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Nature-Based Solutions in integrated drainage and climate change mitigation projects in the city of São Paulo (Brazil)

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ABSTRACT

The results of the floods in the city of São Paulo cause serious problems to society that tend to be aggravated by the effects of climate change. Thus, the design of urban drainage works plays a central role in mitigating these problems. Gray infrastructure is the traditional drainage mechanism usually employed. Nature-Based Solutions are alternatives to traditional solutions that value green and blue infrastructure in cities. This research aims to discuss the synergy between the proposition of Nature-Based Solutions as planning actions to face floods and actions to face climate change adopted by the city of São Paulo. In order to do so, a documentary analysis of the Drainage Guidelines and the Climate Action Plan, technical documents that address the planning of urban drainage in São Paulo, was carried out. It was found that the insertion of NbS associated with the traditional projects of the Drainage Guidelines can contribute to achieving the goals proposed by Planclima-SP, as well as bringing multifunctional benefits, generating resilience and sustainability with regard to urban water management.

KEYWORDS: Nature-Based Solutions. Urban Drainage. Climate Changes.

1 INTRODUCTION

The city of São Paulo faces major flood challenges due to the accelerated urbanization process, which is a characteristic of big cities (COSTA and ROCHA, 2019).

According to the urbanization historical analysis in the city, challenges related to rainwater drainage have been recurrent since 1560, with records of intense precipitation and flooding, causing financial and mobility losses (ACSP, 2014). Different spheres of society suffer from flood impacts, greatly affecting vulnerable populations from areas subject to floods and landslides (VALVERDE, CARDOSO and BRAMBILA, 2018).

Urban planning and rainwater drainage projects must be simultaneously developed (COSTA and ROCHA, 2019). Urban areas with drainage systems are traditional engineering works, called gray infrastructure, which aim to remove rainwater from urban environments and combat flooding. Bezerra et al., (2020) elucidate that traditional drainage systems do not take advantage of the soil absorption potential, contributing to hindering water surface runoff. Solutions on conventional drainage need to be integrated with other measures capable of working together in order to ensure greater drainage system effectiveness (DEPIETRI and MCPHEARSON, 2017).

Thus, Nature-Based Solutions (NbS) have been representing a concept to integrate a series of approaches that use ecosystem potential to face the growing society challenges, including urban drainage (BUSH and DOYON, 2019). NBS are also associated with green and blue infrastructure, corresponding to different typologies of green areas (parks, trees, gardens) and blue areas (watercourses) (KABISCH et al., 2016).

NbS are solutions established in cities aiming at highlighting green and blue infrastructure with the intention to deal with urban challenges intensified with the climate change effects, such as increased flooding, long drought periods, heat islands, etc. Establishing NbS in the urban environment contributes to increase the resilience of cities and the adaptive capacity to face climate challenges (COHEN, 2016; HAASE, 2021).

In an attempt to compensate and mitigate the urban flooding effects, NbS can work along with the Compensatory Drainage measures through projects that involve sustainable practices (OLIVEIRA, BARBASSA and GONÇALVES, 2016). Throughout the globe, these practices

have been gaining prominence for resulting in economic, social and environmental benefits when associated with common urban drainage systems (EMILSSON and SANG, 2017).

Decision makers have noticed challenges the city of São Paulo has been facing on climate change and floods. Thus, São Paulo has developed technical documents, the Watershed Guidelines or Drainage Guidelines (SIURB and FCTH, 2022) and the Climate Action Plan (PlanClima, in Portuguese) (COSTA AGUIAR et al., 2021), which proposes projects, goals and actions to mitigate floods as well as improving hydraulic projects. Rolo et al., (2021) highlight the sustainable urban drainage as a type of NbS to deal with climate change.

This research aims to discuss the strategy the city of has São Paulo adopted to face climate changes, that is, the synergy between the propositions of Nature-Based Solutions as planning actions. Therefore, to verify the sustainable drainage practices associated with Nature-Based Solutions, we analyzed the planning documents of the city, related to urban waters.

