City Climate
Finance Gap Fund

Catalogue of Nature-based Solutions for Open Spaces

Knowledge product

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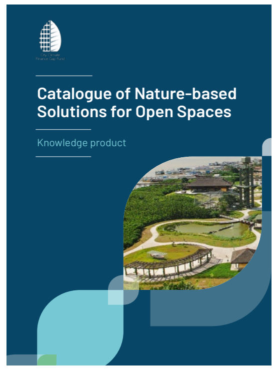
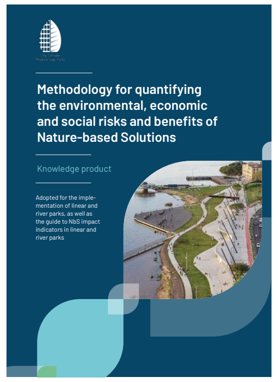
This Catalog is part of a trilogy of materials involving different emphases for Nature-based Solutions (NbS). It presents a Methodology for implementing and quantifying the environmental, economic and social risks and benefits of Nature-based Solutions (NbS), as well as a guide to establishing a business model for linear and riverside parks.

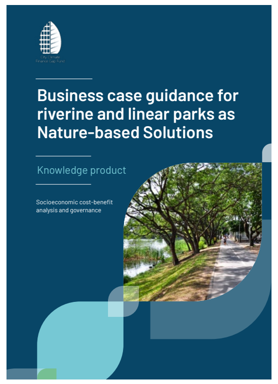
Trilogy



Catalogue of Nature-based Solutions for Open Spaces
The catalogue offers a four-step method for selecting the most suitable NbS for different contexts, ranging from water management to the components of these solutions and the selection of plants for phytoremediation of pollutants. The catalogue aims to guide municipal authorities, urban planners, and environmentalists in incorporating NbS into their planning to create greener cities resilient to climate change. It presents practical Brazilian case studies to demonstrate the importance of NbS in understanding the multifunctionality of open spaces.



Methodology for quantifying the environmental, economic and social risks and benefits of Nature-based Solutions (NbS) adopted in the implementation of linear and riverine parks and guide to NbS impact indicators in linear and riverine parks
This report provides an assessment of methodologies for quantifying the environmental, economic, and social benefits of NbS in linear and riverine parks, as well as a guide to indicators for quantifying the benefits of NbS in green areas. Following a comparative assessment of nine methodologies, the report proposes a robust and relatively simple-to-apply methodology for quantitatively and qualitatively assessing the impact of NbS adopted on liveability, health and fairness of cities for their inhabitants when implemented in linear and riverine parks.



Business case guidance for riverine and linear parks as Nature-based Solutions: socioeconomic cost-benefit analysis and governance
This guide aims to address the lack of comprehensive guidance on NbS for urban planners and managers. It emphasises the multifaceted benefits of riverine and linear parks, such as flood risk management, biodiversity enhancement, and the promotion of human health and well-being. It describes how cost-benefit analysis (CBA) can be used in parks and other NbS projects, and discusses financial sustainability, the importance of community involvement and social governance structures. The goal is to provide professionals with the tools they need to create robust business models that transform the concept of riverine and linear parks into tangible, resilient urban spaces.

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Barigui Park in Curitiba, Paraná (Photo: Pedro Moraes, 2024)

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Flood during extreme rain event in the city of Salvador (Photo: Joa Souza, 2016)

Introduction

The historical relationship between human societies and nature reached a decisive turning point with the establishment of a project of the modern era, characterised by technological advances in the control and manipulation of the natural elements and systems. While this promoted comfort and greater security for the human species (e.g. in terms of protection from the weather), it also initiated a process of progressive degradation and destruction of the planet's ecosystems.

The awakening of a new consciousness that observes and evaluates the impacts caused on a planetary scale, that realises the finiteness and exhaustion of natural elements and processes and that points to new paradigms of human/nature relations, based on different ethical principles, as well as the development of new sciences, new practices and new technologies, is a very recent phenomenon in the history of civilisation (especially since the 18th and 19th centuries, with the Romantic movement in visual arts, literature and philosophy).

In the urban environment, in order for this new „world project" to become a reality that corresponds to ethical principles that are more in line with nature, the scientific and technological parameters of plans and projects must accept the idea that humans are part of nature and implement kinder practices that demonstrate this new way of thinking in the urban landscape.

Above all, observing natural phenomena in order to guide the practices of this new paradigm. Nature is a precious teacher: she knows how to regulate the climate, stabilise slopes and manage water, spreading it out, allowing it to percolate and forming river plains, while providing the conditions for life to flourish and enrich biodiversity. Understanding how nature works, learning from its wisdom and developing models that work with natural systems rather than against them is fundamental in creating a city in which natural systems and socio-cultural processes function, coexist and benefit each other.

Since the 20th century, scientists and other scholars of the natural sciences have gradually become aware of the challenges posed by the increasingly frequent occurrence of severe weather events in countless cities around the world. Therefore, it has become imperative to look for solutions that can replace or complement existing engineering and urban infrastructure technologies. This will ensure the efficiency needed to make cities more resilient to floods, droughts, heat islands and other adverse climate phenomena.

In this sense, it is necessary to develop a new urban lexicon that highlights this new ethic and guides innovative practices. 'Manholes' and 'swimming pools' (used as concrete reservoirs) are being replaced, as we will see below, by 'rain gardens', 'bioswales', 'detention' or 'retention' ponds and 'riverside parks', for example.

This new lexicon responds to a paradigm that is effective in accommodating urban water and qualifies the landscape. It creates living spaces for humans and natural elements, and serves as a green filter that cleans contaminants present in water systems. This new urban configuration thus creates favourable conditions for promoting the sensitive, poetic and aesthetic dimensions of the landscape. A green infrastructure that supports a requalified urban landscape, with unequivocal social and cultural benefits.

The New Urban Agenda (NUA) recognises the importance of seeking 'nature-inspired solutions' that are efficient and sustainable in ensuring safety and improving quality of life for the population, while reducing municipal budget costs (ONU-HABITAT III, 2016). The term 'Nature-based Solutions' (NbS) has therefore been adopted and defended by various international organisations as a strategy to mitigate the effects of climate change on cities. The International Union for Conservation of Nature (IUCN) defines NbS as actions that protect, sustainably manage and restore natural or modified ecosystems, responding effectively and adaptively to social challenges while promoting human well-being and biodiversity benefits (COHEN-SHACHAM et. al, 2016).[1]

In this context, the *City Climate Gap Fund*, which is operated by the European Investment Bank (EIB) and the World Bank, provides emerging and developing countries with technical assistance for projects that aim to increase climate resilience and reduce carbon emissions in the initial phase. As part of this programme, the EIB has partnered with the German technical cooperation agency *Deutsche Gesellschaft für Internationale Zusammenarbeit* (GIZ) GmbH, GIZ BRASIL, to support the municipalities of Campinas and Rio de Janeiro in these areas.

To support the development of this programme in the two municipalities, together with the municipal governments of Campinas and Rio de Janeiro, a consortium comprising the companies Guajava Arquitetura da Paisagem e Urbanismo, Aquaflora Meio Ambiente and Kralingen Economia Ambiental was set up. The aim of the consortium it to help managers of Brazilian municipalities learn about and incorporate NbS into the linear and riverside park projects in their respective localities.

The products developed by the consortium and included in the programme are: the **methodology for quantifying the environmental, economic and social risks and benefits of Nature-based Solutions** (to be adopted in linear and riverside park projects); the **basic project for the Córrego Bandeirantes linear park in Campinas** (with the application of NbS); the **economic-financial modelling for the maintenance of the Jardim Maravilha riverside park in the municipality of Rio de Janeiro**; and the elaboration of this **catalogue of Nature-based Solutions for open spaces**.

We are therefore pleased to present the second edition of the Nature-based Solutions catalogue for open spaces. This new edition differs from the previous one in that we have expanded the scope of the catalogue to ensure that it continues to respond to local needs and is also applicable in an international context. In addition, we have completed a technical review of the contents to ensure that the information provided is up to date with the latest research and practices in this area. The result is a versatile catalogue that we hope will be a valuable tool for planners, landscape architects, environmental managers, and anyone interested in integrating Nature-based Solutions into their projects and communities.

The aim of the catalogue is to provide public authorities with the information they need to select NbS that can be incorporated into public open space projects and integrated into a green infrastructure network for cities. The term 'open spaces' was chosen for the catalogue, rather than 'linear parks', 'riverside parks' or 'green areas', as it represents the scope of applicability of the selected NbS. Open spaces are defined as open areas that are free of buildings and roofs, and can be urban or rural, paved or vegetated, and publicly or privately managed (MAGNOLI, 2006).

The catalogue, structured in two chapters, presents a method for selecting NbS, bringing together technical information, application examples, and the ecosystem services provided, as well as the challenges of their implementation. The **first chapter** suggests a four-step method, structured in four steps, for selecting the most suitable NbS for the local context. The **second chapter** presents an overview of the challenges of implementing NbS in Brazil, addressing important issues for its viability in Brazilian cities. The **concluding remarks** point out the logical sequence of the entire process of developing the method for selecting NbS, which is the subject of this catalogue.

It should be noted that the purpose of this publication is not to exhaust the subject, but rather to provide readers with key concepts for landscape planning and design, focusing on the selection of NbS for open spaces. The aim is not to determine how NbS should be designed or how to measure their hydrological impact, but rather to provide an illustrated technical tool to help select the most suitable ones for each context.

This catalogue provides public authorities and other interested parties with an important starting point from which to learn about NbS for applications in public open space projects, taking into account the current environmental and social urban management issues.

Enjoy!

1 The view that nature sustains the functioning of society and economies around the world was defended during the UN General Assembly in March 2022, where an important warning was also given: "The degradation of ecosystems and loss of biodiversity and ecosystem services will reduce the capacity of nations and their cities to respond to climate change and other challenges" (UNEP, 2022, p. 13).

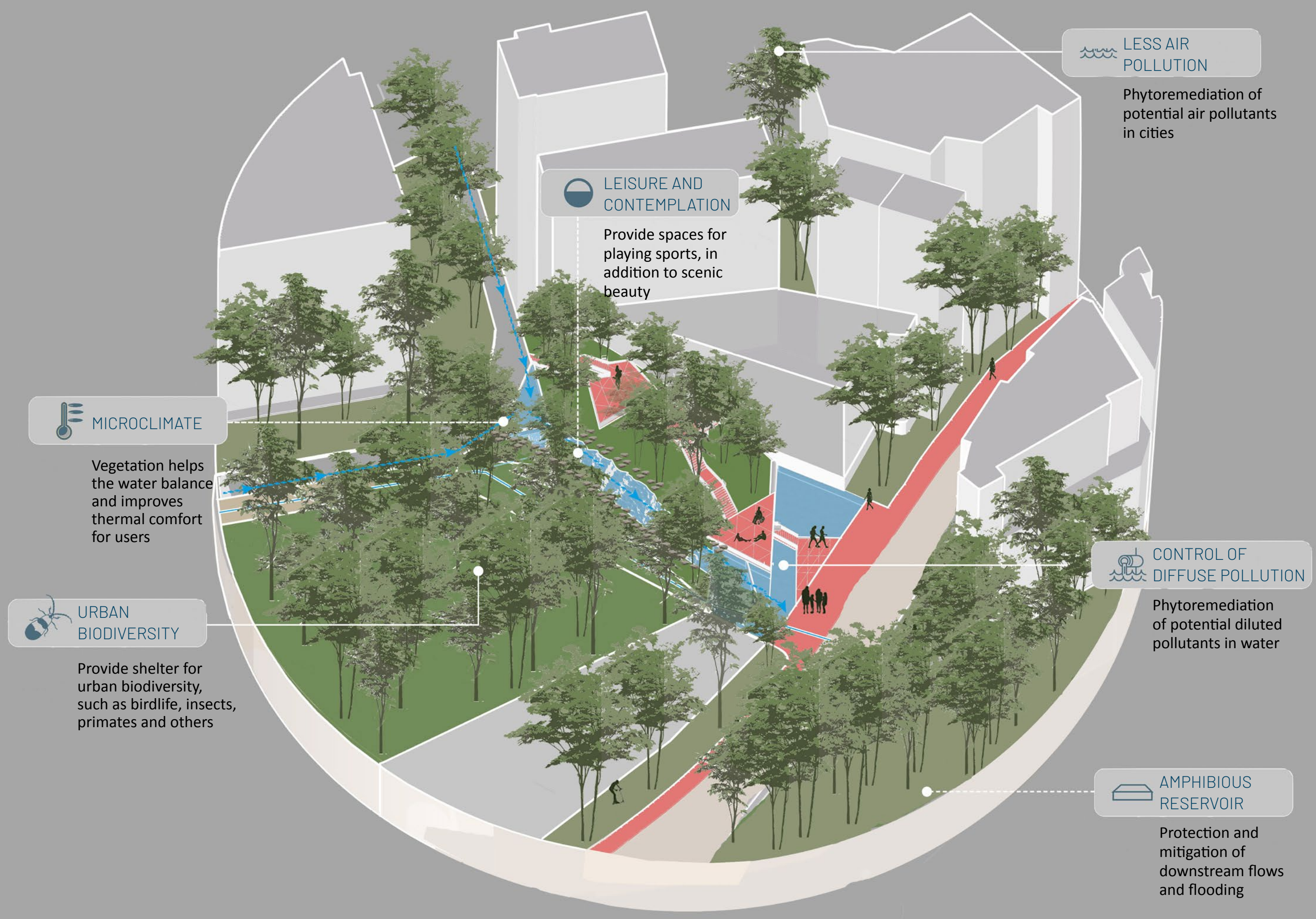


Diagram illustrating the importance of urban green areas (Source: Guajava, 2023)

1 Method for selecting Nature-based Solutions for open spaces

This chapter provides options for projects that incorporate NbS in a variety of open spaces, ranging from the site level to the watershed level. It is worth noting that the catalogue has chosen to focus on NbS related to urban water and sanitation, as well as environmental issues in open spaces, involving the systemic recomposition of landscapes.

NbS should be selected based on the principle that open spaces should fulfil multiple functions. These include connecting fragments of vegetation, safely conducting water, offering microclimatic improvements, serving housing, work, education and leisure uses, ensuring greater social security, accommodating the functions of other urban infrastructures, such as transportation and supply, and fulfilling the objectives of recreation, meeting and environmental and aesthetic improvements (PELLEGRINO et al., 2006).[2] The multifunctionality inherent in the concepts of green infrastructure and BNN makes the proposed design solutions complex, as they must meet a series of performance criteria:

- Reduce flood risks and mitigate the impact of floods by incorporating different measures to contain and infiltrate surface water run-off along the watershed, particularly near the source where precipitation hits the ground;
- Reduce the need for large centralised containment structures by reducing the total volume of surface water run-off;
- Reduce diffuse pollution through phytoremediation of water and soil;
- Improve environmental comfort by contributing to the evapotranspiration process;
- Support life – fauna and flora;
- Provide a better cost-benefit ratio than traditional engineering infrastructures, as they provide multiple functionalities.

Based on these initial considerations, this chapter presents a method for selecting NbS that are ideal for each context. The criteria for selecting NbS for open space projects can vary according to location and territorial dimension, as well as socio-economic, urban planning, environmental and legislative issues.

2 From this vision stems the concept of green infrastructure which, by aggregating urban green corridors, wetlands, hillside reforestation and other low-impact interventions with the best water management practices, provides important contributions to a more ecologically efficient city design, reinforcing the crucial role of vegetated open spaces.

The method for selecting NbS is structured into four main steps:

Step 1

Diagnosis and urban, morphological and hydrological-hydraulic characterisation of the watershed and drainage system

The **first step** includes a:socio-environmental diagnosis and the characterisation of the watershed and drainage system in terms of urban morphology and hydrology;

Step 2

Defining Nature-based Solutions

The **second step** is divided into two major groups. The first includes NbS related to flood mitigation and/or the phytoremediation of waters, while the second includes containment structures associated with NbS that have established uses in urban infrastructure. These engineering solutions combine natural materials with classic civil engineering elements and techniques when necessary. The selection of NbS is based on the degree of suitability of each one (recommended, possible and not recommended) and takes into account the best strategic location, soil type and the hydrological and hydraulic characteristics of the site. The choice is usually made based on the water's reservoir, infiltration and conduction properties. However, other important factors should also be considered such as its influence on the local social context, its capacity to promote ecosystem and cultural services, compliance with legislation and compensatory techniques, and its compatibility with infrastructure and sustainable engineering.

NbS aimed at flood mitigation and/or water phytoremediation

1. Rain garden
2. Rain bed
3. Bioswale
4. Rain terraces
5. Vegetated hydraulic stairs
6. Infiltration pit
7. Detention basin
8. Retention basin
9. Infiltration basin
10. Constructed wetlands
11. Floating filter islands
12. Amphibious reservoir
13. Vegetated polder
14. Step pool

NbS aimed at retaining the banks of streams and rivers, embankments and slopes

1. Wooden cribwall
2. Riverbank cribwall
3. Living grid
4. Stone containment wall
5. Stone wall with vegetation
6. Prefabricated cribwall with vegetation
7. Gabion walls with vegetation
8. Flat gabions - mattress
9. Green stapled soil
10. Geocell containment

Step 3

Defining plant species for NbS

The **third step** presents criteria for defining which plant species can be used in NbS.

Step 4

Measuring ecosystem services and social benefits post-implementation

The **fourth step** discusses aspects relating to the measurement of socio-economic and ecosystem benefits following the implementation of NbS.

Bandeirantes Creek linear park (Guajava Arquitetura da Paisagem e Urbanismo office, photo: Sarah Daher, 2023)

Step 1 Diagnosis and characterisation of the watershed and drainage system in terms of urban morphology and hydrology

The first step in an open space project focusing on urban water and sanitation and environmental issues is to characterise and diagnose the morphology of the contributing watershed and its watercourse(s) whether natural or man-made. This should also include characterising other physical and urban aspects, such as interference with other elements of urban infrastructure. This step precedes the selection of the most appropriate NbS for the context.

Thus, this stage involves surveying and characterising the physical and urban features of the drainage basin and its watercourses. This data will inform the selection and sizing of NbS in landscape projects. The main objective is to identify the various constraints that will influence design decisions.

The analysis is based on the assumption that the project areas have been impacted and altered in terms of their landscape, vegetation cover, hydrological and hydraulic functioningand biogeochemical cycles. The impact can therefore be mitigated by making it compatible with the environmental quality resulting from the planning and design of open spaces, as will be shown in the next steps of the method and in the subsequent chapters of this catalogue.

The initial stage of planning and designing the system consists of an integrated qualitative and quantitative diagnosis of the catchment area and its surrounding urban areas, and identifying potential sites for different NbS. As part of this contextualisation process, we recommend carrying out a landscape study that integrates morphological, hydraulic, ecological and social variables, as detailed below.

It should be noted that each NbS requires a different environmental analysis. This stage therefore provides a general overview of the factors to consider when selecting and designing an NbS.

1. Hydraulic-hydrological diagnosis.
2. Historical evolution of the area and urbanization dynamics.
3. Social and economic environment.
4. Urban design legislation.
5. Biophysical environment.
6. Infrastructure, equipment and urban services.

Hydraulic-hydrological diagnosis of sub-basins and drainage network

In locations affected by flooding and waterlogging, where the NbS are to be applied to mitigate these issues, it is important to conduct a precise hydraulic-hydrological diagnosis. This will enable the quantification of the required volumes and flows to mitigate the effects of urbanisation on the watershed.

Urbanisation impacts the natural hydrological cycle and drainage system of a river basin in different ways. On the one hand, it increases surface run-off flows by intensifying the sealing of the contributing basins, which significantly reduces the amount of infiltration. On the other hand, it reduces the capacity to cushion floods by suppressing floodplains and occupying the larger drainage bed of watercourses with valley bottom roads. This leaves only the smaller bed as a drainage section, which would naturally be occupied by floods. Finally, by straightening and channelising watercourses shortens the space available for run-off (by suppressing meanders) and accelerates run-off (due to smooth linings), which contributes to anticipating and amplifying flood peaks. The combined actions of waterproofing, floodplain suppression and channelisation promote a vicious cycle in which flood volumes increase, while spaces for water are reduced, thus forming the main cause of flooding in urbanised basins.

To address these issues, measures can be taken to restore flood buffer areas and infiltration, as well as to allocate new spaces for water. The aim is to restore the balance of the hydrological cycle in the watershed.

The volumes of run-off that exceed the capacity of the drainage network can be quantified using hydrological-hydrodynamic modelling. This constitutes a hydrological-hydraulic diagnosis of flooding in the basin. Based on this diagnosis, the necessary storage and infiltration volumes to reduce flooding can be defined, as well as the required size of the structures.

The sizing and design criteria, as well as the methodology for hydraulic-hydrological diagnoses must align with the guidelines recommended in the local Drainage and Stormwater Management Plan. If this is not the case, reference literature on sustainable drainage systems that includes minimum design guidelines should be consulted.

In drainage projects, a design precipitation is used as the basis for diagnosis. This is the reference precipitation used to size structures based on historical precipitation data. This data is adjusted

Figure 1 Illustrative photographs of urbanisation without NbS. On the left: a channelled stream with bare banks in Brasilândia; in the centre, a concrete channelled stream in Brasilândia; on the right, a buried stream under a street in Vila Mariana (Photos: Afonso, 2024).

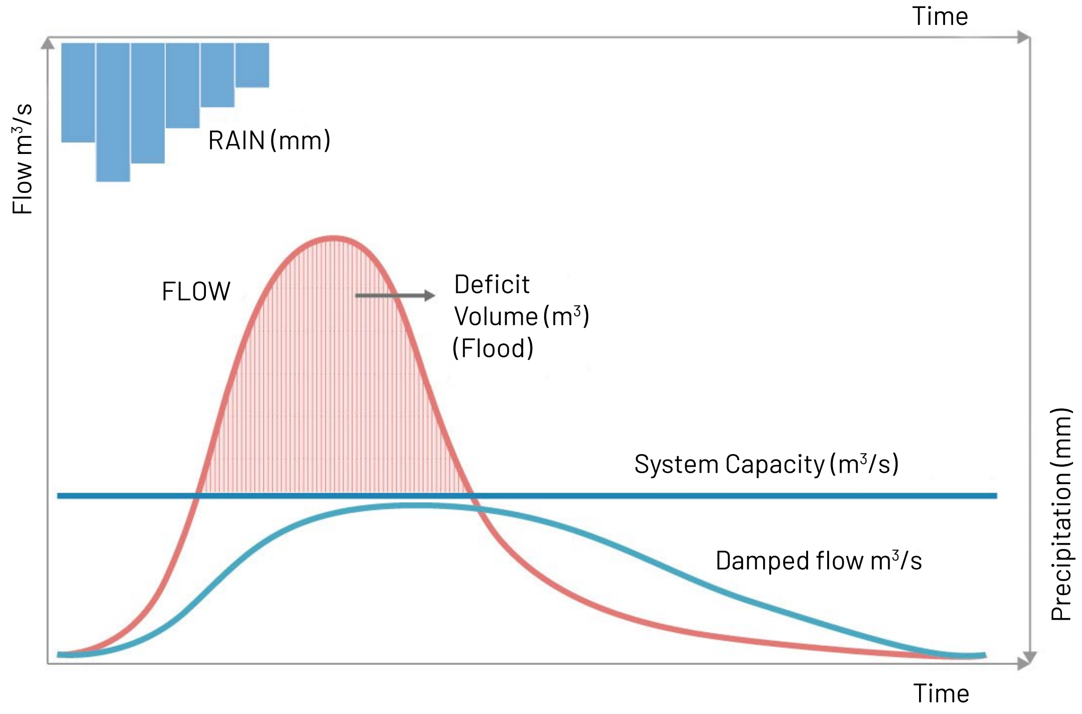


Figure 2 Illustrative graph showing the concept of restricted flow and the method used to determine the necessary detention volume for flood control in the watershed.[3]

using an equation called the **IDF curve (intensity, duration and frequency)**. These equations are determined for different regions and compiled in specific statistical hydrology publications for the various countries and regions worldwide. The IDF curve relates a given precipitation intensity to the duration of the rainfall and its frequency of occurrence. It relates a given intensity of precipitation to the duration of the rainfall and its frequency of occurrence. Intensity is expressed in millimetres of rain, duration in minutes and frequency from a variable called recurrence time (RT), which is the average time, in years, that a given event will be equalled or exceeded. The RT is the inverse of the probability of a given event occurring each year. Therefore, precipitation with an RT of 2 has a 50% probability of occurring each year.

According to recommendations in specialised national and international literature, RTs of 2 to 5 years are adopted for micro-drainage systems and RTs of 10 to 100 years for macro-drainage projects, RT 25 is a fairly common criterion. Therefore, city drainage systems should aim to protect against flooding caused by rainfall with an RT of up to 100 years, based on a set of solutions which, individually, meet lower RT criteria.

3 The blue column chart represents the hyetograph (a graph showing precipitation over time) for the design storm, as indicated on the top horizontal and right vertical axes. The pink, light blue, and dark blue lines are oriented along the lower horizontal and left vertical axes, respectively representing: the pink line, the hydrograph (a graph of surface run-off flow over time) for the existing condition of the watershed, determined by hydrological modelling. The dark blue line: the system's capacity at a specific point in the drainage network. This is determined by the geometry of the watercourse or drainage channel, indicating the maximum flow that can be transported without overflow at that section. Pink hatching: overflow volume. Any run-off volume exceeding the system's capacity indicates the flood volume. The light blue line: attenuated flow after the implementation of attenuation, infiltration and containment measures in the watershed (indicated in brackets).

Regarding the duration of the design rainfall, the literature recommends adopting durations close to the time of concentration of the contributing sub-basins. This corresponds to the average time, counted from the start of the rainfall, that it takes for the entire sub-basin to start contributing run-off to its point of discharge (outflow). However, for urban micro-basins, due to the high degree of waterproofing, which generates very rapid flood peaks. This can result in very short durations of rainfall, as short as a few minutes, leading to very low rainfall levels undersized structures, designed for significantly less rainfall than that which generates flooding in the sub-basins. To address this problem, one-hour precipitation is typically adopted for drainage projects, with durations up to 6 or 12 hours for larger watersheds. In general, urban drainage projects adopt precipitation of 1-, 2- or 6-hour precipitation durations for the design rainfall.

Once the RT and rainfall duration have been defined, a precipitation total is obtained. This total is then used to create a hydrological model of the basin using numerical rainfall-run-off transformation models, such as HEC-HMS and SWMM. These models are commonly used to obtain the corresponding flows and flood hydrographs for the rainfall in question.

By comparing the inflows at the various points in the study basin with the capacity of the existing drainage network, a hydraulic-hydrological diagnosis of the network capacity can be obtained, as well as the flows and deficit volumes of surface run-off for the design rainfall. Hydraulic modelling of the drainage network is necessary for this stage, in which the geometry of the conduits, galleries and channels is entered, including the cross section, longitudinal slope and singularities (e.g. steps, changes in direction and geometry, lining, and the presence of obstacles), as well as their hydraulic parameters (e.g. roughness,) which influence their flow capacity. This hydraulic diagnosis stage can be carried out using software such as HEC-RAS and SWMM or using a simplified methodology can be employed with an approximation to the condition of permanent and uniform flow (Manning's equation). This provides an estimate of the system's capacity in relation to the inflows for the different recurrence times (RTs).

The results of the hydraulic-hydrological diagnosis are given for each RT in terms of deficit volumes, i.e. the volume of direct surface run-off that exceeds the system's capacity. This is the volume that should be buffered by the designed system. The size of the system must take into account the volume of deficit volume diagnosed for the adopted recurrence time (RT) for the project. To this end, a study of alternative interventions should be carried out to determine a combination that address the diagnosis.

If the volumes cannot be fully addressed due to the urban planning and physical environment constraints identified in the earlier stages of the diagnosis, the proportion that can be addressed should be assessed. Decisions on the course of action arising from this information should take into account complementary structural and/or non-structural alternatives, such as structures that complement the NbS, contingency plans based on monitoring and warning systems, and plans for relocating the population in risk areas (in this case, in line with other spheres of urban planning and intervention, such as housing.

The following is a summary of the hydraulic-hydrological diagnosis of the sub-basins and drainage network:

- Identification and characterisation of the natural or artificial drainage network, including open channels, lakes and reservoirs, springs and waterholes, and macro- and micro-drainage galleries, as well as surface drainage inflows that require protection or that can be incorporated into the project. The presence or absence of an artificial drainage network or a watercourse in the area is a limiting factor for the use of detention measures, as it makes it impossible to discharge excess volumes. Since NbS are generally proposed in areas where the terrain has changed infiltration and run-off patterns in the basin, it is necessary to estimate the impact of this on reducing infiltration and consequently increasing surface run-off.
- Analysis of the drainage area and identification of the contributing basin. The drainage area contributes to the NbS and must be delimited by the watershed. This variable enables the type and size of NbS to be defined and is used for the hydrological and hydraulic calculation of more complex interventions, such as detention, retention or infiltration basins, or systems comprising several NbS structures.
- Diagnosis of the topography and slope of the drainage area. Steep terrain with slopes greater than 5% generates high-velocity run-off, which hinders infiltration. In these conditions, materials or structures must be used to reduce the speed of run-off.
- Survey of the soil's infiltration capacity. This parameter is used to determine the size of infiltration structures. Clay soils, for example, have a lower infiltration capacity than sandy soils.
- Surveying the level of the water table. Similar to infiltration capacity, this condition also reduces the infiltration process, as there is a risk of the structure's layers becoming saturated by the water table itself. The minimum distance must be at least 1 metre below the bottom of the infiltration device, taking into account the maximum water table level, as detailed in **step 2**.
- Survey of contaminated areas (soil and water) near solid waste disposal sites, areas with polluted inflows or high sediment rates, and areas showing signs of erosion or fragility of the soil due to water action. Where inflows with high quantities of pollutants, sediment and waste are detected, pre-treatment and frequent routine maintenance are recommended.
- Analysis of soil use and occupation (in the drainage area/contributing basin) and analysis of their relationship with pollution generation. This information indicates the quality of the run-off water and will contribute to the NbS. Diffuse pollution is characterised by being generated mainly through meteorological phenomena and by the washing of urban and rural surfaces, where various types of pollutants are deposited.

Characterisation and urban diagnosis of the subbasins and drainage network

The urban characterisation of the basin's drainage area should focus on interpreting social data and creating local contextualisation maps for the project.

This stage assesses the aspects relating to socio-environmental issues that guide the selection of NbS. As this information is highly complex, the discussion will focus on the most relevant issues for projects using NbS.

Implementing this type of solution in countries with high levels of social inequality, such as Brazil, is extremely challenging. The territories where the interventions will be carried out may be plagued by serious social problems, such as a lack of social housing policies and basic sanitation, and difficulties accessing waste collection and local mobility services. The historical occupation of environmentally sensitive areas in Brazilian cities is also complex, with the absence (or incipiency) of public policies capable of dealing with the quantitative and qualitative challenges of the housing issue pushing the socially vulnerable population to occupy areas of geotechnical risk and permanent preservation areas (PPAs), which are of great environmental sensitivity and unsuitable for housing.

The presence of universal public health and education services is considered to be extremely beneficial in areas of great social fragility. Thus, the NbS can be incorporated into these strategies to help stimulate a more holistic and intersectoral vision of public policies and encourage dialogue between the various stakeholders in these territories. For this reason, using NbS requires and understanding of social territoriality and how local and surrounding communities relate to the environment.

One of the first steps in this phase is to identify the main social actors in the territory and establish dialogue with social practices that can be preserved and with the public agents present, especially schools and basic health units. We suggest creating a schedule for participatory workshops with the community, publicising them, and then setting up a committee with community representatives who will be able to monitor the intervention project more directly and frequently. This will create a participatory basis for the democratic management of the territory. A sense of belonging among the population is important in encouraging the community to take ownership of the space, preserving it and helping with its basic maintenance (e.g. cleaning).

It is therefore recommended that trained professionals, such as social workers, sociologists or local educators, be hired or mobilised to survey local social issues and needs. Once the main stakeholders have been identified, public workshops can be held on the project and on setting up a public monitoring committee that is representative of the area and its needs. One method of achieving this is to hold participatory workshops, establishing a dialogue between those directly affected by the proposed intervention, the project authors and the municipality. Following the participatory workshops, consider the input derived from this dialogue and establish a monitoring committee representative of the local population.

The following factors should be considered in the analysis:

Historical evolution of the area and urbanisation dynamics

- Identification of areas available for implementing the designed NbS structure;
- Historical survey of the region, considering regional context, social and environmental dynamics and the impact of these factors on the built environment;
- Historical analysis of the territory's occupation based on its structuring elements.

Social and economic environment

- Study of the administrative division, boundaries and the presence of urban and rural areas and conservation units;
- Characterisation of land use and occupation, focusing on the relevant categories;
- Analysis of economic dynamics, covering production profiles, sectors and the most relevant input and product flows that may influence land use and occupation, including transport infrastructure;
- Study of demographic and household dynamics, occupation profiles and patterns (public, private, small, medium or large rural properties) and future trends;
- Assessment of the provision of basic sanitation services in its four components (water, sewage, waste and drainage);
- Socio-spatial organisation of the population and community mosaic to help identify social groups and movements, collectives involved in cultural promotion, indigenous and quilombola communities, and other stakeholders and community representatives. This mapping will facilitate the population's participation in a participatory planning and design process;

- Mapping of schools and public children's and youth centres to promote environmental and landscape education;
- Mapping of local social groups and organizations that already interact with the intervention environment, in order to establish community dialogue;
- Characterisation of public organisations and projects that already have an impact on public policies in the territory, particularly those relating to social assistance, health and education. Consideration should also be given to urban mobility projects, waste collection and other public initiatives.

Urban design legislation

- Survey of legal norms and legal instruments relating to environmental and urban law, particularly acts of municipal competence, such as the Master Plan (which defines urban planning instruments) and other legislation relating to urban zoning and land use in the municipality;
- Analysis of national policies and their impact at the local level, particularly with regard to urban green spaces and the protection of water resources;
- Identification of administrative processes that enable the revision of legal instruments aimed at the NbS.

Biophysical environment

- Identification of significant vegetated areas, in order to restrict urbanisation in suitability area and to verify the possibility of incorporating these areas into the project;
- Survey of endemic and regional biodiversity (fauna and flora) to determine the most appropriate species for the context;
- Diagnosis of the relationship between the built environment and the natural environment, identifying areas of conflict between urban occupation, environmental quality and natural resources;
- Diagnosis of the composition and structure of the landscape using metrics;
- Identification of the status of remaining vegetation;
- Survey of risk areas, as soil subsidence can be mitigated by certain NbS;
- Analysis of soil type, identifying infiltration capacity and susceptibility to erosion.

Infrastructure, equipment and urban services

- Survey of road infrastructure that may interfere with the area available for NbS, and contribute to diffuse pollution;
- Characterisation of land use by prevalence to understand how the population appropriates NbS;
- Analysis of the environmental sanitation conditions, including a survey of the water supply network, sewage collection network, drainage, solid waste collection and disposal as well as ecopoints which influence point or diffuse pollution loads;
- Characterisation of housing precariousness (presence of tenements and irregular occupations);
- Population density versus building density;
- Analysis of the spatial distribution of the populations surrounding the region under study, and assignment of economic values to the expected improvement in quality of life (e.g. fewer losses due to flooding, fewer absences due to health problems);
- Identification of buildings (and their respective foundations) to be protected, with a minimum distance of 2 meters to be kept between these buildings and the NbS;
- Identification of underground interferences that could affect the proposed structure, as well as existing structures that could be at risk from the proposed project.

Based on the categorisation of the watershed, this survey can propose, a plan and project for the open spaces, selecting the ideal NbS for each context, as will be seen in the next step.

Central Park in Santo André, São Paulo, landscape architects: Raul Pereira and Martha Gavião (Photo: Paula Martins Vicente, 2010)

Step 2 Defining Nature-based Solutions

Once the hydrological-hydraulic diagnosis and the assessment of urban, socio-economic and environmental constraints carried out in **Step 1** have been completed, the project's objectives can be defined.The next stage is to select Nature-based Solutions (NbS) that best suit the specific demands identified begins.

This catalogue presents NbS that can be applied to different urban contexts, specifically open spaces. Each infrastructure must be adapted to the previously analysed needs, characteristics and local environments. They must be implemented and monitored by trained technical professionals from relevant fields.

The decision on which NbS to adopt must be based on an analysis of various data, including the location of the project, soil characteristics (pedology) and hydrological conditions.

It is worth noting that the catalogue divides the NbS into two major groups: the first group, listed in **Table 1**, aims to mitigate floods and/or phytoremediate water, while the second group, listed in **Table 2**, aims to stabilise slopes.

Groups

1st Group: NbS aimed at flood mitigation and/or water phytoremediation of water

2nd Group: NbS aimed at stabilising stream and river banks, embankments and slopes

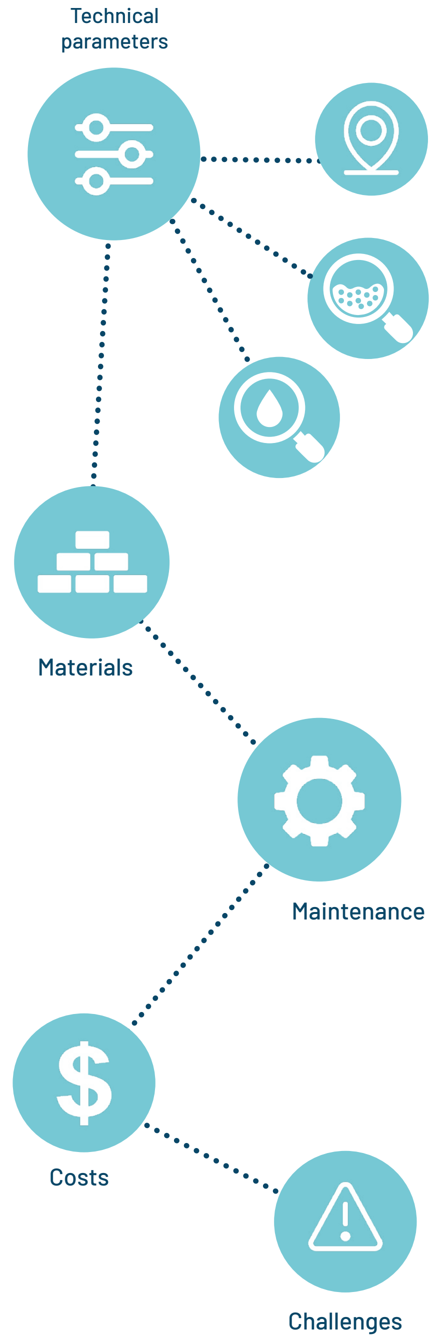


Diagram presenting selection criteria for NbS devices.

1st Group

NbS aimed at flood mitigation and/or phytoremediation of water

1st Group: NbS aimed at flood mitigation and/or phytoremediation of water

To help choose NbS aimed at flood mitigation and/or phytoremediation of water, we recommend using the criteria listed in Table 1. The table provides an assessment of the degree of suitability of each NbS for flood mitigation and/or phytoremediation of water, categorised as **recommended**, **possible** or **not recommended**[4] – of each NbS, according to the layers of location, pedology/topography and hydrology. The details of these layers of information are explained below.

For each NbS, the technical parameters for selection are described, as well as information on pedology, topography and hydrology, strategic location, required materials, vegetation, maintenance, the cost of implementation, and possible planning and execution challenges.

