained, both in the center and on the periphery (MIRANDA, 2020). Figure 5 presents the flood areas in the city of Miranda (2020). With the signaling of areas served by a drainage network, flooding goes beyond the floodplains (lowlands) and floods upland areas, but is more severe in areas with less infrastructure and a higher concentration of poor people.

Figure 05: Flood susceptibility chart for the territory of Belém with flooding points for March 2020.



Source: Miranda (2020: p. 152).

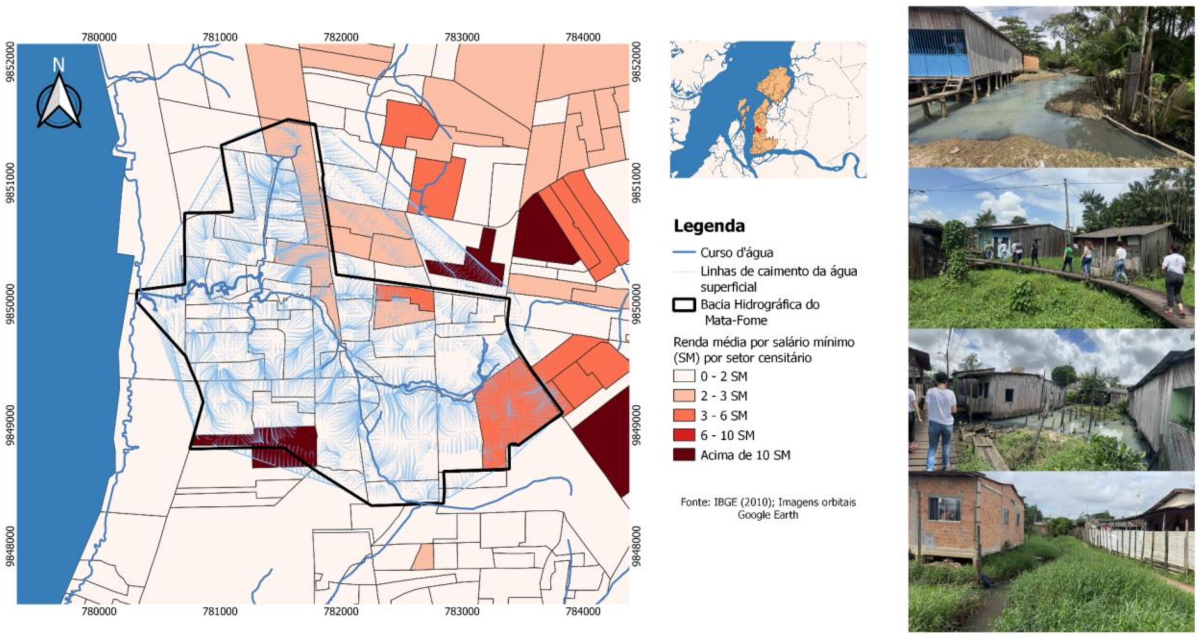
In this context, it is clear that infrastructure solutions and, especially, sanitation solutions, need to be planned in order to integrate social and environmental processes, particularly with regard to urban rivers. Conventional infrastructures are neither efficient nor adequate, and contribute to reinforcing the socio-environmental inequalities observed in the area, from the perspective of climate change and urban resilience. Integrated solutions, which valorize the potential of the natural landscape, people's relationship with this landscape and their housing culture, are more suitable for managing rivers in an urban context, and there is an urgent need to return the infiltration capacity to the soil through technologies based on nature (NEU, 2022).

3.2 Characterization of the Mata-Fome Watershed

The Mata-Fome Watershed presented a typical occupation of the expansion area of the MRB. In fact, its name refers to the first riverside occupations that used water as a source of food (SILVA & LUZ, 2016). This was a forest area that became reduced by the advance of informal land occupation and the consolidation of a low-income neighborhood.

The watershed is delimited to the west by Guajará Bay, and borders the Cajé watershed to the north, Val-de-Cans, to the south, and Maguari, to the east. It has an area of approximately 6.6 km² and a population of 66,418, according to the IBGE census (2010). It is made up of 5 river channels, with the main "channel" having the same name as the watershed (the Channal, and no longer the river, Mata-Fome) with its source close to Avenida Augusto Montenegro and a water flow in a West-to-East direction, towards Guajará Bay. Two channels to the north flow in a north-south direction into the main channel, and two channels to the south, whose sources are located in institutional areas, flow into the waters of Guajará Bay (SILVA & RODRIGUES, 2019). The socioeconomic profile of the area is mostly of poor families (with incomes of up to 2 minimum salaries), followed by varied socioeconomic profiles of housing complexes and private enterprises in the area (Figure 6).