2 SOLUTIONS FOR FACING URBAN FLOODS

This section shows a brief characterization of traditional approaches to urban drainage, known as gray infrastructure; Nature-Based Solutions approaches, which also represent green and blue infrastructure; and compensatory drainage measures.

2.1 TRADITIONAL APPROACHES FOR DRAINING RAINWATER

Brazilian cities, such as São Paulo, adopt traditional drainage measures towards rainwater management. These measures refer to projects mostly related to the use of resistant and/or concrete materials, which seek to mitigate the impacts caused by excessive precipitation in urban centers (DAVIS and NAUMANN, 2017).

Traditional measures look for promoting the rapid removal of rainwater and include micro drainage and macro drainage systems (CANHOLI, 2014).

Micro drainage systems act as the inlet device of drainage systems and are responsible for conducting water to the macro drainage system. They include mechanisms such as rainwater galleries, storm drains, connecting pipes, street gutters and curbs (SMDU, 2012). In turn, macro drainage systems address larger dimensions such as channels, reservoirs, rainwater galleries (SMDU, 2012).

Depietri and McPhearson (2017) reveal that due to extreme events, traditional drainage approaches may not be sufficient to deal with floods and the aggravations caused by climate change.

According to the Intergovernmental Panel on Climate Change report (IPCC, 2018), between 2021 and 2040 there will be a warming of 1.5 ºC in pre-industrial temperatures worldwide. Furthermore, Marengo et al., (2020) reveal precipitation increases over the last 20 years in São Paulo, evidencing the IPCC's perspectives on more intense rain in the coming years, followed by longer drought periods in the cities.

2.2 NATURE BASED SOLUTIONS

Nature-Based Solutions (NbS) refer to a set of solutions inspired and supported by nature aiming at dealing with social challenges such as those extreme events generate, seeking to instigate human well-being and verify ecosystem benefits. NbS actions include ecosystem protection, management and restoration measures, whether natural or modified (COHEN, 2016).

NbS bring multifunctional benefits when implemented in cities, for positively influencing environmental, economic and social aspects (MARTINS et al., 2020). Table 1 shows some NbS practices that cities may include in urban planning, contributing to flood reduction.

Table 1 - Description of NbS.

NbS Practices	**Description/Benefits**
Green roofs	Roofs cover about 40 to 50% of impermeable areas in cities; constructing roofs made of vegetation increases permeable areas in large cities, promoting practices. This constructive system results in some benefits such as flood reduction, aesthetic and energy efficiency improvements in buildings, biodiversity increase and heat islands reduction (SHAFIQUE, KIM and RAFIQ, 2018; PORTO *et al.,* 2018).
Green gutters	It refers to "a shallow depression with soil prepared for planting several species, sized to receive a small area runoff" (SOUZA, CRUZ and TUCCI, 2012). Vegetation is usually placed in its vicinity; it is interesting due to existing vegetation and microorganisms that contribute to pollution removal of cities, as well as rainwater control. It is a mechanism that can be placed into individual lots or parking lots; it also works as landscaping approaches for housing or multihousing projects. (HINMAN and WULKMAN, 2012).
Urban agriculture	As a social function to inactive land, community vegetable gardens promote income and food security. This NbS system promotes water infiltration and storage and fosters biodiversity and the economy of cities (EVERS *et al.,* 2022).
Linear parks	These are continuous sets of green spaces along landscape elements such as rivers, streams and streets. They contribute to rainwater storage in periods of intense precipitation, as well as promoting green areas increase, thus generating leisure areas (EVERS *et al.,* 2022).

Source: Own authorship.

NbS contribute to reducing vulnerabilities, increasing urban resilience and improving the population quality of life for contributing to the challenges caused by increased temperatures and floods (EMILSON and SANG, 2017).