TECHNICAL PARAMETERS TO BE TAKEN INTO ACCOUNT WHEN CHOOSING

STRATEGIC LOCATION

PEDOLOGY/TOPOGRAPHY

- Soil permeability and hydraulic conductivity in mm/h
- Slope
- Sediment load
- Type of soil
- Terrain characteristics/Interference register

HYDROLOGY

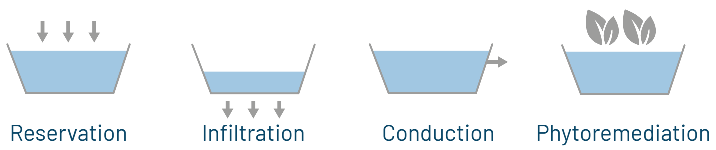
- Flow control/Interception capacity
- Water table level
- Drainage and water run-off

MATERIALS REQUIRED

MAINTENANCE

COST OF IMPLEMENTATION

POSSIBLE CHALLENGES IN PLANNING AND EXECUTION



4 Table data based on authorial studies by the team of this catalogue (GIZ; RIGHETTO, 2009).

Rain garden

Rain bed

Bioswale

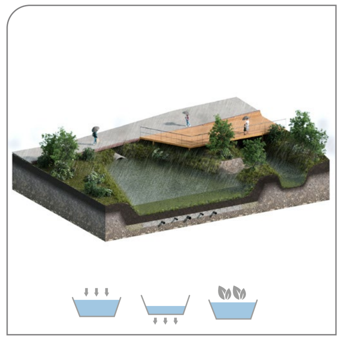
Rain terraces

Vegetated hydraulic stairs

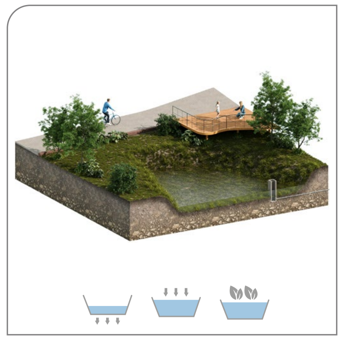
Infiltration pit

Detention basin

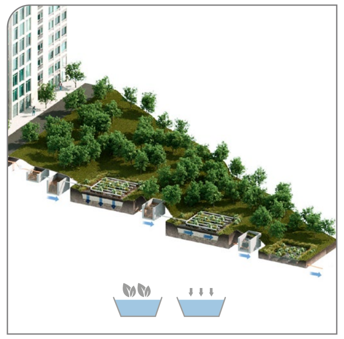
Retention basin



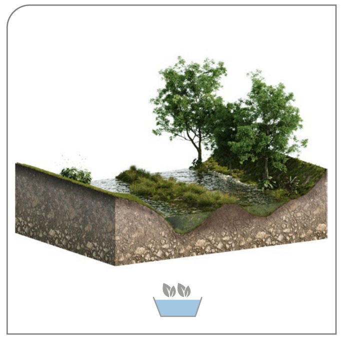
Infiltration basin



Constructed wetlands



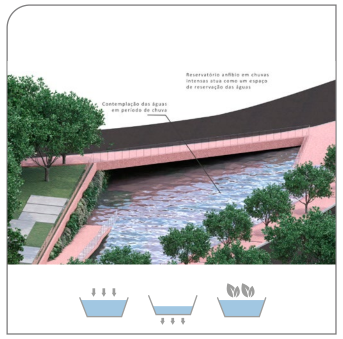
Floating filter islands



Floating filter islands

Step pool

Amphibious reservoir



Vegetated polder

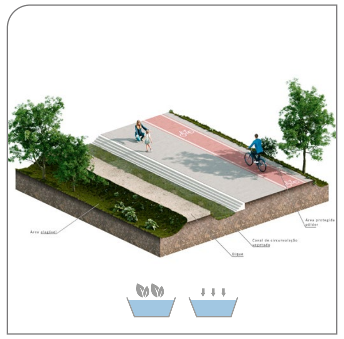


Table 1 Criteria for defining NbS according to layers of information, location, pedology and hydrology.

Level of interaction between device and SDG: high | medium | low

NbS DEVICES			Rain garden	Rain bed with infiltration	Rain bed without infiltration	Bioswale	Rain terrace	Hydraulic vegetated ladder	Infiltration pit	Detention basin	Retention basin	Infiltration basin	Wetlands	Amphibious reservoir	Vegetated polder	Step pool
PEDOLOGY AND TOPOGRAPHY	Soil Permeability (hydraulic conductivity in mm/h)	infiltrating soil (> 3.6 mm/h)	high	high	low	medium	medium	medium	high	high	medium	high	high	high	medium	medium
		non-infiltrating soil (< 3.6 mm/h)	high	low	high	medium	medium	medium	low	high	high	low	high	high	medium	medium
	Slope	0 to 5%	high	high	high	high	high	high	high	high	high	high	high	high	medium	high
		> 5%	low	low	low	medium	medium	high	high	high	medium	medium	low	high	low	medium
	Sediment load	Low solids intake	high	high	medium	medium	medium	medium	high	high	high	high	high	high	medium	high
		High solids intake	low	low	medium	medium	medium	low	low	medium	high	high	high	medium	medium	medium
	Soil types (hydrological soil groups, cf. Natural Resources Conservation Service – United States (NRCS-USDA)	Group A Infiltration rate > 8 mm/h	high	high	high	high	high	medium	high	medium	medium	high	medium	high	medium	medium
		Group B Infiltration rate between 4 and 8 mm/h	high	high	high	high	high	medium	high	high	medium	high	medium	high	medium	medium
		Group C Infiltration rate between 1.5 and 4 mm/h	high	medium	medium	medium	medium	medium	medium	high	high	medium	medium	high	medium	medium
		Group D Infiltration rate < 1.5 mm/h	low	low	low	low	low	medium	low	high	high	low	medium	high	medium	medium
LOCATION	Susceptibility to waterlogging and flooding	Permanently flooded area	low	low	low	low	low	low	low	low	low	low	high	low	low	high
		Floodable area	medium	medium	high	high	medium	high	low	high	high	medium	high	high	high	high
		Reservation areas	high	high	high	high	high	high	high	high	high	high	medium	high	high	high
	Road system	Sidewalks	medium	high	high	high	high	high	high	low	low	low	low	low	low	low
		Traffic circles	high	medium	medium	low	low	low	high	medium	medium	medium	low	low	low	low
		Street corners	high	high	medium	medium	low	medium	medium	low	low	low	low	low	low	low
		Central median	high	high	medium	medium	high	medium	high	medium	medium	medium	medium	low	low	low
	Lot size	< 100 m²	high	high	high	high	high	high	high	medium	medium	medium	high	low	low	medium
		> 100 m²	high	high	high	high	high	high	high	high	high	high	high	high	high	high
	Under a slab	Under a slab	low	low	high	low	low	medium	low	high	high	low	high	low	low	low
HYDROLOGY	Flow control / interception capacity	RT 2 – 5 years	high	high	low	medium	medium	high	high	high	high	high	high	high	high	high
		RT 5 – 10 years	high	medium	low	low	low	high	high	high	high	high	high	high	high	high
		RT 10 – 25 v		medium	low	low	low	medium	medium	high	high	high	high	high	high	high
		RT 25 – 100 years	low	low	low	low	low	low	low	high	high	high	high	medium	high	high
	Proximity to the water table	< 1 m Alluvial Plain	low	low	medium	medium	medium	medium	low	medium	high	low	medium	low	high	medium
		> 1 m	high	high	medium	medium	medium	medium	high	high	low	high	high	high	high	medium
	Drainage and water run-off	Detention	high	high	high	high	high	high	high	high	medium	medium	high	high	high	high
		Retention	low	low	low	low	low	low	low	low	high	high	medium	medium	low	medium
		Conduction	medium	low	low	high	medium	high	low	low	low	low	low	low	high	high
		Infiltration	high	high	low	low	medium	low	high	medium	medium	high	low	medium	low	low

TECHNICAL DATA SHEET TEMPLATE

The different NbS sheets are described in detail below:

Description of the NbS sheets listed in Table 1: Rain garden, rain bed, bioswale, detention basin, retention basin, infiltration basin, rain terrace, vegetated ladder, hybrid wetland, constructed filter island, amphibious reservoir, vegetated polder, step pool, infiltration pit

NAME OF NATURE-BASED SOLUTION

GENERAL DESCRIPTION:

Definition of the NbS's concept and objectives

TECHNICAL PARAMETERS TO BE TAKEN INTO ACCOUNT WHEN CHOOSING:

(structured by the information layers in Table 1)

STRATEGIC LOCATION:

refers to the ideal location for implementing NbS. This layer addresses the availability of space for implementing NbS and defining strategic locations for capturing urban run-off.

The method suggests identifying the open space in which the NbS will be applied to ensure it is used to its full potential. It is important to specify whether it will be used in a road system, on a plot of land, under a slab, on riverbanks, on slopes or on embankments. Analysing the terrain and other criteria related to rainwater run-off is crucial to determine which NbS to implement effectively, creating a systemic network that can be replicated on different scales. Within the road system, each section (sidewalks, traffic circles, corners and central medians) has a strategic potential for different drainage devices. For example, sidewalks can receive NbS aimed at infiltrating rainwater, such as rain beds; central medians are excellent areas for bioswales that promote the routing of rainwater; and traffic circles are ideal for detention basins.

PEDOLOGY/TOPOGRAPHY:

To achieve good results, the drainage system must be designed with all the input, output and status variables involved taken into account. The input variable is the volume of direct surface run-off (DSR) conveyed to the system, which depends on the design rainfall, the connected area and the sealing rate of that area. The status variable is the volume of water retained by the system during tits operating time. The output variables are infiltration and excess flow into the drainage network. Infiltration analysis is a fundamental component of the system and is defined based on the properties of the porous medium. These properties are determined by soil characterisation tests, primarily the granulometric analysis test, which determines the percentage of clay, silt, sand and gravel present in the sample, and the permeability test, which determines the speed at which water percolates through the soil. This data provides criteria relating to soil permeability, infiltration capacity, water storage in the soil (in mm) and sediment load. To choose the appropriate drainage device, it is important to carry out a pedological profile of the site and then select the device that best matches the soil type. According to the data:

Soil permeability and hydraulic conductivity in mm/h:

to assess rainwater infiltration, it is necessary to study the saturated hydraulic conductivity at the project site. Hydraulic conductivity is a property that governs the movement of water in the soil. It is numerically equal to the volume of water that passes vertically through a $1 \times 1 \times 1\,m^3$ soil sample in one second, under a total potential difference of $1\,J/m^3$. Therefore, it is a coefficient that expresses the ease with which water is transported through the soil (Libardi, 2018). Water moves more slowly in unsaturated soil than in saturated soil, due to the discontinuities between the pores and water and air. Thus, when soil humidity is equal to saturation humidity, its hydraulic conductivity is at its maximum (Libardi, 2018). To determine the saturated hydraulic conductivity of soils, the constant – load permeability test must be carried out, which is standardised by NBR-13292 and based on Darcy's law. This law relates to the flow velocity to the hydraulic conductivity coefficient, the length of the soil sample and the hydraulic load to which it is subjected. References indicate that soils with a hydraulic conductivity between 10^{-3} and 10^{-6} m/s (greater than 3.6 mm/h) are more suitable for implementing infiltration techniques (Righetto et al., 2009). However, NbS can be applied to soils with values lower than these, as long as they are combined with storage techniques that provide a sufficient delay time to compensate, in part, for the shorter infiltration time that these soils will allow. One example of such a technique is the use of storage layers in stone reservoirs.

Slope:

this influences the choice of NbS, since lanes with a slope of more than 5% do not allow the sufficient time for water to infiltrate. On steep slopes, where there is a risk of erosion and landslides, it is possible to use solutions such as rain terraces, can be used to contain and treat water in order to protect the embankments. These solutions can be implemented on various scales, taking into account factors such as the height of the dams, energy dissipation, and the cost of implementation. Other forms of embankment and slope containment solutions can be employed, such as vegetated gabions. Depending on the location, these NbS can be implemented individually or as a system, either by repeating the same solution or by combining solutions. This depends on the analysis of the site's characteristics and needs.

Sediment load:

when there is a high sediment load, it is recommended not to use devices for surface water run-off to avoid high maintenance costs for cleaning up any sediment and coarse solids. On sites with a high pollutant load, rainwater infiltration devices must be used as part of a rigorous phytoremediation project to avoid soil and groundwater contamination and the high maintenance costs that could result from rapid soil clogging.

Type of soil:

important pedological information includes the hydrological classification of soils[5]. One practical and widely used method is the classification of soils into Hydrological Soil Groups, as proposed by the Natural Resources Conservation Service (NRCS, formerly the Soil Conservation Service (SCS)) of the United States Department of Agriculture (USDA). This system has been adapted by various authors

5 Sartori et al. (2005) adapted the hydrological classification of soils developed by the United States Department of Agriculture (USDA) to the context of the soils found in Brazil.

for the Brazilian Soil Classification System (SiBCS), particularly in the work of Sartori et al. (2005).

In the NRCS classification, soils in group A have a high infiltration rate (greater than 7.62 mm/h), while soils in groups B, C and D have progressively lower rates. The least permeable soils in group D have infiltration rates of less than 1.27 mm/h (SARTORI et al., 2005). Compared to the classification of soils in terms of their hydraulic conductivity (RIGHETTO et al., 2009), soils in groups A and B, which have infiltration rates greater than 3.81 mm/h (SARTORI et al., 2005), can be considered the most suitable for NbS aimed at increasing infiltration.

These two classes include all types of latosols, red or red-yellow argisols that do not show abrupt textural changes, red nitosols and quartz neosols. To design an infiltration system that achieves good results, it is necessary to carry out soil characterisation tests, such as the granulometric analysis, to determine the percentages of clay, silt, sand and gravel present in a given sample.

The coarse fraction of the soil (gravel and sand) is much more permeable than the fine fraction (clay and silt), making it preferable in the composition of the NbS to enable adequate infiltration rates of rainwater. However, other characteristics interfere with this process, such as the degree of soil compaction, so, in addition to the granulometric analysis, a permeability test and infiltration tests are necessary to better characterise the porous medium and enable more accurate sizing of the NbS.

Sandy soils with a high percolation capacity, for example, are ideal for devices that work mainly on water infiltration. Conversely, in soils with low infiltration rates, infiltration devices associated with stone reservoirs that promote temporary water storage can be used to balance the buffering time with the water infiltration time in soils with lower percolation rates.

It is important to foresee overflows connected to the rainwater system, as its capacity to receive run-off must be studied. These overflows are essential to ensure that the sheet of water does not remain in the system for too long to maintain drainage efficiency. In watertight solutions, the buffering function is primarily confined to the mineral drainage layer, as can be seen in the rain beds.

Terrain characteristics / interference register:
implementation requires that the presence of any interfering facilities be ascertained before work begins, especially when inserted in consolidated urban areas. If possible, this should be done during the design phase to check whether they can be relocated or adapted to the project configuration. Paying attention to the characteristics and interferences of the terrain:

- **Presence of underground installations:** one should pay attention to the presence of underground installations (e.g. electricity, telephone or sewage systems) and analyse the possibility of relocating them or adapting the project configuration. If they are located in consolidated urban areas, it is necessary to check for the presence of any installations before work begins. If possible, this analysis can be carried out on site or through documentation from the relevant agencies during the design phase. The same applies to the implementation of NbS on large sites intended for urban and/or linear parks: cooperation between government departments and agencies to exchange documentation and information is essential for good planning of the sustainable drainage of the project.
- **Existing afforestation:** the site where the NbS are to be installed must be analysed for the presence of trees. It is necessary to ensure that the trees are a species that are adapted to wet soil conditions; otherwise they may be damaged by these changes in the soil which could result in them dying and causing further damage to the site if they fall.
- **Destination of the surplus volume of Direct Surface Drainage – DSD:** NbS must have conduits to direct excess flooding to the nearby drainage network or watercourse, in order to avoid overflow into adjacent areas which could cause inconvenience and pose risks. In locations where there is no nearby drainage network or watercourse to discharge the surplus volume, the infiltration and storage capacity should be assessed and compared with the flood volume for the considered recurrence time, and alternatives for routing the surplus flood should be investigated. If it is not feasible to safely infiltrate, store and route the entire DSD surplus volume, the feasibility of installing the device should be assessed, taking into account all the risks involved.
- **Availability of area:** each site must be analysed according to its needs and characteristics in order to determine the best design option. The project must comply with local urban planning regulations, whether for roadways, sidewalks, parks, etc.

HYDROLOGY:

refers to the data needed to select the appropriate NbS. The following must be analysed: the rainfall and flow rate at the project site; the depth of the water table, and how run-off water will be directed (retention, conduction and infiltration). According to the data:

Flow control / Interception capacity:
NbS distributed throughout the watershed and incorporated into the urban landscape can provide diverse benefits for urban centres if implemented systematically and redundantly. For controlling small flows (e.g. rainfall with an RT of up to 10 years), the NbS strategies that are widespread in the basin are efficient and can provide both ecosystem and landscape benefits. For rainfall with longer recurrence times (RT greater than 10 years), which is known to produce larger volumes of water, basins and/or reservoirs with multiple uses are an interesting idea for macro-drainage solutions in cities.

Water table level:
this factor directly influences the choice of the type of NbS to be planted in each location, as its depth affects the storage capacity of the mineral layers and soil infiltration. For NbS designed to collect and absorb water, the water table must be analysed to identify the most suitable solution and maximum depth for the intervention. Superficial depths pose risks when using infiltration structures as they can become saturated during prolonged rainfall, increasing the risk of groundwater contamination (RIGHETTO et al., 2009). These solutions should only be used when not watertight if the maximum water level (WL_{max}) of the groundwater in the rainy season is at least 1 m below the land's surface. Where the water table is high, the system's effectiveness must be assessed, as infiltration will be compromised. This will require pipes to connect to the conventional drainage network, and the system must be watertight with walls on the sides and bottom to prevent groundwater from entering the structure. If you do not have access to information on the depth of the water table at the NbS installation site, you should check whether there is a body of water within 50 m and whether the installation will be located within an alluvial plain. If either of these conditions applies, the infrastructure must be watertight and have a drain. If the NbS is more than 50 m from a body of water and outside an alluvial plain, it does not need to be watertight, regardless of the permeability of the existing soil.

Drainage and water run-off:
divided into infiltration, detention, conduction and retention capacities.

MATERIALS REQUIRED:

the material resources needed to implement the NbS, such as sand, stones, vegetation and geotextile. It should be noted that Geotextiles are synthetic material blankets that serve three purposes: acting as a filter layer, contributing structurally and preventing clogging (the blockage of the structure's voids by particles present in the direct surface water flowing into it). These materials are therefore extremely useful and recommended for NbS structures as they are easy to install, cost-effective and thin. They enable quality control and adequate hydraulic properties, which endorses their use in filtering systems. Geotextiles function correctly as filters when they fulfil mechanical and durability criteria and are correctly sized so that the opening of their pores reaches the soil's retention capacity and prevents the passage of soil particles. This material is expected to guarantee the hydraulic efficiency of the NbS, by allowing water to pass through while preventing the occurrence of two undesirable phenomena in the structure: clogging and retrogressive erosion.

MAINTENANCE:

in general, NbS aim to reduce long-term maintenance costs. Initial monitoring of the system may be necessary to assess its effectiveness and determine if elements such as seedlings need to be replaced. It is recommended that the local population participate in the care and basic manual maintenance of these infrastructures, such as removing accumulated rubbish, to ensure that water can pass through the different NbS. Community participation is fundamental to the social appropriation process and should be encouraged through educational training cycles aimed at raising awareness of the importance of these practices and how to maintain them effectively. However, it is assumed that formal responsibility for maintenance and cleaning services lies with the municipality. Nevertheless, the population can be a valuable asset, given their daily interaction with public facilities.

COST OF IMPLEMENTATION:

estimated based on general variables and parameters to obtain a cost per m^2. The cost of implementing each NbS involves variables that must be considered, whether by the public entity or in a public-private partnership. The main cost items are:

- **Area available for NbS implementation:** the cost may vary according to the level of intervention required and the size of the NbS implementation area. The budget should allow for a reduction in the cost per m^2 as the intervention area increases. In some cities, suppliers tend to reduce their costs by buying materials in bulk. If the area is under the supervision of a department other than the state, the operating costs must also be considered;
- **Type of soil and the need to intervene in its composition:** the type of existing soil and the water table can impact costs. The soil itself can affect the structure, requiring enclosing walls and pipes, among other things;
- **Development of the technical project:** if it is not carried out by the municipality's own technical staff it requires the hiring of a company and/or a specialised professional;
- **Workforce:** if there are no professionals from the municipality available to carry out the service, the cost of hiring these professionals should be calculated;
- **Excavation:** determine whether the service will be carried out manually or by machine, and calculate the costs attributed to each option based on local needs;
- **Transportation of materials:** it is recommended that, when not contaminated, materials be reused for the system itself, thus reducing the cost of transporting residues. For example, concrete removed from a sidewalk to create a rain bed can be reused in the lower filter layer instead of gravel or hand stones;
- **Gutter blocks and curbs:** the cost varies according to the project and site requirements;
- **Conduits and conductors:** the cost varies according to the project and site requirements;
- **Soil, sand, gravel and geotextile:** the total cost of these items can vary according to the size of the infrastructure and the need to increase or reduce certain layers;
- **Vegetation:** the final cost of vegetation can vary depending on the size of the infrastructure and the species used;
- **Materials specific to NbS:** as pumps are a variable cost item, their price can vary according to the project and anticipated site requirements.

The items above are intended as a guide to possible variables, as the cost can vary for each NbS and design situation the cost can vary, depending on local needs, design parameters and other factors. It is always possible to minimise costs during construction. Therefore, the professional responsible for the project must consider the following: the possibility of reusing existing materials on site (thus reducing input costs and transportation of residues); defining suitable species (thus reducing their mortality rate); and the suitability of the project for the site (thus reducing the need for future maintenance). An NbS system should allow for a reduction in infrastructure maintenance over time.

POSSIBLE CHALLENGES IN PLANNING AND EXECUTION:

these are divided into the following categories: choice of land, clogging, suitable vegetation, the qualifications of technicians and public policies. Clogging is the process of obstructing the filtering system, which can be caused by the soil particles themselves (physical clogging), by microorganisms (biological clogging) or iron oxide (chemical clogging). Retrogressive erosion (or piping) occurs when soil is being carried through the filter system, which can result in the structure being ruined. Both phenomena are to be expected at the start of the system's operation, but the correct sizing of the filter medium is necessary to prevent this process from continuing throughout the structure's useful life. The clogging potential of a geotextile in a given medium can be measured by carrying out laboratory tests using permeameters. These are small cylinders that replicate the filter medium used in the field. Water is then flowed through the permeameter and the evolution of permeability over time is calculated. Graphs of permeability over time can then be used to monitor the system.

The NbS for open spaces are presented below, alongside their characteristics, selection criteria and recommendations.

Diagram of Orla do Guaíba urban park in Porto Alegre, Rio Grande do Sul, office of Jaime Lerner Arquitetos Associados

- Rain garden -

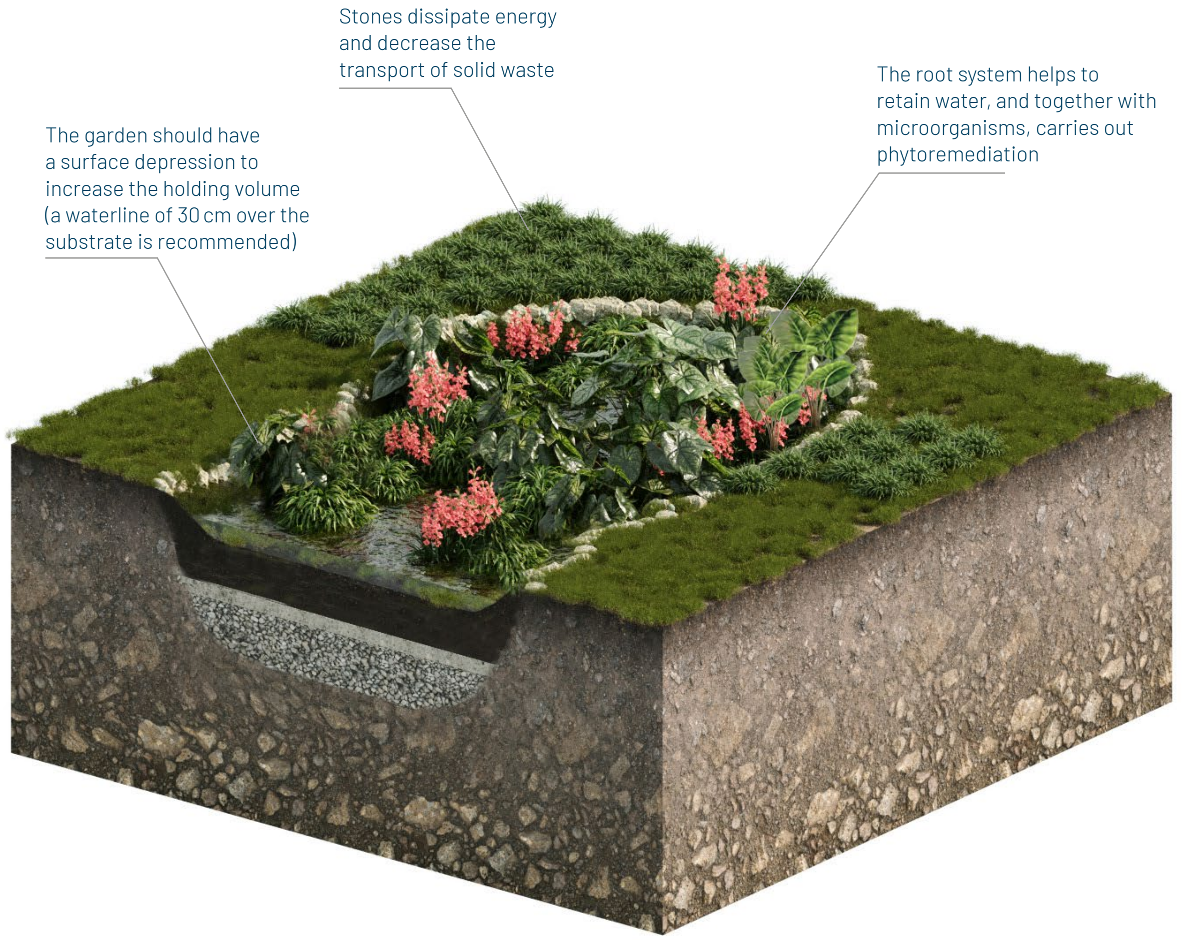


Figure 3 Rain garden (Source: Guajava, 2023).

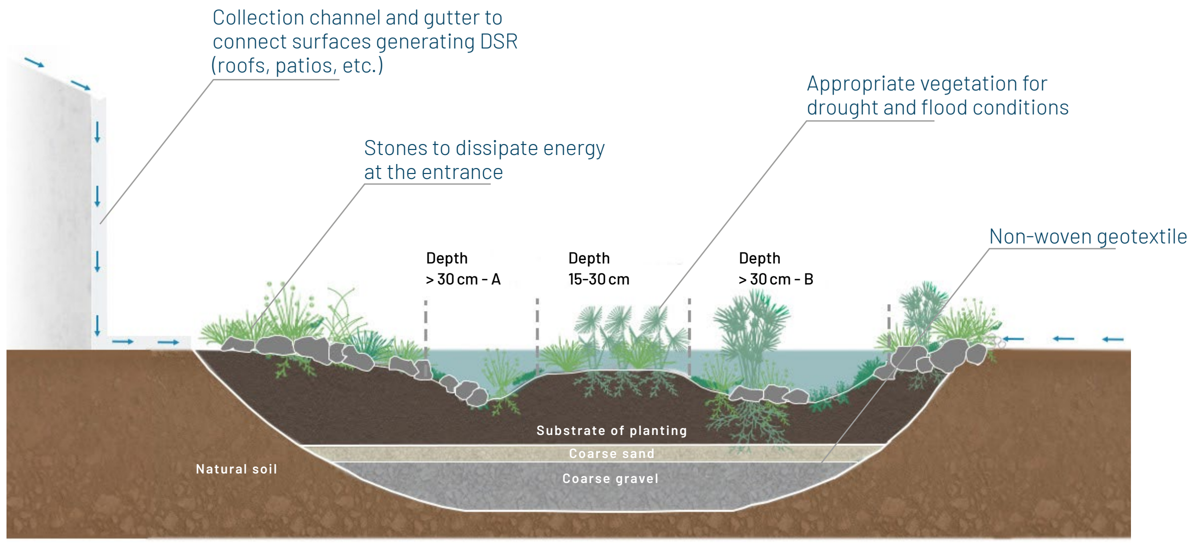


Figure 4 Rain garden – schematic cross-section (Source: Guajava, 2023).

A rain garden is a topographical depression designed to collect and absorb surface run-off from rain, roofs, sidewalks, streets and other impermeable surfaces. This significantly reduces the amount of water directed to the conventional urban drainage system (CORMIER; PELLEGRINO, 2008).

The efficiency is achieved through storage spaces created by the filtering layers of the garden, with some of the water being absorbed and filtered by the vegetation. Other factors include the existing soil, if it allows this absorption, and the conventional drainage network, when there is a connection.

TECHNICAL PARAMETERS TO BE CONSIDERED WHEN CHOOSING:

STRATEGIC LOCATION:

Mainly in squares and parks. Ideal for reservoir areas. Not recommended for roads or sidewalks.

PEDOLOGY/TOPOGRAPHY:

Soil permeability:
to achieve good results, the drainage system must be designed taking into account all the input, output and status variables involved.

The input variable is the volume of direct surface run-off (DSR) conveyed to the system, which depends on the design rainfall, the connected area, and its impermeability rate. The status variable is the buffered volume during the system's operating time. The output variables are infiltration and excess flow into the drainage network.

Infiltration analysis is a fundamental component of the system and is defined based on the properties of the porous medium. These properties are determined by soil characterisation tests, mainly the granulometric analysis test, which determines the percentage of clay, silt, sand and gravel present in the sample, and the permeability test, which determines the speed at which water percolates through the soil. The coarse fraction of soil (gravel and sand) is much more permeable than the fine fraction (clay and silt), making it preferable in the composition of NbS to enable adequate infiltration rates of rainwater. However, other obstacles interfere with this process, such as the degree of soil compaction. Therefore, in addition to the granulometry test, a permeability test and infiltration tests are necessary to characterise the porous medium and enable more accurate sizing of the NbS.

Slope:
the NbS should not be installed on land with a slope of more than 5% in order to maximise its effectiveness. On flat terrain or terrain with a slope of up to 5%, the area designed to capture and absorb water is more efficient, as it enables the water to remain in place for proper absorption by the NbS. On steeper terrain, however, some of the water will pass through the device without being absorbed, thus reducing its effectiveness.

Sediment load:
the input of solids into the system is low. Mechanisms for retaining solids must be provided in order to prevent sediment from entering the system and causing clogging. Consider installing filters and enveloping structures with non-woven geotextiles.

Types of soil:
the system is best suited to soils with low run-off potential and high infiltration rates, as well as soils with moderate infiltration rates and good drainage. These soils are classified as belonging to hydrological soil groups A and B[6] according to the hydrological soil classification of the Natural Resources Conservation Service (NRCS) of the United States (adapted for Brazilian soils by Sartori et al., 2005).

Terrain characteristics / interference register:
the implementation of this NbS, especially when inserted in consolidated urban areas, requires the verification of the presence of any installations before work begins. Ideally, this should be done during the design phase to establish whether they can be relocated or adapted to the project configuration. This analysis can be carried out on site or using documentation from the relevant agencies. The same applies to the implementation of NbS on large plots intended for urban and/or linear parks. In this case, cooperation between departments and agencies to exchange documentation and information is essential for the sustainable drainage system to be planned well. The presence of trees on the site should be analysed to ensure that they are species adapted to wet soil conditions; otherwise they could be damaged by these changes in the soil.

HYDROLOGY:

Flow control / interception capacity:
to define the return time associated with the operation of the NbS, the calculations must be carried out in accordance with municipal standards. This involves taking into account the design rainfall and the connected areas, including direct surface connections and the links from the drainage system to the device. A rain garden with a gravel layer depth between 0.70 m and 1.00 m deep is considered to have the capacity to accumulate, on average, the volume of a connected area equivalent to 20 times the surface area of the garden, depending on the degree of impermeability of the connected surfaces.

Water table level:
in areas with high a water table (less than 1 m deep), the system's effectiveness will be reduced due to low absorption. Therefore, an alternative device is recommended, such as watertight rain beds with walls on the sides and bottom of the system to prevent groundwater from entering the structure.

6 Which have infiltration rates greater than 3.81 mm/h (SARTORI et al., 2005).

Drainage and water run-off:
rain garden's main hydric regulation characteristics are infiltration and detention. They are designed so that, within a maximum of 72 hours[7], there is no more standing water on the surface of the garden. They also rely on evaporation, evapotranspiration and overflow.

We recommend downloading the BIM family, which is available via the following link: www.guajava.com.br

MATERIALS REQUIRED:

Gravel or hand stone:
a storage and transfer layer of gravel, preferably no. 5, or hand stone or concrete residues removed from the site (without contaminating components that could affect the water table). This layer temporarily accumulates water before being it is supplied to the water table or directed to the conventional drainage system. This is the main water storage layer, so this material should be given the greatest possible thickness while respecting the minimum substrate requirements for vegetation.

Geotextile:
this geosynthetic has been widely used in drainage and filtration systems and can be classified according to its manufacturing process as woven, non-woven or knitted. To perform its filtering function, the non-woven type must be used. The fibres in this product are arranged in a random orientation, which prevents water from passing freely through the geosynthetic. Geotextiles are easy to install, low cost, small in thickness and enable quality control with adequate hydraulic properties. These characteristics endorse the use of this material in filtering systems.

Sand:
sand increases porosity and aeration, helping the infiltration and redistribution of water in the soil. The sand layer should be at least 10 cm thick to increase the permeability and infiltration of the NbS.

Substrate / soil:
we recommend using compost made from black earth and worm humus in a 1 : 1 ratio. It can be mixed with sand to increase its permeability. The substrate layer must be at least 25 cm thick to allow plants to grow well.

Stones from around the NbS:
handstones, cobblestones and other residual or ornamental materials can be used around or at the entrances to the device to dissipate the energy of the water. If no material is used, the force of the water will erode the substrate, soil and vegetation, damaging the bed over time.

Vegetation:
it absorbs nutrients and water that flow into the rain garden, releasing water vapour back into the atmosphere through transpiration. The plants' deep roots also create channels through which rainwater infiltrates the soil. Plant species (autochthonous) suitable for moist soils are ideal; the recommended vegetation is listed in Step 3 of this catalogue. Consider local climatic conditions when choosing species.

7 More information described in Step 2 of this catalogue.

MAINTENANCE:

- Pay attention to the accumulation of sediment and debris and replace vegetation when necessary.
- Foresee an additional quantity of seedlings amounting to 2% to 5% of the total value to mitigate initial losses due to seedlings dying shortly after planting during the adaptation period (a one-off action during implementation).
- Remove residue manually[8] (periodic and recurring action).
- Restore filter layers by clogging NbS (a one-off action when infiltration is not occurring).

COST OF IMPLEMENTATION:

Variable[9] between USD $80.00 and USD $140.00 per m^2.

POSSIBLE CHALLENGES IN PLANNING AND EXECUTION:

Land:
difficulty in obtaining prior information on underground installations, often interfering with the revision of the project after the start of construction.

Clogging:
maintenance for NbS should be contracted for between 5 and 10 years after implementation to recover infiltration capacity.

Suitable vegetation:
the availability of (autochthonous) plant species suitable for wet soils.

Qualification of technicians:
the availability on the market of trained technicians with the specific knowledge to correctly analyse all the information and then monitor its execution.

Public policies:
absence of public policies and participatory planning and governance for the inclusion of NbS in urban planning.

8 Action taken by the agency responsible for maintaining and cleaning the area and/or by a civil person. Indicates the incentive to adopt urban green areas to help maintain them.

9 According to the area, design and configuration of the NbS, materials, labor, vegetation.

Figure 5 Rain garden in an integrated NbS system implemented in Parque Municipal Lagoa do Nado, Belo Horizonte/MG (Landscape Architecture Project by Guajava Arquitetura da Paisagem e Urbanismo, Paulo Pellegrino, and Silvio Motta; photo: Nereu Jr, 2021).

Figure 6 Rain garden implemented in Praça Tancredo Neves, Contagem/MG (Landscape Architecture Project by Guajava Arquitetura da Paisagem e Urbanismo, Paulo Pellegrino, and Silvio Motta; photo: Meridiano Filmes, 2021).

Figure 7 Rain garden implemented in Largo das Araucárias, São Paulo/SP (Fluxus Project, photo: Fernando Sassioto, 2017).

Figure 8 Rain garden implemented at Umapaz, São Paulo/SP (Fluxus Project, photo: Guilherme Castagna, 2016).

- Rain bed -

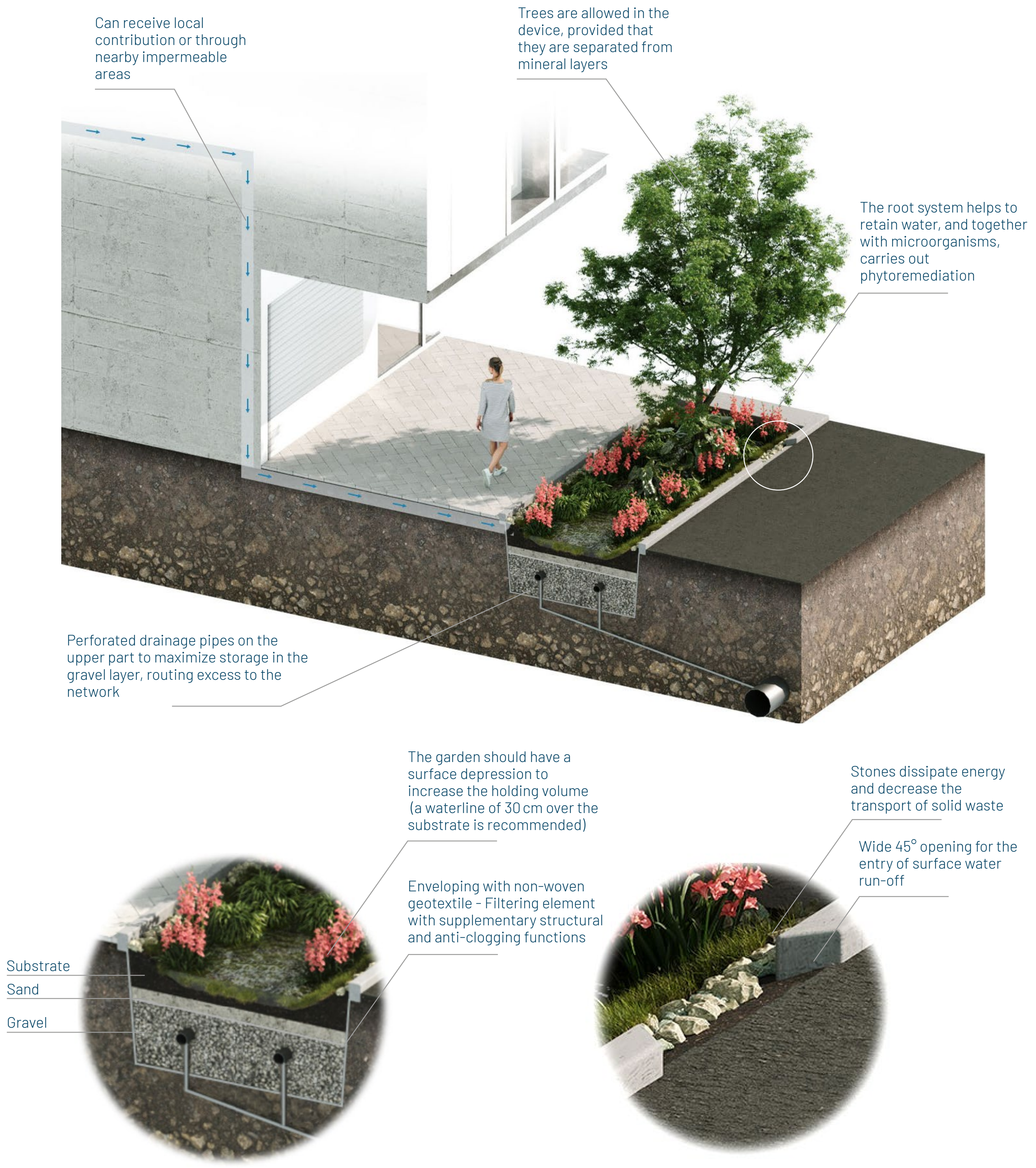


Figure 9 Rain bed (Source: Guajava, 2023).

A rain bed is the technical name used for a rain garden that has been compacted into a small available urban space (CORMIER; PELLEGRINO, 2008), with the same function of collecting and absorbing surface run-off from impermeable surfaces.

The water collected in the rain bed should be drained within a few hours after a light to moderate rainfall event and between 24 and 72 hours after a precipitation event, to prevent the proliferation of insects, algae and bacteria on the site.

Rain beds can be watertight and, if necessary, can contain an outlet to help control overflow and a pipe to direct the surplus water collected into the existing conventional drainage system. Stones are also used to dissipate water energy at the entrance to the device.

TECHNICAL PARAMETERS TO BE CONSIDERED WHEN CHOOSING:

STRATEGIC LOCATION:

Road system, especially sidewalks, parking spaces on roads and in parking garages.

PEDOLOGY / TOPOGRAPHY:

Soil permeability:
to achieve good results, the drainage system must be designed taking into account all the input, output and status variables involved. The input variable is the volume of direct surface run-off (DSR) conveyed to the system, which is a function of the design rainfall, the connected area and its impermeability rate. The status variable is the buffered volume during the system's operating time. The output variables are infiltration and excess flow into the drainage network. Infiltration analysis is a fundamental component of the system and is defined based on the properties of the porous medium. These properties are determined by soil characterisation tests, mainly the granulometric analysis test, which determines the percentage of clay, silt, sand and gravel present in the sample, and permeability test, which determines the speed at which water percolates through the soil. The coarse fraction of soil (gravel and sand) is much more permeable than the fine fraction (clay and silt), making it preferable in NbS composition of to enable the adequate infiltration rates of rainwater. However, other characteristics interfere with this process, such as the degree of soil compaction. Therefore, in addition to the granulometry test, a permeability test and infiltration tests are necessary to better characterise the porous medium and enable more precise sizing of the NbS.