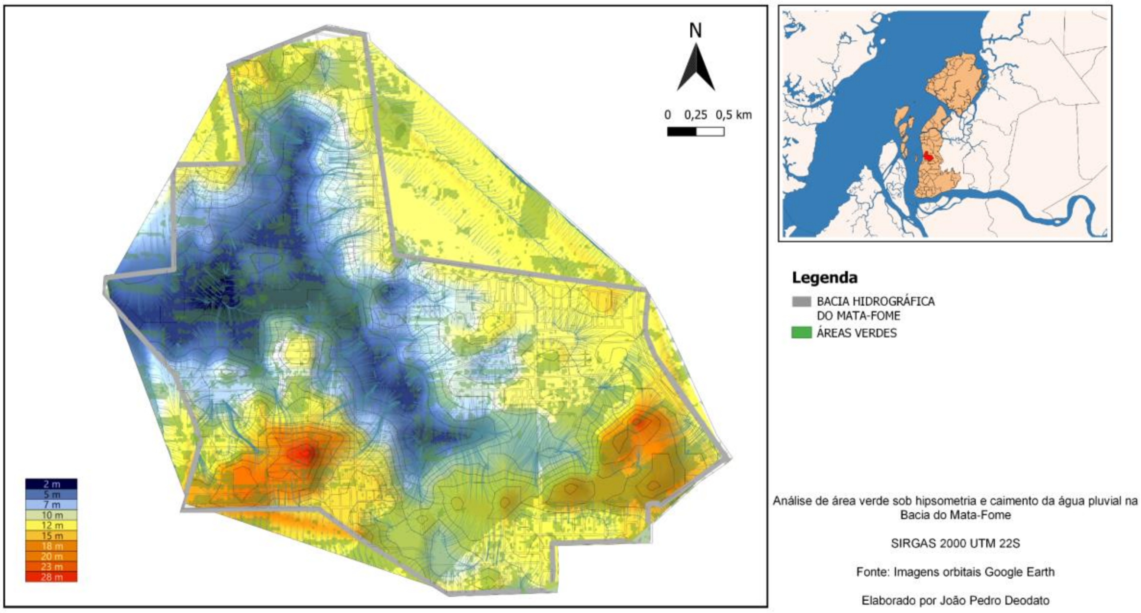
Figura 06: Flood susceptibility chart for the territory of Belém with flooding points for March 2020 and records of the current land occupation of the floodplain with stilt houses and planks.



Source: IBGE (2010) and modelling of water drop in the Rhinoceros 3D program. Own elaboration (2022). Photographs: Authors, April 2023.

In the area, there are different types of land occupation: stilt houses, buildings on pilotis, and masonry houses. In terms of use, in addition to individual housing, there are medium-sized commercial and service uses and housing subdivisions. Silva and Rodrigues (2019) identified that between 2006 and 2018, the vegetation cover in the Mata-Fome Watershed was reduced by 13%. They indicated that, although there are large green areas in the watershed, the environmental quality oscillates between medium and low, because these areas are inaccessible and insufficient for the population. The existing green, permeable areas are concentrated in the institutional areas, and the areas of lower altitude are impermeable (Figure 07). According to Carmona (2010), there is no riparian forest in the areas close to the banks of the Mata-Fome *igarapé* (creek), due to the land occupation of the floodplains and floodplain areas, which promotes erosion and silting along the entire margin.

Figure 07: Analysis of the green area and the rainwater drop path with hypsometry in the Mata-Fome watershed.



Source: Own elaboration (2022).

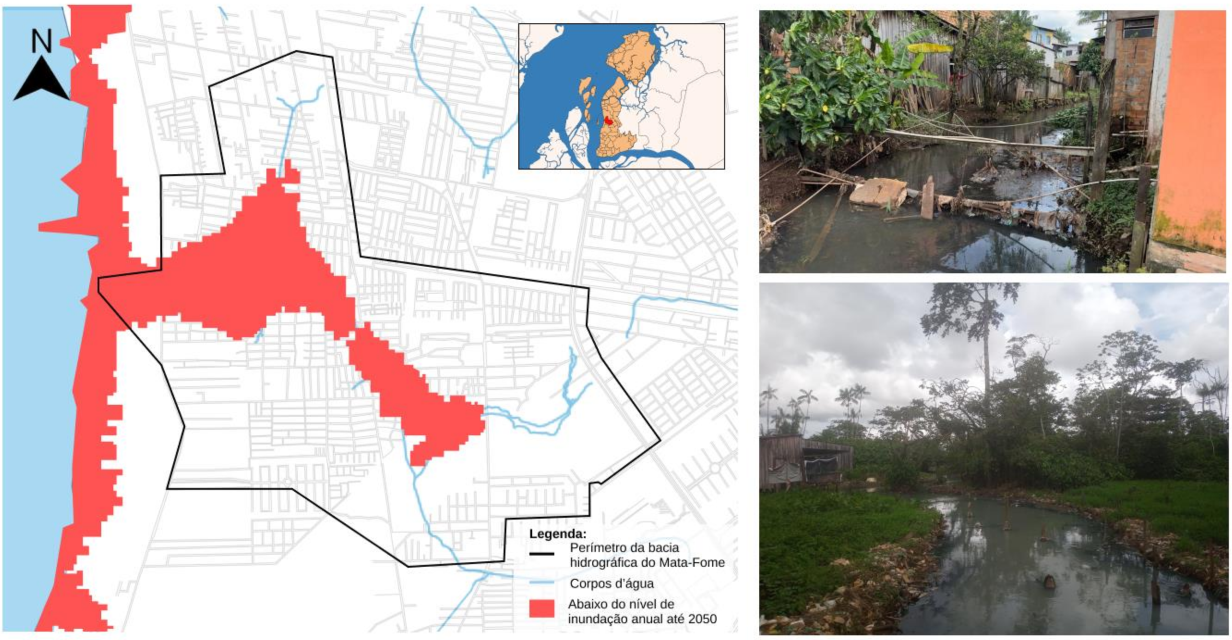
Currently, the flow of rainwater runoff in the watershed, accomplished with micro-drainage, leaves the areas of higher altimetry levels toward the lower levels (Figure 7). This movement is natural, but it is hampered by the lack of vegetation and permeable areas in the lower areas, which potentiates the negative effects of climatic events and poses a risk to residents. As a result of the lack of investments in infrastructure, the soil, rivers and the Mata-Fome *igarapé* are polluted because of garbage and domestic sewage being thrown into it and also the existence of artesian wells with no sanitary protection. The situation is further aggravated by the lack of garbage collection, which pollutes the rivers and obstructs the flow of rainwater, thereby expanding the natural flood areas (CARMONA et al., 2010). As a result, 70% of medical consultations at health centers are due to diseases associated with a lack of basic sanitation and ingesting contaminated water, unfit for human consumption (CARMONA et al., 2010).