2.3 COMPENSATORY DRAINAGE MEASURES

Rainwater compensatory drainage means technologies with less constructive complexity than traditional systems and with lower environmental impacts, which aim to improve rainwater retention and infiltration, thus reducing the investments for urban traditional drainage mechanisms (OLIVEIRA, BARBASSA and GONÇALVES, 2016).

These measures are little widespread in drainage projects and look for compensating or mitigating the urban flood effects in cities. There are measures specific for gray works, for not being part of the green infrastructure, such as micro reservoirs built in lots and buildings, as well as permeable pavements (CANHOLI, 2014).

However, these compensatory measures gain strength when combined with NbS practices in which constructing green roofs, green gutters, urban agriculture, among others, are interesting for urban drainage purposes (CANHOLI, 2014).

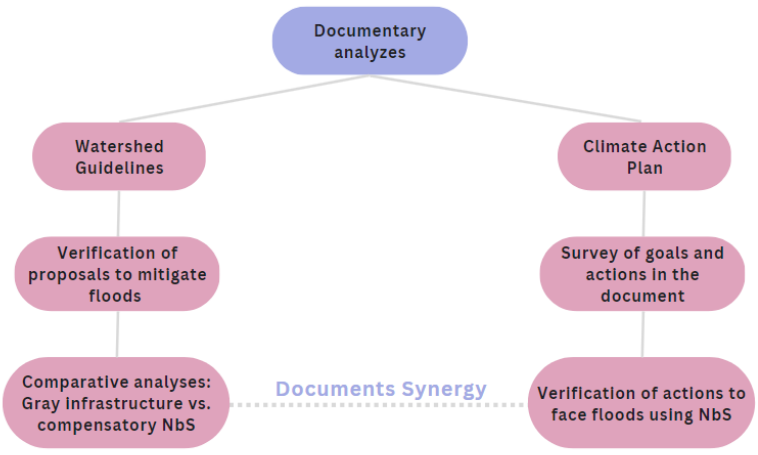
3 METHODS

This research has methodological procedures based on documentary analysis. According to Junior, Oliveira and Schnekenberg (2021), the idea of a documentary analysis is to provide crucial information to unravel the research issue of a scientific discussion and bases on the understanding of various documents that should provide a framework and foundation for the study.

Thus, it must consider the context and usefulness of the analyzed documents, based on intense archive verification, providing interpretations and complements to the research (JUNIOR, OLIVEIRA, SANTOS & SCHNEKENBERG, 2021).

The documentary analysis was on the 12 Watershed Guidelines prepared by the Municipal Secretariat of Urban Infrastructure and Works (SIURB) and the Technological Center of Hydraulics Foundation (FCTH) and the Climate Action Plan developed by the city hall of São Paulo. Figure 1 shows the flowchart of the methodological stages.

Figure 1: Organization chart of the methodology.



Source: Own authorship.

3.1 DOCUMENTARY ANALYSIS - PLANCLIMA

The city of São Paulo developed the Climate Action Plan, named Planclima-SP, which addresses the climate change agenda included in the municipal decision-making processes. This document aims at mitigating carbon emissions and climate change impacts, promoting resilience and reducing inequalities by the year 2050, focusing on sustainable guidelines (SVMA and C40, 2020).

In 2016, Brazil and several countries around the world signed the Paris Agreement, which provided subsidies for the Planclima-SP, since, at that moment, the countries made a commitment to encourage guidelines to face climate change in the large metropolises in the world (SVMA and C40, 2020).

Figure 2 shows this document, organized into five main strategies. Each goal reflects 44 specific actions, designed to achieve the objectives of the plan.

Figure 2 - Five strategies of the Climate Action Plan – SP.

Source: Adapted from SVMA and C40, 2022.

According to SVMA and C40 (2022), urbanization occurred so quickly that the city population began to take the place of the rivers. Soon, the city faced significant changes in its natural characteristics, affecting issues related to air humidity, precipitation, rainfall patterns and temperatures. Planclima-SP is geared towards contemplating this perspective.