Slope:
they should not be installed on land with a slope of more than 5% in order to maximise the effectiveness of the NbS. On flat terrain or terrain with a slope of up to 5%, the area designed to capture and absorb water is more efficient, as it enables the water to remain in place for proper absorption by the NbS. On steeper terrain, however, some of the water will pass through the device without it being absorbed, thus reducing its effectiveness.

Sediment load:
the input of solids into the system is low in the five situations illustrated for rain beds and infiltration systems when curbs are installed above sidewalk level. Mechanisms for retaining solids must be provided in order to prevent sediment from entering the system and causing clogging. Consider installing filters and enveloping structures with non-woven geotextiles.

Types of soil:
the system is best suited to soils with low run-off potential and high infiltration rates, as well as soils with moderate infiltration rates and good drainage, from hydrological soil groups A and B, according to the hydrological soil classification of the Natural Resources Conservation Service (NRCS) of the United States (adapted for Brazilian soils by Sartori et al., 2005).

Terrain characteristics / interference register:
the implementation of this NbS, especially when inserted in consolidated urban areas, requires the verification of the presence of any installations before work begins. Ideally, this should be done during the design phase to establish whether they can be relocated or adapted to the project configuration. This analysis can be carried out on site or using documentation from the relevant agencies. The same applies to the implementation of NbS on large plots intended for urban and/or linear parks. In this case, cooperation between departments and agencies to exchange documentation and information is essential for the sustainable drainage system to be planned well. The presence of trees on the site should be analysed to ensure that they are species adapted to wet soil conditions; otherwise they could be damaged by these changes in the soil.

HYDROLOGY

Flow control / interception capacity:
to define the device's return time, calculations must be carried out in accordance with municipal standards. This takes into account the index of the public rainwater gallery with which the NbS will be correlated.

Water table level:
in places where the water table is high (less than 1 m deep), the system's effectiveness will be compromised due to low absorption. Therefore, it is recommended that pipes are used to connect it to the conventional drainage network. In this case, the NbS must also be watertight, i.e. it must have walls on the sides and bottom of the system to prevent groundwater from entering the structure.

Drainage and water run-off:
the main characteristic of hydric regulation is detention, and also infiltration when the system is not watertight. They are designed so that, within a maximum of 72 hours[10], there is no standing water left on the surface of the bed, regardless of the design choice.

We recommend downloading the BIM family, which is available via the following link:
www.guajava.com.br

10 More information described in Step 2 of this catalogue.

MATERIALS REQUIRED:

The materials required for the filtering layers of the rain bed – in order of application in NbS – and materials for dissipating water energy are described below:

Gravel or hand stone:
a storage and transfer layer of gravel, preferably no. 5, or hand stone or concrete residues removed from the site (without contaminating components that could affect the water table). This layer temporarily accumulates water before being supplied to the water table or directed to the conventional drainage system. This is the main water storage layer, so this material should be given the greatest possible thickness while respecting the minimum substrate requirements for vegetation.

Geotextile:
this geosynthetic has been widely used in drainage and filtration systems and can be classified according to its manufacturing process as woven, non-woven or knitted. To perform its filtering function, the non-woven type must be used. The fibres in this product are arranged in a random orientation, which prevents water from passing freely through the geosynthetic. Geotextiles are easy to install, low cost, small in thickness and enable quality control with adequate hydraulic properties. These characteristics endorse the use of this material in filtering systems.

Sand:
the sand layer increases the infiltration and redistribution of water in the soil. The use of sand increases porosity and aeration, helping water to penetrate through this layer. The sand layer should be at least 10 cm thick to increase the permeability and infiltration of NbS when there is available area.

Substrate / soil:
composed of black earth and worm humus in a 1 : 1 ratio. It can be mixed with sand to increase its permeability. The substrate layer must be at least 25 cm thick to allow plants to grow well.

Vegetation:
it absorbs nutrients and water that flow into the rain bed, releasing water vapour back into the atmosphere through transpiration. The plants' deep roots also create channels through which rainwater infiltrates the soil. Plant species (autochthonous) suitable for moist soils are ideal; the recommended vegetation is listed in Step 3 of this catalogue. Consider local climatic conditions when choosing species.

Stones from around the NbS:
handstones, cobblestones and other residual or ornamental materials can be used around or at the entrances to the device to dissipate the energy of the water. If no material is used, the force of the water will erode the substrate, soil and vegetation, damaging the bed over time.

MAINTENANCE:

- Consider the accumulation of sediment and debris and replace vegetation when necessary.
- Foresee an additional quantity of seedlings amounting to 2% to 5% of the total value to mitigate initial losses due to seedlings dying shortly after planting during the adaptation period (a one-off action during implementation).
- Remove residue manually[11] (periodic and recurring action).
- Restore filter layers by clogging NbS (a one-off action when infiltration is not occurring).

COST OF IMPLEMENTATION:

Variable between USD $80.00 and USD $140.00 per m^2.

POSSIBLE CHALLENGES IN PLANNING AND EXECUTION:

Land:
difficulty in obtaining prior information on underground installations, often interfering with the revision of the project after the start of construction.

Clogging:
maintenance for NbS should be contracted for between 5 and 10 years after implementation to recover infiltration capacity.

Suitable vegetation:
the availability of (autochthonous) plant species suitable for wet soils.

Qualification of technicians:
the availability on the market of trained technicians with the specific knowledge to correctly analyse all the information and then monitor its execution.

Public policies:
absence of public policies and participatory planning and governance for the inclusion of NbS in urban planning.

11 Action taken by the agency responsible for maintaining and cleaning the area and/or by a civil person. Indicates the incentive to adopt urban green areas to help maintain them.

Figure 10 Rain bed implemented at Cidade Universitária Armando Salles de Oliveira, University of São Paulo (Project by Maria Cristina S. Pereira and Lucas Gobatti, along with their advisors Rodolfo Scarati and Brenda Chaves; photo: Sarah Daher, 2022).

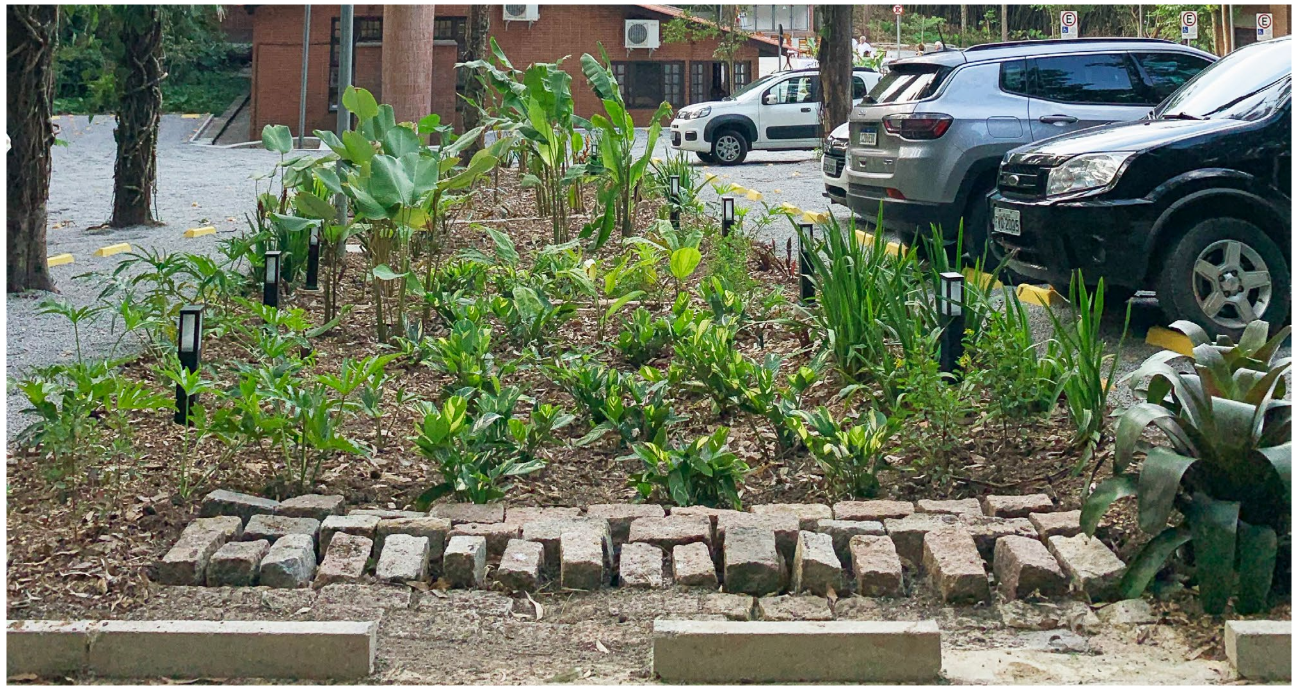


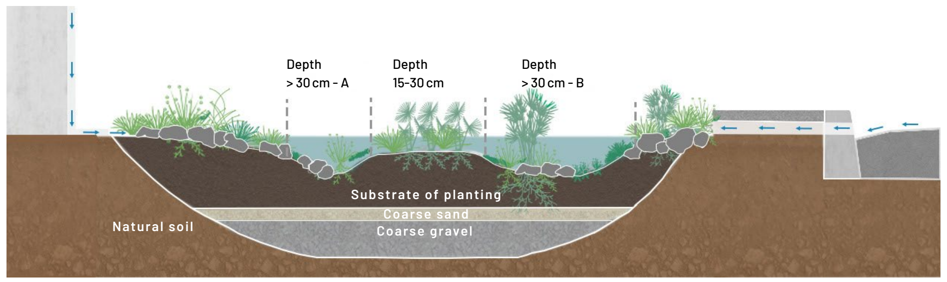
Figure 11 Integrated NbS system involving bioswales, rain bed, and rain gardens implemented at Cidade Universitária Armando Salles de Oliveira, University of São Paulo (Project by Paulo Pellegrino, Daniel Falconi, Silvio Motta, and Stefanie Gonzaga; photo: Daniel Falconi, 2023).

Table 2 Characteristics of five design possibilities for the rain beds.

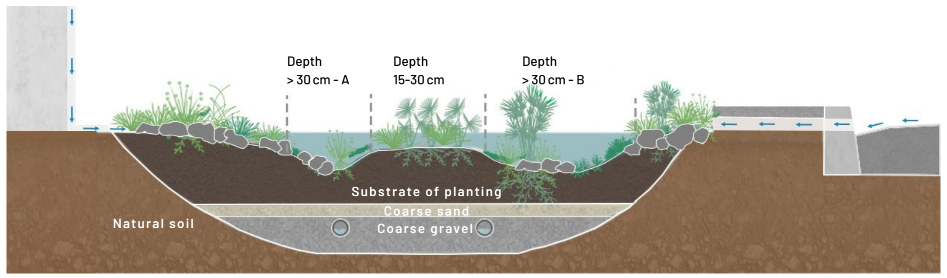
Characteristics of the soil	Variables of the beds		
	Side wall	Bottom layer of the bed	Pipe / Duct connection to existing conventional drainage
Sandy soil, infiltration greater than 30 mm/h Low water table: the maximum water table level must be up to 1 metre below the bottom of the infiltration device	No	No	Variable according to project rainfall
Sandy loam soil, infiltration between 20–30 mm/h Low water table: the maximum water table level should be up to 1 metre below the bottom of the infiltration device; check the condition of the soil (impermeable <10 mm/h)	No	No	Yes
Loamy soil, infiltration between 10–20 mm/h Nearby building less than 2 metres, outside the floodplain	Yes	No	Variable according to project rainfall
Loamy clay soil, infiltration between 5–10 mm/h Nearby building less than 2 metres away, outside the floodplain, check soil condition (impermeable <10 mm/h)	Yes	No	Yes
Clay soil, infiltration less than 5 mm/h Floodplain (high water table), regardless of proximity to buildings	Yes	Yes	Yes

Characteristics of five design options for rain beds

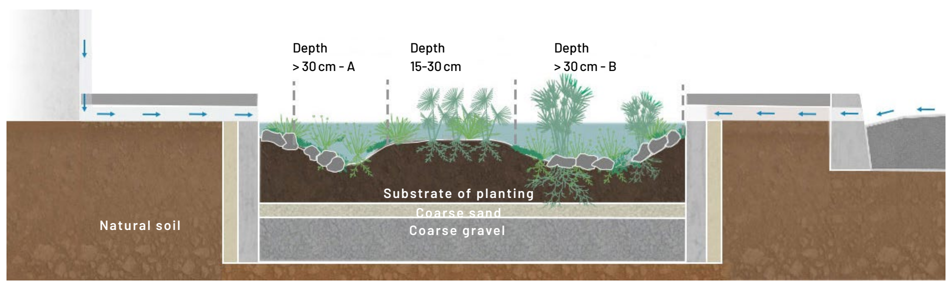
☒ Side wall
☒ Bottom slab
☒ Drainage pipes



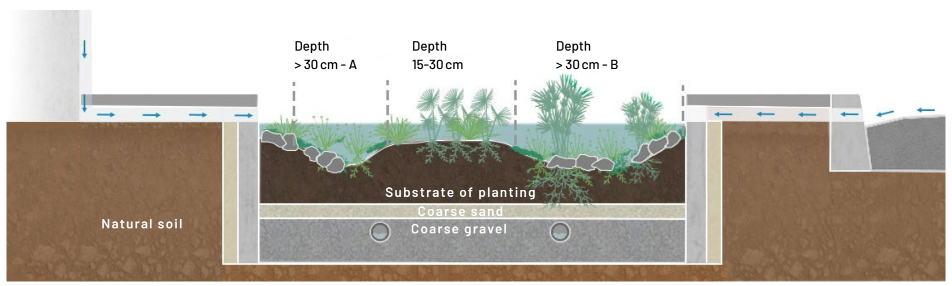
☒ Side wall
☒ Bottom slab
☑ Drainage pipes



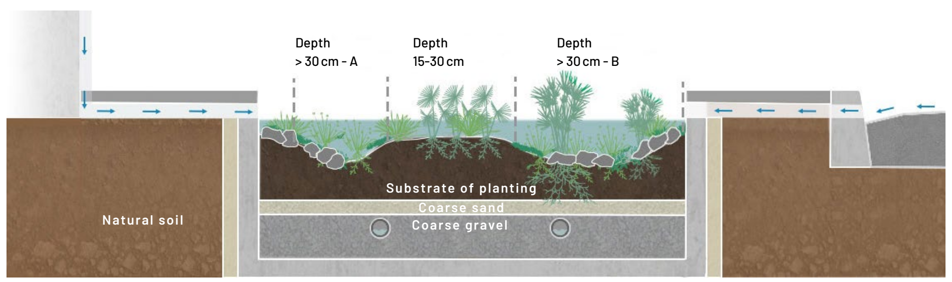
☑ Side wall
☒ Bottom slab
☒ Drainage pipes



☑ Side wall
☒ Bottom slab
☑ Drainage pipes



☑ Side wall
☑ Bottom slab
☑ Drainage pipes



- Bioswale -

Figura 12 Biovaleta (Fonte: Guajava, 2023).

Bioswales, also known as vegetated bioretention ditches, are shallow, sloping vegetated depressions (CORMIER; PELLEGRINO, 2008) with a linear configuration. This NbS is designed to collect, treat and infiltrate surface rainwater run-off and it can also be used to direct and guide the water to another system (conventional or sustainable) via the slope of the land. In steeper areas, dams (fins and sills) should be incorporated into the bioswale to reduce the speed of water run-off, as should other NbS such as vegetated hydraulic stairs.

Graduated side slopes, such as embankments, offer greater design and planting flexibility compared to bioretention NbS with fixed vertical walls, such as rain beds and rain terraces. In most cases, bioswales are shallow and do not need to be deeper than 60 cm.

TECHNICAL PARAMETERS TO BE CONSIDERED WHEN CHOOSING:

STRATEGIC LOCATION:

In central medians and parking lots, in narrow places for convey in water or even in wide areas associated with rain gardens, rain beds and polders.

PEDOLOGY / TOPOGRAPHY:

Soil permeability:
does not have a direct influence as a criterion for the bioswale, since it acts mainly to conduct surface rainwater run-off.

Slope:
when implanted on land with a slope of up to 5%, NbS is more effective in terms of water detention and conduction. However, on land with a slope of more than 5%, dams are necessary to reduce the speed of water conduction and maintain high effectiveness without overloading the vegetation and soil. The degree of inclination of the sides of the bioswale (embankments) must be defined according to the rate of soil erosion, or even the specific contextual requirements and concerns of the site, such as the presence or absence of curbs and other design specifics. The embankments may differ from one side to the other.

Sediment load:
The input of solids into the system is low.

Types of soil:
the system is best suited to soils with low run-off potential and high infiltration rates, as well as soils with moderate infiltration rates and good drainage, from hydrological soil groups A and B, according to the hydrological soil classification of the Natural Resources Conservation Service (NRCS) of the United States hydrological soil classification (adapted for Brazilian soils by Sartori et al., 2005).

Terrain characteristics / interference register:
the implementation of this NbS, especially when inserted in consolidated urban areas, requires the verification of the presence of any installations before works commence, or during the design phase, if possible, to verify whether they can be relocated or adapted to the project configuration. This analysis can be carried out on site using secondary data and documentation provided by the relevant agencies, supplemented by the completion of an interference register. The same applies to the implementation of NbS on large plots intended for urban and/or linear parks.

HYDROLOGY

Flow control / interception capacity:
to define the device's return time, calculations must be carried out in accordance with municipal standards, taking into account the index of the public rainwater gallery to which the NbS will be correlated.

Water table level:
in places where the water table is high (less than 1 m deep), the system's effectiveness will be compromised due to low absorption. Therefore, it is recommended that pipes are used to connect it to the conventional drainage network. In this case, the NbS must also be watertight, i.e. it must have walls on the sides and bottom of the system to prevent groundwater from entering the structure.

Drainage and water run-off:
the main characteristics of hydric regulation are the detention and conduction of water, as well as infiltration. These can be associated with conventional drainage pipes or other NbS such as rain gardens, rain beds and polders. The system must be free of water accumulation within 72 hours of rainfall.

MATERIALS REQUIRED:

Gravel or hand stone:
a storage and transfer layer of gravel, preferably no. 5, or hand stone or concrete residues removed from the site (without contaminating components that could affect the water table). This layer temporarily accumulates water before being supplied to the water table or directed to the conventional drainage system. This is the main water storage layer, so this material should be given the greatest possible thickness while respecting the minimum substrate requirements for vegetation.

Geotextile:
this geosynthetic has been widely used in drainage and filtration systems and can be classified according to its manufacturing process as woven, non-woven or knitted. To perform its filtering function, the non-woven type must be used. The fibres in this product are arranged in a random orientation, which prevents water from passing freely through the geosynthetic. This is achieved by using a blanket to separate the soil layer from the drainage layer below. This prevents the soil from being carried away, thus ensuring that the system does not become clogged prematurely. Geotextiles are easy to install, inexpensive, thin and enable quality control with adequate hydraulic properties, characteristics that endorse their use in filtering systems. Where there is a concrete base to guide the flow of water, it is possible to cover it with a geomembrane to make it watertight and prevent the roots from puncturing the concrete if they pass through the geotextile.

Sand:
the sand layer aims to increase the infiltration and redistribution of water in the soil. The use of sand increases porosity and aeration, helping water to penetrate through this layer. The sand layer should be at least 10 cm thick, when space is available, to increase the device's permeability and infiltration.

Substrate / soil:
composed of black earth and worm humus in a 1 : 1 ratio. It can be mixed with sand to increase its permeability. The layer of substrate must be at least 25 cm thick for the plants to grow well.

Vegetation:
it absorbs nutrients and water that flow into the rain garden, releasing water vapour back into the atmosphere through transpiration. The plants' deep roots also create channels through which rainwater infiltrates the soil. Plant species (autochthonous) suitable for moist soils are ideal; the recommended vegetation is listed in Step 3 of this catalogue. Consider local climatic conditions when choosing species.

Stones from around the NbS:
handstones, cobblestones and other residual or ornamental materials can be used around or at the entrances to the device to dissipate the energy of the water. If no material is used, the force of the water will erode the substrate, soil and vegetation, damaging the bed over time.

Energy dissipation flaps:
when inserted into slopes with an incline of more than 5%, dams are necessary to reduce the speed of the flowing water and maintain high efficiency without putting pressure on the vegetation and soil in the NbS. These dams can be made of stones, bricks or any other suitable dam material.

Pipes:
a drain pipe runs along the entire length of the bioswale at a slope of 0.1% towards the drainage box, conveying water.

MAINTENANCE:

- Foresee an additional quantity of seedlings amounting to 2% to 5% of the total value to mitigate initial losses due to seedlings dying shortly after planting during the adaptation period. This is a one-off action during implementation.
- Remove residue manually[12] (recurring action).
- Restore filter layers by clogging NbS (one-off action when infiltration is not occurring).

12 Action taken by the agency responsible for maintaining and cleaning the area and/or by a civil person. Indicates the incentive to adopt urban green areas.

COST OF IMPLEMENTATION:

Variable between USD $40.00 and USD $100.00 per m^2.

POSSIBLE CHALLENGES IN PLANNING AND EXECUTION:

Land:
difficulty in obtaining prior information on underground installations, often interfering with the revision of the project after the start of construction.

Suitable vegetation:
the availability of (autochthonous) plant species suitable for wet soils.

Qualification of technicians:
the availability on the market of trained technicians with the specific knowledge to correctly analyse all the information and then monitor its execution.

Public policies:
absence of public policies and participatory planning and governance for the inclusion of NbS in urban planning.

Figure 13 Bioswale in an integrated NbS system implemented in Parque Municipal Lagoa do Nado, Belo Horizonte/MG (Landscape Architecture Project by Guajava Arquitetura da Paisagem e Urbanismo, Paulo Pellegrino, and Silvio Motta; photo: Meridiano Filmes, 2021).

Figure 14 Bioswale in an integrated NbS system implemented at Cidade Universitária Armando Salles de Oliveira, University of São Paulo (Project by Paulo Pellegrino, Daniel Falconi, Silvio Motta, and Stefanie Gonzaga; photo: Daniel Falconi, 2023).

- Rain terraces -

Figure 15 Rain terrace on embankments (Source: Guajava, 2023).

Rain terraces are concave structures, transversal to the direction of the slope of the land. They are embedded in sections of embankments and built using stone walls or small vegetated gabions. They are filled with layers of mineral elements of different sizes, similar to rain gardens.

This is a NbS was developed by Guajava Arquitetura da Paisagem e Urbanismo together with the team from the Hydraulics Technology Center Foundation (FCTH) and the São Paulo Municipality, and was inspired by Chinese agricultural terraces. The aim of these structures is to collect and absorb surface rainwater run-off, thereby significantly reducing the amount of water directed to the area below the embankment, typically a watercourse or rainwater gallery, while also favouring embankment stability in areas on the banks of rivers, streams and creeks.

The are efficient at collecting water through the storage spaces in the created cavities, existing soil (if it allows this absorption) and the conventional drainage network (if connected). Another advantage is that they stabilise the embankments by creating vegetated steps through which water flows more slowly, thus recharging the water table.

TECHNICAL PARAMETERS TO BE CONSIDERED WHEN CHOOSING:

STRATEGIC LOCATION:

On any type of embankment, providing structural benefits even in places with a steep slope.

PEDOLOGY / TOPOGRAPHY:

Soil permeability:
to achieve good results, the drainage system must be designed taking into account all the input, output and status variables involved. The input variable is the volume of direct surface run-off (DSR) conveyed to the system, which is a function of the design rainfall, the connected area and its impermeability rate. The status variable is the buffered volume during the system's operating time. The output variables are infiltration and excess flow into the drainage network. Infiltration analysis is a fundamental component of the system and is defined based on the properties of the porous medium. These properties are deter-mined by soil characterisation tests, mainly the granulometric analysis test, which determines the percentage of clay, silt, sand and gravel present in the sample, and permeability test, which deter-mines the speed at which water percolates through the soil. The coarse fraction of soil (gravel and sand) is much more permeable than the fine fraction (clay and silt), making it preferable in NbS composition of to enable the adequate infiltration rates of rainwater. However, other characteristics

interfere with this process, such as the degree of soil compaction. Therefore, in addition to the granulometry test, a permeability test and infiltration tests are necessary to better characterise the porous medium and enable more precise sizing of the NbS.

Slope:
terraces should be built in sections transversal to the direction of the land's greatest slope and can be built on embankments with a slope of up to 18%[13] (MACHADO; WADT, 2021). However, it should be noted that the greater the slope, the greater the need for reinforcement in the wall structures.

Sediment load:
the input of solids into the system is low. Mechanisms for retaining solids must be provided in order to prevent sediment from entering the system and causing clogging. Consider installing filters and enveloping structures with non-woven geotextiles.

Types of soil:
when installing rain terraces, it is crucial to assess the stability of the embankment. These structures periodically store water, so this factor must not pose a landslide risk. To select the best materials for the structure, such as stones, gabions or trunks, it is necessary to assess the natural stability of the soil through geotechnical studies of soil resistance.

Terrain characteristics / interference register:
the implementation of this NbS, especially when inserted in consolidated urban areas, requires the verification of the presence of any installations before work begins. Ideally, this should be done during the design phase to establish whether they can be relocated or adapted to the project configuration. This analysis can be carried out on site or using documentation provided by the relevant agencies. The same applies to the implementation of NbS on large plots intended for urban and/or linear parks. In this case, cooperation between departments and agencies to exchange documentation and information is essential for the sustainable drainage system to be planned well. The presence of trees on the site should be analysed to ensure that they are species adapted to wet soil conditions; otherwise they could be damaged by these changes in the soil.

HYDROLOGY:

Flow control / interception capacity:
to define the device's return time, calculations must be carried out in accordance with municipal standards. This takes into account the index of the public rainwater gallery with which the NbS will be correlated.

Water table level:
in areas with high a water table (less than 1 m deep), the system's effectiveness will be reduced due to low absorption. Therefore, an alternative device is recommended, such as watertight rain beds with walls on the sides and bottom of the system to prevent groundwater from entering the structure.

13 According to the analysis on Terracing in Rice Cultivation (MACHADO; WADT, 2021).

Drainage and water run-off:
the main characteristics of hydric regulation are water detention and infiltration. These can be associated with conventional drainage pipes or other NbS such as bioswales or rain beds. If the aim is to reduce the speed of surface run-off to downstream areas of the basin, it is recommended that more than one rain terrace is installed and connected by bioswales. The system must be free of water accumulation within 72 hours of rainfall.

MATERIALS REQUIRED:

Gravel or hand stone:
a storage and transfer layer of gravel, preferably no. 5, or hand stone or concrete residues removed from the site (without contaminating components that could affect the water table). This layer temporarily accumulates water before being supplied to the water table or directed to the conventional drainage system.

Sand:
the sand layer aims to increase the infiltration and redistribution of water in the soil. Sand increases porosity and aeration, helping water to penetrate through this layer.

Materials required for the terrace structure:
stones that can be aligned and mortared to create structural walls or gabions that can be vegetated. The choice varies according to the type and resistance of the soil.

Suitable vegetation:
vegetation and substrate suitable for each region type, with strong roots to help stabilise embankments and withstand periods of high humidity. The recommended vegetation is listed in Step 3 of this catalogue.

MAINTENANCE:

- During implementation, allow for an additional quantity of seedlings amounting to 2–5% of the total value to mitigate initial losses due to seedlings dying shortly after planting during the adaptation period.
- The drainage of the terraces should be checked periodically after periods of heavy rainfall to ensure that the overflows and bioswales connected to the system are working properly.
- Periodically check for damage to the structures of stones or gabions that form the terraces and make structural reinforcements when necessary to prevent future landslides;
- Any residues that impede the flow of water should be periodically removed by hand.[14]

14 Action to be taken by the agency responsible for maintenance and cleaning or a civil person. We recommend encouraging the adoption of green areas.

COST OF IMPLEMENTATION:

Wall structures: mortared stone, USD$ 50.00 per m^2; gabion, variable between USD$ 50.00 and USD$ 70.00 per m^2.

Filters and gardens: variable between USD$ 75.00 and USD$ 160.00 per m^2.

POSSIBLE CHALLENGES IN PLANNING AND EXECUTION:

Land:
difficulty in obtaining prior information on underground installations, often interfering with the revision of the project after the start of construction.

Suitable vegetation:
the availability of (autochthonous) plant species suitable for wet soils.

Qualification of technicians:
the availability on the market of trained technicians with the specific knowledge to correctly analyse all the information and then monitor its execution.

Public policies:
absence of public policies and participatory planning and governance for the inclusion of NbS in urban planning.

Figure 16 Rain terrace at the Bandeirantes Creek Linear Park (Project by Guajava Arquitetura da Paisagem e Urbanismo, 2023).

- Vegetated hydraulic stairs -

Figure 17 Vegetated hydraulic stairs (Source: Guajava, 2023).

Vegetated hydraulic stairs are structures built in areas with a steep gradient to conduct and reduce the speed of rainwater run-off. The steps act as energy dissipators and, when covered in vegetation, they also increase the roughness of the area and improve the quality of the water that percolates through the vegetation.

Gabions are the most suitable material for this type of structure as they can adapt to different geometries, provide space for planting vegetation (especially fodder crops) and can be made in different sizes. Gabion construction requires fewer elements, only stone, gabion mesh and excavation machinery being needed to build the stairs. Alternatively, you can use concrete walls and permeable or semi-permeable floors, structured with stones or even gabions.

TECHNICAL PARAMETERS TO BE CONSIDERED WHEN CHOOSING:

STRATEGIC LOCATION:

On roadways, embankments and high-slope margins, to convey rainwater; preferably in areas associated with rain gardens and rain beds. Also in micro-drainage channels in areas of high slope where it is not possible to install bioswales.

PEDOLOGY / TOPOGRAPHY:

Soil permeability (hydraulic conductivity in mm/h):
does not directly influence for the suitability of the stairs, since they mainly act as a conduit for rainwater run-off.

Slope:
recommended for implementation on terrains with a slope of more than 5%, as it can route flows where other solutions cannot overcome steep slopes.

Sediment load:
due to the high slope of the terrain, the amount of solids allowed to influence water quality is low, resulting in high run-off velocities and low infiltration time in the structure.

Types of soil:
the system is best suited to soils with low run-off potential and high infiltration rates, as well as soils with moderate infiltration rates and good drainage. These soils are classified as belonging to hydrological soil groups A and B[15] according to the hydrological soil classification of the Natural Resources Conservation Service (NRCS) of the United States.

15 Which have infiltration rates greater than 3.81 mm/h (SARTORI et al., 2005).

Terrain characteristics / interference register:

the implementation of this NbS, especially when inserted in consolidated urban areas, requires the verification of the presence of any installations before work begins. Ideally, this should be done during the design phase to establish whether they can be relocated or adapted to the project configuration. This analysis can be carried out on site *using secondary data and documentation provided* by the relevant agencies, complemented by the completion of a specific interference register. The same applies to the implementation of NbS on large plots intended for urban and/or linear parks. In this case, cooperation between departments and agencies to exchange documentation and information is essential for the sustainable drainage system to be planned well.

HYDROLOGY:

Flow control / interception capacity:

it is important to follow the calculations and standards established for conventional hydraulic stairs, and to install secure walls and containments. This will ensure adequate water run-off in the channels intercepted by the earthworks, while at the same time guaranteeing the safety of these areas and reducing potential erosion damage. It is essential to promote the dissipation of velocities to enable water to flow under favourable conditions to the outflow points previously determined.

Water table level:

in places where the level of the water table is high, it is recommended that the steps be watertight.

Drainage and water run-off:

their main characteristics of their hydric regulation are water detention and conduction. They can be used alongside conventional drainage pipes or other NbS, such as rain gardens, rain beds and polders.

MATERIALS REQUIRED:

Substrate / soil:

composed from black earth and worm humus in a 1 : 1 ratio. It can be mixed with sand to increase its permeability. The substrate layer must be at least 25 cm thick for the plants to grow well.

Vegetation:

it absorbs nutrients and water that flow into the rain bed, releasing water vapour back into the atmosphere through transpiration. The plants' deep roots also create channels through which rainwater infiltrates the soil. Plant species (autochthonous) suitable for moist soils are ideal; the recommended vegetation is listed in Step 3 of this catalogue. Consider local climatic conditions when choosing species.

Gabions:

they allow the steps of the stairs to be adapted to different embankment situations, as well as the planting of coverings.

Concrete blocks or bricks:

these can be used to build concrete walls associated with permeable or semi-permeable floors, with a stone or gabion base. The covering materials must provide a suitable environment for vegetation to grow.

Base structure:

rock, mortar stone and reinforced concrete can be used as the structural base of the hydraulic ladder. They must be durable and resistant to withstand the hydraulic load and vegetation.

Stones for energy dissipation:

handstones, cobblestones, residual and other ornamental materials can be used where the water falls to dissipate the energy. If these materials are not used, the force of the water will erode the substrate, soil and vegetation over time, damaging the device.

MAINTENANCE:

- Foresee an additional quantity of seedlings amounting to 2–5% of the total value to mitigate initial losses due to seedlings dying shortly after planting during the adaptation period (a one-off action during implementation).
- Periodically check for damage to the structures of stones or gabions that form the terraces and make structural reinforcements when necessary, preventing future landslides (recurring action);
- Manually remove residue that impedes the flow of water[16] (recurring action).

COST OF IMPLEMENTATION:

Variable[17] between USD$ 120.00 and USD$ 240.00 per m^2.

POSSIBLE CHALLENGES IN PLANNING AND EXECUTION:

Land:

difficulty in obtaining prior information on underground installations, often interfering in the revision of the project after the start of construction.

Suitable vegetation:

the availability of (autochthonous) plant species suitable for wet soils.

Qualification of technicians:

the availability on the market of trained technicians with the specific knowledge to correctly analyse all the information and then monitor its execution.

Public policies:

absence of public policies and participatory planning and governance for the inclusion of NbS in urban planning.

16 Action taken by the agency responsible for maintaining and cleaning the area and/or by a civil person. We indicate the incentive to adopt urban green areas.

17 According to the area, design and configuration of the NbS, materials, labor, vegetation.

Figure 18 Vegetated hydraulic stairs in a project for the Grotas of Maceió/AL (Source: UN and Guajava, 2021).

- Vegetated hydraulic stairs -

Figure 19 Vegetated hydraulic stairs in an ecological alleyway designed and executed as part of the Canteiro Escola Águas Urbanas project in the Alvarenga neighborhood, São Bernardo do Campo-SP (Project and photo collection: LABHAB FAUUSP).

- Infiltration pit -

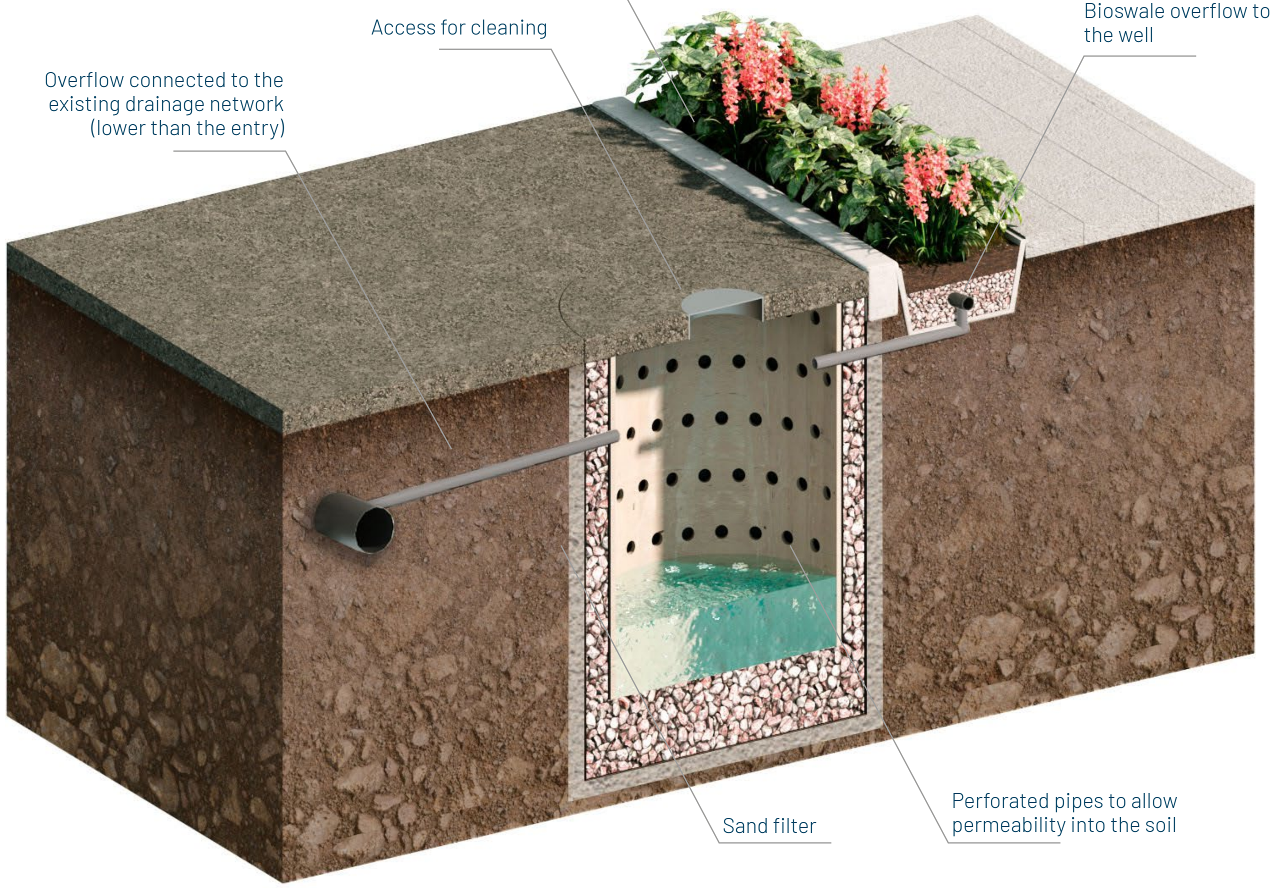


Figure 20 Infiltration pit (Source: Guajava, 2023).

An infiltration pit is a rainwater retention system that operates in a small area. It to mitigate the effects of surface run-off by capturing and infiltrating rainwater directly from the source into the soil. The System is designed to buffer peak flows that could overwhelm the conventional drainage system, reduce the volume of surface run-off by infiltrating surplus rainwater into the soil, and contribute to aquifer replenishment.

The system consists of a pit dug into the ground and lined with perforated concrete pipes, allowing the water to come into contact with the soil and thus ensuring infiltration. Infiltration pits can be wrapped in geotextile blankets, both on all sides and at the bottom of the pit. Coarse aggregates, most commonly gravel, are also used in the bottom layer, to maximise the infiltration rate.

Like other NbS, the infiltration pits work in cooperation with the 'grey' drainage system, helping to prevent it from collapsing.

TECHNICAL PARAMETERS TO BE CONSIDERED WHEN CHOOSING:

STRATEGIC LOCATION:

Preferably under sidewalks, streets and avenues.

PEDOLOGY / TOPOGRAPHY:

Soil permeability:
the more permeable the soil, the greater the infiltration capacity of the structure. In clay soils, the infiltration capacity is lower when compared to the infiltration capacity of sandy soils.

Slope:
there are no restrictions on the slope of the terrain, since the pits have been excavated. Similarly, there are no restrictions on the slope of the area contributing to the structure since it is also excavated. However, at the design stage, it should be taken into account that high-slope terrain produces high-velocity run-off. NbS should not be used in collapsible soils[18].

Sediment load:
in areas with high sediment or residue production, grating or sedimentation structures should be installed at the entrance to the structure or upstream. In this case, the structures should also be cleaned and maintained more frequently.

18 Soils that show a sudden reduction in volume after an increase in humidity.

Types of soil:
the system is best suited to soils with low run-off potential and high infiltration rates, as well as soils with moderate infiltration rates and good drainage. These soils are classified as belonging to hydrological soil groups A and B[19] according to the hydrological soil classification of the Natural Resources Conservation Service (NRCS) of the United States (adapted for Brazilian soils by Sartori et al., 2005). Use on group C soils with low infiltration rates is tolerated, but priority should be given to the volume of water stored, as the system will be less effective on group A and B soils.

Terrain characteristics / interference register:
the system does not require large areas, but it does require depth. Any existing or planned underground and adjacent installations must be surveyed and identified. Projects must take into account the necessary adjustments or protection of these structures.

HYDROLOGY

Flow control / Interception capacity:
small NbS, capable of temporarily storing medium volumes of rainfall with high return period (RT > 10 years). Storage must take place over a relatively short period of time, as the pit must be emptied within 24 hours to be ready to receive surplus volumes from the next heavy rainfall event. This requires the outlet structures of the pit to be correctly sized.

Water table level:
in places where the water table is high, infiltration into the system will be compromised due to low absorption. Therefore, its use should be avoided.