Miranda (2020) demonstrated that there was a correlation between socio-environmental inequalities in the MRB and flooding, race and class, and that injustices and socio-environmental racism are intrinsic to the socio-spatial dynamics of Belém. In the Mata-Fome Watershed, new housing solutions have been imposed, without considering the needs of the riverside community and the practice of urban agriculture. Both the way of living on stilts, and the way of producing from land management, should be included in the official characterization of the area, and not rejected as being inappropriate practices.

3.2.1. Projections and impacts of climate change in the Mata-Fome watershed

The Climate Central platform (2022) has developed dynamic maps for different levels of pollution, temperature increase and rising tides according to the projections made by the IPCC (2022) in relation to climate change. For the Mata-Fome watershed, the projection is that the area with the lowest altitudes (Figure 7) will be submerged if there is a global temperature increase of 1.5°C, thereby permanently flooding what today represents the flooding point (Figure 8).

Figure 08: Simulation of land that will be below the annual flood level by 2050 and current conditions of improvised water supply pipes.



Source: Climate Central (2022). Photographs: Authors, April, 2023. Own elaboration, 2023.

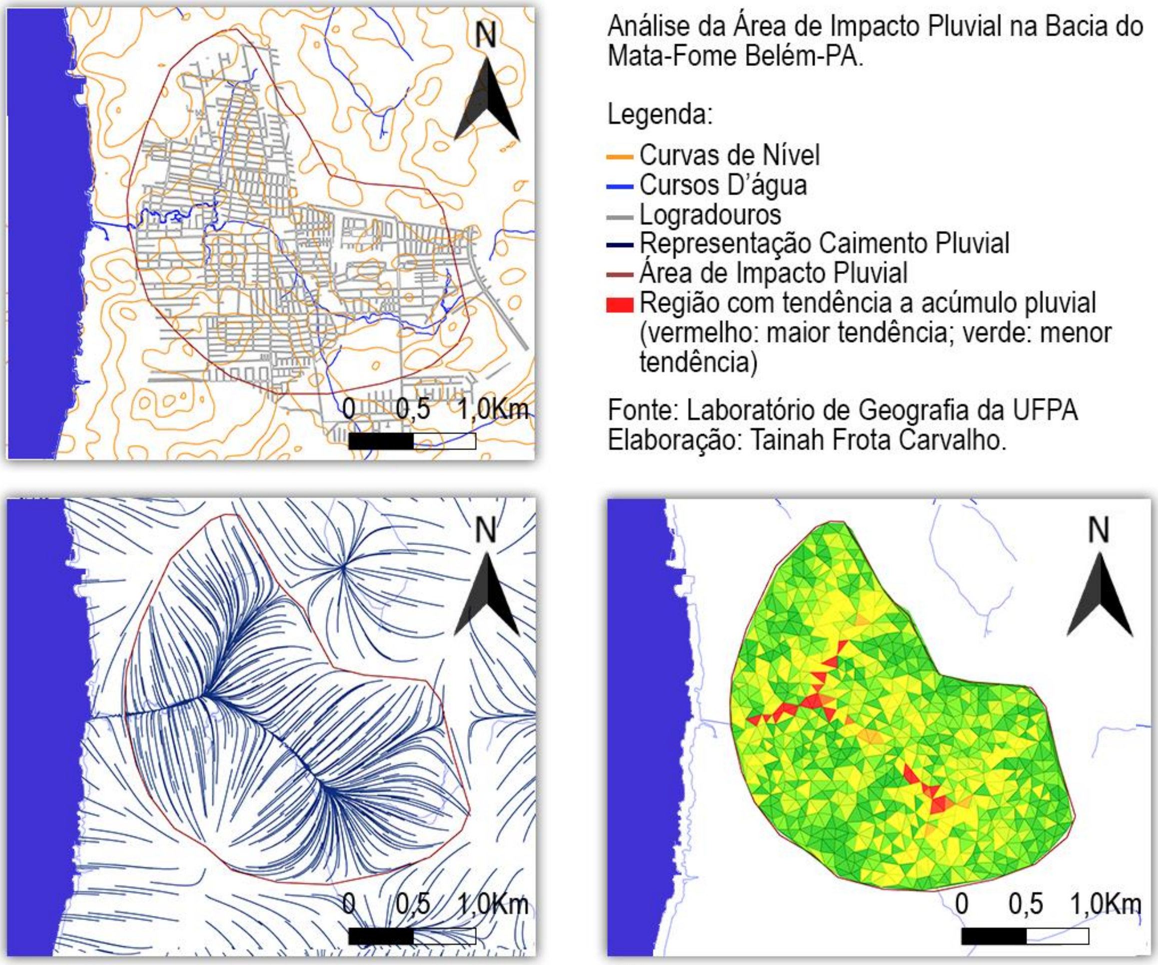
Given this trend, the lack of vegetation cover, pollution in urban rivers and the lack of ecosystem services in the region will exacerbate the risks associated with climate change in the watershed. Thus, populations that currently suffer from a lack of urban infrastructure, basic sanitation, diseases caused by water contamination and neglect of their socio-environmental relationships will be subject to greater socioeconomic vulnerability and environmental injustice, and will be disproportionately affected due to their socioeconomic conditions.