Strategy 2: "Adapting the city of today to the city of tomorrow" is about urban resilience, reduction of social vulnerabilities and conservation of primordial society functions due to extreme events. Thus, in this documentary analysis of the Planclima-SP we evaluated some actions of Strategy 2 (Figure 2), regarding handling floods using NbS.

In this regard, the criterion addresses measures that foster environmental awareness and education for the São Paulo community, as well as integrating NbS practices into traditional drainage systems (SVMA and C40, 2020).

3.2 DOCUMENTARY ANALYSIS – WATERSHED GUIDELNES

The Drainage Guidelines on Rainwater intend to plan actions to deal with floods through critical watersheds in the city of São Paulo (SIURB and FCTH, 2022).

They were foreseen in the Municipal Plan of Rainwater Management System (PMAPSP), elaborated by the Municipal Secretariat of Urban Infrastructure and Works (SIURB)

in co-participation with the Technological Center of Hydraulics Foundation (FCTH), of the University of São Paulo (USP).

There are twelve Drainage Guidelines, published between 2016 and 2021. Each of them has about two and three measures designed as possible solutions to deal with floods in hydraulic projects in the city of São Paulo.

The software Personal Computer Storm Water Management Model (PCSWWM) simulated each measure, making it possible, from a computational interface, to create projects and tactics for the surface runoff of rainwater in urban regions (ROSSMAN, 2015). Besides the hydrological simulation, the Guidelines also estimated the investment costs of the proposed works, with base values referenced in the years of the documents publication.

The documentary analysis verified the measures proposed in the rainwater drainage plans regarding:

a) Gray Works – Traditional drainage methods, such as channeling, reservoirs and micro reservoirs, dikes etc.;

b) Nature-Based Solutions – Linear parks, green roofs, green walls, green gutters, urban agriculture etc.

4 CONSIDERATIONS AND DISCUSSION

4.1 PLANCLIMA ANALYSIS

Figure 3 shows the actions included in Strategy 2 of Planclima-SP regarding coping with floods using NbS.

The development of the documentary analysis of the Climate Action Plan in São Paulo made it possible to verify actions and goals that seek to integrate NbS within the rainwater urban planning. These actions show that the government recognizes that flood impacts felt by the population can be especially aggravated by the climate change effects.

Action 22 was stipulated for compliance between 2021 to 2032 and addresses the increase in permeable areas in public spaces, both in new spaces and in existing spaces. The purpose is to generate permeable areas by applying NbS, integrating them into rainwater planning, considering practices such as green roofs, cisterns, green gutters etc.

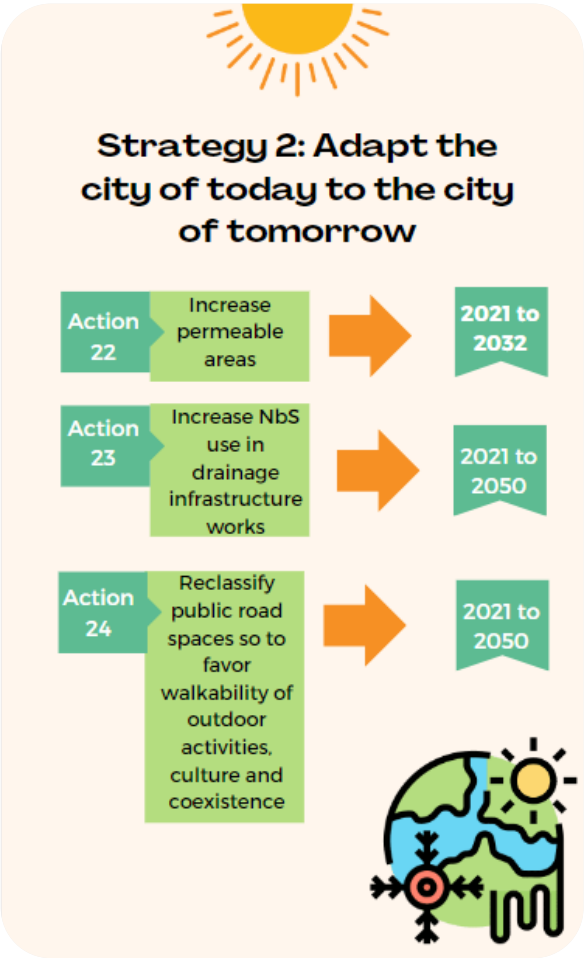
According to the Planclima, guidelines should exist to support the increase in permeability in the city and create a Manual of Sustainable Drainage Solutions, which will cover NbS in an integrated way with existing traditional methods (SVMA and C40, 2020).