Drainage and water run-off:
this contributes to the rainwater detention process.

MATERIALS REQUIRED:

Perforated concrete pipe:
precast concrete pipes with holes to facilitate contact with the ground.

Geotextile blanket:
permeable blanket with mechanical and hydraulic properties that is used to wrap the pit and enable the soil to achieve maximum infiltration.

Overflow pipe:
this pipe is responsible for sending water from the infiltration pit to the public drainage system when it is full.

Connecting drainpipe:
also known as a horizontal conduit, is used to direct the rainwater collected by the building to the drainage pit.

Coarse aggregate layer:
layer used at the bottom of the pit, usually with gravel no. 3.

Inspection box:
it is used to check that there are no blockages in the drainage system or overflow.

19 Which have infiltration rates greater than 3.81 mm/h (SARTORI et al., 2005).

MAINTENANCE:

- Attention should be paid to sediment and debris accumulation of. It is recommended to check the inspection box to release the pipe in the event of clogging.

COST OF IMPLEMENTATION:

Variable between USD$ 70.00 and USD$ 130.00 per m^2.

POSSIBLE CHALLENGES IN PLANNING AND EXECUTION:

Land:
difficulty in obtaining prior information on underground installations, interfering with the prior assessment of infiltration. interferences in the subsoil that have not been mapped can cause problems when carrying out excavations in areas planned for infiltration pits in the drainage project.

Qualification of technicians:
the availability on the market of trained technicians with the specific knowledge to correctly analyse all the information and then monitor its execution.

Figure 21 Infiltration pit (Source: Thays Santos Ferreira, 2018).

- Detention basin -

Figure 22 Detention basin (Source: Guajava, 2023).

A detention basin is a structure designed to temporarily accumulate rainwater, enabling flows compatible with the capacity of the downstream drainage network or watercourse to be transferred (BAPTISTA; NASCIMENTO; BARRAUD, 2005). Depending on the permeability of the local soil and whether or not there is vegetation inside, infiltration and evapotranspiration processes can also be attributed to these basins.

These structures can be described as depressions in the ground that can be covered or uncovered and have inlet and outlet devices that allow rainfall to accumulate inside. During periods without rain, the basin remains dry and can be used for other purposes, such as green spaces, sports facilities and public squares. Ideally, it should be completely emptied within 24 hours. In addition to flood control, projects should incorporate multiple benefits and be implemented in parks, open spaces, other leisure and recreation areas (CITY OF PORTLAND, 2020).

Depending on their configuration in relation to the watercourse, detention basins can be classified as in-line or off-line. The choice between the two options mainly depends on the available area and the required storage volume, since the offline configuration can store larger volumes as the reservoir's bottom can be much deeper than the riverbed. In this case, a pumping system is required to empty the structure (ABCP, 2015). In the in-line option, the reservoir is located along the riverbed itself, and water is stored by installing a flow control structure across the waterway. This structure has an opening near the riverbed that allows the base flow to pass through while restricting the passage of the flood wave.

TECHNICAL PARAMETERS TO BE CONSIDERED WHEN CHOOSING:

STRATEGIC LOCATION:

Downstream of the contributing basin, in the macro-drainage.

PEDOLOGY / TOPOGRAPHY:

Soil permeability:
the greater the permeability of the soil, the greater the infiltration capacity of the structure. Clay soils have a lower infiltration capacity than sandy soils.

Detention basins installed in highly permeable soils will increase infiltration capacity for flood abatement, whereas in poorly permeable soils, they will only be used for detention.

Slope:
should not be installed on terrain with a slope of more than 5%. If the terrain exceeds this limit, it must be levelled before the structure can be installed. There are no restrictions on the slope of the area contributing to the structure. However, at the design stage, consider that high-velocity run-off is produced by terrains with a high slope.

Sediment load:
in areas with high sediment or residue production, sedimentation structures should be installed either upstream or at the entrance to the structure. These structures should also be cleaned and maintained more frequently. Vehicle access must be provided for the periodic removal of sediment in order to maintain the useful volume of the structure.

Types of soil:
as it is a detention structure, the project will have to be adapted to local soil conditions. It can therefore be implemented in groups A, B, C and D of soils, as characterized by the US Natural Resources Conservation Service (NRCS). As infiltration is not the main purpose of this structure, the system can be adapted to soils with low run-off potential and high infiltration rates, as well as soils with low to moderate infiltration rates.

Terrain characteristics:
at the design stage, the survey and identification of existing or planned underground and adjacent installations should indicate the appropriate adjustments or protections for these structures.

HYDROLOGY

Flow control / interception capacity:
the basins are medium and large NbS and are capable of temporarily storing large volumes of rainfall with high return periods (RT > 10 years). Storage must take place over a relatively short period of time, as the basin must be emptied within 24 hours to be ready to receive the surplus volumes from the next heavy rainfall event. This requires the outlet structures to be correctly sized. The basins buffer flood peaks and eventually reducing surface run-off volumes through infiltration processes, when they exist. Basins are designed to store large volumes of rainfall; therefore, if they are properly sized, they can be installed in flood-prone areas to accommodate excess volumes. Avoid permanently flooded areas.

Water table level:
in places where the water table is high, the structure should be wrapped and made impermeable, preventing groundwater from entering the structure and reducing its storage capacity.

Drainage and water run-off:
contribute to the process of rainwater detention. Depending on the permeability conditions of the local soil and the existence or not of vegetation within them, the basins can also be attributed to the processes of infiltration and evapotranspiration.

MATERIALS REQUIRED:

Soil:
depending on the soil conditions and topography of the area in which the structure will be located, provisions should be made for supplying earth to compact the walls of the structure.

Covering:
materials for the construction of the device's inlet and outlet structures and covering, if necessary.

Stones from around the NbS:
handstones, cobblestones and other residual or ornamental materials can be used around or at the entrances to the device to dissipate the energy of the water. If no material is used, the force of the water will erode the substrate, soil and vegetation, damaging the device over time.

Vegetation:
it absorbs nutrients and water that flow into the rain bed, releasing water vapour back into the atmosphere through transpiration. The plants' deep roots also create channels through which rainwater infiltrates the soil. Plant species (autochthonous) suitable for moist soils are ideal; the recommended vegetation is listed in Step 3 of this catalogue. Consider local climatic conditions when choosing species.

MAINTENANCE:

- Cleaning and desilting to remove sediment and residues.
- Maintenance of vegetation, when necessary.
- Cleaning and unblocking the structure's inlet and outlet devices, as well as the drainage system that collects and conveys the water to the basin.
- Maintenance of electromechanical equipment.

COST OF IMPLEMENTATION[20]:

Cost of acquisition of the area to implement the structure.

Cost of implementation: USD$ 140.00 per m^3.

Cost of implementation of green infrastructure and public facilities: USD$ 60.00 per m^2.

POSSIBLE CHALLENGES IN PLANNING AND EXECUTION:

Land:
detention basins require large areas to be set up (> 100 m^2), making them difficult to implement in densely populated areas. In smaller areas, it is advisable to disperse the NbS.

20 Source: FCTH/SIURB-PMSP, 2022.

Suitable vegetation:
selection and availability of plant species that can withstand drought and flooding.

Qualification of technicians:
the projects must be developed by a technical team comprising engineers, architects and other relevant professionals. Hydrological and hydraulic studies must be carried out to determine the size of the structure and assess the impact of its implementation on the watershed. Topographical surveys and geotechnical studies of the area must also be conducted. Therefore, it is necessary to train a qualified workforce to design, implement, operate and maintain these systems.

Public policies:
absence of public policies and participatory planning and governance for the inclusion of NbS in urban planning. To be accepted by the residents, the definition of the technology must consider sanitary and aesthetic aspects.

Figure 23 Detention basin in Porto Alegre with an impermeable bottom, used when there is a risk of groundwater contamination due to high pollutant loads (Photo: Erika Tominaga, 2023).

Figure 24 Detention basin at Miriti Golf Club in Marituba/PA (Hidrobotânica Project, photo: Roberto Ferrari, 2023).

- Retention basin -

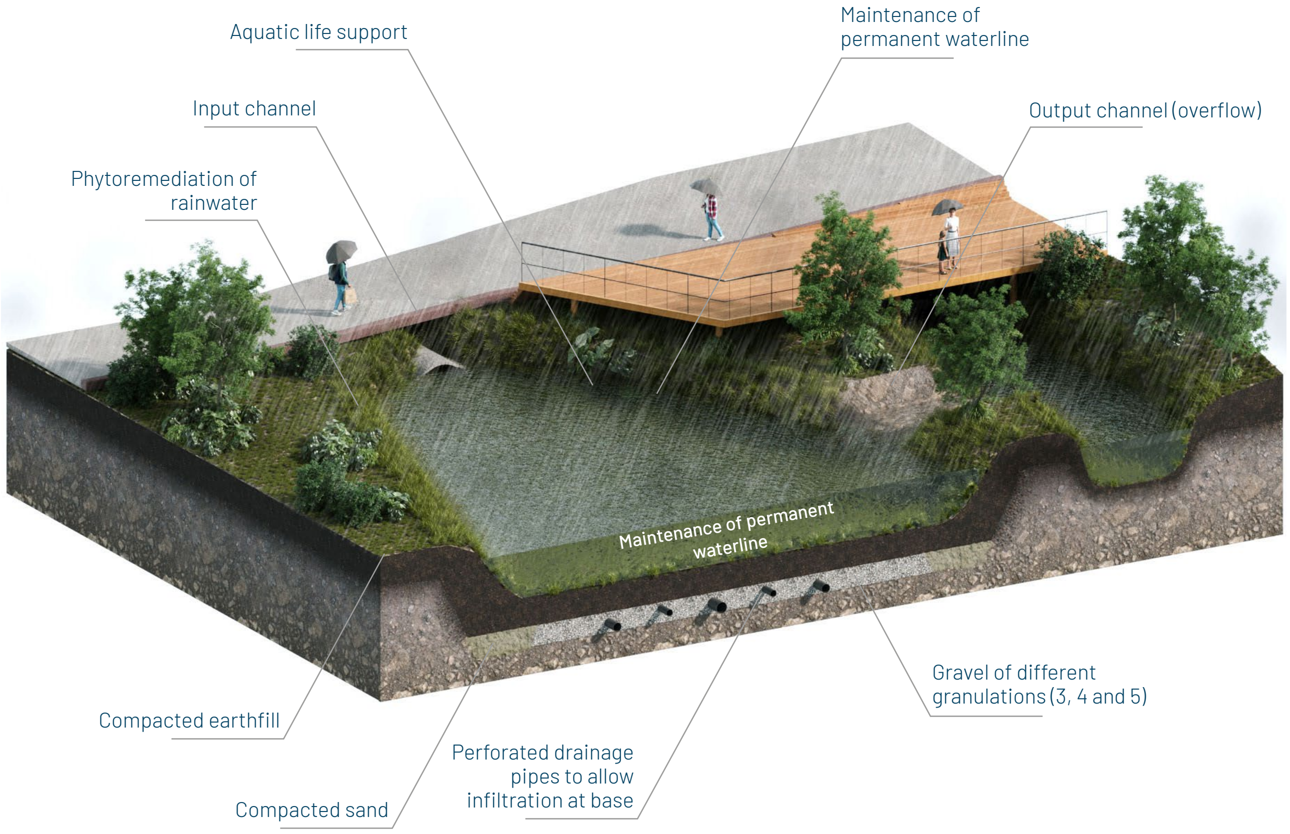


Figure 25 Retention basin (Source: Guajava, 2023).

A retention basin is a storage structure with a permanent water surface. This allows it to be used alongside parks and other green spaces for leisure and contemplation. Water is stored for long periods, enabling solid particles to settle and reducing pollutant loads through biological processes and sedimentation. One of the major benefits of this type of structure is the presence of aquatic life, which requires proper maintenance to sustain a balanced ecosystem (UACDC, 2010).

Retention basins consist of a spillway to maintain the base flow and an extravasor for flows that exceed the structure's capacity. The retention volume obtained corresponds to the difference in height between the permanent water level, which is maintained by the normal level spillway, and the maximum water level, which is allowed by the safety spillway. The permanent water level must be set around 1 m deep to preserve aquatic life, reduce diffuse pollution and allow for additional flood control storage.

Retention basins can also contain filtration islands to increase phytoremediation processes and enhance the landscaping of the system.

TECHNICAL PARAMETERS TO BE CONSIDERED WHEN CHOOSING:

STRATEGIC LOCATION:

Downstream of the contributing basin, in the macro-drainage systems.

PEDOLOGY / TOPOGRAPHY:

Soil permeability:
the greater the permeability of the soil, the greater the infiltration capacity of the structure. Clay soils have a lower infiltration capacity than sandy soils. Retention basins installed in highly permeable soils with low rainfall or a deep water table will not maintain a permanent water table during droughts. In highly permeable areas, it is possible to compact the soil or adopt a clay layer at the bottom of the structure.

Slope:
should not be installed on terrain with a slope of more than 5%. If the terrain exceeds this limit, it must be levelled before the structure can be installed. There are no restrictions on the slope of the area contributing to the structure. However, at the design stage, consider that high-velocity run-off is produced by terrains with a high slope.

Sediment load:
in areas with high sediment or residue production, sedimentation structures should be installed either upstream or at the entrance to the structure. These structures should also be cleaned and maintained more frequently.

Types of soil:
in soils with high permeability rates, compaction or the addition of a clayey layer at the bottom of the structure should be considered. This will allow the project to be adapted to the local soil conditions, enabling installation in soils of groups A, B, C and D, as defined by the United States Natural Resources Conservation Service (NRCS).

Terrain characteristics:
the survey and identification of existing or planned underground and adjacent installations. The projects must indicate the appropriate adjustments or protections for these structures.

HYDROLOGY

Flow control / interception capacity:
the basins are medium and large NbS capable of temporarily storing large volumes of rainfall with high return periods (RT > 10 years). Storage must take place over a relatively short period of time, as the basin must be emptied within 24 hours in order to be ready to receive the surplus volumes from the next heavy rainfall event.

This requires the correct sizing of the outlet structures. Basins have the function of buffering flood peaks and eventually reducing surface run-off volumes through infiltration processes, when these exist. Basins are designed to store large volumes of rainfall; therefore, if they are properly sized, they can be installed in flood-prone areas to accommodate excess volumes. Avoid permanently flooded areas.

Water table level:
if installed in areas where the water table is deep, it will not be possible to maintain a permanent surface of water during the dry season, when the structure is no longer receiving run-off.

Drainage and water run-off:
these contribute to the process of rainwater detention. The process of evapotranspiration can also be attributed to the retention basins, depending on whether vegetation exists on their margins.

MATERIALS REQUIRED:

Soil:
depending on the soil conditions and topography of the area in which the structure will be located, provisions should be made for supplying earth to compact the structure's walls.

Covering:
materials for the construction of the device's inlet and outlet structures and covering, if necessary.

Stones from around the NbS:
handstones, cobblestones and other residual or ornamental materials can be used around or at the entrances to the device to dissipate the energy of the water. If no material is used, the force of the water will erode the substrate, soil and vegetation, damaging the device over time.

Vegetation:
it absorbs nutrients and water that flow into the rain garden, releasing water vapour back into the atmosphere through transpiration. The plants' deep roots also create channels through which rainwater infiltrates the soil. Plant species- (autochthonous) suitable for moist soils are ideal; the recommended vegetation is listed in Step 3 of this catalogue. Consider local climatic conditions when choosing species.

The materials to be used vary according to the project.

MAINTENANCE:

- Cleaning and desilting to remove sediment and residues.
- Maintenance of the surrounding vegetation to ensure a balanced environment for aquatic life and its surroundings.
- Cleaning and unblocking the structure's inlet and outlet devices, as well as the drainage system that collects and conveys the water to the basin.

COST OF IMPLEMENTATION[21]:

Cost of implementation: USD$ 140.00 per m^3.

Cost of implementation of green infrastructure and public facilities: USD$ 60.00 per m^2.

POSSIBLE CHALLENGES IN PLANNING AND EXECUTION:

Land:
retention basins require large areas (> 100 m^2) to be set up, which makes them difficult to implement in densely populated areas as they require open spaces.

Appropriate sizing:
hydrological and hydraulic studies must be carried out to determine the size the structure and assess the impact of its implementation on the watershed. Topographical surveys and geotechnical studies of the area must also be conducted.

Suitable vegetation:
selection and availability of plant species that can withstand drought and flooding.

21 Source: FCTH/SIURB-PMSP, 2022.

Qualification of technicians:
the projects must be developed by a technical team comprising engineers, architects and other relevant professionals. Therefore, it is necessary to train a qualified workforce to design, implement, operate and maintain these systems.

Public policies:
absence of public policies and participatory planning and governance for the inclusion of NbS in urban planning.

Figure 26 Retention basin in Barigui Park, Curitiba/PR (Curitiba Municipal Government collection, photo: advjmneto, 2022).

- Retention basin -

Figure 27 Retention basin in Aclimação Park (Landscape architecture project by Roberto Coelho Cardoso and retention basin project by Hidrostudio Engenharia, photo: Jean Matheus Suplicy, 2023).

- Infiltration basin -

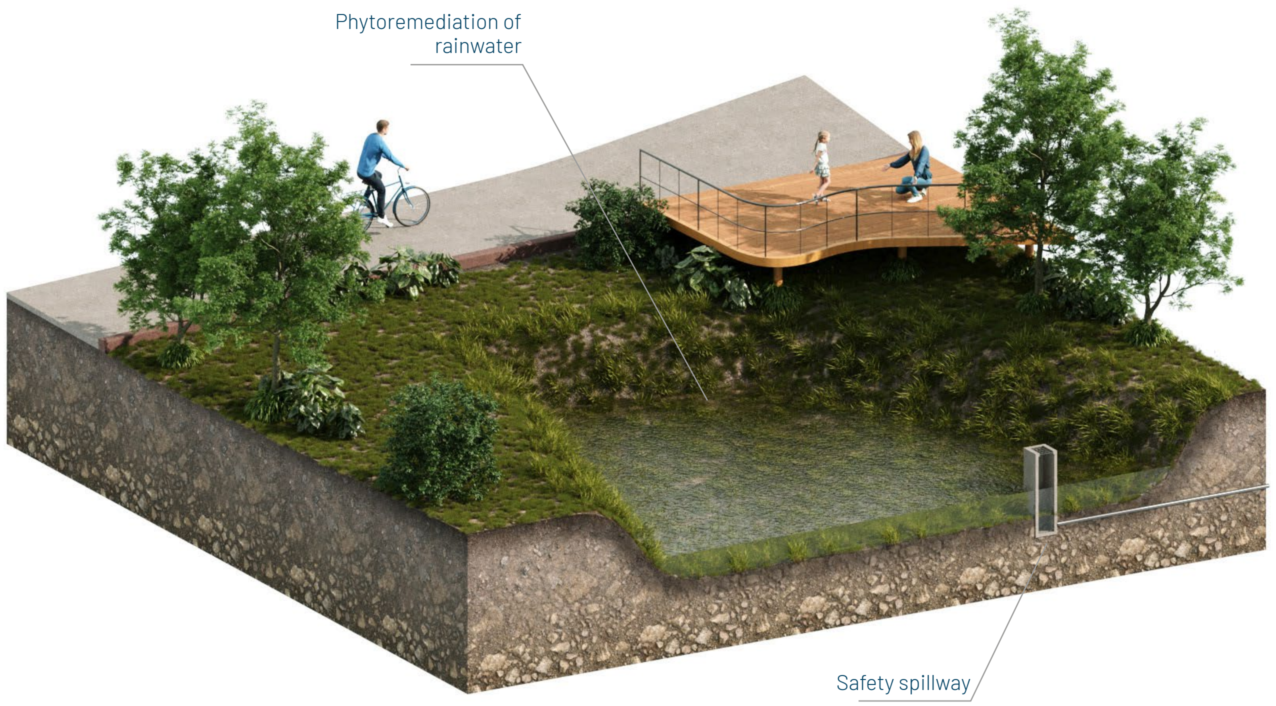


Figure 28 Infiltration basin (Source: Guajava, 2023).

Infiltration basins are shallow depressions in the ground built to stop and optimise the infiltration of rainwater, while also providing temporary storage. These structures do not have a permanent water surface and should be installed in areas where the soil has high permeability rates (greater than 3.6 mm/h). They have no hydraulic outlet devices except for a safety spillway, which is used when the basin's designed capacity is exceeded (SMDU, 2012).

Other positive aspects of infiltration basins include improving water quality and recharging underground aquifers. Pollutants are removed through the processes of filtration and phytoremediation of rainwater. These functions are similar to those of rain gardens and other phytoremediation measures, but infiltration basins can be implemented to receive contributions from much larger areas.

TECHNICAL PARAMETERS TO BE CONSIDERED WHEN CHOOSING:

STRATEGIC LOCATION:

Downstream of the contributing basin, in the macro-drainage.

PEDOLOGY / TOPOGRAPHY:

Soil permeability:
to achieve good results, the drainage system must be designed taking into account all the input, output and status variables involved. The input variable is the volume of direct surface run-off (DSR) conveyed to the system, which depends on the design rainfall, the connected area, and its impermeability rate. The status variable is the buffered volume during the system's operating time. The output variables are infiltration and excess flow into the drainage network. Infiltration analysis is a fundamental component of the system and is defined based on the properties of the porous medium. These properties are determined by soil characterisation tests, mainly the granulometric analysis test, which determines the percentage of clay, silt, sand and gravel present in the sample, and the permeability test, which determines the speed at which water percolates through the soil. The coarse fraction of soil (gravel and sand) is much more permeable than the fine fraction (clay and silt), making it preferable in the composition of NbS to enable adequate infiltration rates of rainwater. However, other obstacles interfere with this process, such as the degree of soil compaction. Therefore, in addition to the granulometry test, a permeability test and infiltration tests are necessary to characterise the porous medium and enable more accurate sizing of the NbS. Infiltration basins should be installed on soils with a minimum permeability of 3.6 mm/h.

Slope:
should not be installed on terrain with a slope of more than 5%. If the terrain exceeds this limit, it must be levelled before the structure can be installed. There are no restrictions on the slope of the area contributing to the structure. However, at the design stage, consider that high-velocity run-off is produced by terrains with a high slope.

Sediment load:
since infiltration basin failure is mainly caused by the sediment accumulation (clogging) which reduces or even interrupts infiltration processes, sedimentation structures should be installed upstream or at the entrance to the basin in areas with high sediment or residue production. These structures should also be cleaned and maintained more frequently.

Types of soil:
soils with a high or moderate infiltration rate, groups A and B, according to the hydrological soil classification of the Natural Resources Conservation Service (NRCS) of the United States.

Terrain characteristics:
survey and identification of existing or planned underground and adjacent installations. The projects must indicate the appropriate adjustments or protections for these structures.

HYDROLOGY

Flow control / interception capacity:
the basins are medium and large NbS and are capable of temporarily storing large volumes of rainfall with high return periods (RT > 10 years). Infiltration basins have the function of buffering flood peaks and eventually reducing surface run-off volumes through infiltration processes, when they exist. Basins are designed to store large volumes of rainfall; therefore, if they are properly sized, they can be installed in flood-prone areas to accommodate excess volumes. Avoid permanently flooded areas.

Water table level:
it is not suitable where the water table is high.

Drainage and water run-off:
contribute to the process of rainwater detention. The process of evapotranspiration can also be attributed to the infiltration basins, depending on whether or not vegetation exists at their margins.

MATERIALS REQUIRED:

Soil:
depending on the soil conditions and topography of the area in which the structure will be located, provisions should be made for supplying earth to compact the walls of the structure.

Covering:
materials for the construction of the device's inlet and outlet structures and covering, if necessary.

Stones from around the NbS:
handstones, cobblestones, residual and other ornamental materials can be used around (when there are no guidelines) or at the entrances to the device to dissipate the energy of the water. If no material is used, the force of the water will erode the substrate, soil and vegetation, damaging the device over time.

Vegetation:
it absorbs nutrients and water that flow into the rain bed, releasing water vapour back into the atmosphere through transpiration. The plants' deep roots also create channels through which rainwater infiltrates the soil. Plant species (autochthonous) suitable for moist soils are ideal; the recommended vegetation is listed in Step 3 of this catalogue. Consider local climatic conditions when choosing species.

The materials to be used vary according to the project.

MAINTENANCE:

- Cleaning and desilting to remove sediment and residues.
- Maintenance of surrounding vegetation when necessary.
- Cleaning and unblocking the structure's inlet and outlet devices, as well as the drainage system that collects and conveys the water to the basin.

COST OF IMPLEMENTATION[22]:

Cost of acquisition of the area to implement the structure.

Cost of implementation: USD$ 140.00 per m^3.

Cost of implementation of green infrastructure and public facilities: USD$ 60.00 per m^2.

POSSIBLE CHALLENGES IN PLANNING AND EXECUTION:

Land:
infiltration basins require large areas to be set up (> 100 m^2), which makes them difficult to implement in densely populated areas, needing open areas.

Appropriate sizing:
hydrological and hydraulic studies must be carried out to determine the size of the structure and assess the impact of its implementation on the watershed. Topographical surveys and geotechnical studies of the area must also be conducted.

22 Source: FCTH/SIURB-PMSP, 2022.

Suitable vegetation:
selection and availability of plant species (local natives) that can withstand drought and flooding.

Qualification of technicians:
the projects must be developed by a technical team comprising engineers, architects and other relevant professionals. Therefore, it is necessary to train a qualified workforce to design, implement, operate and maintain these systems.

Public policies:
absence of public policies and participatory planning and governance for the inclusion of NbS in urban planning. To be accepted by the residents, the definition of the technology must consider sanitary and aesthetic aspects.

Figure 29 Infiltration basin at Miriti Golf Club in Marituba/PA (Hidrobotânica Project, photo: Roberto Ferrari, 2023).

Figure 30 Beija Flor Park, Goiânia/GO (Project by Yara Hasegawa, photo: Francine Sakata, 2015).

- Constructed wetlands -

Figure 31 Hybrid wetland (Source: Guajava, 2023).

A constructed wetland is a natural technology that can treat different types of polluted water. Also known as a treatment wetland, constructed floodplain or filter garden, this NbS imitates natural wetlands, which are often referred to as "kidneys of the earth" (SHARIFI et al., 2013) due to their ability to filter and purify water.

This technology optimises the ability of plants to phytoremediate water. Together with support material and microorganisms, plants can absorb nutrients such as nitrogen, phosphorus and potassium, break down contaminants and reduce the population of pathogens through physical, chemical and biological processes. This NbS differs in that it enables sewage to be considered a new source of resources, providing economic benefits to the local population alongside land-scape beautification.

Constructed wetlands are categorised into two groups according to how the effluent flows.

- *Surface flow constructed wetlands (apparent effluent)*: these are similar to natural wetlands in that they have an apparent water surface. They require a larger surface area and can handle a lower pollutant load than subsurface flow constructed wetlands. They are most commonly used for urban rainwater management to mitigate diffuse pollution (RUSSEL, 2021). They should be built in line with the urban drainage infrastructure network, to intercept and treat polluted run-off before it reaches the nearest water body, thereby improving surface water quality. It is recommended that they should cover between 1% and 5% of the capture area (RUSSEL, 2021). The greater the distance downstream from the capture area, the greater the load of pollutants collected; it is therefore, they must be positioned strategically to treat the greatest possible load of pollutants.
- *Subsurface flow constructed wetlands (non-appearing effluent):* the effluent flows below the level of the substrate. They are more efficient at removing pollutants per unit area. They are most commonly used to treat effluents with a higher pollutant load. Depending on the direc-tion of flow within each treatment unit, they can be classified as having vertical or horizontal flow. They can also operate in a hybrid mode, combining the two systems to achieve an even higher level of treatment. Each module has its own specific features and benefits.

As it is a flexible technology, it can be used in various technological configurations (SEZERINO et al., 2018) to treat different types of effluent: residential, industrial and agricultural waste, landfill leachate, sludge and rainwater run-off, as well as for the recovery of polluted water bodies.

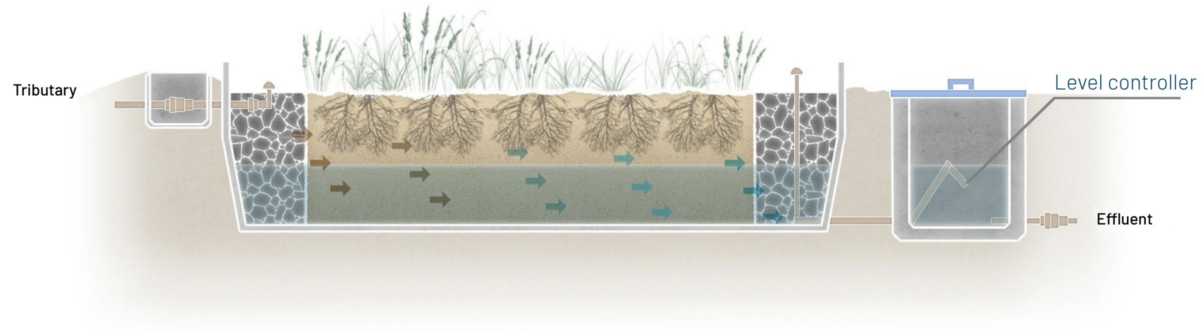


Figure 32 Constructed wetland with subsurface horizontal flow (Adapted from SEZERINO; PELISSARI, 2021).

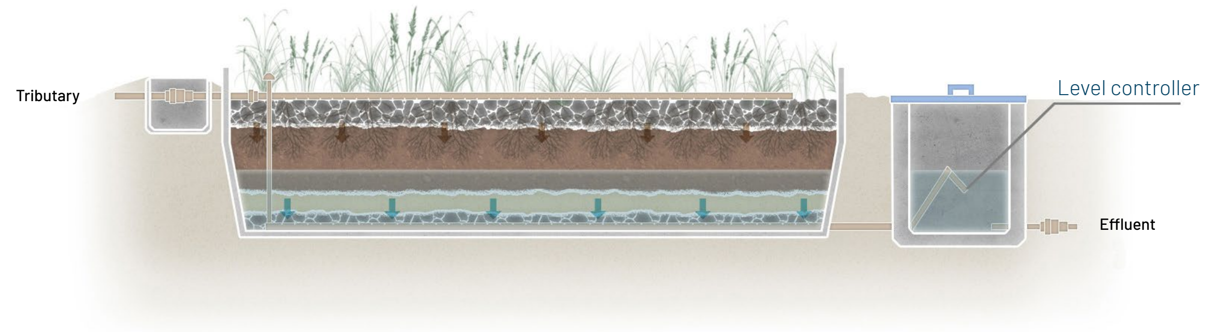


Figure 33 Constructed wetland with subsurface vertical flow (Adapted from SEZERINO et al., 2018)

TECHNICAL PARAMETERS TO BE CONSIDERED WHEN CHOOSING:

STRATEGIC LOCATION:

Areas without access or with restricted access to the sewage collection system.

Treatment of effluent from sanitary equipment and/or kiosks installed in parks or squares where green areas are available.

Areas where irregular sewage disposal has been identified and where areas are available.

After discharging from galleries or streams with a high organic load, wetlands can be integrated into the landscape and treat this contribution before it is discharged into the main water body.

New buildings and subdivisions where constructed wetlands can be planned to integrate architecture and engineering into the landscape.

PEDOLOGY / TOPOGRAPHY:

Soil permeability:
constructed wetlands for sewage treatment are watertight structures that can be installed in different types of soil where the infiltration capacity does not interfere with the functioning of the system.

Slope:
can be installed on terrains with different slopes. In the case of several reactors being used together, the slope of the land can help the system to work by gravity alone, eliminating the need for energy input. On flat terrain, however, it may be necessary to use a motorised pump to feed the downstream reactors. On terrain with a slope of up to 18%, the embankment can be terraced to accommodate the devices, and the steeper the slope, the greater the need for wall structure reinforcement.

Sediment load:
constructed wetlands can function as an NbS for sediment retention (SEZERINO et al., 2018). Inputting coarse solids into the system must be avoided to prevent clogging of the pipes and damage to submerged motor pumps or other equipment. This can be achieved by installing a grid system upstream of the system. The pollutant load carried by the system can vary from low to high, making it a flexible system and adaptable to the characteristics of the effluent.

Types of soil:
as it is a watertight system, the type of soil does not directly affect the operation of the system, but it can impose constraints on the construction method used.

Terrain characteristics:
the implementation of this NbS, especially when inserted in consolidated urban areas, requires the verification of the presence of any installations before work begins, or ideally during the design phase to ascertain whether they can be relocated or adapted to the project configuration. This analysis can be carried out on site or through documentation provided by the relevant agencies. The same applies to the implementation of NbS on large plots intended for urban and/or linear parks. Cooperation between departments and agencies to exchange documentation and information is essential for the sustainable drainage system to be planned well. You should also analyse the presence of trees or buildings on the site that could cause shading and reduce the system's efficiency.

HYDROLOGY

Flow control / efficiency in treatment:
the performance of these systems depends on choosing the appropriate configuration for each type of wastewater, the application rate, the hydraulic detention time and the local climatic conditions (MATOS; MATOS, 2021). It is important to define and monitor the hydraulic regime, which is defined by three aspects the amount of sewage applied in relation to the area of the wetlands in a given time period, and how it is applied, i.e. whether it is applied intermittently (in batches) and/or whether the modules operate continuously or with rest periods. As it is an open system, factors such as rainfall, evaporation and evapotranspiration interfere with the water mass control in the system (SEZERINO et al., 2018). Permanently flooded areas are natural wetlands and should be well conserved and managed as far as possible. If they are degraded, information on the recovery of this biome should be consulted, and the problem should be dealt with at source. If one of the causes is contamination due to the irregular dumping of pollutants, constructed wetlands can be installed upstream. In flooded areas, wetlands can be installed as long as there is an outlet connected to the collection network. In areas earmarked for reservoirs, constructed wetlands can help to reduce flood peaks.

Water table level:
this factor influences the choice of structure and, consequently, its cost. Excavated structures are less expensive because you don't need material or labour to build the tank, but they are not always recommended, as in the case of places where the water table is very shallow.

Drainage and water run-off:
the hydric regulation and water (rainwater and residual) treatment characteristics of constructed wetlands contribute to the depollution and replenishment of water bodies. Treated effluent can be reused (for non-potable purposes) and contributes to the municipality's water security by temporarily storing rainwater and helping to reduce peak flows (EISENBERG et al., 2022). It also contributes to evaporation and evapotranspiration.

MATERIALS REQUIRED:

Constructed elements:
for systems built underground, structural brickwork can be considered, consisting of concrete blocks filled with concrete and reinforcement, or pre-moulded fibreglass structures.

Waterproofing:
for brickwork systems, a waterproofing additive can be used in the internal plaster. The use of asphalt blankets is not recommended (SEZERINO et al., 2018). For excavated systems, a 0.8 mm HDPE (high density polyethylene) geomembrane can be used, with the use of geotextile (e.g. Bidim blanket) for its mechanical protection, installed below and above it to form a sandwich.

Filter material:
in constructed wetlands, the filter material plays a fundamental role. In addition to physical filtering, it contributes to biochemical processes by providing a habitat for both the root systems of macrophytes and the microbial biofilms. It also carries out the adsorption process whereby pollutants are retained by chemical attraction to some compounds on the surface of the filter material grains (SEZERINO et. al. 2018). The filter material must have good hydraulic conductivity (good permeability) to maintain adequate flow conditions and promote the adsorption of inorganic compounds while minimising the risk of clogging. The most commonly used materials are gravel, crushed stone, sand and soil. However, a number of alternative materials are being studied in order to reduce costs and reuse solid residues discarded from other activities, such as construction waste, shells, PET bottles and tyre chips (SEZERINO; PELISSARI, 2021).

Vegetation:
plants are a fundamental factor in the functioning of constructed wetlands, which is why this NbS has its own specific topic (see Step 3 of this catalogue for more information).

MAINTENANCE:

Although they are known for their lower operating and maintenance costs, operational control is required to guarantee the success of the system as specified in the design. This includes:

- Macrophyte management: periodic pruning of the aerial part of the vegetation according to the life cycle of each species and pest control. Pruning stimulates plant growth and helps to remove pollutants and organic matter from the effluent.
- Control of invasive species that could harm the system.
- Cleaning the grating, where solid debris accumulates.
- Maintaining the proper functioning of any equipment (e.g. motor pumps, valves, registers, etc.).
- Monitoring of the system's operating performance involves collecting and analysing water quality samples of the incoming and output effluent. This is done in accordance with water quality analysis methodologies specified in Wastewater Analysis – Standard Methods, by the American Public Health Association (APHA), as accepted by ABNT in accordance with Decree 8468/76, Article 16.
- The most intensive maintenance period is during the establishment of the vegetation, when replanting may be necessary. Effective plant management improves the system performance and has positive environmental landscaping benefits.

COST OF IMPLEMENTATION:

Variable between USD$ 240.00 and USD$ 400.00 per m^2.

POSSIBLE CHALLENGES IN PLANNING AND EXECUTION:

Land:
constructed wetlands require a larger area than conventional technologies, such as the upflow anaerobic sludge blanket (UASB) reactor or activated sludge, making them difficult to implement in urban centres. However, this issue can be addressed by using existing green spaces or creating constructed wetland parks.

Clogging:
the right choice of materials for the filter medium is essential to slow down the clogging process. Prior washing of the filter material is recommended to remove particles that could accelerate this process.

Suitable vegetation:
the choice of native and local plant species that are suitable for the type of residual water is fundamental to the success of the treatment.

Embankments:
if of excavation on embankments is required, ensure that they are built to withstand the weight of the filter material and the treated volume without collapsing.

Contamination:
if effluents are contaminated with heavy metals and these can be incorporated into the plant tissue, the pruning material must be disposed of appropriately in accordance with current legislation.

Qualification of technicians:
Projects must be developed by a technical team made up ofcomprising engineers, architects and other relevant professionals. Hydrological and hydraulic studies must be carried out to determine the size of the structure and assess its impact on the watershed, as well as. Topographical surveys and geotechnical studies of the area. It must also be conducted. Therefore, it is necessary to train a qualified workforce to design, implement, operate and maintain these systems.

Public policies:
absence of public policies and participatory planning and governance for the inclusion of NbS in urban planning. To be accepted by the residents, the definition of the technology must consider sanitary and aesthetic aspects.

Figure 34 Constructed wetland at Cidade Jardim Station in São Paulo/SP (Project by Vertical Garden and Guajava, photo: Sarah Daher, 2023).

Figure 35 Constructed wetland at Cidade Jardim Station in São Paulo/SP (Project by Vertical Garden and Guajava, photo: Sarah Daher, 2023).

- Floating filter islands -

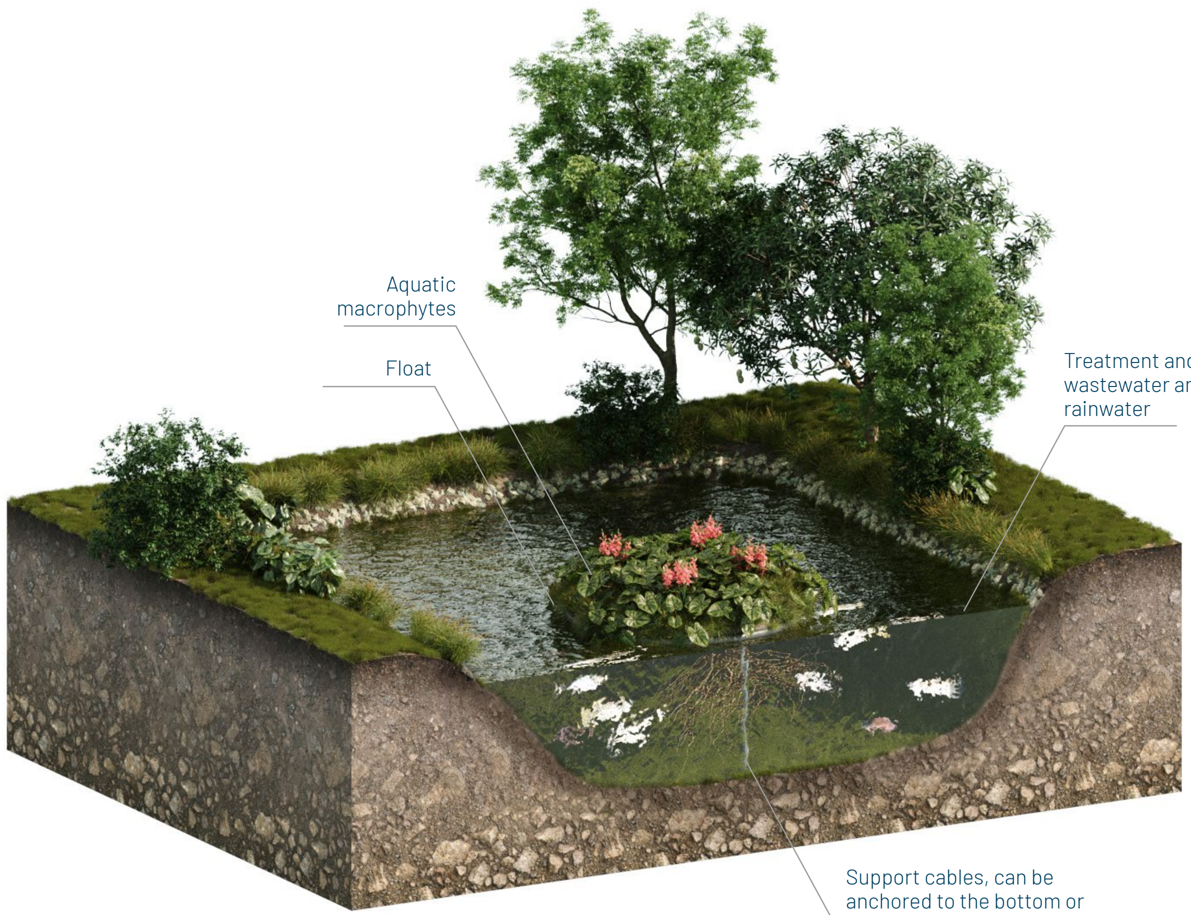


Figure 36 Floating filter islands (Source: Guajava, 2023).