Meanwhile, according to the forecasts of tide tables made available by the Brazilian Navy (2022) for Belém in 2023, the occurrence of maximum tidal altitudes of up to 3.6m will continue. Based on 3D modeling, it is calculated that the accumulation of a volume of water of 2.42 x 106m3 will be absorbed by the Mata-Fome River, thereby increasing the flooding of its floodplain. This fact highlights the importance of the contribution of high tides to the design of solutions for the periodic flooding observed in the Mata-Fome watershed.

3.2.2. Rainfall analysis of the Mata-Fome watershed

The rainfall analysis of the study watershed delimits the rainfall impact area on the rivers, or the region that contributes to the occurrence of floods, which may or may not extrapolate the official planning areas. The modeling resources, processed through a geometric simulation algorithm of the water behavior on the land in question (through its level curves), generate a graphical representation of the rainfall and spatialization of the vulnerability gradient (Figure 9).

Figure 09: Analysis of the Rainfall Impact Area in the Mata-Fome Watershed

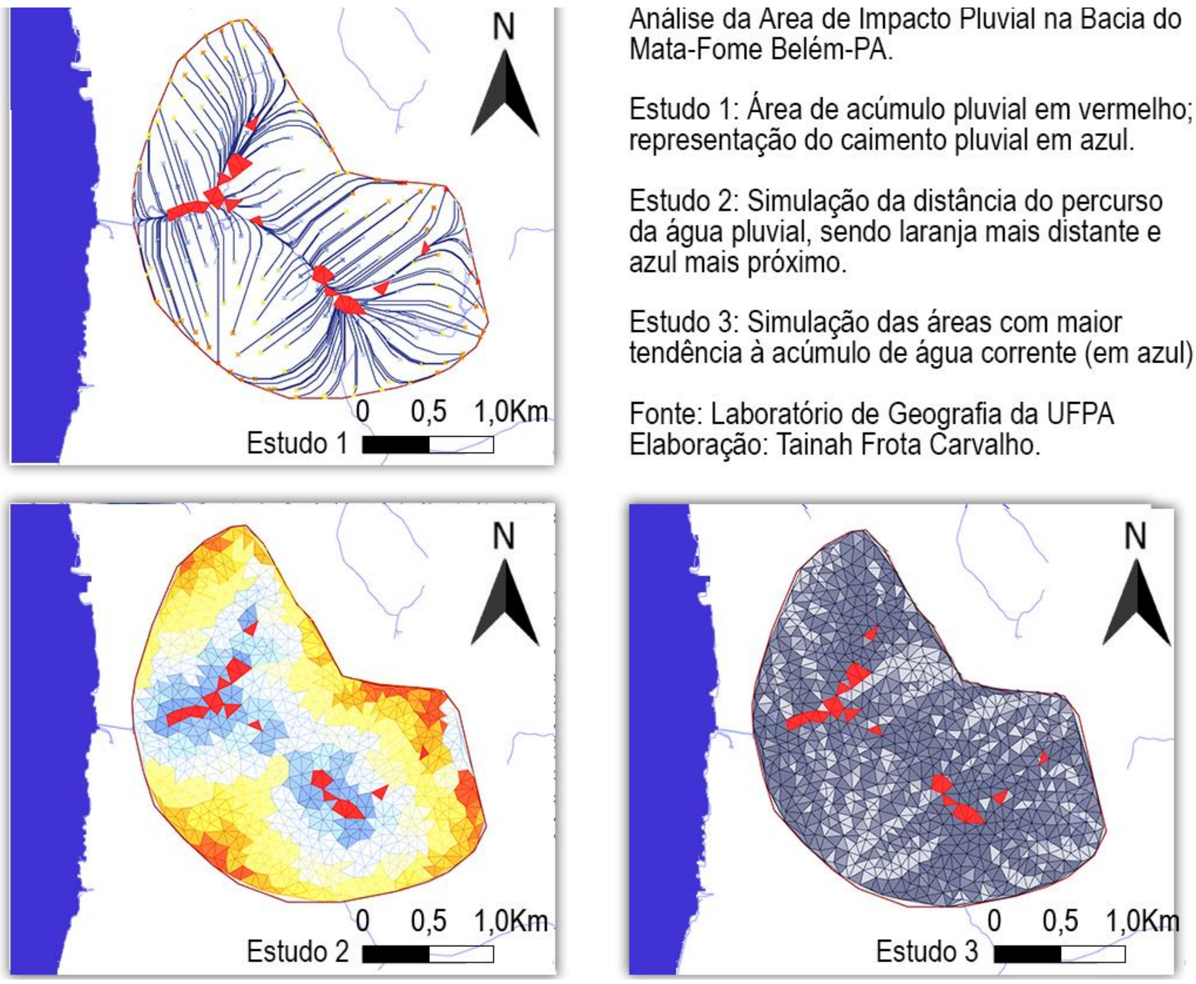


Source: Laboratório de Geografia at the Universidade Federal do Pará (UFPA) and the rainwater drop modeling in Rhinoceros 3D. Own elaboration (2022).