In turn, action 23 deals with "Increasing the NbS use in drainage infrastructure works", which addresses the stimulation of ecosystem services in drainage projects. By 2025, there should be a survey of possible places where NbS can integrate into public works (SVMA and C40, 2020).

Action 24 refers to "Upgrading public road spaces in order to favor walkability, outdoor activities, culture and coexistence", advocating afforestation, rain gardens, green roofs and linear parks to instigate recreation, culture and leisure activities for society. This practice

strongly associates with the NbS principles, with regard to promoting biodiversity and quality of life improvement (SVMA and C40, 2020).

Figure 3 - Actions in the strategy "Adapting the city of today to the city of tomorrow".



Source: Own authorship.

The Climate Action Plan outlined in its actions 22, 23 and 24 guidelines aimed at promoting NbS in urban planning, reducing impermeable areas and creating a Sustainable Urban Drainage Guideline. Therefore, it is evident the importance of inserting sustainable rainwater management practices in urban rainwater drainage projects.

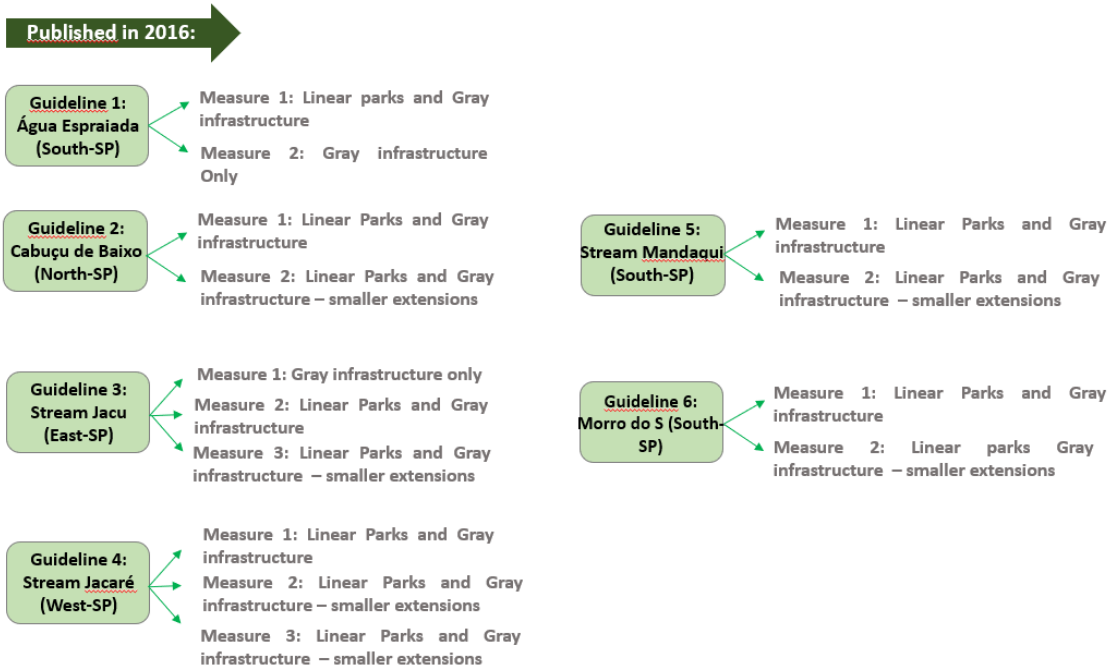
Thus, the Planclima-SP emphasizes the importance of mitigating the impacts aggravated by climate change, contributing to better quality of urban life.