Floating filter islands, also known as floating wetlands, consist of a floating infrastructure on which emergent vegetation is established. The upper parts of this vegetation develop mainly above the water surface, while the roots extend down into the water column. The plants grow in a hydroponic system and develop an extensive root system that can absorb nutrients directly from the water column (PAVLINERI et al., 2017).

Unlike other constructed wetlands in that they are implemented directly into the surface water bodies, are easy to install and do not require land acquisition (SHAHID et al., 2019). They are considered an efficient and low-cost alternative, commonly used in lakes, ponds, rivers, streams, springs and even marine environments (TAKAVAKOGLOU et al., 2021).

Floating filter islands provide an artificial habitat for emergent plants. They can be constructed using various floating materials or purchased as a ready-made system in modules from companies that sell them. The roots are submerged in the water, where the development of a dense root system is fundamental to the system's performance (PAVLINERI et al., 2017). The roots and the porous support medium provide a habitat for microorganisms that form the biofilm, in which most of the nutrient absorption and degradation takes place. The islands can be free-standing or anchored to the bottom or edge of the body of water.

TECHNICAL PARAMETERS TO BE CONSIDERED WHEN CHOOSING:

STRATEGIC LOCATION:

They were developed mainly to reduce pollution caused by excess nutrients and pollutants, and are therefore recommended for use in eutrophic lakes and ponds, rivers and streams contaminated by residual water, and retention basins for rainwater treatment. They can also be used in springs to improve water quality.

They are recommended for use in slow-flowing water, although they can tolerate fluctuations in flow and water depth.

PEDOLOGY / TOPOGRAPHY:

Soil permeability:
does not apply, since it is placed in water bodies.

Slope:
follows the slope of the water body.

Sediment load:
can be used to treat different types of polluted water, and are highly efficient at removing nutrients, suspended solids, algae and metals. They can treat rainwater, sewage and residual waters from agriculture, industry and aquaculture.

Types of soil:
does not apply.

Terrain characteristics:
preferably installed in bodies of water with low water flow and velocity. Floating islands are able to withstand flooding and extreme rainfall. The modules can be anchored to the bottom or the side, and move up and down according to the water level. However, if they are not anchored and the water level changes, they can drift towards the shore and become rooted, thus losing their floating island properties.

HYDROLOGY

Ecosystem service:
improve transparency and prevent the growth of green algae; the biofilm that forms on the roots and substrate helps to remove pollution, sludge and excess nutrients. They also provide a safe habitat for fish, birds and other animals such as turtles and pollinating insects.

Flow control:
they are recommended for slow-flowing waters, with a minimum depth of 0.8 m to prevent the roots from sticking to the bottom of the body of water (HEADLY; TANNER, 2008).

MATERIALS REQUIRED:

Floating materials:
PVC pipes, recyclable materials such as PET bottles, natural materials such as bamboo, plastic sheets or foams can be used.

Planting substrate:
coconut fibre can be used; some companies that sell floating filter islands offer their own planting mix.

Anchoring system:
can be made with blocks, helical anchors or poles.

Suitable vegetation:
choosing native and local plant species that are suitable for the type of residual water is fundamental to the success of the treatment.

MAINTENANCE:

- Macrophyte management involves periodic pruning of the aerial parts of the vegetation according to each species' life cycle, as well as pest control. Pruning stimulates plant growth, helps remove pollutants and organic material from the water body and prevents stored nitrogen and phosphorus from entering the water when the plants die and decompose.
- Control of invasive species that could harm the system.
- Maintenance can be carried out by moving to the Floating Filter Island, or by pulling it to the shore if it is anchored to the side and its size allows it to be moved.
- Monitoring plant health, including the root system.
- Monitoring of the system's operating performance involves collecting and analysing water quality samples of the incoming and output effluent. This is done in accordance with the water quality analysis methodologies specified in Wastewater Analysis – Standard Methods, by the American Public Health Association (APHA) as accepted by ABNT in accordance with Decree 8468/76, Article 16.

COST OF IMPLEMENTATION:

Variable[23] between USD$ 40.00 and USD$ 140.00 per m^2.

They can be built or purchased by specialised companies which offer the product in different sizes, formats, modular systems and even custom sizes.

POSSIBLE CHALLENGES IN PLANNING AND EXECUTION:

Water level:
in order to function, floating filter islands require a permanent water level to maintain the vegetation. A depth of between 0.8 and 1.5 m should be considered prevent the roots from sticking to the bottom of the body of water.

Vegetation:
local native species should be considered, based on the characteristics of the local water body. The roots of some species grow up to 1.5 m deep, while others grow to a depth of 0.4 to 0.8 m.

Anchoring:
anchoring is not always necessary, but there is a risk of the island being hit by the wind or being directed towards the coast, which would cause it to lose its island characteristics. The type of anchoring required must be defined based on the characteristics of the water body to be treated and must allow for variations in the water level, taking into account the projected flow speed and maintenance.

Qualification of technicians:
the availability on the market of trained technicians with the specific knowledge to correctly analyse all the information and then monitor its execution.

Public policies:
absence of public policies and participatory planning and governance for the inclusion of NbS in urban planning.

23 According to the area, design and configuration of the NbS, materials, labor, vegetation.

Figure 37 Floating filter islands at Pesqueiro do Carmo, São Paulo/SP (Master's project by Cleandho Marcos de Souza, 2020, photo: Cleandho Marcos de Souza, 2019).

Figure 38 Floating filter islands at Burle Marx Park in São Paulo/SP (Project provided by Água V during the Responsib'ALL DAY 2018 - Pernod Ricard, photo: Sarah Daher, 2019).

- Amphibious reservoir -

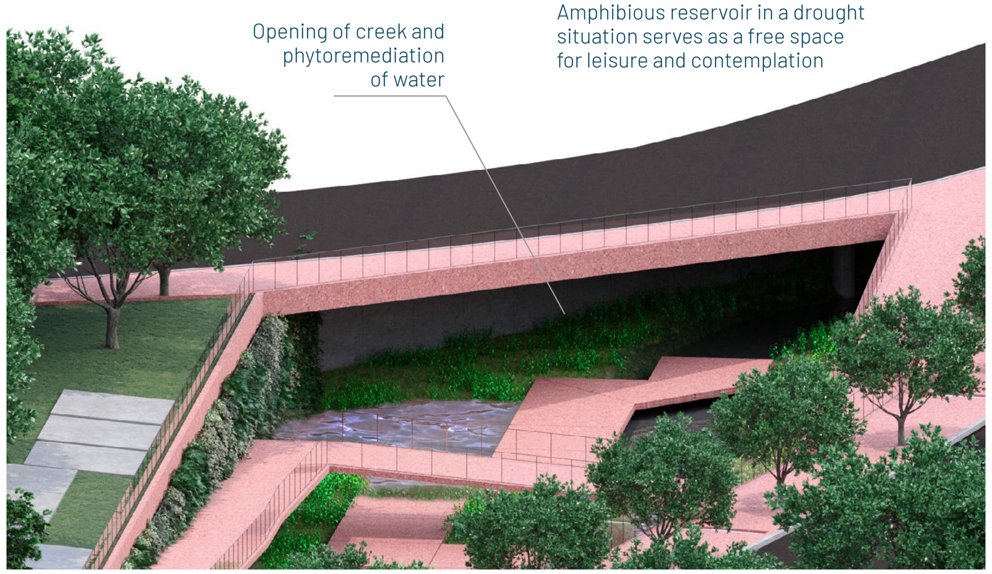


Figure 39 Full amphibious reservoir, external view (Source: FCTH, 2021).

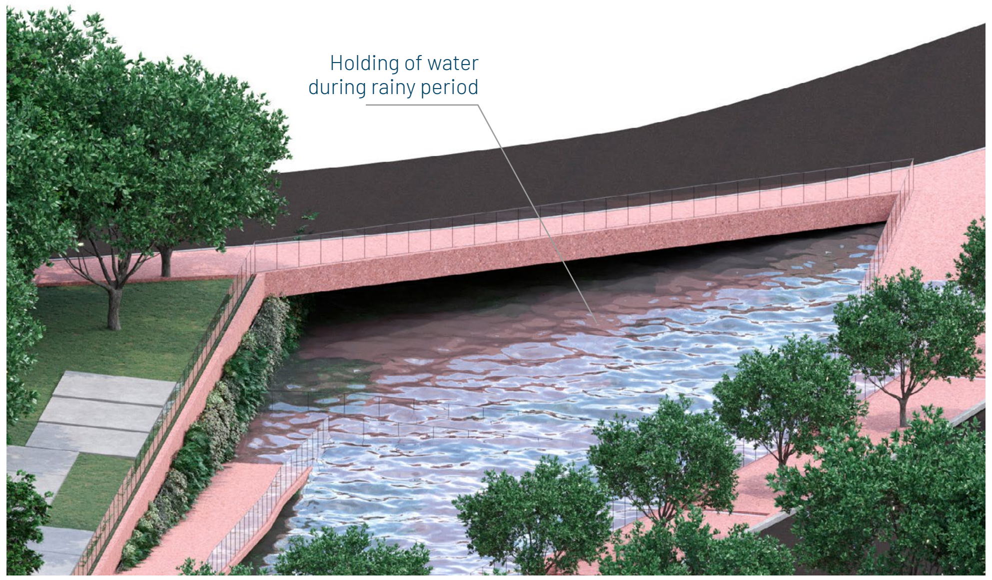


Figure 40 Full amphibious reservoir, internal view (Source: FCTH, 2021).

The amphibious reservoir is a rainwater reservoir system developed by Guajava Arquitetura da Paisagem e Urbanismo, in collaboration with the Hydraulics Technology Center Foundation and the São Paulo Municipality. It is intended as an alternative to replace traditional reservoirs.

Unlike 'swimming pools', it integrates the leisure function with landscape recovery actions, such as opening up a stretch of a canalised urban stream and restoring its floodplain, as well as phytoremediating rainwater and river water using filtering islands, in addition to fulfilling the reservoir function. The name 'amphibious' comes from its ability to function during both flood and drought periods, much like some of our frogs and toads. It is a complex structure which includes different NbS that contribute to environmental improvement by treating rainwater, infiltrating it and replenishing the water table, and promoting plant recomposition.

In this system, the flow of rainwater and river water flow through different treatment stretches (if the stream is open inside the in-line reservoir). Initially, any solid residue is retained in a grid system that facilitates maintenance and cleaning, alongside a sedimentation basin at the entrance to the reservoir. The next stage involves increasing the roughness of the stream banks by planting flood-tolerant species to slow down the speed of run-off and allow phytoremediation and deposition of fine sediments on the small islands formed by the branching of the waters. During periods of heavy rainfall, the reservoir fills to capacity and functions like a traditional reservoir, with appropriate control mechanisms in place. Finally, the water is directed back into the gallery and the reservoir is then cleaned as usual.

TECHNICAL PARAMETERS TO BE CONSIDERED WHEN CHOOSING:

STRATEGIC LOCATION:

The amphibious reservoir is designed to eliminate the need for conventional reservoirs and must be installed in accordance with hydraulic engineering criteria, depending on the need for flood control.

The implementation of a rainwater detention reservoir must be analysed by hydraulic engineers who are specialised in the containment of rainfall, as calculations of flow and resistance, as well as environmental, urban and structural impacts are required.

PEDOLOGY / TOPOGRAPHY:

Soil permeability:
the more permeable the soil, the greater the infiltration capacity of the structure. Since this is a flood detention structure, this parameter is not very significant.

Slope:
must not be installed on terrains with a slope of more than 5%. If the terrain is not level, it must be levelled before installation.

Sediment load:
in areas with high sediment or residue production, sedimentation structures should be installed upstream or at the entrance to the structure.

Amphibious reservoirs should only be implemented in streams with high pollutant loads if pollution control systems are provided upstream of the reservoir.

Types of soil:
as this is a flood detention structure, this parameter is not very significant.

Terrain characteristics:
at the design stage, the survey and identification of existing or planned underground and adjacent installations, should indicate the appropriate adjustments or protections for these structures.

HYDROLOGY

Flow control / interception capacity:
as an area for disposing of rainwater, an amphibious reservoir should have a similar capacity to a conventional reservoir. This can be improved by installing a micro-drainage network consisting of NbS such as biovalets and rain gardens which can reduce the flow and speed of run-off and improve the infiltration and quality of the water before it reaches the reservoir.

Water table level:
in places where the water table is high, the structure should be wrapped and made impermeable, preventing groundwater from entering the structure and reducing its storage capacity.

Drainage and water run-off:
contribute to the process of rainwater detention. Depending on the permeability conditions of the local soil and the existence or not of vegetation within them, the basins can also be attributed to the processes of infiltration and evapotranspiration.

SPECIFIC CRITERIA FOR THIS NBS:

A system for pumping rainwater from the reservoir into the existing drainage network after it has run its course or in the event of a system overflow.

Creation of circulation areas, access networks and public facilities in and around the reservoir, so that it can contribute to the contemplation and leisure activities of the local population. Landscaping to improve the environment of the region.

MATERIALS REQUIRED:

In addition to the materials, three types of systems are required for the amphibious reservoir:

A constructive system, for when the reservoir walls are made of concrete, and materials to create a naturalised reservoir, such as drainage soil and vegetation suitable for wetlands.

A hydraulic pump system, installation and operating area (pump room), in the case of offline devices.

Access system for cleaning the reservoir (access route for cleaning vehicle).

Materials required for the microdrainage system – check the specifications detailed in this catalogue for each NbS, such as:

Gravel or hand stone:
the layer of gravel, preferably no. 5, or the use of hand stone or concrete residues removed from the site (without contaminating components that could affect the water table). This layer temporarily accumulates water before being it is supplied to the water table or directed to the conventional drainage system.

Sand:
the sand layer aims to increase the infiltration and redistribution of water in the soil. Sand increases porosity and aeration, helping water to penetrate through this layer.

Suitable vegetation:
vegetation and substrate that are suitable for each region and have strong roots to help stabilise walls or embankments (if the reservoir does not have reinforced concrete walls). The vegetation must also be resistant to periods of high humidity.

MAINTENANCE:

- Maintain the planting of permanent native vegetation, avoiding degradation caused by deforestation or the presence of invasive species.
- Check the drainage of the micro-drainage systems connected to the reservoir's macro-drainage system after periods of heavy rainfall. Ensure that the overflows and NbS connected to the system are functioning.
- Ensure that the amphibious reservoir is cleaned after its operation during periods of flooding and disinfected when polluted water enters.
- Create a maintenance schedule for the cleaning access and the reservoir pump system.

COST OF IMPLEMENTATION:

Cost of acquisition of the area to implement the structure.

Cost of implementation: USD$ 140.00 per m^3.[24]

Cost of implementation of green infrastructure and public facilities: USD$ 60.00 per m^2.

POSSIBLE CHALLENGES IN PLANNING AND EXECUTION:

Area:

amphibious reservoirs require large areas for their implementation (> 100 m^2), making them difficult to install in densely populated areas as they require open spaces. Create leisure areas connected to the system in order to bring landscape and social benefits to the urban environment.

Appropriate sizing:

hydrological and hydraulic studies must be carried out to determine the size of the structure and assess its impact on the watershed. Topographical surveys and geotechnical studies of the area must also be conducted.

Suitable vegetation:

selection and availability of plant species suitable (autochthonous) for drought and flood conditions.

Qualification of technicians:

the projects must be developed by a technical team comprising engineers, architects and other relevant professionals. It is therefore necessary to train a qualified workforce to design, implement, operate and maintain these systems.

Public policies:

absence of public policies and participatory planning and governance for the inclusion of NbS in urban planning. To be accepted by the residents, the definition of the technology must consider sanitary and aesthetic aspects.

24 Source: FCTH/SIURB-PMSP, 2022.

Figure 41 Amphibious reservoir project Abegoária, from the Verde Pinheiros Watershed booklet by the Hydraulic Technology Center Foundation (FCTH)(Guajava Arquitetura da Paisagem e Urbanismo, 2020).

- Vegetated polder -

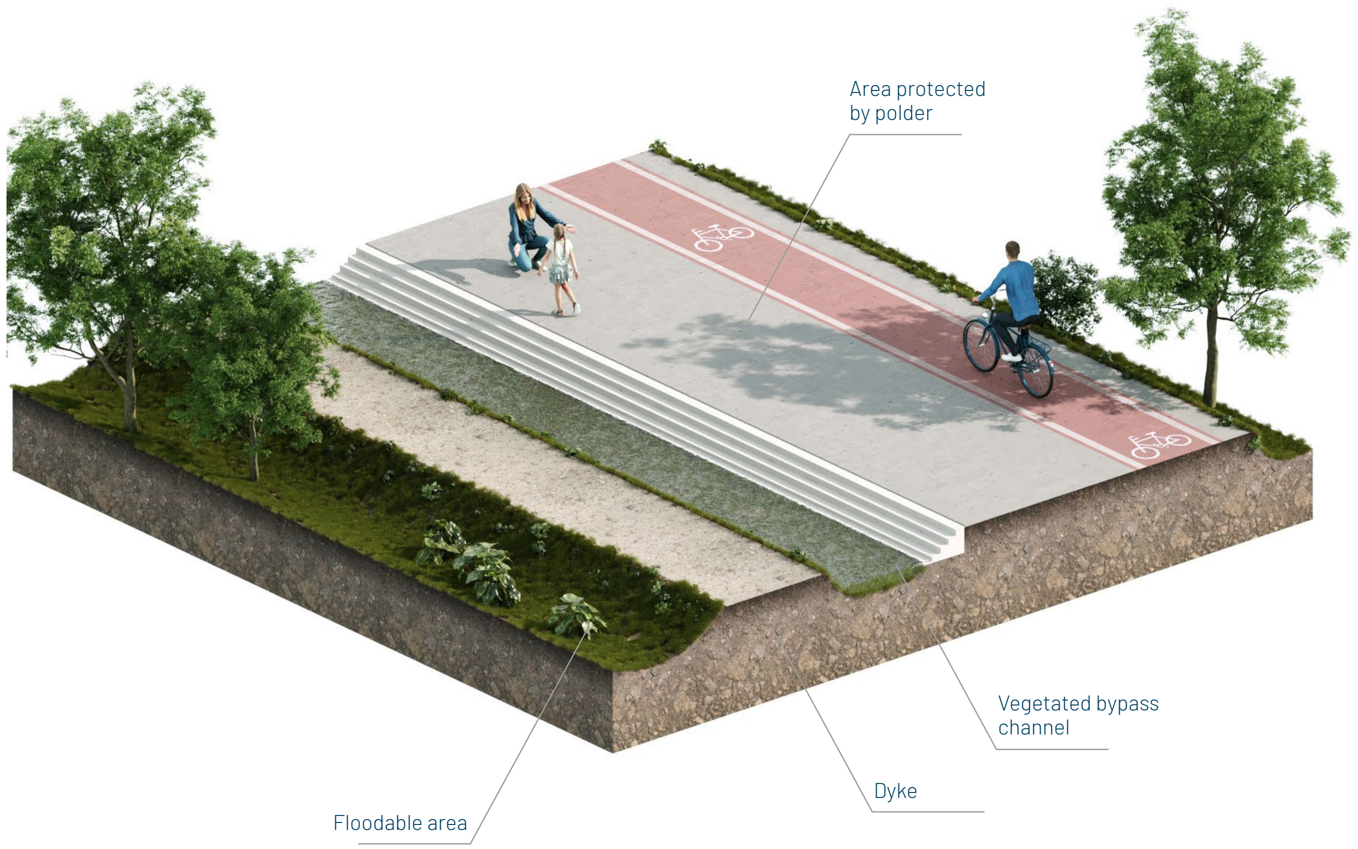


Figure 42 Vegetated polder (Source: Guajava, 2018).

The conventional solution for building a polder system consists of a dyke, a detention reservoir, a network of galleries and channels to collect and convey rainwater to the reservoir. There is also a system of pumps to return the accumulated water in the reservoir to the river. In this scenario, the drainage of the region inside the polder will be conducted to the reservoir. The dimensions of this reservoir are small compared to a conventional detention reservoir, but this is justified by its function as a passage box for the flood volume to be pumped.

This same system can be made more efficient and ecological building it in conjunction with the NbS to create a hybrid infrastructure. The following changes, devised by the Guajava Arquitetura da Paisagem e Urbanismo team of technicians, are therefore important:

The dyke should be constructed using natural materials to allow the planting of native vegetation with phytoremediation potential. However, it must have an impermeable core of compacted clay to prevent water from percolating from the body of water into the low-lying area, which the dyke is designed to isolate. A bikeway could also be built on top of the dyke, with walkways connecting to the surrounding area providing circulation, viewpoints and adjoining leisure spaces. The reservoir should also be impermeable to prevent the main body of water from filling the structure through percolation of water through the ground.

The micro-drainage network for the constitution of an NbS should preferably comprise of bioswales, rain gardens, rain beds, vegetated retention basins and other appropriate NbS, in accordance with the above suggestion. The channel parallel to the dyke should be replaced by a large bioswale to lead the rainwater to the amphibious reservoir. The traditional reservoir could be replaced with an amphibious reservoir, as detailed in this catalogue.

TECHNICAL PARAMETERS TO BE CONSIDERED WHEN CHOOSING:

STRATEGIC LOCATION:

In low-lying urbanised areas, near rivers, streams or the sea.

PEDOLOGY / TOPOGRAPHY:

Soil permeability:
the bioswale is the only permeable part of the polder system. For the drainage system to achieve good results in terms of water absorption, soil characterisation tests must be carried out, such as granulometric analysis. This determines the percentage by weight that each specified particle size range represents in the total mass tested. These tests identify the amount of clay, silt, sand and gravel present in a given sample. The coarse

fraction of the soil (gravel and sand) is much more permeable than the fine fraction (clay and silt) and is therefore preferable in the composition of infiltration measures. Conversely, dykes must be impermeable and consist of compacted clay or silt.

Slope:
the dyke and the reservoir have no limitations in terms of slope. For the projected biovalley, when installed on land with a slope of up to 5%. However, when installed on land with a slope of more than 5%, dams must be used to reduce the speed of water conduction and to maintain high effectiveness of the NbS for water infiltration and conduction without carrying vegetation and soil. The degree of inclination of the sides of the Bioswale (embankments), on the other hand, must be defined according to the rate of soil erosion or the specific contextual requirements and concerns of the site, such as the presence or absence of curbs and other design specifics. Embankments can differ from one side to the other. The dyke must be tied into the terrain at its initial and final points and along the entire stretch to be protected. It must follow the natural slope of the terrain longitudinally to ensure the protection of low-lying areas with flood levels below the crest of the dyke along its entire length.

Sediment load:
the input of solids into the system is high and requires cleaning after each rainfall. Mechanisms for retaining solids must be provided in order to prevent sediment from entering the system and causing clogging.

Types of soil:
the system is best suited to soils with low run-off potential and high infiltration rate and soils with a moderate infiltration rate that are well-drained. Groups A and B are included in the Hydrological Soil Groups as defined by the United States Soil Conservation Service (SCS-USDA).

HYDROLOGY

Flow control / interception capacity:
to define the device's return time, calculations must be made in accordance with municipal standards, taking into account the index of the public rainwater gallery index to which the NbS will be correlated.

Water table level:
in areas with a high water table (less than 1 m deep), the system's effectiveness will be reduced due to low absorption. It is therefore recommended that the dyke is watertight to prevent groundwater from entering the structure.

Drainage:
the various NbS detailed in this catalogue can be applied to the vegetated polder system, provided the recommendations for connection to existing drainage systems are followed and the calculated flows are met.

SPECIFIC CRITERIA FOR THIS NBS:

Construction of the barrage dyke:
The base of the dyke should be constructed using tradition engineering, with the necessary foundations, structures and resistant materials. Regarding the surface finishing, it is recommended that a natural earth covering be applied with the necessary substrates for planting low- and medium-sized creeping and herbaceous plant species. This will help to retain humidity, reduce the speed of rainwater run-off and maintain the natural containment of the embankments, while also creating a pleasant landscape that favours local biodiversity.

Bioswale for conveying rainwater to the reservoir:
as an alternative to the traditional concrete channel, bioswales should be designed in accordance with the calculated flow rate for the system. They should have sufficient width, depth and roughness to ensure the proper flow of water drained from the lower area, which should be isolated using watertight measures. This will also ensure maximum soil permeability and phytoremediation provided by the ideal vegetation. Follow the bioswale guidelines on indicated in this catalogue, considering the necessary proportions for the calculated flow rate for the system.

Reservoir:
to dispose rainwater from the vegetated polder system, it is recommended that an amphibious reservoir with an impermeable structure should be created. Its capacity should be reduced compared to that of a conventional reservoir volume, as it must be sized to accommodate the pumping system in full operation.

Pumping system:
for rainwater from the reservoir to the watercourse during a flood event. Unlike the conventional detention reservoir, which is only emptied after the precipitation event, the polders must work as soon as the passage reservoirs begin to fill.

MATERIALS REQUIRED:

Materials required for the dyke structure:
the materials are defined in the project and depend on the local situation. They should be compacted soil (clay or silt) or concrete to ensure effective hydraulic isolation of the lower area to be protected.

Suitable vegetation:
vegetation and substrate suitable for each type of region are required, with strong roots to help stabilise embankments and withstand periods of high humidity.

System for extracting the stored volume:
hydraulic pump system, installation area and pump room.

MAINTENANCE:

- Provide for an additional 2–5% of the total amount of seedlings to mitigate initial losses due to seedlings dying shortly after planting during the adaptation period (a one-off action during implementation);
- Check the drainage of the soil after periods of heavy rainfall to ensure that the overflows and the bioswale connected to the system are functioning correctly (recurring action);
- Manually remove residues that impede the flow of water[25] (recurring action);
- Create a maintenance schedule for the cleaning access to the reservoir and the pump system;
- Check the dyke structures for damage and make structural reinforcements when necessary.

25 Action taken by the agency responsible for maintaining and cleaning the area and/or by a civil person. We indicate the incentive to adopt urban green areas.

COST OF IMPLEMENTATION:

Construction of the dyke: USD$ 2,800.00 per m^2.

Construction of the bioswale: variable[26] between USD$ 40.00 and USD$ 100.00 per m^2.

Construction of the reservoir and pumping: USD$ 640.00 per m^3.

POSSIBLE CHALLENGES IN PLANNING AND EXECUTION:

Land:
difficulty in obtaining prior information on underground installations, often resulting in revisions to the project after construction has begun.

Clogging:
maintenance of NbS should be contracted for between 5 and 10 years after implementation to recover their infiltration capacity.

Suitable vegetation:
availability of autochthonous plant species suitable for wet soils.

Qualification of technicians:
the availability on the market of trained technicians with the specific knowledge to correctly analyse all the information and then monitor its execution. Implementation should be analysed by hydraulic engineers who specialise in rainfall containment areas, as this is a system that has a major impact on the landscape along rivers and on people living with flooding.

Public policies:
absence of public policies and participatory planning and governance for the inclusion of NbS in urban planning.

26 According to the area, design and configuration of the NbS, materials, labor, vegetation.

Figure 43 Vila Leopoldina Vegetated polder, from the Vila Leopoldina Watershed booklet by the Hydraulic Technology Center Foundation (FCTH)(Project by Guajava Arquitetura da Paisagem e Urbanismo, 2022).

Figure 44 Jardim Helena Vegetated polder, from the Lageado Watershed booklet by the Hydraulic Technology Center Foundation (FCTH)(Guajava Arquitetura da Paisagem e Urbanismo, 2022).

- Step pool -

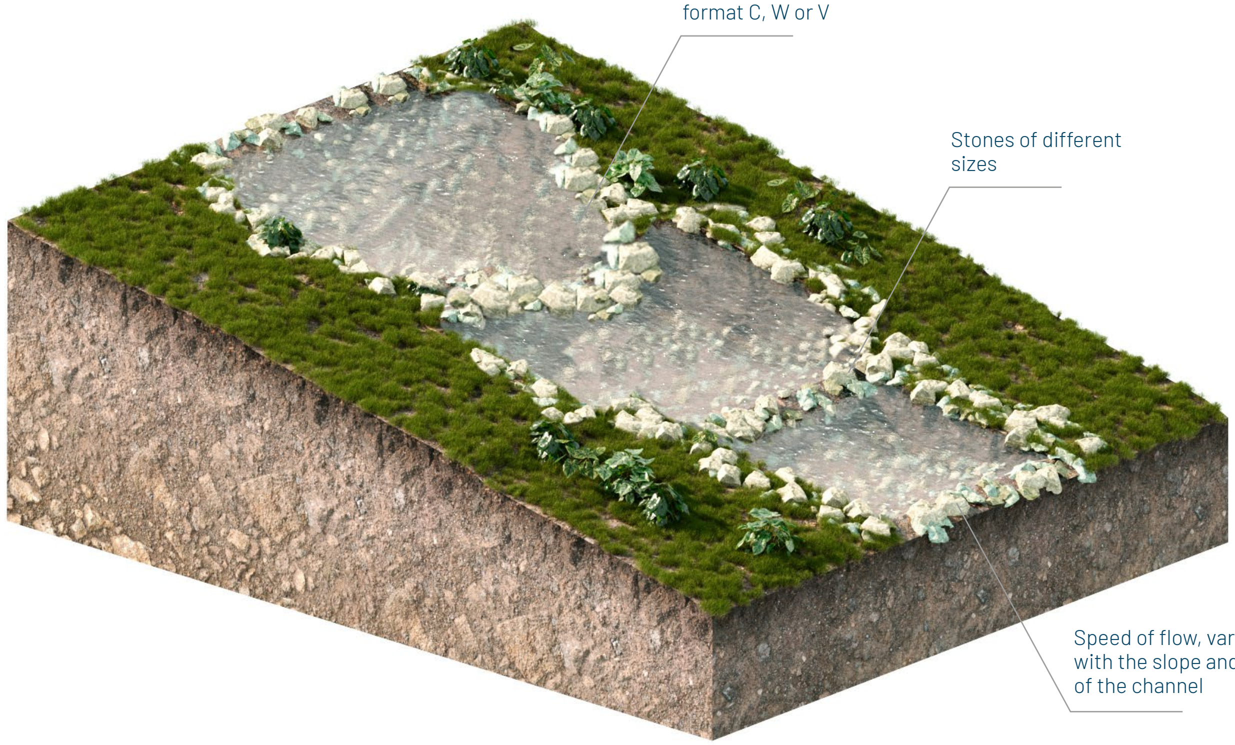


Figure 45 Step pool (Source: Guajava, 2021).

Step pools are pools with regenerative steps designed to transport rainwater (AACG, 2010). This NbS involves building an alternating sequence of pools that play a crucial role in reducing the risk of watercourses becoming unstable during periods of intense precipitation, when run-off speeds increase, causing erosion and other structural problems.

Grey stormwater drainage infrastructure concentrates rainfall run-off in pipes. When these pipes empty into the valley floor, the concentrated flow and high velocity can cause extensive erosion and increase sediment in waterways. Step pools, on the other hand, dissipate the flow of energy during heavy rainfall events. During low-flow conditions, they act as rainwater ponds and treat the water through plant phytoremediation, thereby improving water quality and supplying shallow underground reservoirs.

This technology involves placing stone barriers along the watercourse to form small reservoirs between them. When necessary, these areas can be excavated to increase the reservoir capacity and help reduce the speed of the water. However, different barrier designs must be created for each type of site, for each type of site, taking into account the varying storage needs, the need to reduce the speed of run-off and the need to treat the banks. In this way, the barrier designs can be customised for each context to efficiently meet the desired objectives.

This NbS offers benefits in terms of water quality and channel recovery, as well as hydraulic improvement without increasing local flood risks.

TECHNICAL PARAMETERS TO BE CONSIDERED WHEN CHOOSING:

STRATEGIC LOCATION:

The system is designed for installation in watercourses where run-off needs to be slowed down and where there is enough space to create pools to store increased flow during periods of heavy rainfall. It also allows for the construction of firm embankments that will not be damaged by excavation.

PEDOLOGY / TOPOGRAPHY:

Soil permeability:
does not apply, since it is allocated under the bed of streams, creeks and rivers.

Slope:
the barriers should be created to reduce the flow velocity. The greater the natural slope, the greater the need to reduce the velocity to improve flood control downstream.

Sediment load:
in areas with high sediment or residue production, sedimentation basins should be installed upstream or at the entrance to the structure.

Types of soil:
as this structure is designed to reduce the speed of water run-off, this parameter is not very significant.

HYDROLOGY:

Flow control / interception capacity:
this is an important variable because, when the flow contribution increases considerably during rainfall events, the risk of stability problems, increased flow velocity and flood risks along the watercourse also increases proportionally. This condition should therefore be studied when planning the number of barriers and the depth of pools, to ensure that natural flow is not impeded and that the system is effective at all times.

Drainage and water run-off:
these contribute to the process of rainwater detention; depending on the permeability of the local soil and the presence or absence of vegetation within them, the basins can also facilitate the processes of infiltration and evapotranspiration.

SPECIFIC CRITERIA FOR THIS NBS:

Depth of pools:
the greater the depth, the greater the whirling effect produced within the pools formed by the barriers. Pools can be deeper where there is a greater natural slope, and where there is not, it is possible to excavate to create deeper areas and promote greater flow retention.

Margin dimension:
the wider the watercourse, the greater the variety of shapes that can be created with the stones. Water treatment zones can be created between the margins and the dams when the channel is wider.

MATERIALS REQUIRED:

Materials required for the dam structure:
stones of different sizes that can guarantee different types and configurations of 'pools'. The stones must be a suitable size and have the necessary strength to withstand the flow of water. Rocks can also be used to create uneven surfaces and barriers between the pools.

Substrate:
the soil is used to fill the spaces between the stones, providing a suitable substrate for vegetation to grow. It is important to use soil that is rich

Suitable vegetation:
the choice of native and local plant species that are suitable for the type of residual water is fundamental to the success of the treatment.

MAINTENANCE:

- Maintenance should focus on the accumulation of sediment and residue, as well as replacing vegetation when necessary.
- Foresee an additional quantity of seedlings amounting to 2–5% of the total value to mitigate initial losses due to seedlings dying shortly after planting during the adaptation period (a one-off action during implementation);
- Remove residue manually[27] (recurring action);
- Check for damage to the stone structures forming the dams and reinforce them when necessary to prevent future rock or soil slides (recurring action).

COST OF IMPLEMENTATION:

Variable[28] between USD$ 80.00 and USD$ 140.00 per m^2.

POSSIBLE CHALLENGES IN PLANNING AND EXECUTION:

Land:
difficulty in obtaining prior information on the type of soil, which interferes with the stability of the planned.

Suitable vegetation:
availability of plant species native to the area that rare suitable for waterlogged soils.

Qualification of technicians:
the availability on the market of trained technicians with the specific knowledge to correctly analyse all the information and then monitor its execution.

Public policies:
absence of public policies and participatory planning and governance for the inclusion of NbS in urban planning.

Flow:
understanding the flow variables according to the periods of drought and flood and designing dam structures that do not interfere with the natural flow of the watercourse are the biggest challenges when applying this type of infrastructure. The main objective is to contribute to the control of downstream flows without damaging drainage in the area.

27 Action taken by the agency responsible for maintaining and cleaning the area and/or by a civil person. We indicate the incentive to adopt urban green areas to help maintain them.

28 Implementation costs vary according to a number of factors, such as the width of the watercourse, the size and quantity of stones needed for the dams, the cost of labor to place them, among others.

Figure 47 Downstream view of the step pool implemented at Lago Cabrinha, Londrina/PR (Landscape Architecture Project by Guajava Arquitetura da Paisagem e Urbanismo, Paulo Pellegrino, and Silvio Motta; photo: Meridiano Filmes, 2022).

Figure 48 Upstream view of the step pool implemented at Lago Cabrinha, Londrina/PR (Landscape Architecture Project by Guajava Arquitetura da Paisagem e Urbanismo, Paulo Pellegrino, and Silvio Motta; photo: Sarah Daher, 2023).

2^{nd} Group

NbS aimed at retaining the banks of streams and rivers, embankments and slopes

2nd Group: NbS aimed at retaining the banks of streams and rivers, embankments and slopes

This item presents NbS for embankment containment. It is designed to prevent soil erosion and stabilise land that has been planted with specific vegetation. The roots of the plants, for example, act like a net, holding the soil in place and reducing the risk of landslides. Slopes stabilised through NbS can help mitigate the impact of disasters such as landslides, which is especially critical in areas prone to heavy rainfall or extreme weather events. Therefore, implementing NbS in such areas not only reinforces environmental safety, but also protects communities.

Table 3 indicates the degree of suitability of each containment NbS, whether it is recommended, possible or not recommended[29], according to the location, pedology/topography and hydrology layers. The details of these information layers are explained below. It should be noted that these NbS are not directly associated with flood mitigation, unlike the NbS listed in Table 1.

For each of the NbS, the technical parameters for selection are described, as along with information on pedology, topography and hydrology, strategic location, materials required, vegetation, maintenance, implementation costs and possible planning and execution challenges.

Bioengineering primarily employs living construction materials (seeds, plants, parts of plants, etc.) that can (or cannot) be combined with inert materials. It can be used as a substitute, but mainly as a useful and sometimes necessary supplement to classic civil engineering techniques (Schiechtl, 1980). Bioengineering techniques can be applied in solving problems involving geotechnical and hydrological instability and the control of surface erosion. To this end, the solutions involve the design of ecosystems in dynamic balance (Sousa, 2015; Sousa; Sutili, 2017).

Plants for bioengineering interventions are chosen based on technical, ecological and landscape-related criteria (Sousa, 2015).

These Nature-based Solutions have a low environmental impact, with more flexible and permeable construction schemes that can be seamlessly integrated with nature without any settling or movement of the soil, and without changing the soil's hydraulic conductivity (Sousa, 2015).

Furthermore, bioengineering offers more economical construction solutions compared to traditional ones (Bonatti; Marongiu, 2013; Fernandes; Freitas, 2011; Studer; Zeh, 2014).

Structure of the form

TECHNICAL PARAMETERS TO BE TAKEN INTO ACCOUNT WHEN CHOOSING:

- STRATEGIC LOCATION
- TERRAIN CHARACTERISTICS
- HYDRAULICS
- GEOMETRY
- TYPE OF VEGETATION

MATERIALS REQUIRED

MAINTENANCE

COST OF IMPLEMENTATION:

POSSIBLE CHALLENGES IN PLANNING AND EXECUTION

Source: Baseado em Rita Sousa, 2023

29 Table data based on studies by the team responsible for this catalogue (GIZ; RIGHETTO, 2009).

Table 3 Criteria for defining NbS to contain stream and river margins, embankments and slopes, according to layers of information on location, hydraulics, geometry and vegetation.

TYPES OF EMBANKMENT CONTAINMENT			Wooden cribwall	Living support wall on riverbanks	Living grid	Stone containment wall	Stone wall with vegetation	Prefabricated cribwall with vegetation	Gabion walls with vegetation	Flat gabions - mattress	Green stapled soil	Geocell containment
LOCATION	Terrain characteristics	Riverbanks	high	high	medium	medium	medium	low	high	high	medium	high
		Hillsides	low	high	high	high	high	high	low	low	high	high
		Embankments	high	medium	medium	high	high	low	high	high	high	high
HYDROLOGY	Upper limits for channel speeds	1.5 m/s	high	high	high	high	high	high	high	high	high	high
		2.5 m/s	low	low	low	high	high	high	high	high	high	high
		3.0 m/s	low	low	low	high	high	high	low	low	low	low
		4.0 m/s	low	low	low	high	low	low	low	low	low	low
GEOMETRY	Allowed height	Up to 5 m	high	high	high	high	high	medium	high	high	medium	high
		Over 5 m	low	low	high	medium	medium	high	high	medium	high	high
	Slope	Up to 40°	high	high	high	low	low	high	medium	high	high	high
		Between 40° and 70°	medium	low	high	high	high	high	high	high	high	high
		Over 70°	low	low	low	high	high	medium	high	low	medium	medium
VEGETATION	Type	grasses / forage	high	high	high	high	high	high	high	high	high	high
		creepers	high	high	high	high	high	high	high	high	high	high
		shrubs	medium	medium	high	low	low	high	low	low	medium	medium

Level of interaction between device and SDG: high medium low

TECHNICAL DATA SHEET TEMPLATE

Description of the NbS sheets listed in Table 3: Wooden cribwall, Riverbank cribwall, Living grid, Stone containment wall, Stone wall with vegetation, Prefabricated cribwall with vegetation, Gabion walls with vegetation, Flat gabions, Green stapled soil.