After delimiting the area of rainwater accumulation, a second sequence of simulations was carried out to delve deeper into the impact area. The water drop analysis was detailed to enable the extraction of different numerical and spatial information, for more precision in aiding decision making (Fig. 8). In this step, representations were generated that inform the distances that the water has to run to the river. For example, the maximum distance covered from the brightest orange triangles to the river is 1,310m.

Another relevant piece of information is where there is a tendency for water to accumulate on the path taken from the point of fall to the watercourses. In Study 3 (Figure 10), triangles with a darker blue hue indicate where water tends to accumulate — this visual data is useful so as to better understand what would be the ideal location for installing equipment/infrastructure solutions.

Figure 10: Analysis of the Rainfall Accumulation Area in the Mata-Fome Watershed.



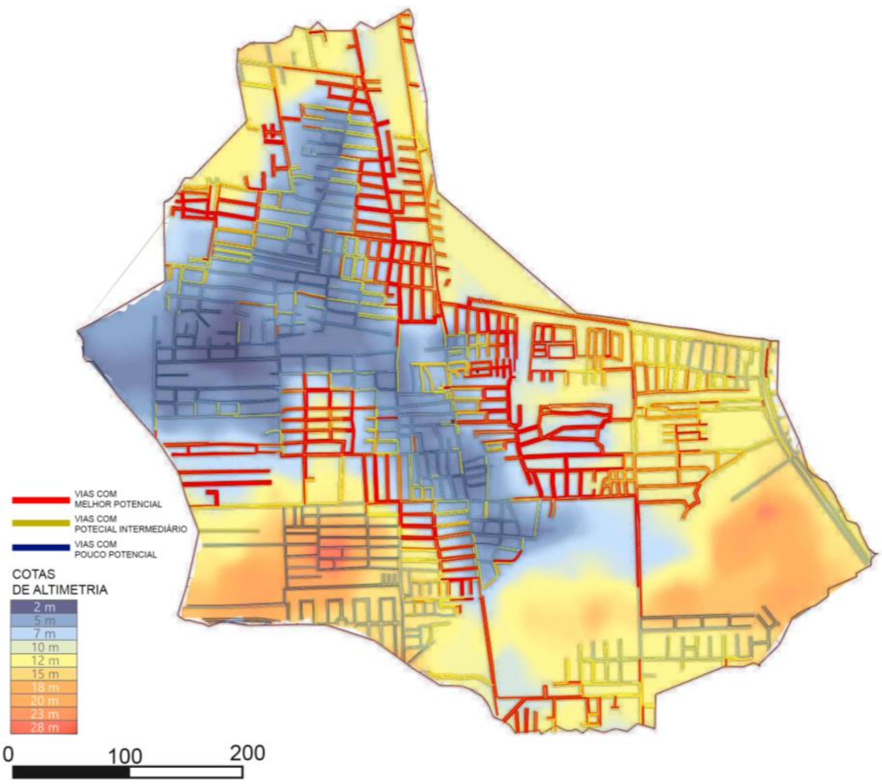
Source: Laboratório de Geografia at UFPA and the rainwater drop modeling in Rhinoceros 3D. Own elaboration (2022).

The modeling also generates the empirical equation to calculate the surface runoff in the studied impact area (Equation 1). The equation enables the volume to be calculated of the reservation or absorption demand of this water through the infrastructure equipment and results in a value in liters per hour (SILVA et al., 2013). The impact area has about 5,019 km2. The runoff rate (f) was defined for a return period of 100 years, i.e., 100 years is the average interval in which precipitation greater than or equal to 180mm/h is expected to occur, in the case of Pará, according to Souza et al., (2012). The result obtained is 6.32 · 108 L/h, and this value is used as a basis for calculating the absorption capacity of infrastructure equipment.

$$R = \frac{(A \times \alpha \times f)}{\Delta t} \quad (1)$$

In addition, an algorithm capable of analyzing the potential for implementing green infrastructure for each route, street or avenue present in the study area was used, taking as a criterion its efficiency in water retention capacity. The algorithm used data and inputs to develop a multicriteria analysis capable of understanding aspects of the complex urban fabric, which are spatialized in Figure 11. The results marked in red indicate the routes that would be more effective to receive green infrastructure, considering topographical and morphological aspects of the city, while yellow represents the routes with intermediate potential and, in blue, the routes with low efficiency in the implementation of green infrastructure. This algorithm has a complex analysis structure, which uses georeferenced data to generate analyzes from a 3D modeling of the city. Thus, it becomes possible to understand and compare the degree of efficiency that a green infrastructure equipment could achieve when it is implanted in a certain place to the detriment of the system.

Figura 11: Analysis of the Potential for Implementing Green Infrastructure in the Mata-Fome Watershed.