4.2 ANALYSIS OF WATERSHED GUIDELINES

By analyzing the Watershed Guidelines of the city of São Paulo, we found briefly and theoretically reference of compensatory drainage measures such as green roofs, green gutters and community vegetable gardens. We generally noted that the proposals in the twelve guidelines were primarily of Gray Constructions and Linear Parks. NbS allied with compensatory

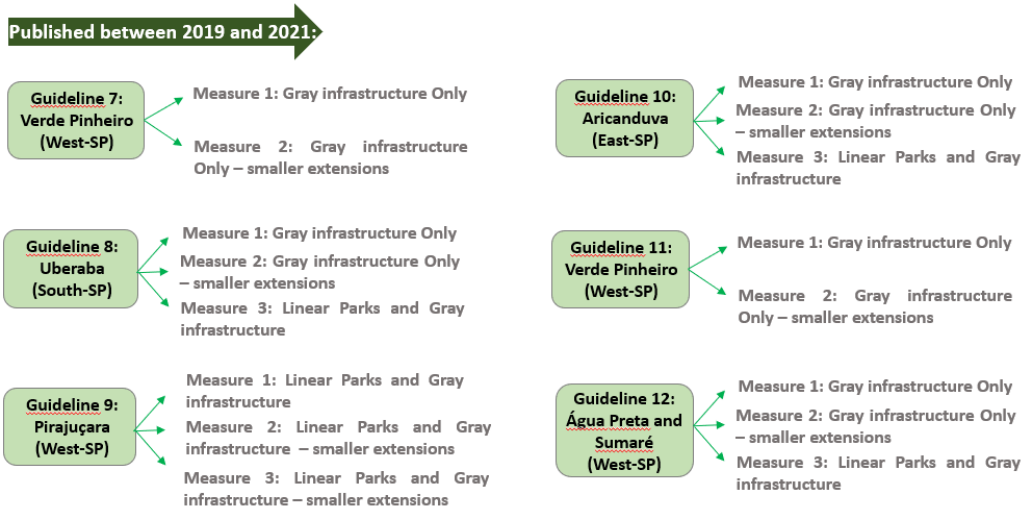
measures are not simulated and budgeted to be more widely considered in urban planning. Figures 4 and 5 summarize the proposals in each document.

Figure 4 - Summary of the proposals suggested in the Watershed Guidelines in 2016.



Source: Own authorship.

Figure 5 - Summary of the proposals suggested in the Watershed Guidelines between 2019 and 2021.



Source: Own authorship.

When comparing the publications from 2016 and the most recent, 2019-2021, there was a drop in the proposition of linear parks.

In 2016, parks comprehended 83% of the main alternatives; in most recent documents, it reduced to approximately 17%.

According to the twelve Guidelines, São Paulo currently bases mostly into mechanisms based on Gray Infrastructure to deal with floods. These methods have greatly contributed to rainwater planning management in the urban scenario, for managing to retain a potential rain volume, especially during high precipitation peak. However, given the challenges aggravated by climate change, there is a need to encourage NbS practices with traditional methods, thus reaching the multifunctional benefits embraced by NbS.

4.3 ANALYSIS OF SYNERGIES IN THE NbS PROPOSAL IN THE PLANNING DOCUMENTS FOR DEALING WITH FLOODS AND CLIMATE CHANGE

The comparative analysis between the Planclima-SP and the Watershed Guidelines showed synergies in actions for flood control and coping with the aggravation caused by climate change in São Paulo.