NAME OF NATURE-BASED SOLUTION

GENERAL DESCRIPTION: DEFINITION OF NBS'S CONCEPT AND OBJECTIVES

TECHNICAL PARAMETERS TO BE TAKEN INTO ACCOUNT WHEN CHOOSING:

(structured by the information layers in Table 3)

STRATEGIC LOCATION:

refers to the ideal open space for implementing NbS. This layer addresses the availability of space for implementing NbS and defining strategic locations for capturing urban run-off.

The different types of containment must consider the topographic profile to choose the best solution for mitigating erosion processes and maintaining land stability. As these retaining walls mitigate the occurrence of landslides caused by applied forces, such as thrust, soil weight and infiltrated water, greater care is required in executing the associated NbS drainage to prevent collapse of the structure.

TERRAIN CHARACTERISTICS:

segmented into three types, which are riverbanks, slopes and embankments.

HYDRAULICS:

the design conditions related to the flow limits in channels for selecting the appropriate NbS to contain the margins of water bodies. According to the data:

Allowable flow velocity limits:
defines the maximum permissible velocities depending on the type of lining. This prevents siltation due to very low flow velocities, which tend to encourage the deposition of sediments carried by the flow at the bottom of the channel, and erosion of the channel due to very high flow velocities, which tend to erode the margins and compromise the structure, while also promoting siltation. Therefore, before selecting the containment method, it is necessary to carry out a hydrological and hydraulic study to calculate the flow velocity in the various sections of a channel. This will then allow to define the most suitable containment method the design slope to maintain the limit velocities. The maximum speed limits, depending on the type of soil, are widely documented in the literature by type of lining and by type of soil. In general, these limits are: 1.5 m/s for soil-lined channels; 2.5 m/s for gabion-lined channels; 3.0 m/s for mortared stone-lined channels; and 5.0 for concrete-lined channels. According to current literature, the minimum acceptable limits range from 0.6 to 1.0 m/s.

GEOMETRY:

refers to the geometry data that dictates the forces required by the retaining structures. The greater the height and the steeper the slope, the greater the thrust acting on the retaining structure. According to the data:

Allowed height:
this is a condition for the use of NbS, since greater heights result in greater stresses on the structure.

Slope:
influences the choice of NbS, since greater slopes result in greater stresses on the structure.

VEGETATION:

attention must be paid to integrating the type of vegetation with the type of containment required. According to the data:

Type of vegetation:
segmented into three classifications, depending on the support structure of the vegetation (grasses, climbers or shrubs). Shrubby vegetation should be avoided in some types of containment, especially gabion, as its roots can damage the stone structure, and stone, as there is a risk of displacement in the structure. Grasses, on the other hand, are recommended for most types of containment, but only moderately indicated for stone due to the energy transmitted by a flood wave, which could dislodge the vegetation. Climbing plants, however, are recommended for all the proposed NbS.

MATERIALS REQUIRED:

are the material resources needed to install the NbS, such as wood, drainage pipes, vegetation, sleepers, beams and piles; local vegetable soil, wire mesh, stones, etc.

MAINTENANCE:

in general, NbS aim to reduce maintenance costs in the long term. Initial monitoring of the system may be necessary to check its effectiveness and whether elements such as seedlings need to be replaced. It is recommended that the population participate in the care and basic manual maintenance of these infrastructures, such as removing accumulated rubbish, which can hinder water entering the different NbS.

COST OF IMPLEMENTATION:

Estimated based on general variables and parameters to obtain a cost per m^2. The cost of implementing each NbS involves variables that must be considered, whether by the public entity or in a public-private partnership.

POSSIBLE CHALLENGES IN PLANNING AND EXECUTION:

are divided into categories according to the type of slope, terrain and maintenance.

- Wooden cribwall -

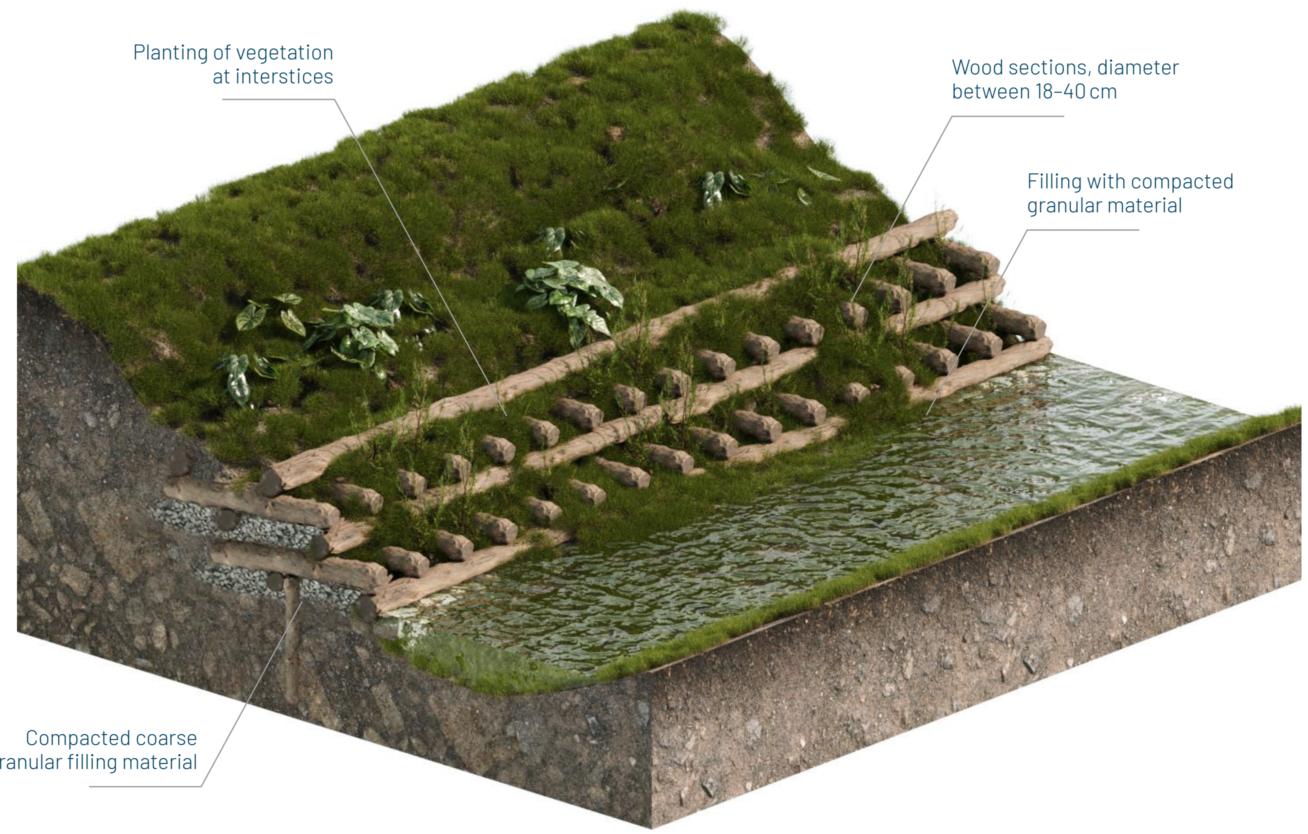


Figure 49 Wooden cribwall (Source: Guajava. Adapted from Helgard, Z., 2007).

The wooden cribwall is a structure designed to stabilise riverbanks and embankments. It is made up of a layered arrangement of wooden logs.

During the filling of the wall with drainage material, cuttings or rooted woody plants are inserted. These should be placed so that they rise from the wall and extend along it until they reach the natural terrain. In the case of a wall used to protect riverbanks, longitudinal branches are used instead of live stakes to prevent sediment being carried away.

TECHNICAL PARAMETERS TO BE CONSIDERED WHEN CHOOSING:

STRATEGIC LOCATION:

Mainly for the consolidation and stabilisation of riverbanks and low steep embankments.

TERRAIN CHARACTERISTICS:

this solution is best suited to embankments and riverbanks, and is not suitable for hillsides as it must be carried out on level grounds.

HYDRAULICS:

Allowable flow velocity limits:
due to both the material supporting the containment (wood) and the fill (soil), this solution cannot withstand high-velocity water flows. Such flows would damage the structure and cause the fill to be carried away. Therefore, it is suitable for velocities of up to 1.5 m/s.

GEOMETRY:

Allowed height:
this containment structure is suitable for low embankments and shallow riverbanks. A height limit of 5 m is recommended to ensure safety.

Slope:
due to the type of structure and material, this solution is more suitable for sites with slight slopes, preferably up to 40 degrees.

TYPE OF VEGETATION:

the vegetation used in this solution creates a reinforcing effect on the terrain, noticeable as the plants' root systems develop. This contributes to the stabilisation initially provided by the wooden structure. Grasses and climbing plants are best suited for this purpose.

MATERIALS REQUIRED:

Wood:
the wood[30], with a diameter of 18 to 40 cm, is used for structural purposes to ensure the stability of the containment structure. The logs must be interconnected to form a stable and resistant structure in the shape of a 'bonfire', arranged sub-horizontally and longitudinally in relation to the watercourse.

Drainage pipes:
the structure must include drainage pipes to drain rainwater and prevent soil erosion.

Local vegetable soil:
between the layers, compacted soil should be applied, which can be material taken from the margins during their preparation.

Vegetation:
initially, plants have no structural function. However, after development, they take on a structural support role through their root system. The deep roots of plants also create channels through which rainwater infiltrates the soil. Plant species that are suitable for moist soils are ideal. Consider local climatic conditions when choosing species.

MAINTENANCE:

Attention must be paid to maintaining the infrastructure, since the containment is made of wood and will require maintenance when it poses a risk to the containment system.

COST OF IMPLEMENTATION

Variable[31] between USD$ 160.00 and USD$ 1,500.00 per m^2.

30 Reforestation wood commonly used in construction (such as Eucalyptus or Pinus), which requires treatment to combat biological agents.
31 According to the height, area, design and configuration of the NbS, materials and labor.

POSSIBLE CHALLENGES IN PLANNING AND EXECUTION:

Land:
although it is a less expensive option, because it allows the use of materials found on site, attention must be paid to the height of the slope or riverbank to be contained and the bearing capacity of the existing soil. This requires greater care during execution to ensure the site is completely safe, stabilised and consolidated.

Suitable vegetation:
availability of plant species suitable for wet soils.

Qualification of technicians:
the availability on the market of trained technicians with the specific knowledge to correctly analyse all the information and then monitor its execution.

- Wooden cribwall -

Figure 50 On the left bank, wooden cribwall with a double layer planted with native shrubs and live bundles, coconut biomat, and hydroseeding; on the right, cylindrical gabion filled with stones and vegetated coconut bio-retainer, Ribeira de Gende, Portugal (Project by Rita Sousa, photo: Rita Sousa, 2011).

- Riverbank cribwall -

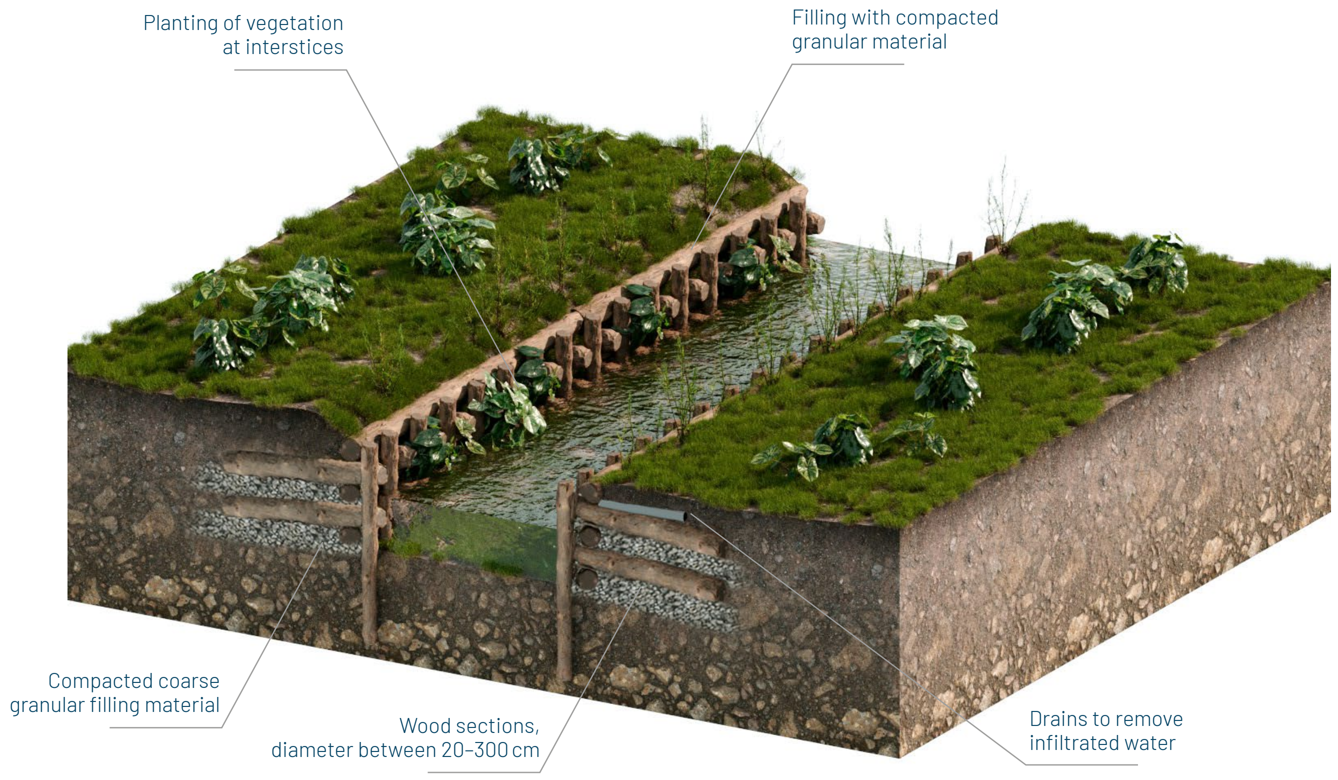


Figure 51 Riverbank cribwall (Source: Guajava. Adapted from Helgard, Z., 2007).

The riverbank cribwall is a structure designed mainly to stabilise the steep or subvertical margins of streams and rivers, using wood as the main retaining element.

Wooden stakes are set vertically, and a horizontal row of logs is placed on top of them These logs are then nailed and tied with wires or ropes, to guarantee the stability of the containment. Next, logs are nailed perpendicular to the margin and the process is repeated until the entire height of the riverbank is protected. Grasses and climbers are planted to help retain the surface layer and give the riverbank a more pleasant landscape appearance.

TECHNICAL PARAMETERS TO BE CONSIDERED WHEN CHOOSING:

STRATEGIC LOCATION:

Mainly for the consolidation and stabilisation of steep river margins.

TERRAIN CHARACTERISTICS:

this solution is best suited to riverbanks, mainly due to the ease with which it can be implemented. It can also be used in stream channels and subvertical rivers.

HYDRAULICS:

Allowable flow velocity limits:
due to both the materials supporting the containment (wood) and the fill (soil), this solution cannot withstand high-velocity water flows. Such flows would damage the structure and cause the fill to be carried away. Therefore, it is suitable for velocities of up to 1.5 m/s.

GEOMETRY:

Allowed height:
this containment structure is suitable for shallow river margins. A height limit of 5 m is recommended to ensure safety.

Slope:
this solution is suitable even for terrain with steep slopes, ideally up to 70 degrees.

TYPE OF VEGETATION:

the vegetation used in this solution creates a reinforcing effect on the terrain, noticeable as the plants' root systems develop. This contributes to the initial stabilisation provided by the wooden structure. Grasses and climbing plants are best suited for this purpose.

MATERIALS REQUIRED:

Wood:
wooden logs[32] with a diameter of between 20 and 30 cm and a length of up to 3 m. These logs must be interconnected to form a stable and resistant structure. They should be arranged sub-horizontally and longitudinally in relation to the watercourse.

Drainage pipes:
the structure must include drainage pipes to drain rainwater and prevent soil erosion.

Filling:
under the water, the interstices must be filled with stones and, at the top, the filling between the layers must be made with compacted soil. This soil can be made using material taken from the margins during preparation.

Vegetation:
initially, plants have no structural function. However, after development, they take on a structural support role through their root system. The deep roots of plants also create channels through which rainwater infiltrates the soil. Plant species that are suitable for moist soils are ideal. The recommended vegetation is listed in Step 3 of this catalogue. Consider local climatic conditions when choosing species.

MAINTENANCE:

Attention must be paid to maintaining the infrastructure, since the containment is made of wood and will require maintenance when it poses a risk to the containment system.

COST OF IMPLEMENTATION:

Variable[33] between USD$ 120.00 and USD$ 200.00 per m^2.

32 Reforestation wood commonly used in construction (such as Eucalyptus or Pinus), which requires treatment to combat biological agents.
33 According to the height, area, design and configuration of the NbS, materials and labor.

POSSIBLE CHALLENGES IN PLANNING AND EXECUTION:

Land:
difficulty in obtaining prior information on underground installations, often leads to revisions to the project after construction has begun.

Suitable vegetation:
it is important to choose the choose plants that are suited to the local climate and soil conditions, and that have strong roots to help stabilise the wall.

Maintenance:
living supporting walls require regular maintenance to ensure that the plants continue to grow, thus helping stabilise the wall and prevent structural problems with the beams.

- Riverbank cribwall -

Figure 52 Riverbank cribwall at Córrego do Judas in Severo Gomes Park, São Paulo/SP (Photo: Pedro Algodoal, 2023).

- Living grid -

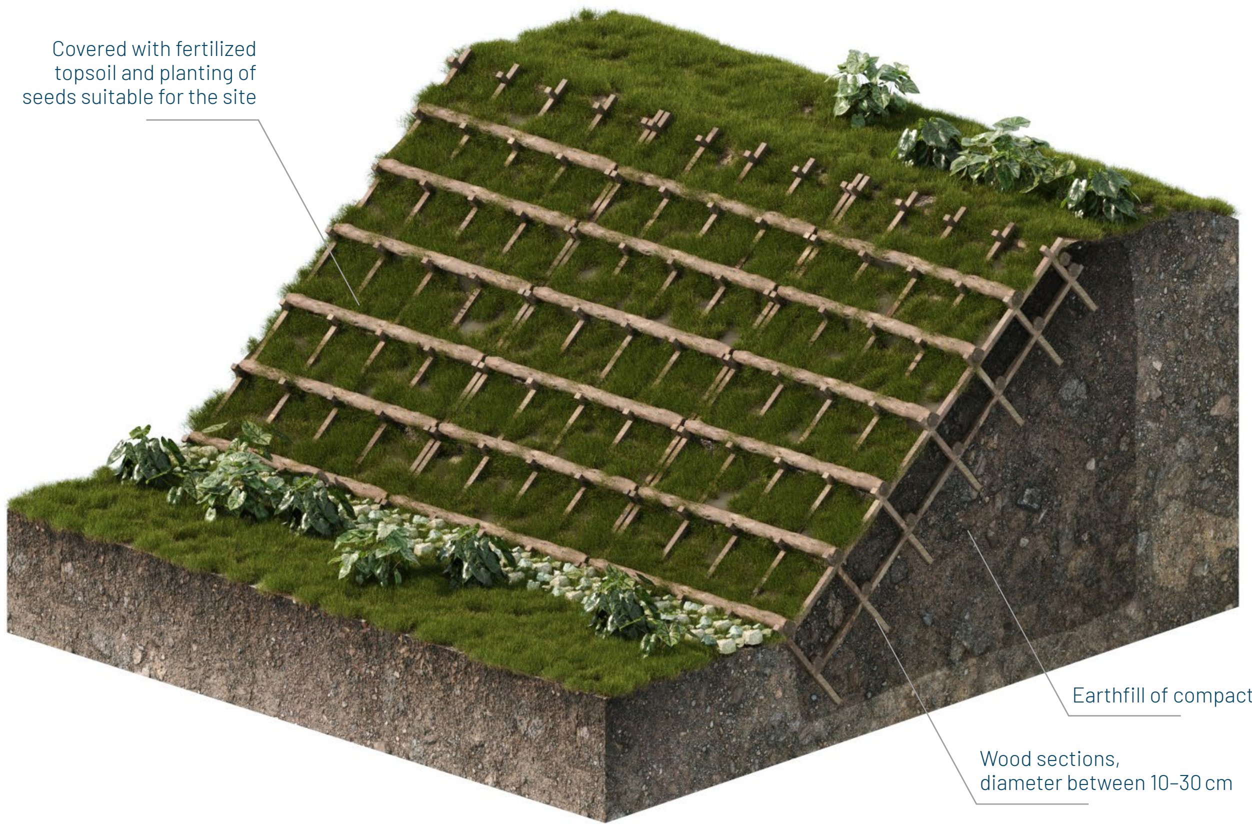


Figure 53 Living grid (Source: Guajava).

Living grids are containment structures made up of single- or double-walled wooden grids. They are used to stabilise high terrains and steep slopes, with a maximum height and slope of up to 20 m and 70 degrees.

The grids are fixed to the ground with nails or other types of anchoring such as wooden or metal stakes, plant ties with trellises or root systems. The method used depends on the type of terrain and site conditions. While the grid is being filled with soil, strips of vegetation containing branches clumped plants or transplanted plants are inserted, and/or seeds are sown after the wooden structure has been installed.

The appropriate selection of plants and anchoring techniques must be considered according to site conditions, climate, wind strength and other environmental factors.

TECHNICAL PARAMETERS TO BE CONSIDERED WHEN CHOOSING:

STRATEGIC LOCATION:

For the stabilisation of high hillsides and steep slopes, with a maximum height and inclination of up to 20 m and 70 degrees.

TERRAIN CHARACTERISTICS:

this solution is mainly used on hillsides, but can also be used on steep embankments or vertical riverbanks. Its structure better supports the contained material due to the use of the wooden grid and vegetation.

HYDRAULICS:

Allowable flow velocity limits:
due to the material supporting the containment (wood) and the fill (soil), this solution cannot withstand high-velocity water flows, as this flow would cause damage to the structure and would also cause the fill to be carried away. It is therefore suitable for velocities of up to 1.5 m/s.

GEOMETRY:

Allowed height:
this containment structure is suitable for low embankments due to the method of combining wood weave and planted vegetation, which makes projects with containment heights of up to 20 m feasible.

Slope:
due to the structure and materials used, this solution is more suitable for sites with slight slopes, of up to 70 degrees.

TYPE OF VEGETATION:

the vegetation used in this solution creates a reinforcing effect on the terrain, noticeable as the plants' root systems develop. This contributes to the initial stabilisation provided by the wooden structure. Grasses and climbing plants are best suited for this purpose.

MATERIALS REQUIRED:

Wood:
the wood[34] has a structural function, ensuring the stability of the structure until the vegetation develops and root formation is consolidated. The logs must be interconnected to form a stable and resistant structure in the shape of a 'bonfire'.

Vegetation:
initially, plants have no structural function. However, after development, they take on a structural support role through their root system. The deep roots of plants also create channels through which rainwater infiltrates the soil. Plant species (autochthonous) that are suitable for moist soils are ideal. The recommended vegetation is listed in Step 3 of this catalogue. Consider local climatic conditions when choosing species.

MAINTENANCE:

- Attention must be paid to maintaining the infrastructure, since the containment is made of wood and, which will require maintenance when it poses a risk to the containment system.
- Furthermore, regular maintenance of living grids is also essential to ensure their effectiveness as living structures, such as pruning and monitoring plant growth.

COST OF IMPLEMENTATION:

Variable[35] between USD$ 100.00 and USD$ 120.00 per m^2.

34 Madeira de reflorestamento comumente utilizada na construção civil (como Eucalipto ou Pinus) sendo necessário tratamento da madeira para combate a agentes biológicos.

35 According to the height, area, design and configuration of the NbS, materials and labor.

POSSIBLE CHALLENGES IN PLANNING AND EXECUTION:

The implementation of living grid containment does present any major difficulties.

- Living grid -

Figure 54 Living grid combined with a live grid, Vesuvio National Park, Italy (Project by Gino Menegazzi, photo: Rita Sousa, 2023).

- Stone containment wall -

Figure 55 Stone containment wall (Source: Guajava).

A stone containment wall is a structure built to stabilise the ground on slopes and embankments. Support walls up to 10 m high[36] are built, preferably using materials obtained close to the site, to help reduce material transportation costs. If there are no suitable stones available in the area, then stones that best suit the characteristics of the region should be chosen.

The foundations must be below the ground level and drainage must be guaranteed to drain away the volume of infiltrated water, particularly during periods high precipitation. Combined solutions can be used, either with conventional drainage or with sustainable drainage.

TECHNICAL PARAMETERS TO BE CONSIDERED WHEN CHOOSING:

STRATEGIC LOCATION:

On embankments and slopes that need stabilisation.

TERRAIN CHARACTERISTICS:

this solution is mainly used on slopes and embankments and can even be used on vertical river margins due to its resistance.

HYDRAULICS:

Allowable flow velocity limits:
as most of the containment material is made up of stones, this solution is suitable for speeds of up to 3.0 m/s.

GEOMETRY:

Allowed height:
this this containment structure is suitable for slopes up to 10 m high, acting as an NbS mostly used in cuttings.

Slope:
due to the type of structure and material, this solution is more indicated for sites with steeper embankments and slopes. It is not recommended for use on softer terrain as the cost-benefit ratio of the solution is less favourable due to a loss of effectiveness.

36 It requires a geotechnical assessment of the site to correctly calculate the dimensions of the containment wall.

TYPE OF VEGETATION:

vegetation will grow on the crest of the wall, if there is sufficient space. The growth of spontaneous vegetation should also be anticipated, depending on the edaphic and climatic conditions.

MATERIALS REQUIRED:

Stones:
that can be aligned and mortared to create structural walls.

Drainage pipes:
the structure must include drainage pipes to drain rainwater that has infiltrated the soil. Thie relieves the structure of additional thrust generated by the rainwater.

MAINTENANCE:

- Maintenance care must focus on the infrastructure of the containment wall.
- It is recommended that intervention and maintenance are carried out on the wall when a block falls or when there are loose blocks.

COST OF IMPLEMENTATION:

Variable between USD$ 40.00 and USD$ 60.00 per m^3.

POSSIBLE CHALLENGES IN PLANNING AND EXECUTION:

The construction of a stone wall does not pose major difficulties.

Figure 56 Stone containment wall at Linear Ribeirão Caulim, São Paulo/SP (Collection of the Secretaria do Verde e Meio Ambiente, São Paulo City Hall, photo: Wellington Nagano, 2015).

- Stone wall with vegetation -

Figure 57 Stone wall with vegetation (Source: Guajava).

A stone wall with vegetation is a structure built mainly to stabilise the ground on slopes and embankments. Support walls up to 10 m high[37] are built, preferably using materials obtained close to the site, helping to reduce material transportation costs. If there are no stones available in the area, then stones that best suit the characteristics of the region should be chosen. Defining the height requires a geotechnical assessment of the site to correctly calculate the dimensions of the containment wall.

Depending on the size of the stones, this solution can be built mechanically or manually, with the placement of living material. During construction, the stones are placed in vegetable soil and plants or stakes are placed into the spaces between them.

TECHNICAL PARAMETERS TO BE CONSIDERED WHEN CHOOSING:

STRATEGIC LOCATION:

On embankments and slopes that need stabilisation.

TERRAIN CHARACTERISTICS:

this solution is mainly used on slopes and embankments. It can also be used on vertical river margins due to its resistance.

HYDRAULICS:

Allowable flow velocity limits:
as most of the containment material is made up of stones, this solution is suitable for speeds of up to 3.0 m/s.

GEOMETRY:

Allowed height:
this containment structure is suitable for slopes up to 10 m high, acting as an NbS mostly used in cuttings. The thickness varies depending on factors such as the type of soil, the diameter of the stones and the height of the wall. It usually varies between 30 cm and 1 m.

37 It requires a geotechnical assessment of the site to correctly calculate the dimensions of the containment wall.

Slope:
due to the type of structure and material, this solution is more indicated for sites with steeper embankments and slopes. It is not recommended for use on softer terrain as the cost-benefit ratio of the solution is less favourable due to the loss of its effectiveness.

TYPE OF VEGETATION:

species of climbing plants are planted, together with a favourable substrate, during the construction of the wall to help with surface run-off and infiltration. Their roots grow through the voids left by the stones, forming a kind of weave that helps to support the wall and prevents material from passing through behind the retaining wall.

MATERIALS REQUIRED:

Stones:
that can be aligned and mortared to create structural walls.

Drainage pipes:
the structure must include drainage pipes to drain rainwater that has infiltrated the soil. This relieves the structure of the additional thrust generated by rainwater.

Vegetation:
initially, plants have no structural function. However, after development, they take on a structural support role through their root system. The deep roots of plants also create channels through which rainwater infiltrates the soil. Plant species suitable for moist soils are ideal. Consider local climatic conditions when choosing species.

MAINTENANCE:

Attention must be paid to maintaining the infrastructure, since the containment is made of wood and, which will require maintenance when it poses risks to the containment system.

COST OF IMPLEMENTATION:

Variable between USD$ 50.00 and USD$ 80.00 per m^3.

POSSIBLE CHALLENGES IN PLANNING AND EXECUTION:

The construction of a stone wall does is not particularly difficult.

Figure 58 Stone wall with vegetation with native shrub plants in live riprap, Location: Uruguay River downstream of the Itá Hydroelectric Dam, Brazil (Project by Rita Sousa, Junior Dewes, and Fabrício Sutili; photos: Junior Dewes and Rita Sousa).

Figure 59 Stone wall with vegetation at Trilho das Vinhas in Cascais, Portugal (photo: Ana Coelho, 2023).

- Prefabricated cribwall with vegetation -

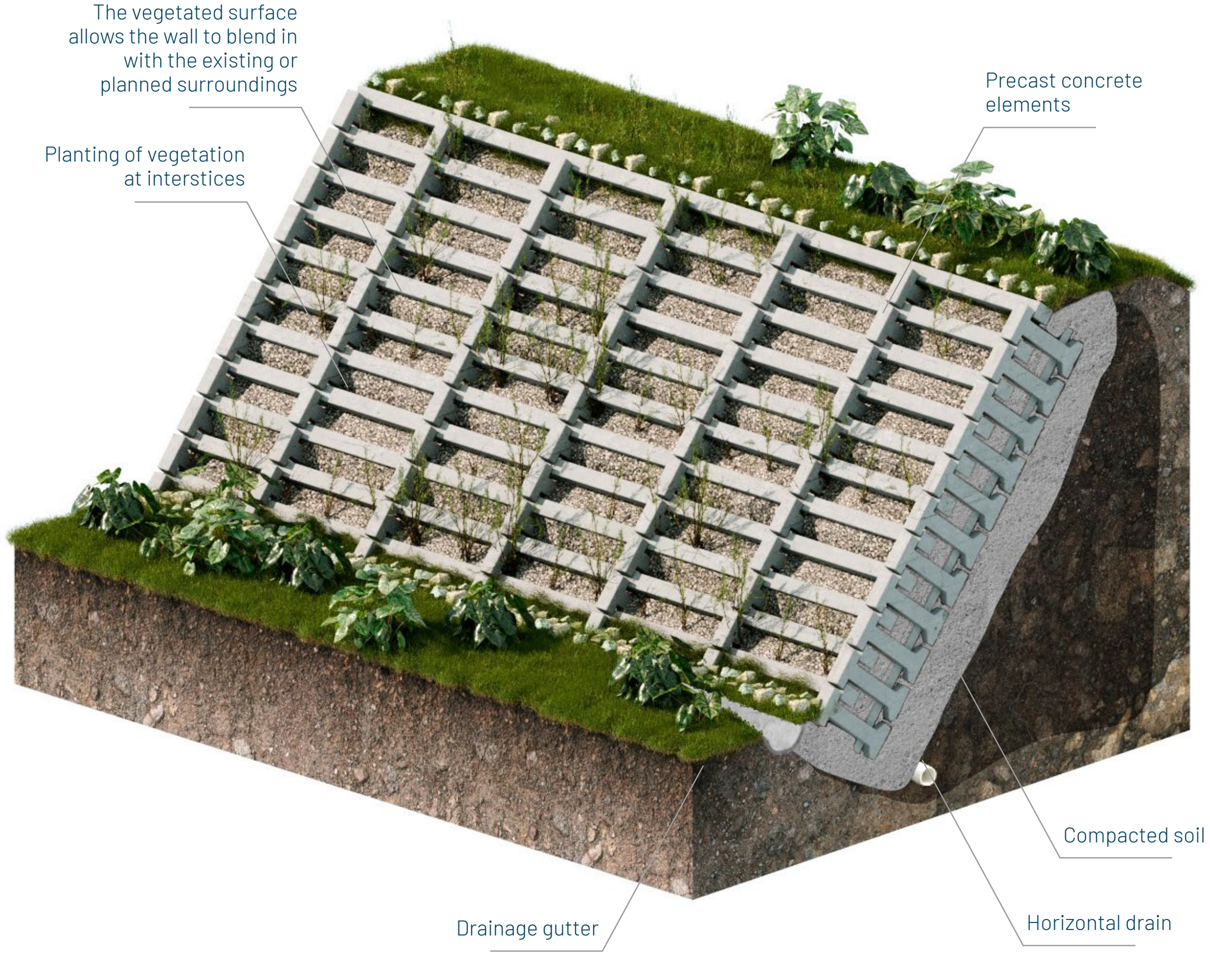


Figure 60 Prefabricated cribwall with vegetation (Source: Guajava).

The prefabricated cribwall with vegetation is generally used on slopes, especially because of its high resistance. Its structure can be single or double and is made of prefabricated concrete elements.

During construction, the elements are filled with granular material and rooted plants can be planted in the gaps – using the vegetation strip method – with vegetable soil.

TECHNICAL PARAMETERS TO BE CONSIDERED WHEN CHOOSING:

STRATEGIC LOCATION:

On steep slopes requiring consolidation.

TERRAIN CHARACTERISTICS:

this solution is mainly used on slopes, and can even be used on steeper embankments, as its structure better supports the contained material with the railing and vegetation.

HYDRAULICS:

Allowable flow velocity limits:
this solution is not suitable for riverbanks. The concrete structure supports high-velocity surface run-off, but the fill material can be carried away, so it is recommended for velocities of up to 3.0 m/s for precast concrete elements.

GEOMETRY:

Allowed height:
this containment structure is suitable for slopes that are higher than their base level, due to the executive method of combining the weave of the prefabricated structure with the planted vegetation, which guarantees a tolerable safety factor of up to 20 m in height.

Slope:
due to the type of structure and material, this solution is more suitable for sites with steeper slopes of up to 70 degrees.

TYPE OF VEGETATION:

the vegetation used in this solution creates a reinforcing effect on the terrain, noticeable as the plants' root systems develop. This contributes to the initial stabilisation provided by the prefabricated structure. Grasses, vines and also shrubs are suitable for this purpose.

Other technical data:

The development of the plants' root systems will create an armouring effect in the soil, contributing to the drainage and stabilisation of the system.

The beams and columns must be interconnected in such a way as to form a stable and resistant structure, arranged sub-horizontally and longitudinally in relation to the embankment.

Between the layers, the filling should be made of compacted soil or granular material (such as crushed stone and sand), which can be obtained from the slopes during construction.

MATERIALS REQUIRED:

Crossbeams, beams and stakes:

these precast elements are structural and ensure the stability of the structure. The use of vegetation in the solution consolidates the stability of the containment by forming roots. These elements must be interconnected to form a stable, resistant structure in the shape of a 'bonfire'.

Drainage pipes:

the structure must include drainage pipes to drain rainwater and prevent soil erosion.

Local vegetable soil:

between the layers, compacted soil must be applied. This can be material taken from adjacent areas during the preparation of the containment.

Vegetation:

initially, plants have no structural function. However, after development, they take on a structural support role through their root system. The deep roots of plants also create channels through which rainwater infiltrates the soil. Plant species suitable for moist soils are ideal. Consider local climatic conditions when choosing species.

MAINTENANCE:

Verification of structural integrity: it is important to regularly check the structural integrity of the cribwall structure to ensure that it is in good condition and shows no signs of failure, such as cracks or breaks. If necessary, preventive maintenance should be carried out on the structure.

COST OF IMPLEMENTATION:

Variable[38] between USD$ 200.00 and USD$ 400.00 per m^2.

38 According to the height, area, design and configuration of the NbS, materials and labor.

POSSIBLE CHALLENGES IN PLANNING AND EXECUTION:

Suitable vegetation:

availability of plant species (autochthonous) suitable for wet soils.

Qualification of technicians:

the availability on the market of trained technicians with the specific knowledge to correctly analyse all the information and then monitor its execution.

- Prefabricated cribwall with vegetation -

Figure 61 Prefabricated cribwall with vegetation (Source: United Crib Blocks Constructions).

- Gabion walls with vegetation -

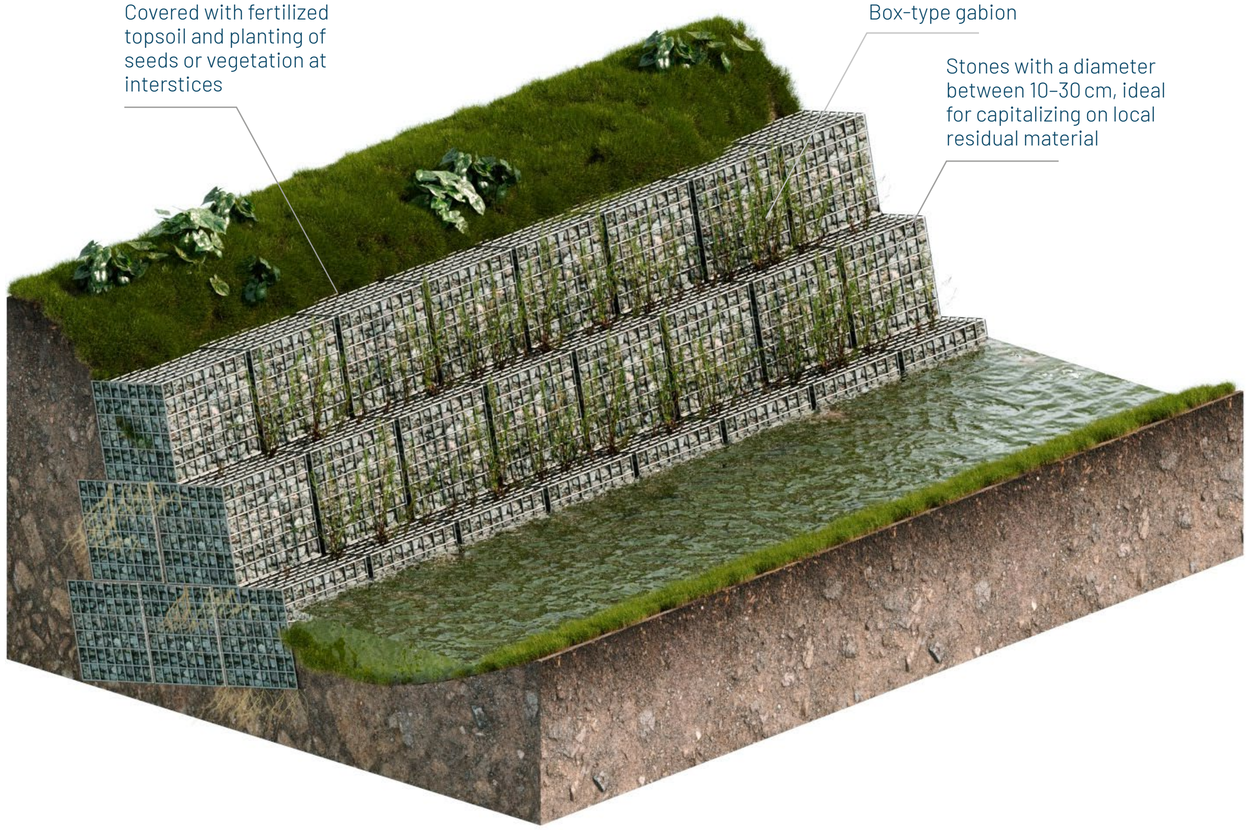


Figure 62 Gabion walls with vegetation (Source: Guajava).

Gabion walls with vegetation are containment structures made up of large, prefabricated metal cages in any shape, which are filled with stone blocks. Plant stakes and rooted plants in composted vegetable soil are placed between each element.