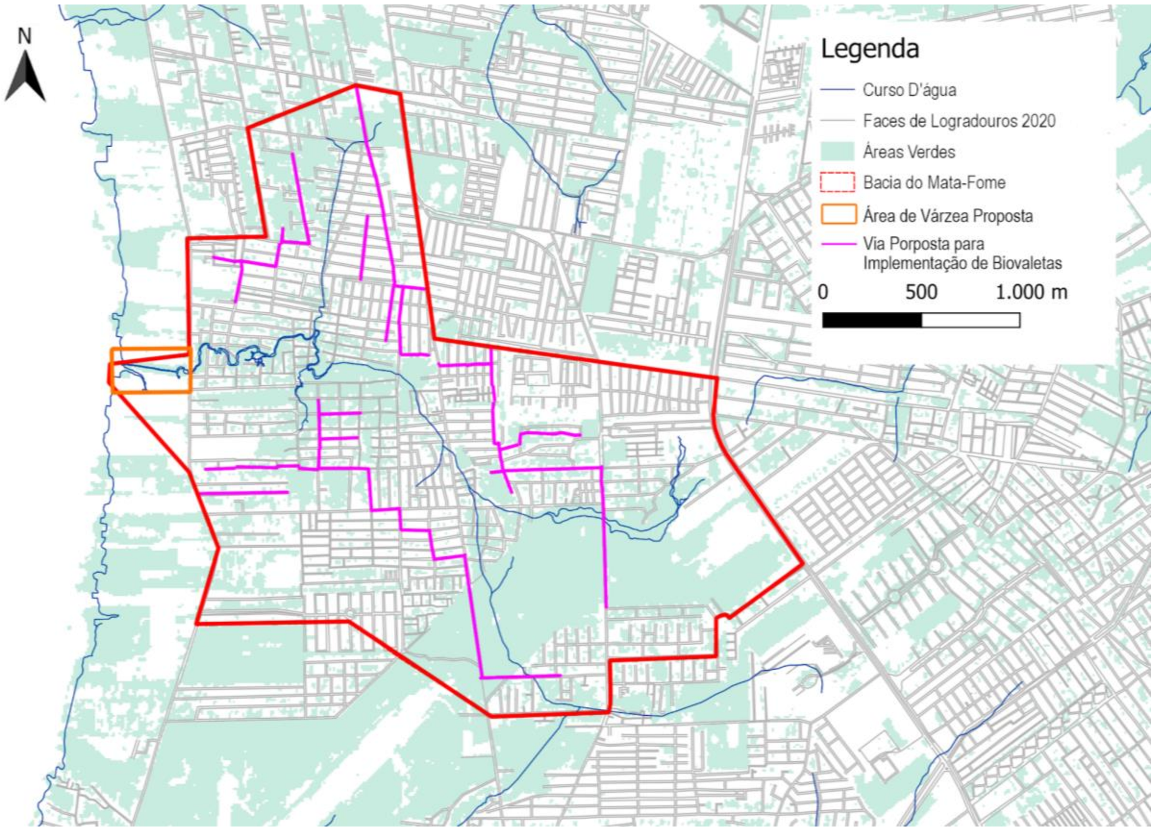


Source: Laboratório de Geografia at UFPA, and rainwater drop modelling with Rhinoceros 3D. Own elaboration.

4. Action proposals

In view of the above, some routes were chosen as being key for intervention, due to their size, extension and distribution along the area of rainwater impact, making them, in turn, ideal for implementing bio-culverts (Figure 12). Currently these routes are quite arid, they have sidewalks of minimal width, compared to the width of the lanes intended for vehicles. At the point of the studied system, where the *igarapé* meets the bay, there is an opportunity to create a natural floodable space, a retention basin that could absorb part of the water from the tidal flood. Thus, it will be possible to maintain the historical characteristic of the floodplain area, valorizing it as a natural resource.