The Watershed Guidelines are documents that can help putting into practice the goal 23 of the Planclima-SP, for bringing detailed and constructive information on critical watersheds and streams that suffer with floods in the city of São Paulo. Considering NbS would also make it possible to achieve goals 22 and 24.

However, while the Planclima-SP seeks to boost NbS to deal with floods, the temporal analysis of the Watershed Guidelines shows that its main NbS proposal – linear parks – has been losing ground for gray infrastructure solutions over time. These documents have a high potential for mitigating the society's impacts, especially if they are prepared collaboratively, outlining common goals. In this regard, it is important to insert compensatory NbS practices in the Watershed Guidelines, in addition to the mainly theoretical presentation.

Linear parks are an NbS practice (Table 1) and, therefore, reducing the proposition of these actions to technical documents for coping with floods is adverse since combining green infrastructure with gray infrastructure brings benefits for society. In addition, the Planclima-SP goals move towards the opposite direction to this outcome, by stimulating NbS in urban drainage projects to mitigate the climate effects. We should consider that São Paulo is a highly urbanized city, and, therefore, spaces for building linear parks are not always available. This may be the reason for reducing the NbS proposition in the Drainage Guidelines over time.

Some new synergies can be considered for future Drainage Guidelines, in addition to the linear parks. Using NbS may be considered with compensatory drainage practices. Normal roofs are approximately 50% impermeable areas within cities, therefore, inserting green roofs and/or urban agriculture may increase permeable areas, in addition to bringing benefits in facing floods and sustainability (SHAFIQUE, KIM and RAFIQ, 2018).

Green gutters can also be part of urban planning, as in sidewalks, which is relevant in having NbS into urban planning.

5 FINAL CONSIDERATIONS

This research showed that traditional measures or gray infrastructure is the primary basis in planning of coping with urban floods in the city of São Paulo. NbS refer mainly to linear

parks whose proposition has been reduced in the most recent Drainage Guidelines. However, the broad NbS use in rainwater management is São Paulo's plan to deal with climate change.

Thus, we found that the synergy between the Nature-Based Solutions proposition as planning actions to face floods and actions to deal with climate changes that the city of São Paulo has adopted has limitations, but can be expanded.

Both the Watershed Guidelines and the Planclima-SP are technical documents that reflect the municipal authorities' recognition on the need to mitigate the harmful urbanization effects, aggravated by the climate change, felt by the population. However, it is possible to overcome this mismatch between the Drainage Guidelines and the Planclima proposals.

Implementing linear parks is not always possible; however, the next Drainage Guidelines may include other NbS, such as green gutters, green roofs and urban agriculture in the list of actions, in order to expand this synergy and maximize the benefits. Therefore, we highlight the importance for the Watershed Guidelines to include compensatory NbS practices, other than to present merely theoretical content in the archives.

Urban floods cause several social impacts such as quality of life reduction, economic impacts and urban mobility, loss of material goods and even diseases caused by water transmission (CANHOLI, 2014; ONUBR, 2017; IBGE, 2014). Thus, promoting the synergy of these urban drainage measures is imperative so that they can mitigate the negative consequences, since, due to climate change, flooding will be aggravated.

In this regard, NbS prove to be sustainable practices that expand green areas and ecosystem services; integrating them into traditional drainage projects brings benefits for the entire social context.

NbS along with the traditional projects of the Drainage Guidelines can contribute to achieving the goals that Planclima-SP proposes, as well as bringing multifunctional benefits, generating resilience and sustainability on urban water management.

For future studies, we recommend hydrological simulation, as well as those studies the Drainage Guidelines performed for gray infrastructure, focusing on compensatory NbS practices in order to verify the benefits these systems can bring to mitigate floods and to contribute to reach the goals set by Planclima-SP.

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