In longitudinal structures, they protect the margins, while in transverse structures, they stabilise the base of unstable slopes.

TECHNICAL PARAMETERS TO BE CONSIDERED WHEN CHOOSING:

STRATEGIC LOCATION:

Mainly for protecting margins or stabilising the bases of unstable slopes.

TERRAIN CHARACTERISTICS:

this solution is mainly used on slopes and riverbanks, especially on steeper embankments or vertical riverbanks, as its structure better supports the soil to be contained by the gabion and the vegetation.

HYDRAULICS:

Allowable flow velocity limits:
for surface run-off, the metal structure and stone filling support high flow velocities, but the filling material and the prepared vegetable soil can be carried away when the velocity exceeds 2.5 m/s.

GEOMETRY:

Allowed height:
this containment structure is suitable for slopes that are higher than their base level, due to the executive method of combining the weave of the prefabricated structure with planted vegetation. This guarantees a tolerable safety factor of up to 20 m in height.

Slope:
due to the type of structure and material, this solution is more suitable for sites with steeper slopes of up to 70 degrees of the slope or embankment.

TYPE OF VEGETATION:

climbing plant species are planted together with a favourable substrate during the construction of the wall to help with surface run-off and infiltration. Their roots grow through the voids left by the stones, forming a kind of weave that helps to support the wall and prevent material from passing through from behind the retaining wall.

Execution:
quick and simple, providing an immediate containment effect. It allows the use of stones found on site, reducing execution costs.

Permeable solution:
allows water to pass between the stones, so there is no need for auxiliary drainage[39].

MATERIALS REQUIRED:

Wire mesh:
used to contain the filling and give shape to the gabion device, commonly used in cubic shapes with edges of 0.5 m or 1 m.

Stones:
you can use hand stones or grave, which is more common, l to fill in the meshes. Pay attention to the grain size of the stones used, as they should be larger than the openings in the wire mesh.

Drainage pipes:
the structure must include drainage pipes to drain rainwater and prevent soil erosion.

Vegetation:
initially, plants have no structural function. However, after development, they take on a structural support role through their root system. The deep roots of plants also create channels through which rainwater infiltrates the soil. Plant species suitable for moist soils are ideal. Consider local climatic conditions when choosing species.

MAINTENANCE:

It will require maintenance to ensure the safety of the structure, especially after the movement of earth near the installed containment.

COST OF IMPLEMENTATION:

Variable[40] between USD$ 40.00 and USD$ 60.00 per m^2.

39 The need to include auxiliary drainage must be assessed by the technician responsible for the work.
40 According to the area, design and configuration of the NbS, materials and labor.

POSSIBLE CHALLENGES IN PLANNING AND EXECUTION:

Execution:
the gabion wall with vegetation is easy to implement as it is made up of prefabricated elements.

- Gabion walls with vegetation -

Figure 63 Gabion wall with spontaneous vegetation, Goiânia/GO (Collection of Belgo Soluções Geotech, photo: Flávio Fontes da Cruz, 2024).

- Flat gabions – mattress -

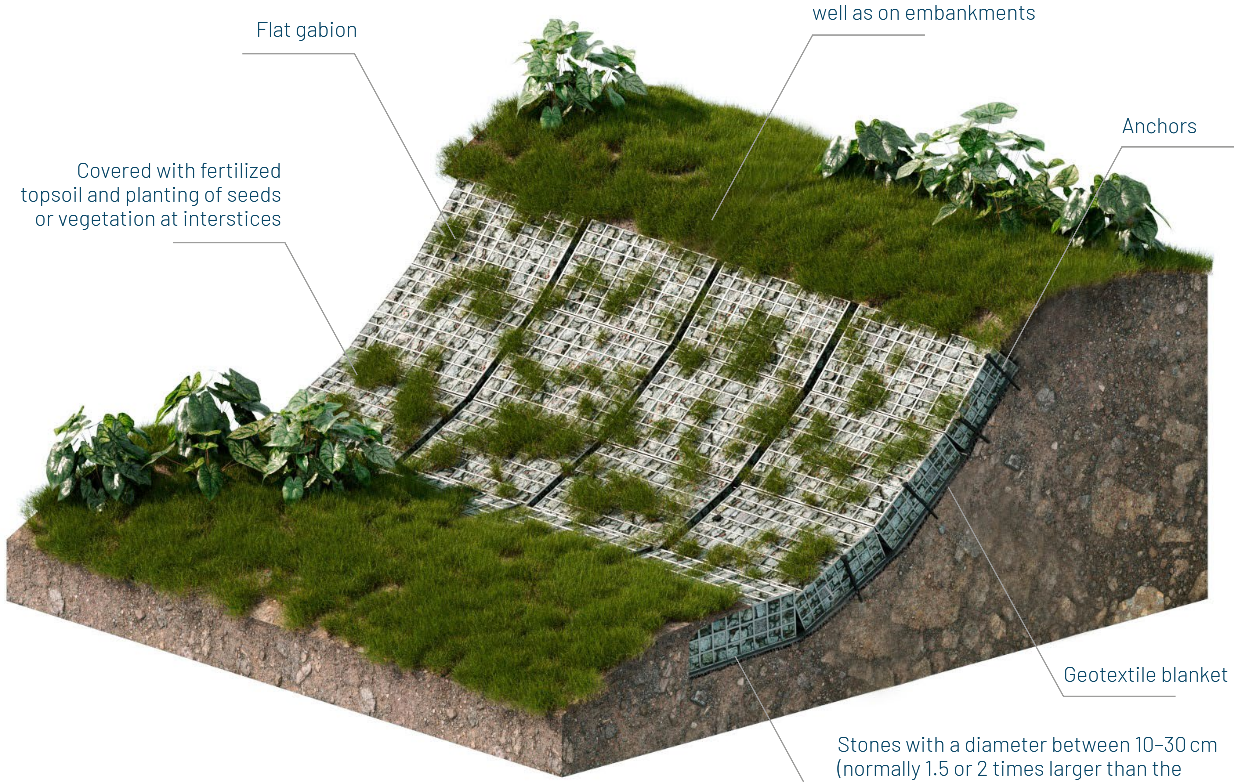


Figure 64 Flat gabions (Source: Guajava).

Flat gabions are installed on rocky slopes with stones and/or little vegetation. The aim is to encourage extensive vegetation growth by means of rectangular metal gabions that must be anchored. The upper and lower metal meshes are sewn together (like a metal mesh mattress) and filled with stones, ideally obtained on site, to reduce costs and transportation of materials. Where it comes into contact with the soil, the gabion plane should be wrapped in geotextile to act as a filter and prevent the filling from being carried away.

To help the vegetation cover develop more quickly, it is recommended that fertilised topsoil and planting seeds of species suitable for the site are used. Once developed, the vegetation will create a mesh through its roots, strengthening the protection of the slope.

TECHNICAL PARAMETERS TO BE CONSIDERED WHEN CHOOSING:

STRATEGIC LOCATION:

On slopes where vegetation needs to be included and on river margins.

TERRAIN CHARACTERISTICS:

this solution is mainly used on embankments and riverbanks, even on steep slopes of up to 70 degrees, because its structure better supports the material to be contained with the gabion and vegetation.

HYDRAULICS:

Allowed flow velocity limits:
or surface run-off, the metal structure and stone filling support high water flow velocities, but the filling material and the preparation of the vegetable soil can be carried away when the velocities exceed 2.5 m/s.

GEOMETRY:

Allowed height:
this containment structure is suitable for slopes that are higher than their base level, due to the executive method of combining the metal mesh and the planted vegetation, which guarantees a tolerable safety factor up to a height of 5 m.

Slope:
due to the type of structure and material, this solution is more suitable for sites with greater heights and slopes, which can reach 70 degrees of inclination of the embankment or hillside.

TYPE OF VEGETATION:

species of grass or vines are planted, together with a suitable substrate, during the construction of the wall to help with surface run-off. Their roots grow through the voids left by the stones, forming a kind of web that helps to support the wall and prevent material from passing through from behind the containment.

Other technical data:
it differs from the box gabion in that it has a large surface area and small thickness, making it ideal for covering and protection, but not for containment.

The flexibility of the material allows it to be installed in soft soil with a low load-bearing capacity, without the risk of breakage.

The use of flat gabions for covering does not prevent water percolating between the river and the ground, thus maintaining the level of the existing water table level.

When in contact with water, the wire is susceptible to corrosion, a layer of galvanisation and polymer is needed to extend the life of the material.

MATERIALS REQUIRED:

Wire mesh:
used to contain the filling and give shape to the gabion device, commonly used in mantle formats with a thickness of between 10 cm and 30 cm;

Stones:
you can use hand stones or, more commonly, gravel to fill in the meshes;

Vegetation:
initially, plants have no structural function. However, after development, they take on a structural support role through their root system. The deep roots of plants also create channels through which rainwater infiltrates the soil. Plant species suitable for moist soils are ideal. Consider local climatic conditions when choosing species.

Geotextile:
to perform its filtering function, the non-woven type must be used. The fibres in this product are arranged in a random orientation, which prevents water from passing freely through the geosynthetic. Geotextiles are easy to install, low cost, small in thickness and enable quality control with adequate hydraulic properties. These characteristics endorse the use of this material in filtering systems.

MAINTENANCE:

They require maintenance when the structure breaks down. The time it takes for this to happen depends on factors such as the presence of water and salinity, abrasion caused by wind and/or water, exposure to contaminants, and soil resistivity.

COST OF IMPLEMENTATION:

Variable[41] between USD$ 40.00 and USD$ 60.00 per m^2.

POSSIBLE CHALLENGES IN PLANNING AND EXECUTION:

Execution:
flat gabions are easy to implement, as they are made up of prefabricated elements.

- Flat gabions – mattress -

Figure 65 Flat gabion in Presidente Epitácio/SP (Collection of Belgo Soluções Geotech, photo: Flávio Fontes da Cruz, 2024).

41 According to the area, design and configuration of the NbS, materials and labor.

- Green stapled soil -

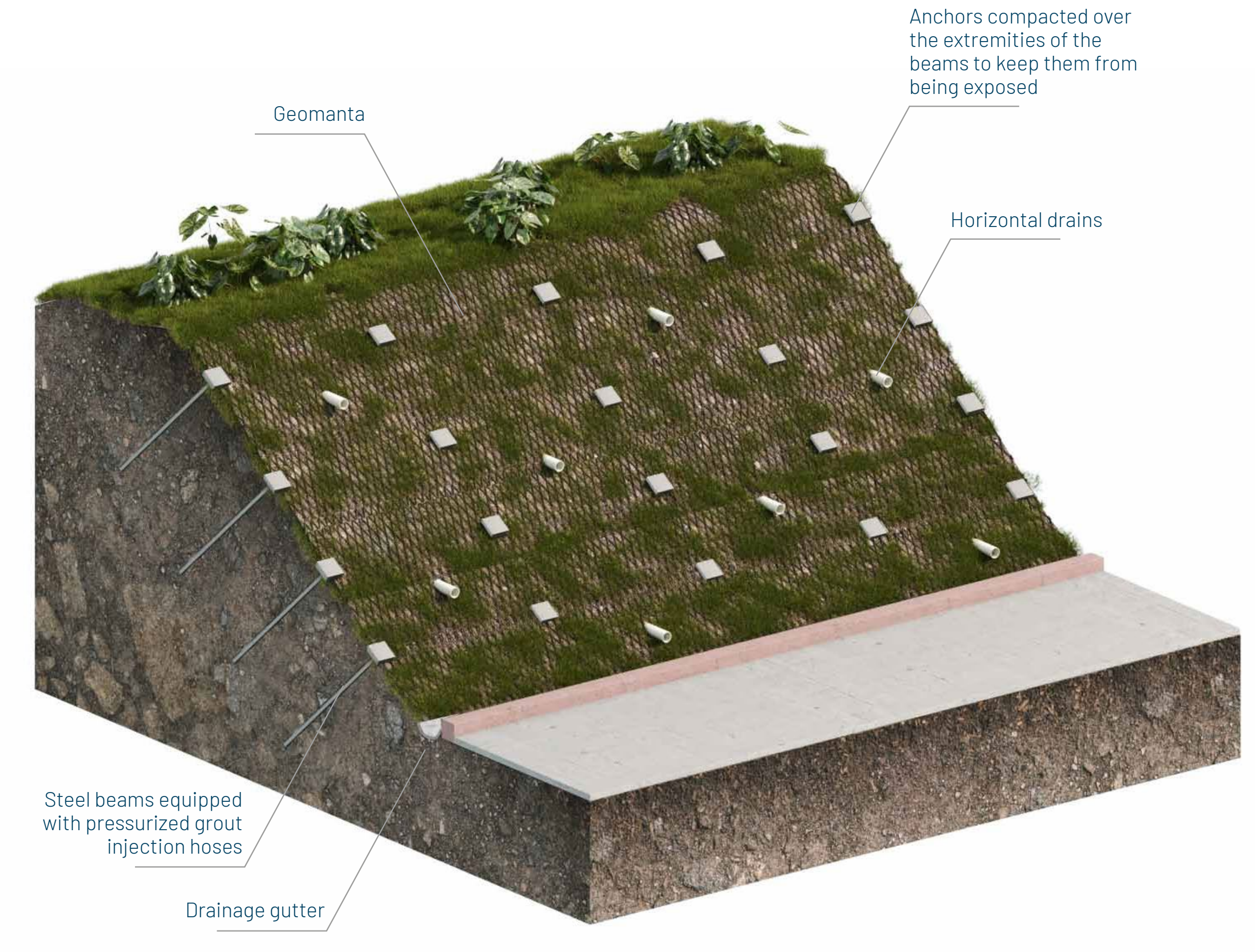


Figure 66 Green stapled soil.

Green stapled soil containments techniques are used to stabilise embankments and hillsides, and to prevent landslides. They are made up of a series of elements, such as grass, plants, mesh and staples. They are installed in the ground by injecting cement grout to form a grid-like structure that helps to contain the local soil.

Green stapled soil containment is a more natural and landscaped option than other, more conventional embankment stabilisation techniques, such as concrete walls or barriers. They can also be more effective in areas with unstable soils, as the vegetation helps to absorb water, and the roots create a mesh on the surface that can help prevent further landslides.

TECHNICAL PARAMETERS TO BE CONSIDERED WHEN CHOOSING:

STRATEGIC LOCATION:

Hillsides or embankments with high slopes of up to 70 degrees, except in places where there is an outcropping of bedrock.

TERRAIN CHARACTERISTICS:

green stapled soil containments are highly adaptable to the type of terrain on which they are installed. However, they are not effective or cost-effective on riverbanks due to the difficulty of executing the installation process involving machinery (e.g. drilling equipment to install the staples, backhoes to move materials, scaffolding) and personnel on flooded and steep riverbanks, making them a less attractive alternative in these cases.

HYDRAULICS:

Allowable flow velocity limits:
the staple mesh and surface grid material are resistant to incident water flows on the NbS, but the mesh filling (soil, sand and stones) cannot withstand high-speed water flows, as this causes the filling material to be carried away. Therefore, it is suitable for speeds of up to 2.5 m/s.

GEOMETRY:

Allowed height:
it is used for embankments that are higher than the level of their footing and can be installed up to 20 m high. However, it is less effective and cost-efficient on lower sites, as the cost of mobilising personnel and equipment is the same for small or large areas.

Slope:
due to the flexibility of this containment structure, it is suitable for both softer and steeper terrains, with slopes of up to 70 degrees.

TYPE OF VEGETATION:

grasses or creepers absorb water that falls on the ground, and their roots create a surface mesh that can help prevent further landslides.

MATERIALS REQUIRED:

Staples:
these are usually made of metal or plastic and are fixed into the ground using mechanised drilling.

Mesh:
the mantle that covers the embankment face can be made of wire mesh or geotextile, so that the system as a whole works to stabilise the site.

Vegetation:
initially, plants have no structural function. However, after development, they take on a structural support role through their root system. The deep roots of plants also create channels through which rainwater infiltrates the soil. Plant species that are suitable for moist soils are ideal. Consider local climatic conditions when choosing species.

MAINTENANCE:

Maintenance care should focus on the structure. It is recommended that a pull-out test is carried out on the staples to ensure that they have been installed in accordance with the design. Repairs should be carried out immediately when there are any gaps in the mesh or damage.

COST OF IMPLEMENTATION:

Variable[42] between USD$ 160.00 and USD$ 200.00 per m^2.

42 According to the area, design and configuration of the NbS, materials and labor.

POSSIBLE CHALLENGES IN PLANNING AND EXECUTION:

Suitable vegetation:
availability of plant species suitable for wet soils.

Qualification of technicians:
the availability on the market of trained technicians with the specific knowledge to correctly analyse all the information and then monitor its execution.

- Green stapled soil -

Figure 67 Nailed soil at Cidade Universitária Armando Salles de Oliveira, University of São Paulo (photo: Sarah Daher, 2024).

- Geocell containment -

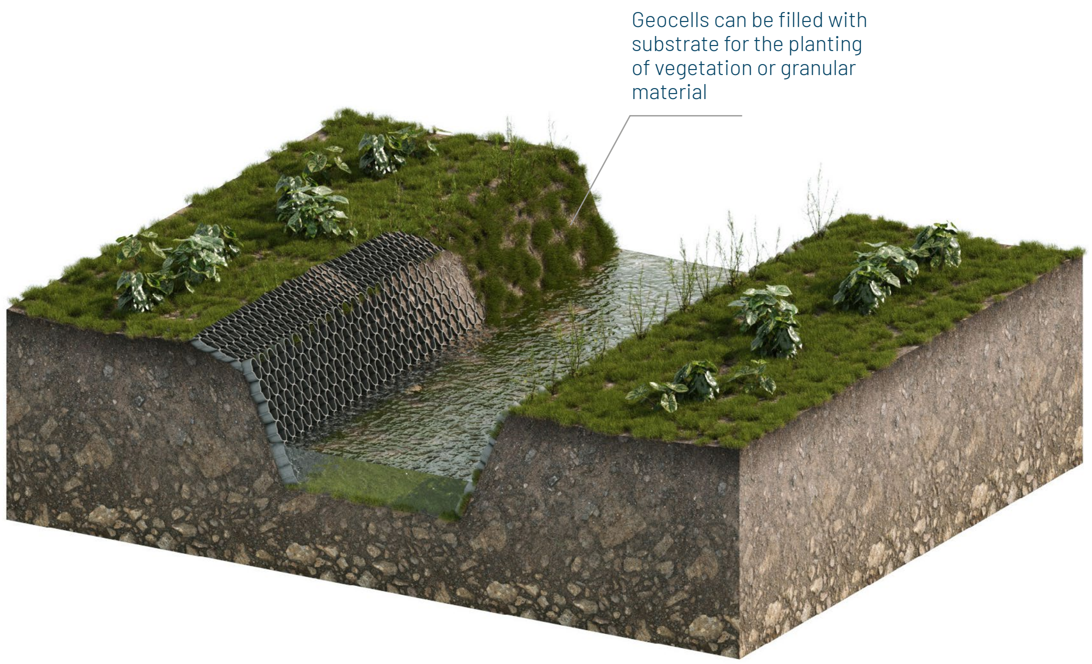


Figure 68 Surface geocell containment in embankment (Source: Guajava, 2023).

Figure 69 Structural geocell containment in embankment (Source: Guajava, 2023).

Geocell containment is a technique used to stabilise embankments and riverbanks and prevent landslides. It is made up of a series of elements, including geocells (a beehive-shaped layer of geosynthetic mesh), sand, stones, soil, staples and plants. The geocell mantle can be stretched over the are to be contained and anchored to the ground with staples or bolts to hold the geo-synthetic mesh in place. Alternatively, it can be laid in overlapping layers to create a structure embedded in the embankment, with each layer supporting the one above until the required height is reached.

Geocells are usually made of HDPE or polyester, and their mesh has a hexagonal cell shape, although there are other geometric shapes. The geocells are placed on the ground in layers to form a kind of 'mesh' that helps to contain the local soil. The mesh can be of variable height, allowing the cells to be filled. This can be sand, soil or gravel, which is then added on top of the geocells to fill the spaces between them and form a solid surface. Plants can be inserted into the surface to help stabilise the soil and improve the appearance of the embankment.

TECHNICAL PARAMETERS TO BE CONSIDERED WHEN CHOOSING:

STRATEGIC LOCATION:

Embankments with high slopes, riverbanks and areas of instability.

TERRAIN CHARACTERISTICS:

embankment containments with geocells are an effective option for stabilising steep embankments and riverbanks with unstable soils. They are lightweight and easy to transport and install, and can be adapted to different types of terrain and local conditions.

HYDRAULICS:

Allowable flow velocity limits:
the mesh material is resistant to water flows incident on the NbS, but the filling of the cells (soil, sand, stones) cannot withstand high-speed water flows, as this causes the filling material to be carried away. Therefore, it is suitable for speeds of up to 2.5 m/s.

GEOMETRY:

Allowed height:
due to the flexibility of this containment structure, it is suitable for embankments that are higher than the level of their footing, as well as for deeper riverbanks. They can be built up to 20 m high.

Slope:
due to the flexibility of this containment structure, it is suitable for both softer and steeper embankments. However, its effectiveness and cost-effectiveness decrease when the slope exceeds 70 degrees, making it a less attractive alternative in these cases.

TYPE OF VEGETATION:

the vegetation planted on the surface creates a mesh-like structure with branches and roots that help drain surface water and carry away materials.

Other technical data:
it can be carried out in overlapping layers or on the surface of embankments to provide containment;

The material to be chosen for filling may vary according to the location.

MATERIALS REQUIRED:

Geocell mantle:
this geotextile serves a structural function in this NbS, containing the filling with a thickness between 5 cm and 30 cm.

Anchor bolts for fixing the geocell mantle:
they are usually made of metal or plastic and are fixed in the ground through perforations between 20 cm and 1 m. They serve as part of the geocell's support system.

Material for filling cells:
a layer used to fill the geocells, usually with gravel no. 3, but it can also be a plant substrate, sand or compacted soil.

Vegetation:
initially, plants have no structural function. However, after development, they take on a structural support role through their root system. The deep roots of plants also create channels through which rainwater infiltrates the soil.

MAINTENANCE:

Although geocells have a long lifespan and are resistant to damage caused by water, wind and bad weather, it is recommended to repair the membrane that any flaws in the stitching or in fixing it to the ground are repaired to maintain the functional capacity of the NbS.

COST OF IMPLEMENTATION:

Variable[43] between USD$ 100.00 and USD$ 140.00 per m^2.

POSSIBLE CHALLENGES IN PLANNING AND EXECUTION:

Installation:
the installation of geocells requires expertise, equipment and a qualified workforce to ensure that they are positioned correctly.

Drainage:
it is important to ensure that the surface drainage of the embankment, in particular, is functioning properly to prevent water accumulation and soil and filling erosion.

Figure 70 Geocell for surface erosion control at Cidade Universitária Armando Salles de Oliveira, University of São Paulo (Project by Paulo Pellegrino, Daniel Falconi, Silvio Motta, and Stefanie Gonzaga; photo: Daniel Falconi, 2023).

43 According to the area, design and configuration of the NbS, materials and labor.


Orla do Piratininga Park, Niterói, Rio de Janeiro (Photo: Dionê Maria Marinho Castro, 2023).

Step 3 Defining plant species for NbS

When using NbS in open space projects, it is extremely important to choose the right plant species, as the specific characteristics of the vegetation directly impact the efficiency and effectiveness of the different systems.

The main expected attributes of vegetation are the ability to bio-retain water, absorb nutrients, phytoremediate pollutants, stabilise the soil and sustain the soil layer in the long term. However, in projects involving public spaces such as linear and riverine parks, the ability of vegetation to provide a beneficial and aesthetically pleasing and beneficial landscape experience become quite relevant, such as: the ability, contribute to ecological balance, and preserve biodiversity, especially considering the connectivity of green areas within ecological corridors, becomes quite relevant.

The main attributes expected of vegetation are:

- **the ability to bioretain water;**
- **absorb nutrients;**
- **phytoremediate pollutants;**
- **stabilize the soil and sustain the soil layer in the long term.**

The general criteria for choosing vegetation are related to the following factors:

Climate: the right vegetation for each NbS varies according to the region in which they are installed. The choice should consider regional climatic conditions and how resilient the species are to humidity, drought and storms. Generally, native species are more resistant to local climatic conditions and perform better.

Soil: the choice of vegetation must take into account the soil layer used for bioretention. For example, in soils with a higher concentration of organic matter will supper a greater variety of species, while soils with rapid drainage (either through subdrainage devices or due to high infiltration rates in native soils with) will support fewer plant options.

Presence of pollutants: the choice of vegetation must take into account the different pollutants in the soil and water. In wetlands in particular, macrophyte species offer important benefits due to their tolerance of eutrophic environments and their high capacity to absorb pollutants. In the implementation of wetlands and filter islands in particular, the choice of vegetation deserves special attention. As these systems are permanently or partially flooded, they require aquatic macrophytes, palustrine plants or plants that can withstand periods of flooding. Aquatic macrophytes play a key ecological role in maintaining these ecosystems. The choice of macrophytes depends on the characteristics of the effluents to be treated and their availability in the region where the wetland will be installed. Therefore, native species adapted to local conditions should be prioritised for optimal performance.

Handling: species that require less maintenance should be prioritised. Emergent macrophytes, for example, can remain in floodplains for long periods without pruning or root zone maintenance. Floating species are easier to remove in surface flow systems, enabling constant biomass management according to plant growth and facilitating greater nutrient removal. When choosing species, priority should be given to those that require low maintenance to minimise the need for mowing, pruning, weeding and irrigation. The use of fertilisers or pesticides should also be avoided.

Size of vegetation: plants of various sizes are used in NbS, but the height of the plants at maturity must be taken into account. For example, the choice of tree species should be made during the design phase of the project, taking into account soil conditions that will allow the trees and their roots to grow healthily over time. If there are existing trees on the site, their roots must be protected from the mineral layers of the NbS to avoid instability.

Visibility: the location of trees must consider the existing infrastructure and respect the necessary setbacks. In facilities with intersections, pedestrian crossings and sidewalks, for example, the maximum height of mature plants should be approximately 60 cm to avoid compromising pedestrian visibility. If they are planted at the back of the installation, the height of the plants can be greater, provided it does not exceed 60 cm from street level. The volume of the crown and branching throughout the tree's life must also be considered to ensure there is adequate headroom on both the sidewalk and the roadside.

Quantity of plants: the density of the planting will vary according to the size of the species and its ability to propagate. It can range from 4 to 8 seedlings per m^2, and in some cases of fast-spreading species such as *Typha domingensis*, planting 2 seedlings per m^2 can be considered in suitable environmental conditions. Planting at an adequate density is important for closing off the system and avoiding maintenance against invasive species.

Economic sustainability: the choice of vegetation should also consider economic sustainability. For example, it is recommended to encourage the cultivation of commercially valuable species, such as fodder for animal feed, species for the production of pharmaceuticals and cosmetic products, and species for the production of fibres for craft or industrial use (e.g. cattail). Commercial floristic species such as strelitzia, anthurium, agapanthus and yellow lily are also recommended (MATOS; MATOS, 2021).

Table 4 summarises the specific characteristics required for each NbS:

Table 4 Vegetation attributes by type of NbS.

NbS	Vegetation attributes
Rain garden Rain bed	• capacity to withstand the expected volume of water expected for the system; • ability to withstand direct exposure to the sun; • resilience to withstand periods of extreme humidity and drought; • being autochthonous (i.e. synergy with local climate, soil and humidity conditions and non-use of fertilisers and chemicals); • low maintenance requirements; • the ability to perform phytoremediation mechanisms.
Bioswales Hydraulic vegetated ladder	• ability to withstand the expected volume of water for the system; • resilience to withstand periods of drought; • high evapotranspiration rate (helps to remove a greater volume of water in a short space of time); • low maintenance requirements; • deep, thick roots with high biomass production and organic matter removal; • ability to perform phytoremediation mechanisms.
Rain terrace Step pool	• be riparian vegetation native to the site; • adapted to soils that are temporarily or permanently wet and susceptible to periodic flooding; • have good water conditions, but no excess water.
Vegetated polder Detention basin Retention basin Infiltration basin Sedimentation basin Amphibious reservoir Wetland Filter island	• be native and adapted to local conditions; • low maintenance requirements; • ability to survive pollution and sediment loads; • the capacity and performance of bioretention and phytoremediation mechanisms; • be macrophytes (either emergent or floating species) or terrestrial species with dense root systems or rhizomes, cultivated by hydroponics.

Many botanical species used in NbS have the potential for bioretention of pollutants and phytoremediation. Tables 5 and 6 show some of these species, which have been identified in studies (PINHEIRO, 2017[44]) and in projects involving NbS in the south-east region of Brazil. This list includes native species, as well as some naturalised and cultivated exotic species, as described in the section *Contribution to biodiversity conservation*.

44 Consulted (PINHEIRO, 2017) and on a technical visit to the Piratininga Waterfront Park project in the city of Niterói/RJ in 2022.

Table 5 Plant species used in the rain garden, rain bed and bioswale.

Plant species used in the rain garden, rain bed and bioswale **Origin:** N (Native) Na (Naturalised) C (Cultivated)				
Scientific name Popular name	Origin	Phytogeographic domain *	Form of life	Potential action
***Dichondra microcalyx* (Hallier f.)** Mouse ear	N	Mata Atlântica, Pampa	Herba-ceous	Bioretention of oil and grease, organic matter, nitrate, nitrite, Fe, Zn, Cu and Cd, and SDT
***Neomarica caerulea* (Ker Gawl.) Sprague** Walking iris	N	Mata Atlântica	Herba-ceous	Bioretention of oil and grease, organic matter, nitrate, nitrite, Fe, Zn, Cu and Cd, and SDT
***Sphagneticola trilobata* (L.) Pruski** Bay Biscayne creeping-oxeye	N	Caatinga, Cerrado, Mata Atlântica, Pampa, Pantanal	Herba-ceous	Bioretention of oil and grease, organic matter, nitrate, nitrite, Fe, Zn, Cu and Cd, and SDT
***Solidago sp* (L)** Showy goldenrod	N	Caatinga, Cerrado, Mata Atlântica, Pampa	Herba-ceous	Phytoremediation of total petroleum hydrocarbons (TPH), solvents, polycyclic aromatic hydrocarbons
***Costus spiralis* (Jacq.) Roscoe** Spiral ginger	N	Amazônia, Caatinga, Cerrado, Mata Atlântica	Herba-ceous	Bioretention of oil and grease, organic matter, nitrate, nitrite, Fe, Zn, Cu and Cd, total dissolved solids
***Heliconia psittacorum* L.f.** Parrot's beak	N	Amazônia, Caatinga, Cerrado, Mata Atlântica e Pantanal	Herba-ceous	Bioretention of oil and grease, organic matter, nitrate, nitrite, Fe, Zn, Cu and Cd, total dissolved solids
***Ctenanthe setosa* (Roscoe) Eichler** Grey star	N	Mata Atlântica	Herba-ceous	Bioretention of oil and grease, organic matter, nitrate, nitrite, Fe, Zn, Cu and Cd, total dissolved solids
Alternanthera brasiliana Large purple alternanthera	N	Amazônia, Caatinga, Cerrado, Mata Atlântica	Herba-ceous semi-erecta	Bioretention of oil and grease, organic matter, nitrate, nitrite, Fe, Zn, Cu and Cd, total dissolved solids
***Festuca* L.** Grass	N	Mata Atlântica, Pampa	Herba-ceous	Phytoremediation of organic compounds, TPH; HPA, BTEX
***Stenotaphrum secundatum* (Walter) Kuntze** St. Augustine grass	N	Caatinga, Mata Atlântica	Herba-ceous	Treatment of organic compounds HTP, HPA
***Axonopus compressus* (Sw.) P. Beauv.** Giant missioneira grass, turf	N	Amazônia, Caatinga, Cerrado, Mata Atlântica	Herba-ceous	Remediation of organic compounds TPH
***Allamanda cathartica* L.** Golden trumpet	N	Amazônia, Cerrado, Mata Atlântica	Shrub Climber	Bioretention of oil and grease, organic matter, nitrate, nitrite, Fe, Zn, Cu and Cd, total dissolved solids
***Senna obtusifolia* (L.) H.S. Irwin & Barneby** Sicklepod	N	Amazônia, Caatinga, Cerrado, Mata Atlântica, Pantanal	Arbusto	Treatment of TPH
***Galinsoga parviflora* Cav.** Guasca	Na	Mata Atlântica	Herba-ceous	Bioretention of oil and grease, organic matter, nitrate, nitrite, Fe, Zn, Cu and Cd, total dissolved solids
***Vertivera zizanioides* (L.) Nash** Vertiver	Na	Amazônia, Cerrado, Mata Atlântica	Herba-ceous	Phytoremediation of metals Al, Mn, Mg, As, Cd, Cr, Ni, Cu, Pb, Hg, Se, Zn, pesticides; HTP; and explosives
***Brassica juncea* (L.) Czern.** Mustard greens	Na	Mata Atlântica	Herba-ceous	Treatment of HPAs; As; Cu, Cd, Cr (VI), Ni, Zn; Ni; Se; Hg; inorganic compounds
***Hemerocalis x hybrida* Bergmans** Daylily hybrids	C	–	Herba-ceous	Bioretention of oil and grease, organic matter, nitrate, nitrite, Fe, Zn, Cu and Cd, and SDT Phytoremediation of petrole-um hydrocarbons
***Zea mays* L.** Corn	C	–	Herba-ceous	Treatment for TPH; explo-sives; pesticides; and Cd
***Alocasia macrorrhizos* (L.) G. Don** Giant Taro	C	–	Herba-ceous	Bioretention of oil and grease, organic matter, nitrate, nitrite, Fe, Zn, Cu and Cd, and SDT
***Dietes bicolor* Sweet ex klatt** African iris	C	–	Herba-ceous	Bioretention of oil and grease, organic matter, nitrate, nitrite, Fe, Zn, Cu and Cd, and SDT
***Dianella ensifolia* L. DC** Harebell	C	–	Herba-ceous	Bioretention of oil and grease, organic matter, nitrate, nitrite, Fe, Zn, Cu and Cd, and SDT

With information from Pinheiro, M. B., 2017 and species origin data* from the FLORA E FUNGA DO BRASIL database (JARDIM BOTÂNICO DO RIO DE JANEIRO, 2023). Available at: http://floradobrasil.jbrj.gov.br/. Accessed on: 4 jan. 2023.

Table 6 Plant species used in wetlands.

Plant species used in wetlands

(Detention basin, retention basin, infiltration basin, sedimentation basin, amphibious reservoir, wetlands, filter islands)

Scientific name Popular name	Origin	Phytogeographic domain*	Form of life	Potential action in the environment
Ceratophyllum demersum L Hornwort	N	Amazônia, Mata Atlântica, Pampa, Pantanal	Submersed macro-phyte	Treatment of metals Cd, As and Ni; Fe, Zn, Mn, Ni, Pb and Cd, (DBO), ammonia, nitrate and P; N and P; pharmaceuticals; explo-sives; 137Cs, 60Co, 32P, 134Cs, 89Sr; organophosphorus and organochlorine compounds, chlorobenzenes
***Azolla filiculoides** Lam.* Water fern	N	Amazônia, Caatinga, Cerrado, Mata Atlântica, Pantanal	Floating macro-phyte	Treatment of Pb; Hg; Cr and As
***Salvinia minima* Baker** Salvinia minima	N	Amazônia, Cerrado, Mata Atlântica, Pantanal	Floating fern	Treatment of Pb; and N and P from eutrophized environment
***Eichhornia crassipes* (Mart.) Solms** Common water hyacinth	N	Amazônia, Caatinga, Cerrado, Mata Atlântica, Pampa, Pantanal	Floating macro-phyte	Phytoremediation of nutrients N and P; metals Pb, As, Hg, Zn, Se, Cr, Cd, Ni, Cu; heavy metals, organic and inorganic compounds (ammonia, nitrate and phospho-rus), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), turbidity and industrial residues; Hydrocarbons; Cr, Cu, Cd, Ni, Zn, Hg
***Myriophyllum aquaticum* (Vell.) Verdec** Parrot's feather	N	Cerrado, Mata Atlântica, Pampa, Pantanal	Rooted submersed macro-phyte	Treatment of organic com-pounds, explosives; radionu-clides 137Cs, 60Co and 54Mn
***Pistia stratiotes* L.** Water lettuce	N	Amazônia, Caatinga, Cerrado, Mata Atlântica, Pantanal	Floating macro-phyte	Treatment of metals As, Cd, Cu, Ni, Zn, Pb, Cr, Mn, aromatic organic compounds and nitrate; antibiotics
***Potamogeton* L.** Potamogeton	N	Caatinga (stricto sensu), Cerrado (lato sensu), Floresta Estacional Semide-cidual, Restinga	Rooted submersed macro-phyte	Phytoremediation of organochlo-rines and explosives; pesticides
***Typha latifolia* L** Bulrush	N	Amazônia, Mata Atlântica	Emerging macro-phyte	Phytoremediation in the treat-ment of metals Zn, Pb, As and Cd; As, Zn, Cu and Ni; in the removal of organic compounds, DBO and DQO; treatment of effluents from the textile industry; explosives; and has the capacity to remove pesticides, explosives and pharmaceuticals.

Plant species used in wetlands

(Detention basin, retention basin, infiltration basin, sedimentation basin, amphibious reservoir, wetlands, filter islands)

Scientific name Popular name	Origin	Phytogeographic domain*	Form of life	Potential action in the environment
Typha domingensis Pres. Southern cattail	N	Amazônia, Caatinga, Cerrado, Mata Atlântica, Pampa, Pantanal	Emerging macro-phyte	Treatment of metals Cr, Ni, Zn and P; heavy metals, Total Suspended Solids (TSS), DBO; Kjedahl Nitrogen, Al, Fe, Zn and Pb
Typha angustifolia L. Bulrush	N	Cerrado, Mata Atlântica	Emerging macro-phyte	Treatment of DBO, TDS and metals Pb, Mn, Zn and Cu; and wastewater treatment
Bolboschoenus robustus Sturdy bulrush	N	Mata Atlântica, Pampa	Aquatic macro-phyte	Treatment of Total Petroleum Hydrocarbons (TPH). Note: seeds serve as food for aquatic birds, as well as shelter for crabs and for the reproduction of ducks.
***Thalia geniculata* L.** Bent alligator-flag	N	Amazônia, Caatinga, Cerrado, Mata Atlântica, Pampa, Pantanal	Aquatic macro-phyte	Bioretention of Fe, Mn, Cd, Ni, Pb, Cu, Mg
***Canna indica* L.** Indian shot	N	Amazônia, Caatinga, Cerrado, Mata Atlântica, Pampa, Pantanal	Herba-ceous	–
Pontederia cordata Pickerelweed	N	Amazônia, Caatinga, Cerrado, Mata Atlântica, Pampa, Pantanal	Aquatic	–
Sagittaria montevidensis Giant arrowhead	N	Amazônia, Cerrado, Mata Atlântica, Pampa	Aquatic	Phytoremediation of Cu
***Cyperus papyrus* L** Paper reed	Na	Amazônia, Caatinga, Cerrado, Mata Atlântica, Pampa, Pantanal	Aquatic	–

With information from Pinheiro, M. B., 2017 and species origin data* from the FLORA E FUNGA DO BRASIL database (JARDIM BOTÂNICO DO RIO DE JANEIRO, 2023). Available at: http://floradobrasil.jbrj.gov.br/. Accessed on: 4 jan. 2023.

It is particularly important to introduce species that help combat erosion and contribute to the recovery of riparian forest on embankments and bordering watercourses. There is a wide variety of native species are available for this ecological restoration work. For example, the São Paulo state government has compiled a list of over 2,951 species of plant life in all forms (BARBOSA, L. M. et al., 2017), with tree and shrub species being particularly well-suited to producing seedlings.

Ecological adequacy in public parks and gardens

As well as contributing to NbS, the vegetation in parks and public spaces plays other roles, such as structuring the landscape, providing ecosystem services that contribute to human well-being, and are of symbolic and cultural importance, and contributing to biodiversity conservation by providing shelter and a source of food for fauna.

Due to the specificities and ecological complexities of each region, the choice of species for park design should always be informed by the technical expertise of experienced landscapers, forest engineers, botanists and ecologists. Considering the dynamic interaction between species, park vegetation should be the subject of continuous study and monitoring to inform management decisions and new plantings.

From a systemic ecological perspective, three interconnected criteria influence the choice of vegetation in park landscaping projects:

Promoting the well-being of the population and environmental education

The vegetation in parks directly promotes the well-being of visitors, whether through the thermal comfort provided by the shade of the tree canopy, the aromas, or the aesthetic and compositional details of the landscape, not to mention the symbolic aspects that are important for a particular region or culture. To maximise these benefits, park vegetation should be chosen with the possibility of socio-educational activities in mind, such as sensory or medicinal gardens, pollinator gardens (butterfly gardens and meliponariums) and birdwatching tours.