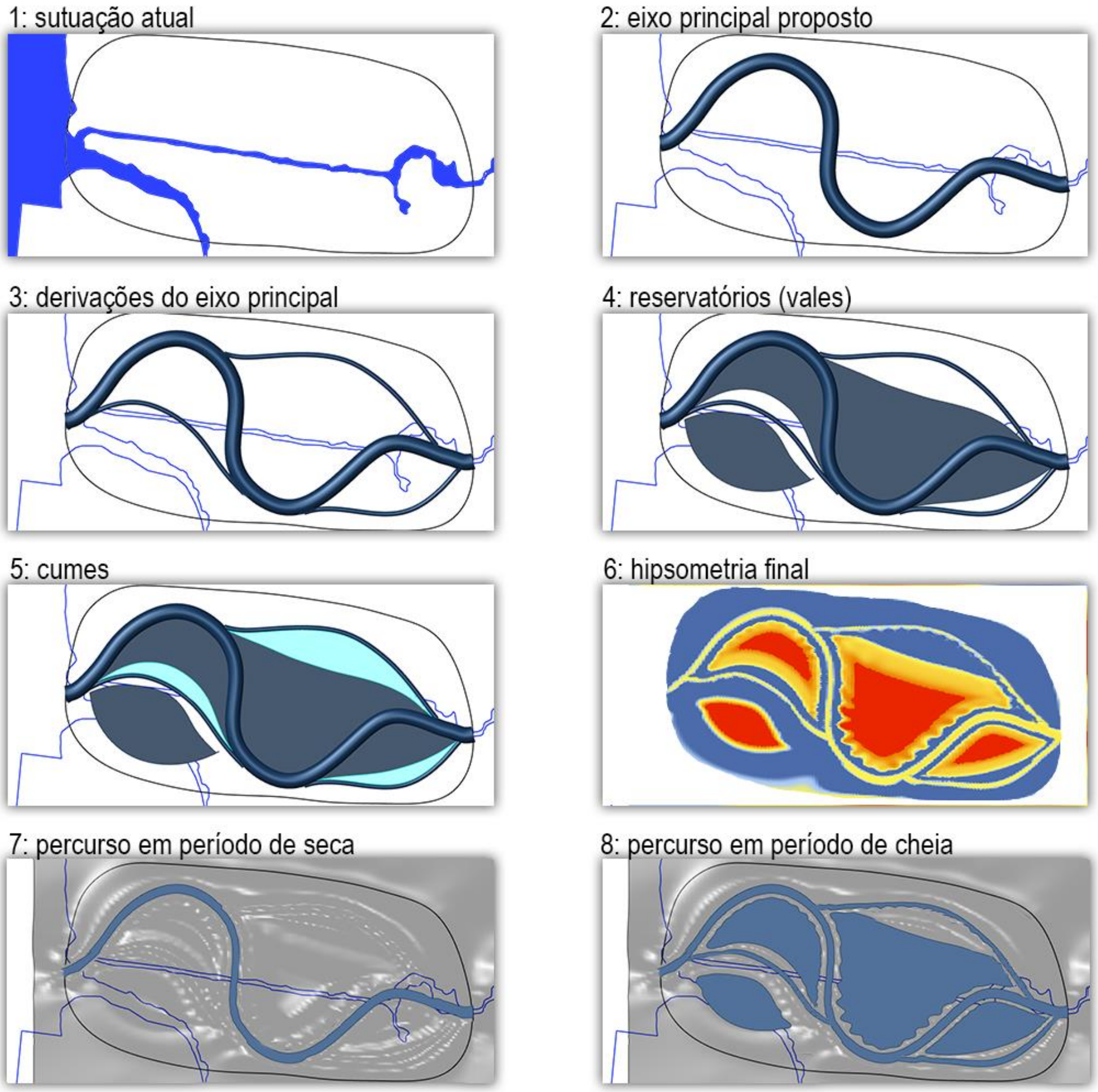
Figura 12: Indication of the intervention routes, marking of the bio-culverts and the proposed floodplain area



Source: Laboratório de Geografia at UFPA. Own elaboration (2022).

Figure 13 details the step-by-step process for delimiting the retention basin (proposed floodplain area, in Figure 13). The artifice capable of delimiting the place of water, part of a main axis (a rectified water body), which currently connects the inlet and outlet points of the water. The modeling carried out with LIM methodology (MOURA et al., 2018) detected the existence of valleys, parallel to the main water body, which could accumulate rainwater. It is possible to plan the use of these valleys in such a way as to prevent the water from invading the community, and induce the formation of a sinuous hybrid body, which will respect the topography of the territory, and that, together with the sources of the waterways, will provide retention for the depth of water and the balance between green infrastructure and gray infrastructure, before the main avenue of access to the studied area. Such green infrastructure will retain part of the water from high tides in the region and will also provide a scenic appeal.

Figura 13: The step-by-step design of the retention basin within the algorithm. 1.Illustration of the current body of water; 2. Illustration of the proposed main body of water to create space for reservoirs; 3. Smaller-scale sources of the main axis (small-scale watercourses); 4. Demarcation of areas for creating reservoirs (in which excess water will be retained during the flood season); 5. Demarcation of areas to create “ridges” to help retain water in “valleys”; 6. Final hypsometry (red for lower levels and blue for higher levels); 7. New *igarapé* proposed in the dry season; 8. Scenario for the *igarapé* in the flood period with occupation of the reservoirs.

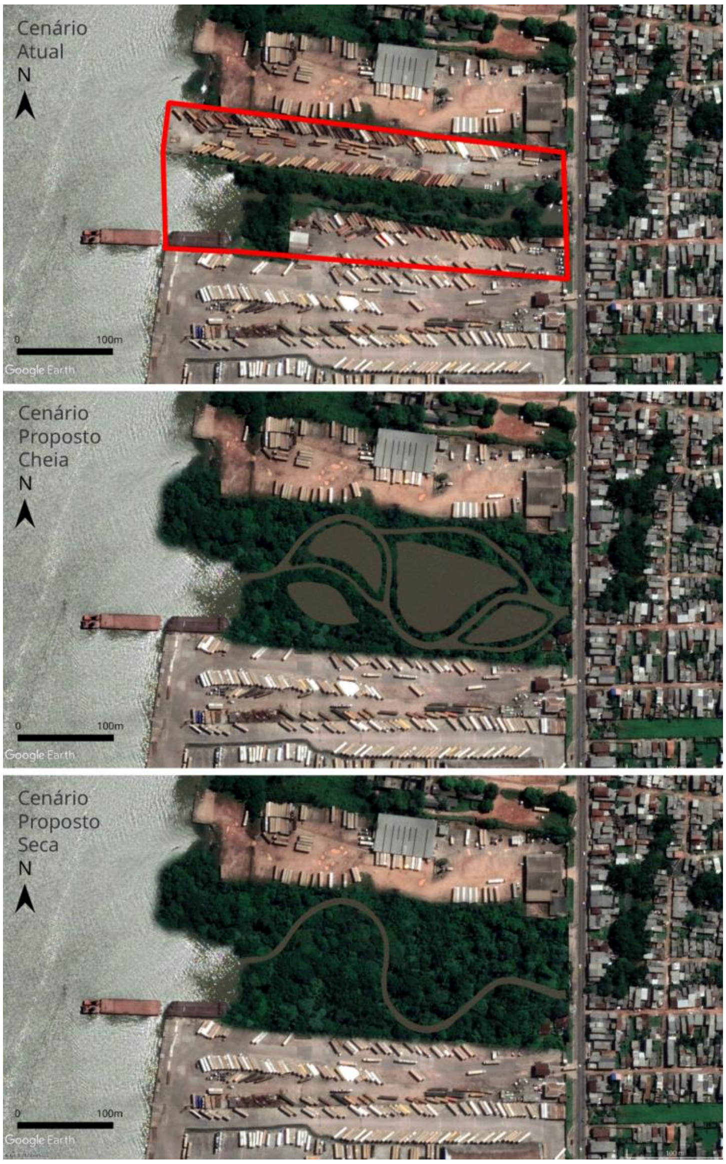


Source: Own elaboration in Rhinoceros 3D (2022).

In Figure 14, the area with potential for creating a retention basin corresponds to the green void. The green infrastructure will be a reservoir with an absorption capacity of 124,486m3 in the flood season, and will have the appearance of a common *igarapé* the dry season.

An intervention such as this would be carried out without the use of concrete or soil sealing the site, maintaining the natural capacity of the land to absorb and to dry out water. The key points are channeling the water to the tributaries and modeling the terrain, since the studies provided by the algorithm indicate that, naturally, the system will work with no major complications, given that it respects the natural behavior of the variables in action.

Figura 14: Images illustrating the intervention during the flood period.



Source: Google Earth, own editing (2022).

5. Final considerations: beyond the design

The production culture of the cities that make up the MRB has rejected the characteristics of their sites and framed the landscape from the production perspective of rationalist cities. This logic should be revised and modified so that local practices are resumed, which are better adapted to the site, and that have a greater capacity to withstand the climatic emergencies that have already impacted the climate, temperature and tides around the world. Thus, the lessons of urban ecology, in defense of a more integrated view of the layers that constitute cities, will be crucial for facing the changes foreseen by the IPCC (2022). The MRB will be strongly impacted by the increase in temperature, changes in the rainfall regime and the advance of the tides and, for this reason, the social agents involved in the management of the city must seek ways in which to make it more resilient. This depends on a change in the way that urban planning understands nature, and on assimilating the fight against socio-environmental inequalities, historically established in this territory, to become part of its goals.

The intervention for the Mata-Fome watershed should be didactic regarding the need to plan the city based on watersheds, and assuming that the reason for these interventions not only involves physical processes, but also social requirements, since the ways of living and producing for certain social groups need to adapt to that landscape. The low income of the population may be compensated by the possibilities of food production and access to resources such as the river and vegetation, which depend on maintaining the natural characteristics of the landscape, as well as its depollution. This exercise needs to be expanded based on dialogue with the population, through discussion strategies regarding tools and technical solutions.

The study of the watershed offers the possibility of a multiscale understanding of the biophysical base of the city, and 3D modeling facilitates the visualization of drainage processes, the main local factor of vulnerability and risk. The superposition of this physical information onto layers of cadastral data, on land use, the conditions of land occupation (typologies) and mobility, enables an understanding of how the speed and volume of water flows are related to everyday life, and thus define acceptable limits for both the ecosystem and the inhabitants. The ideas presented herein help the public sector to make decisions involving the possibility of migrating technologies adopted during the twentieth century to a promising technical repertoire in the twenty-first century, which has been little adopted in the city.

The proposals seek to avoid earthworks and channeling the rivers and to encourage chains of solutions, such as phytoremediation and basic sanitation actions compatible with the conditions of occupation, in order to decontaminate the waters and the resume the activities of the riverside population, which depend on a living river, with the ultimate goal of preventing the disappearance of its practices in an Amazonian metropolis. This approximation would also generate social developments mediated by the landscape, since the possibility of interaction with the waters and with vegetation areas has a strong appeal for the population of Belém, and could create new forms of generating income for the inhabitants of the Mata-Fome watershed.

Modeling may also help in urban control, revealing the interactions between high areas and low areas, since the water contribution involves distances greater than one kilometer, and this directly links occupation typologies and income profiles. Soil sealing in a backyard or the removal of green areas is in the interest of a much larger population than whoever occupies a given plot of land.

It is hoped that this article has demonstrated that computational technologies are able to assist in decision-making on the complementary action of social and physical technologies, and that modeling is able to broaden current environmental understanding, demonstrating that solutions based on nature may also be associated with low-impact economic activities, which were once very common in the floodplains, such as urban agriculture. The time has come to break with the culture established by the alignment plan (Figure 1) and with the concepts of sanitation developed during the twentieth century, which only "solved" certain specific problems, while reinforcing the rejection of nature (the site, rivers, urban forests and biodiversity flows) and the socio-environmental injustice imposed on the low-income layers of the city.

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