Contribution to biodiversity conservation

The biome of origin is the most important factor when selecting species for landscaping projects in parks. Native species should be favoured over exotic ones, as they offer advantages from both ecological and economic perspectives:

Advantages of native species:
they contribute to the conservation of biodiversity by providing food and shelter for fauna; they are easy to access and reproduce in municipal plant nurseries; they are more adaptable to the climate and soil conditions; they have a better metabolic development; they produce healthier flowers and fruit.

Disadvantages of exotic species:
they are susceptible to uncontrolled spread; they threaten native species in the biome; they require more effort (and cost) to control; they are more susceptible to diseases and pests. According to the Convention on Biological Diversity, an exotic species is one that is found outside its natural distribution area and is not native to a biome. Exotic species can be classified as 'naturalised', 'cultivated' or 'invasive'. 'Invasive' species have a high reproduction rate and threaten ecosystems, habitats and native species. They reproduce uncontrollably, competing with native species and threatening their existence. There are also 'naturalised' exotic species that reproduce naturally in a new biome, but without threatening the survival of native species, and 'cultivated' species that have been reproduced with human help, outside their natural distribution area.

It should be noted that not all exotic species have the potential to cause ecological instability or threaten the conservation of native biomes. However, **any exotic species in a conservation area requires constant and adequate control and management to prevent it from becoming invasive.**

Several Brazilian municipalities and their conservation units compile lists of invasive exotic species in their areas, which are updated periodically and should be referred to by the teams responsible for park projects and management. In addition to threatening native biomes, 'invasives' incur significant costs for the public for the necessary biological control measures in conservation units. The best-known examples are the Leucena (*Leucaena leucocephal*), originally from Central America, and the Australian Seafortia Palm (*Archontophoenix cunninghamiana*). In the absence of a unified national plan for controlling invasive species, many Brazilian municipalities and their conservation units have conducted surveys of invasive exotic species and developed management and suppression strategies.

Attracting pollinating fauna

Pollinators and pollination provide ecosystem services (POTTS et al., 2016; COSTANZA et al., 2017) with regulatory functions, such as maintaining the genetic variability of native plant populations that sustain biodiversity and ecosystem functions. They also provide food, such as fruit, seeds and honey, and promote cultural values related to traditional knowledge.

In open spaces intended for public use, such as parks and gardens, botanical species that bear flowers and fruits attractive to pollinating fauna, such as bees, birds, butterflies, beetles and bats, deserve special attention, due to their contribution to biodiversity conservation (MMA, 2006) and the beneficial experiences they can provide to the visiting public, such as contemplation and sensory engagement with nature and its processes (MORAES, 2020).

Pollinator-friendly landscaping projects can create spaces that function as 'living classrooms' - known as 'pollinator gardens' - which are ideal scenarios for environmental education and biodiversity observation and conservation activities.

Species for attracting pollinators

Listed below are some species selected from studies of green areas in terms of the interaction between flora, fauna and pollination in the southeast Brazilian region (GOBATTO; PEREIRA; CHAGAS, 2021). They are identified by their scientific name, botanical family and common name, and classified according to their origin (native, cultivated or naturalised), life form (herbaceous, shrub, arboreal, palmate, aquatic or macrophyte), botanical characteristics (size, light requirements and flowering period), landscape uses and type of visiting pollinators.

Herbaceous

ORIGIN:
N (Native)
Na (Naturalised)
C (Cultivated)
SIZE:
A (Height at adult stage) × D (Diameter).



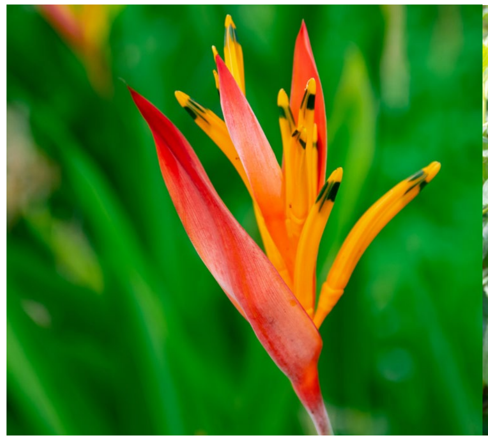


Nº	01	02	03	04	05
Scientific name [Botanical family]	Pachystachys lutea Nees [Acanthaceae]	Ruellia brevifolia (Pohl) C. Ezcurra [Acanthaceae]	Ruellia makoyana Jacob-Makoy ex Closon [Acanthaceae]	Sphagneticola trilobata (L.) Pruski [Asteraceae]	Bidens sulphurea [Asteraceae]
Common name	Camarão amarelo	Pingo-de-sangue	Planta-veludo	Vedélia; Picão-da-praia	Cosmo amarelo
Origin	N	N	N	N	N
Size (A × D)	1.00 × 0.50	0.70 × 0.50	0.30 × 0.45	0.60 × 0.20	0.80 × 0.30
Light requirement	Full sun Part shade	Full sun Part shade	Part shade	Full sun Part shade	Full sun
Flowering period	Spring Summer	All year	Spring Summer	All year	All year
Landscape uses	Living fence Massifs	Massifs	Massifs	Massifs Embankment covering	Massifs Canter
Polinnator or visitor	Bee Hummingbird	Bee Hummingbird	Bee Hummingbird	Bee Butterfly	Bee Butterfly

Photo credits: 1) Sviatlana Zyhmantovich; 2) Mirwanto Muda; 3) Fern; 4) Wirestock; 5) Sarno Markosasi. (Source: istockphoto.com)

Herbaceous

ORIGIN:
N (Native)
Na (Naturalised)
C (Cultivated)
SIZE:
A (Height at adult stage) × D (Diameter).





Nº	06	07	08	09	10
Scientific name [Botanical family]	Heliconia hirsuta "Burle marxii" [Heliconiaceae]	Salvia guaranitica A. St-Hill ex Benth [Lamiaceae]	Salvia splendens Sellow ex Wied-Nuew [Lamiaceae]	Arachis repens Handro [Leguminosae]	Nothoscordum gracile (Aiton) Stearn [Amaryllidaceae]
Common name	Caeté Pacová pequena	Sálvia-azul	Sálvia-vermelha	Grama-amendoim	Alho-silvestre Cebolinha-de-perdiz
Origin	N	N	N	N	N
Size (A × D)	2.00 × 1.00	1.60 × 0.20	0.80 × 0.20	0.20 × 0.30	0.80 × 0.30
Light requirement	Full sun Part shade	Full sun	Full sun	Full sun	Full sun
Flowering period	Summer Autumn	Spring Summer	All year	Spring Summer	Autumn Winter
Landscape uses	Massifs Renque	Isolated Living fence	Massifs Canter	Soil covering	Massifs Medicinal garden
Polinnator or visitor	Hummingbird	Bee Hummingbird Butterfly Dragonfly	Bee Hummingbird Butterfly Dragonfly	Bee	Bee

Photo credits: 6) Rahmad Wijaya; 7) Photohampster; 8) Liane M; 9) Julio Cesar Pires; 10) Deny Novan; (Sorce: istockphoto.com)

Herbaceous

ORIGIN:
N (Native)
Na (Naturalised)
C (Cultivated)
SIZE:
A (Height at adult stage) × D (Diameter).





Nº	11	12	13	14	15
Scientific name [Botanical family]	Thunbergia mysorensis [Acanthaceae]	Clivia miniata Regel [Amaryllidaceae]	Bulbine frutescens (L.) Willd. [Asphodelaceae]	Ageratum conyzoides L. [Asteraceae]	Leucanthemum vulgare Lam. [Asteraceae]
Common name	Sapatinho-de-judia	Clivia	Bulbine	Mentrasto Erva-de-são-joão	Margarida
Origin	Na	Na	Na	Na	Na
Size (A × D)	20.00 × 1.00	0.60 × 0.40	0.30 × 0.30	1.00 × 0.30	0.60 × 0.20
Light requirement	Full sun	Part shade	Full sun	Full sun Part shade	Full sun Part shade
Flowering period	Spring Summer	Spring	All year	Autumn	Summer Autumn
Landscape uses	Pergola	Embroidery	Embroidery Massifs	Canter Medicinal garden	Canter Embroidery Massifs
Polinnator or visitor	Bee Hummingbird	Bee	Bee Butterfly	Bee Butterfly	Bee Butterfly

Photo Credits: 11) Kateryna Kukota; 12) Natalie Board; 13) Igaguri_1; 14) Bush Alex; 15) Iva Vagnerova. (Source: istockphoto.com)

Herbaceous

ORIGIN:
N (Native)
Na (Naturalised)
C (Cultivated)
SIZE:
A (Height at adult stage) × D (Diameter).





Nº	16	17	18	19	20
Scientific name [Botanical family]	Tagetes filifolia Lag. [Asteraceae]	Podranea ricasoliana (Tanfani) Sprague [Bignoniaceae]	Aechmea blanchetiana [Bromeliaceae]	Tradescantia pallida Boom [Commelinaceae]	Malvaviscus arboreus Cav. [Malvaceae]
Common name	Cravinho-da-serra	Sete-léguas	Bromélia	Coração-roxo Trapoeraba-roxa	Malvavisco Hibisco-colibri
Origin	Na	Na	Na	Na	Na
Size (A × D)	0.90 × 0.30	10.00 × 1.00	1.00 × 0.60	0.25 × 0.10	4.00 × 1.00
Light requirement	Full sun Part shade	Full sun	Part shade	Full sun	Full sun
Flowering period	All year	All year	Summer	All year	All year
Landscape uses	Massifs Canter Embankment covering	Pergola	Isolated Canter	Embroidery Soil covering	Living fence Embroidery
Polinnator or visitor	Bee Butterfly	Bee Butterfly Beetles Birds	Bee Beetles Birds	Bee	Bee Hummingbird Butterfly Birds

Photo credits: 16) Martina Unbehauen; 17) Santi Wiwatchaikul; 18) Simona Flamigni; 19) Armankose; 20) E46AV22; (Source: istockphoto.com)

Herbaceous

ORIGIN:
N (Native)
Na (Naturalised)
C (Cultivated)
SIZE:
A (Height at adult stage) × D (Diameter).





Nº	21	22	23	24	25
Scientific name [Botanical family]	Ipomoea horsfalliae Hook. [Asteraceae]	Pelargonium x hortorum L.H.Bailey [Geraniaceae]	Pentas lanceolata (Forssk.) Deflers [Rubiaceae]	Cobaea scandens Cav. Polemoniace	Persicaria capitata H. Gross [Polygonaceae]
Common name	Ipomeia-rubra Trepadeira-cardeal	Gerânio	Show-de-estrelas Estrela-do-Egito	Cobeia Estefânia	Tapete-inglês
Origin	C	C	C	C	C
Size (A × D)	6.00 × 1.00	0.60 × 0.30	0.60 × 0.30	4.00 × 0.30	0.20 × 0.15
Light requirement	Full sun	Part shade	Full sun	Full sun	Full sun Part shade
Flowering period	Spring Summer	Spring Summer	Summer Autumn	Summer	All year
Landscape uses	Pergola	Canter Embroidery	Massifs Embroidery	Pergola	Soil covering Embankment covering
Polinnator or visitor	Bee Butterfly Hummingbird	Bee Butterfly	Hummingbird Butterfly	Bee	Bee

Photo credits: 21) Albin Raj; 22) Michael Meijer; 23) Dani VG; 24) Weisschr; 25) Teddiviscious; (Source: istockphoto.com)

Shrubs

ORIGIN:
N (Native)
Na (Naturalised)
C (Cultivated)
PORTE:
A (Height at adult stage) × **D** (Diameter).





Nº	26	27	28	29	30
Scientific name [Botanical family]	Callistemon viminalis (Sol.ex. Gaertn) G.Don [Myrtaceae]	Bougainvillea spectabilis Willd. [Nyctaginaceae]	Thunbergia erecta (Benth.) T. Anderson [Acanthaceae]	Allamanda laevis Markgr [Apocynaceae]	Osmanthus fragans (Thunb.) Lour. [Oleaceae]
Common name	Escova-de-garrafa	Primavera	Manto-de-rei	Alamanda arbustiva	Jasmim-do-imperador
Origin	C	N	N	N	Na
Size (A × D)	15.00 × 2.00	5.00 × 2.00	3.00 × 0.50	3.00 × 1.00	4.00 × 2.00
Light requirement	Full sun	Full sun	Full sun Part shade	Full sun	Full sun
Flowering period	Spring Summer	Autumn Winter	All year	All year	Spring Summer
Landscape uses	Isolated Living fence	Living fence Pergola	Massifs Living fence	Living fence	Isolated
Polinnator or visitor	Hummingbird Birds	Hummingbird Butterfly	Bee Hummingbird	Bee Hummingbird	Bee

Photo credits: 26) K. Samurkas; 27) Jian Yi Liu; 28) Wahid Hasyim Asyari; 29) Chi Wai Chevy Wan; 30) Marina Denisenko (Source: istockphoto.com)

Catalogue of Nature-based Solutions for Open Spaces

Shrubs

ORIGIN:
N (Native)
Na (Naturalised)
C (Cultivated)
PORTE:
A (Height at adult stage) × **D** (Diameter).





Nº	31	32	33	34	35
Scientific name [Botanical family]	Duranta erecta L. [Verbenaceae]	Lantana camara L. [Verbenaceae]	Rosa x grandiflora Hort. [Rosaceae]	Holmskioldia sanguinea Retz [Lamiaceae]	Ixora coccinea L. [Rubiaceae]
Common name	Pingo-de-ouro	Cambará-amarelo	Rosa, Rosa arbustiva	Chapéu-chines	Ixora-coral
Origin	Na	Na	C	C	C
Size (A × D)	1.50 × 1.00	2.00 × 0.60	2.00 × 0.50	5.00 × 3.00	3.00 × 0.50
Light requirement	Full sun	Full sun	Full sun	Full sun	Full sun
Flowering period	Spring Summer	All year	All year	Spring Summer	Autumn Winter
Landscape uses	Massifs Renque	Massifs Canter	Massifs Isolated	Living fence	Massifs Living fence Renque
Polinnator or visitor	Butterfly	Butterfly	Bee Hummingbird	Hummingbird	Bee Hummingbird

Photo credits: 31) Seathailandd; 32) Winlyrung; 33) Victoria ArtWK; 34) Francisco Herrera; 35) Rafael Goes. (Source: istockphoto.com)

Arboreal and Palmaceous

ORIGIN:
N (Native)
Na (Naturalised)
C (Cultivated)
PORTE:
A (Height at adult stage) × **D** (Diameter).



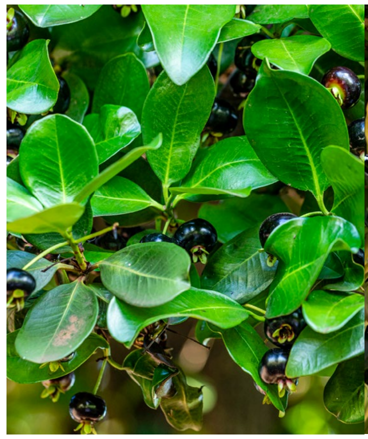



Nº	36	37	38	39	40	41
Scientific name [Botanical family]	Senna alata (L.) Roxb. [Solanaceae]	Psidium cattleianum Sabine [Myrtaceae]	Cordia superba [Boraginaceae]	Cordia ecalyculata [Boraginaceae]	Peltophorum dubium [Fabaceae]	Psidium guajava [Myrtaceae]
Common name	Fedegoso Cassia candelabro	Araçá-amarelo	Babosa branca	Café de Bugre	Canafístula	Goiaba
Origin	N	N	N	N	N	N
Size (A × D)	3.00 × 0.80	6.00 × 3.00	7.00 × 4.00	16.00 × 5.00	25.00 × 5.00	6.00 × 3.00
Light requirement	Full sun	Full sun	Full sun	Full sun	Full sun	Full sun
Flowering period	Autumn	Winter Spring Summer	Spring Summer	Spring Summer	Summer	Spring Summer
Landscape uses	Isolated Woods	Isolated Woods	Isolated Woods	Isolated Woods	Isolated Woods	Isolated Orchard Woods
Polinnator or visitor	Bee	Bee Birds	Bee	Bee	Bee	Bee Birds

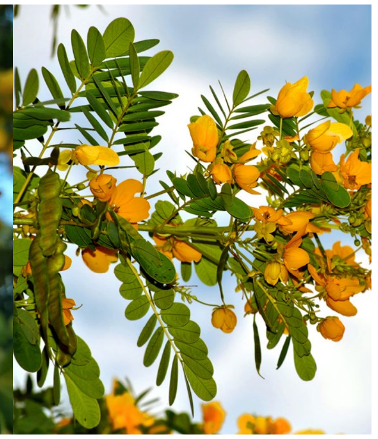
Photo credits: 36) Mansum008; 37) Oscar Yoshinori Toyofuku; 38) Nathalia de Franca Guimaraes; 39) Walter Medina (CC); 40) Nataly Hanin; 41) Sommai photo. (Source: istockphoto.com)

Arboreal and Palmaceous

ORIGIN:
N (Native)
Na (Naturalised)
C (Cultivated)
PORTE:
A (Height at adult stage) × **D** (Diameter).





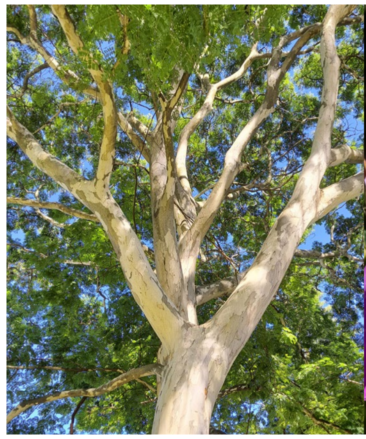



Nº	42	43	44	45	46	47
Scientific name [Botanical family]	Eugenia brasiliensis [Myrtaceae]	Marlierea edulis [Myrtaceae]	Inga vera subsp. affinis [Fabaceae-Mimosoideae]	Bauhinia forficata [Fabaceae-Cercideae]	Paubrasilia echinata [Fabaceae/Caesalpinioideae]	Senna multijuga [Fabaceae/Caesalpinioideae]
Common name	Grumixama	Cambucá	Ingá	Pata de Vaca	Pau-Brasil Ornamental	Pau Cigarra
Origin	N	N	N	N	N	N
Size (A × D)	15.00 × 4.00	20.00 × 4.00	10.00 × 4.00	9.00 × 4.00	25.00 × 5.00	10.00 × 4.00
Light requirement	Full sun	Full sun	Full sun	Full sun	Full sun	Full sun
Flowering period	Spring Summer	Spring Summer	Winter Spring Summer	Spring Summer	Spring Summer	Summer Autumn Winter
Landscape uses	Isolated Renque	Isolated Orchard Riparian forest	Isolated	Isolated Renque	Isolated	Isolated Renque
Polinnator or visitor	Bee Birds	Bee	Bee	Bee	Bee	Bee

Photo credits: 42) Murilo Gualda; 43) Nancy Ayumi; 44) g01xm; 45) Alfribeiro; 46) Julcéia Camillo; 47) PeterEtchells. (Source: istockphoto.com)

Arboreal and Palmaceous

ORIGIN:
N (Native)
Na (Naturalised)
C (Cultivated)
PORTE:
A (Height at adult stage) × **D** (Diameter).






Nº	48	49	50	51	52	53
Scientific name [Botanical family]	Libidibia ferrea [Fabaceae/ Caesalpinioideae]	Tibouchina mutabilis [Melastomataceae]	Syagrus romanzoffiana [Arecaceae]	Euterpe edulis [Arecaceae]	Mauritia Flexuosa [Arecaceae]	Acrocomia aculeata [Arecaceae]
Common name	Pau-Ferro	Manacá-da-serra	Jerivá	Jussara	Buriti	Macaúba, Mucajá
Origin	N	N	N	N	N	N
Size (A × D)	15.00 × 4.00	12.00 × 3.00	15.00 × 4.00	12.00 × 4.00	35.00 × 4.00	15.00 × 4.00
Light requirement	Full sun	Full sun	Full sun	Full sun	Full sun	Full sun
Flowering period	Spring Summer	Summer	Spring Summer	Spring Summer	Summer Autumn	Spring Summer
Landscape uses	Isolated Renque	Isolated Renque	Isolated Renque	Isolated	Isolated Renque	Isolated Renque
Polinnator or visitor	Bee	Bee Butterfly	Bee Birds Small rodents	Bee Birds	Birds Beetles	Birds Beetles

Photo credits: 48) Elis Cora; 49) Cassia Bars; 50)/51) Nancy Ayumi; 52) Oscar Yoshinori Toyofuku; 53) Marianogueira. (Source: istockphoto.com)

Aquatic and Macrophyte

ORIGIN:
N (Native)
Na (Naturalised)
C (Cultivated)
PORTE:
A (Height at adult stage) × **D** (Diameter).





Nº	54	55	56	57	58
Scientific name [Botanical family]	Cyperus papyrus L [Cyperaceae]	Thalia geniculata L. [Marantaceae]	Canna indica L. [Cannacea]	Sagittaria montevidensis [Alismataceae]	Pontederia cordata [Commelinales]
Common name	Papirus	Caeté	Beri, Biri, Bananeirinha	Sagitária Aguapé-de-flecha	Mururé, Aguapé
Origin	Na	Na	N	N	N
Size (A × D)	1.00 × 0.50	2.00 × 0.40	1.20 × 0.30	0.90 × 0.40	0.90 × 0.40
Light requirement	Full sun	Full sun Part shade	Full sun	Full sun	Full sun Part shade
Flowering period	Spring Summer Autumn	Spring Summer Autumn	Spring Summer	Spring Summer	Summer
Landscape uses	Lakes Lake shores	Lakes Lake shores	Massifs Embroidery Renques	Lakes	Lakes
Polinnator or visitor	Bee Hummingbird Moth	Bee Hummingbird	Butterfly Hummingbird Bat	Dragonfly	Bee
Handling recommendations	Despite the ecological advantages of the aforementioned species, such as their phytoremediation properties and their ability to attract pollinating fauna, constant monitoring is recommended in order to identify abnormal growth or uncontrolled reproduction and establish the cause. Management actions may then be necessary, such as species suppression or replacement.				

Photo credits: 54) Noppharat; 55) kendoNice; 56) Jobrestful; 57) shihina; 58) kj2011. (Source: istockphoto.com)


Orla do Guaíba urban park in Porto Alegre, Rio Grande do Sul, office of Jaime Lerner Arquitetos Associados (Photo: Marcelo Donadussi, 2023)

Step 4 Measuring ecosystem services and social benefits post-implementation

Although the scientific community does not agree on the concept of urban green areas as part of an ecosystem, there is growing interest in understanding the ecosystem services provided by these urban green areas (SANDRE, 2022). This is particularly relevant in the context of the green infrastructure networks comprising public open spaces (such as parks, forests and urban squares and trees associated with the road system) and private landscaped area).

This catalogue considers urban green areas to be part of an ecosystem, meaning they provide ecosystem services. It also acknowledges that the NbS present in these green areas provide various ecosystem services, including cultural, provisioning and regulating services (Table 7), and that measuring them in urban areas is inherently complex.

For more details on measuring ecosystem services, we recommend materials from the series:

Methodology for quantifying the environmental, economic and social risks and benefits of Nature-based Solutions (NbS) adopted in the implementation of linear and riverine parks.

It offers a survey of the main international methodologies for quantifying the impacts and benefits of NbS; an assessment of these methodologies with regard to their applicability in quantifying the environmental, economic and social benefits of NbS associated with linear and riverine parks; and a compilation of indicators for measuring the environmental, social and economic benefits of implementing and managing linear and riverine parks.

Table 7 Urban ecosystem services provided by NbS in green infrastructure projects in open spaces (Source: SANDRE, 2022, based by de COSTANZA et al., 2017).

Categories	Type of ecosystem service	Discription
Cultural	Recreation, spiritual, educational, patrimony	Aimed at aesthetic appreciation, recreational values, education, culturally important landscapes
Provision	Food	Eatable plants
	Fibre and energy	Presence of species with potential use as wood, fuel or raw material
Regulation	Hydric regulation Water (flood protection and quality improvement)	Water quantity (reduction of surface run-off and flood risks) Quality (role of biota and abiotic processes in removing or breaking down organic matter, xenic nutrients and compounds)
	Regulating air quality	Pollution reduction The ecosystem's ability to extract chemical substances from the atmosphere (ozone, solid particles)
	Regulating the local climate	Influence of ecosystems on local temperature through vegetation covering
	Regulating the global climate	Influence of ecosystems on global temperature through vegetation cover, by reducing greenhouse gas concentrations (exclusive focus on carbon sequestration)
	Pollination and dispersion	Abundance and effectiveness of pollinating agents, enabling fertilization of flowers and production of fruit, vegetables and grains
	Biological pest control	Pest control by trophic regulation

VARIABLES FOR MEASURING ECOSYSTEM SERVICES

The study of the provision of ecosystem services aims to estimate the positive effects generated by a project that are beneficial to human society, such as, for example, an increase in carbon sequestration, improved environmental comfort or even improved urban drainage resulting from the implementation of a NbS.

Estimates of the generation of benefits from increased ecosystem services usually involve the potential supply of these services, i.e. the hypothetical optimised maximum capacity of a specific area to provide a specific set of benefits within a given timeframe.

This differs from the actual capacity of a given area to provide a specific set of benefits within a given timeframe (BURKHARD et al., 2012). However, this information can only be obtained through detailed monitoring of ecological processes, which is not always feasible for budgetary and operational reasons.

Estimates of the benefits arising from the increased provision of ecosystem services by NbS are generally based on simplifications and approximations, however, it is essential to reduce uncertainties as much as possible during the inference process.

In this context, terrestrial carbon sequestration and storage is arguably the most widely recognised ecosystem service (EGGLESTON, 2006).

Calculating the volume of carbon stored and carbon sequestration rates in detail requires empirical studies and mathematical equations that take into account factors such as urban planting arrangement, the edge effect, and the variability of species and specimen. For example, the ability of a tree to sequester carbon and intercept rainwater depends on its species, but also on factors such as canopy size, maturity and soil conditions, as well as its location. Therefore, it is necessary to understand the differences when transitioning from a single tree to a diverse set and the optimal spatial arrangements for each NbS (e.g. rain gardens) to maximise biomass (SANDRE, 2022).

To simplify the process of generating quantitative estimates of carbon storage and sequestration processes, models can be used to calculate the stored volumes and/or rates of carbon accumulation in vegetation using two basic variables: 1) the average carbon storage values for each NbS per unit area (values obtained from the literature or through field measurements); and 2) the territorial extension of the area under intervention. One such model is the InVEST Carbon Storage and Sequestration model (TALLIS, 2010; STANFORD UNIVERSITY, 2022), which considers up to 4 different 'carbon reservoirs' (above-ground biomass, below-ground biomass, soil and dead biomass).

The interception of rainwater varies according to the arrangement of the tree plantation. The canopy reduces surface run-off and soil erosion by softening the impact of raindrops. The roots, grow and decompose to increase the infiltration capacity of water in the soil, promoting its purification by percolation (XIAO et al., 1998). Vegetation significantly influences the receiving and redistribution of rainfall within the context of a given area's water balance. Depending on competing factors such as soil porosity, landform and previous humidity index, forest coverage can have a significant influence on soil water recharges.[45]

Since isolated trees are more likely to have a lower interception percentage (due to wind speed, decreasing internal precipitation below the canopy in certain locations), it is recommended to decrease their capacity by 15% in urban areas (SANDRE, 2022).

Tree groupings can alter the local microclimate (BROADBENT et al., 2018) by returning rainwater to the lower layers of the atmosphere as water vapor, creating more comfortable humidity and temperature conditions for people.

Pollination is considered an ecosystem service, especially when associated with food production. The global economic valuation of the pollination ecosystem service has been estimated at between US$ 235 billion and US$ 577 billion (POTTS et al., 2016).

Table 8 describes the ecosystem services by landscape project demand and supply. Demand for ecosystem services is defined as the amount of a service required or desired by society. (VILLAMAGNA et al., 2013).

45 Carbon interception consists of the fraction of precipitation retained in the leaves and branches of trees (which returns to the atmosphere as vapor); transprecipitation or internal precipitation (which is the portion of rain that passes through the canopy, reaching the ground in the form of drops); run-off through the trunk; effective precipitation is the sum of these last two water flows (ARCOVA et al., 2003). Interception is calculated by subtracting total precipitation (measured on open ground) from internal precipitation (precipitation that reaches the ground, both from drops that pass directly through the openings between the canopies and from drops that splash from the canopies) and from run-off through the tree trunks.

Table 8 Description of ecosystem services by demand and supply of landscape design (Source: SANDRE, 2022).

Ecosystem service	Factors influencing demand	Future indicators Factors influencing supply
Thermal and environmental comfort [*]	Population density exposed to extreme temperatures	Difference in air and surface temperature (°C) between sunny areas, shaded areas and/or areas close to water elements
	Perceived equivalent temperature (PET)	Decrease in temperature due to tree coverage (°C)
		Perceived equivalent temperature (PET)
Reduction of greenhouse gas concentrations	Increased emissions of gases related to the greenhouse effect	Amount of carbon (CO_2) above ground absorbed and stored by trees in terms of biomass, carbon content (kg/species)
	Reduction in urban tree coverage	Carbon sequestration (kg.year^{-1})
	Storage of carbon tCha^{-1}	
Regulating floods and waterlogging	Local precipitation and interception capacity (m^{3}year^{-1})	Proportion of permeable/impermeable surface of homogeneous land use unit where water cannot infiltrate (%)
	Capacity for infiltration and storage of water in the soil (mm); and water retention by the vegetation soil (ton.km^{-2});	Increased infiltration capacity and water storage in the soil (mm); water retention capacity of the vegetation soil (ton.km^{-2});
	High surface run-off (mm)	Precipitation intercepted by trees; decrease in surface run-off (mm)
	Areas exposed to flooding	Phytoremediation (role of biota and processes for removing or breaking down organic matter and compounds)
	Population exposed to flood risk (% per unit area) and contamination of rainwater and river water by a one-off or diffuse sources	
Air quality regulation	Population exposed to the threshold concentration of pollutants (proximity to the emission source and its intensity)	Average annual pollutant removal rates with increased tree coverage (g/m^2 and kg.ha^{-1} year^{-1})
	Concentration, spatial distribution, obstacles to dispersion and flow of pollutants	Capacity of land use and open spaces to intercept pollution as an obstacle to dispersion

***Thermal comfort** is quantified as the reduction in surface and air temperature resulting from the presence of green open space, i.e. the difference between the temperatures modeled for an impermeable open space and a green space. A number of variables can influence thermal comfort. Monteiro and Alucci (2007) surveyed the state of the art of research into thermal comfort in open spaces and selected models developed specifically for open spaces; presenting a comparison, they criticize their use and suitability and analyse their equations and calculation steps (e.g. Physiological Equivalent Temperature, PET by Höppe, 1999), initial tools for open space design (e.g. Rediscovering the Urban Realm and Open Spaces – RUROS project).

MEASURING BENEFITS

Benefits for public administration

In light of the benefits for public management, the application of the NbS must comply with the legal parameters for protecting the ecologically balanced environment, as guaranteed by Article 225 of the 1988 Federal Constitution. It is important to remember that the Union, states, federal district and municipalities must also combat pollution in all its forms, which highlights the importance of adopting NbS in urban administration whenever possible. Some of the direct and indirect benefits of using NbS in public administration are listed below:

- The possibility of preserving and restoring essential ecological processes and providing ecological management within the framework of urban governance;
- Control of activities that could cause significant environmental degradation;
- Knowledge and use of techniques, methods and substances that promote quality of life and environmental conservation;
- Potential for environmental education initiatives to be developed in collaboration with public authorities;
- Defence of fauna and flora in the urban context.

Economic benefits

In terms of economic benefits, the implementation of NbS can help with the following:

- Reduced maintenance costs for the landscape, as using suitable species that are already adapted to the local climate and soil (preferably native species) reduces the need for care in the medium and long term;
- Improvements to the local environment, landscape and quality of life, thus enhancing the value of private and public properties near these localities;
- The possibility of diversifying uses by different municipal government agencies, linked to health, education and other issues, thereby helping urban development;
- The opportunity to use the NbS as linear parks for public and private events, which boosts the local economy (especially commerce);
- Attracting companies and investors by improving local landscapes and quality of life;
- Reduction in public expenses to mitigate flooding, such as the possibility of infiltration and reduction in the speed of surface run-off, and resolution of other problems usually seen on days of heavy rainfall in cities. This has a direct impact on the costs to various municipal sectors, notably commerce and services, to return to normal.

Social benefits

The increase in green areas through the implementation of Nature-based Solutions (NbS), such as sidewalks, flowerbeds, unused areas, squares, rivers and parks, can bring various social benefits to the local communities directly affected by such interventions, as well as very concrete benefits at a municipal level.

At a local level, these benefits can be seen in terms of mobility, health, formal and non-formal education, culture, sports and leisure and housing:

Health: stimulating physical activity combats sedentary lifestyles, a condition associated with urban environments. More green spaces encourage people to spend their free time exercising. Additionally, there are aspects of health that transcend the biological, providing residents with a sense of well-being that contributes to mental health. Furthermore, the public spaces created by these interventions can be utilised by municipal family health programmes, linked to local Basic Health Units (UBS) and Psychosocial Care Centers (CAPS).

Formal and non-formal education: Nature-based Solutions provide a fertile ground for formal education, as they encourage the incorporation of these discussions about the local physical space to be incorporated into the school curriculum in each territory. A wide range of subjects in the school curriculum can incorporate content relating to biology, geography/geology, mathematics, history, physical education, arts and language, among others, with reference to the NbS interventions carried out in each territory. In addition, local associations can encourage the use and care of spaces through non-formal education activities, generating a sense of belonging among children, teenagers, young people, adults and the elderly through programmes such as parties, themed events and community activities, as well as themed activity groups (e.g. skateboarding, hip-hop, graffiti, soccer, basketball and other sports activities). These can be carried out in the spaces created, as well as in urban gardens, permaculture and urban agroecology spaces.

Culture, sports and leisure: more green spaces in which the population can socialise stimulate cultural participation, sports activities and a more diverse use of free time through various leisure activities. The spaces generated by such interventions can be linked to local cultural groups and public facilities to promote care for the space through public use.

Habitation: the public spaces created can improve residents' perception of their locality, provided other urban policies are implemented, such as solid waste collection and treatment, sewage disposal, urban cleaning, street paving and the installation of public facilities (schools, nurseries, health centres, etc.).

At a municipal level, these local benefits can help to create a municipality that is more resilient to climate change and offers a better quality of life and a stronger sense of community among its residents. Creating more green spaces in the municipality also helps generate local and intersectoral public policy solutions, making the municipal government's actions more effective, efficient and productive.

Green spaces can promote more consistent action by local public schools, basic health units and existing cultural, sports and leisure facilities, as well as integrating proposals for health, education, culture, sports and leisure.

It is worth noting that the social benefits of NbS only occur when they are linked to public policies and urban plans.

Sustainable Development Goals (SDG) and the NbS

In September 2015, the 193 member states of the UN, including Brazil, committed to a universal action plan to address issues in various sectors, such as poverty, hunger, misery, inequalities, diseases, violence, unemployment, environmental degradation and the depletion of natural resources, by the year 2030.

These commitments are linked to a total of 17 Sustainable Development Goals and 169 targets set out in the 2030 Agenda.

The SDGs cover the environmental, economic and social dimensions of sustainable development (BRAZIL, 2023)[46]; each country has its own national targets, taking into account its own circumstances, and must incorporate measures, actions and projects into government policies, programmes and plans.

The NbS presented in this catalogue are directly related to the 6 Sustainable Development Goals listed below:

SDG 3 - GOOD HEALTH AND WELL-BEING: Ensure healthy lives and promoting the well-being of all, at all ages.

46 Information from the Brazilian Indicators for the Sustainable Development Goals page of the Brazilian Institute of Geography and Statistics (IBGE). Available at: https://odsbrasil.gov.br/home/agenda.

SDG 6 - DRINKING WATER AND SANITATION: Ensure availability and sustainable management of water and sanitation for all.

SDG 11 - SUSTAINABLE CITIES AND COMMUNITIES: Make cities and human settlements inclusive, safe, resilient and sustainable.

SDG 13 - ACTION AGAINST GLOBAL CLIMATE CHANGE: Take urgent action to combat climate change and its impacts.

SDG 14 - LIFE IN THE WATER: Conserve and sustainably use the oceans, seas and marine resources for sustainable development.

SDG 15 - TERRESTRIAL LIFE: Protect, restore and promote the sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

The degree of interaction between each NbS and these SDGs can range from low to medium to high, as described in Table 9.

Table 9 Degree of interaction between the NbS Modular System device and SDGs.

NbS modular systems	Sustainable development goals					
Typologies	SDG 3 Health and well-being	SDG 6 Drinking water and sanitation	SDG 11 Sustainable cities and communities	SDG 13 Action against global climate change	SDG 14 Life in water	SDG 15 Terrestrial life
Rain garden	high	high	high	high	low	high
Rain bed	high	high	high	high	low	high
Biovalet	high	high	high	high	low	high
Rain terrace	high	high	high	high	low	high
Hydraulic vegetated ladder	high	high	high	high	low	high
Infiltration pit	medium	high	medium	high	low	high
Detention basin	medium	high	medium	high	low	high
Retention basin	medium	high	medium	high	high	high
Infiltration basin	high	high	medium	high	low	high
Wetland	high	high	high	medium	medium	medium
Amphibious reservoir	high	high	high	medium	medium	high
Vegetated polder	medium	high	high	high	medium	high
Step Pool	medium	high	high	high	high	medium

Level of interaction between device and SDG: low, medium, high

Areião Goiania Park (Photo: Francine, 2015)

2 Overview of NbS in Brazil

In recent years, there has been a significant increase in Nature-based Solutions (NbS) projects in the Brazilian context. These projects offer an innovative way of protecting ecosystems and their biodiversity in the face of the challenges of climate change and environmental degradation.

The projects employ a wide range of strategies and techniques that utilise nature's knowledge to solve socio-environmental challenges. In Brazil, NbS have demonstrated their potential to not only promote biodiversity conservation and generate economic, social and cultural benefits for local communities, as highlighted throughout this catalogue.

Thus, the growth of NbS in Brazil reflects a growing commitment to environmental protection and sustainable development. Incorporating these innovative approaches into public policies and urban planning practices is key for addressing current challenges and creating cities that are more resilient to climate change and extreme rainfall events.

While several projects have been inspired by successful initiatives around the world, it is important to recognise that each scenario has its unique characteristics that extend beyond the technical aspects and the locations where NbS are implemented. The social, economic and cultural scenario, local climate and environmental issues must be considered, as well as the broader national and regional scenarios and different project scales. This is because Brazil has a diversity of biomes, soil types, fauna and political, administrative and cultural structures that directly affect the implementation and maintenance of NbS.

Brazilian society has many different ways of living with the territory. In urban centres, for example, a large part of the population lacks daily contact with green spaces and often has no symbolic or emotional connection to river water, let alone rainwater. Projects proposing the creation of lake areas, reopening of streams or the decision not to seal their banks can be viewed with suspicion by the population. In the city of São Paulo, for example, water is associated with sewage and flooding.

A scenario of environmental re-education needs to be developed that focuses particularly on the importance of natural flows in urban environments and the role of water in cities.

NbS projects encourage people to follow the course of the water on a journey of discovery and reflection, contemplating the streams and listening to the sound of their waters.

Beyond the many structural benefits related to hydric and thermal comfort issues, the opening of a stream in the city symbolically reconnects people with water. Visualising a stream with recovered vegetation on its banks is a pedagogical exercise that aims to restore people's awareness of their surroundings. It is important to associate streams, rivers and creeks with of leisure and contemplation in the city's daily life, rather than allowing them to be forgotten or used solely for sanitation (FCTH, 2021).

This chapter presents cases from the cities of **Belo Horizonte**, **Londrina**, **São Paulo** and **Rio de Janeiro** to evaluate the panorama of Brazilian NbS projects and the challenges for their implementation. These cities are models for application at different planning and design scales. As the case studies in this chapter will show, in cities like Londrina, people live alongside parks in valley bottoms and are accustomed to the permanent presence of rivers. There, the focus becomes preservation and maintaining and cultivating the native vegetation.

As we shall see, the administrative challenges of implementing and managing NbS these are common in many Brazilian cities. These challenges relate not only to convincing municipal decision-makers to adopt NbS, but also to the usual paradigm shifts relating to surface water run-off during implementation. For example, the municipality's technical staff found it difficult to accept simple changes to rain gardens, such as keeping the level of the soil below sidewalk standard and removing curbs, which are common in sidewalk beds. They are greatly concerned that rainwater would destroy the gardens.

In many cities, proposals for materials other than concrete on the banks of streams face difficulties in gaining acceptance. There needs to be permanent dialog with stakeholders and decision, as well as scientific studies proving that appropriately planting species can be enough to guarantee the stability of the margins and good water quality. Conversely, the local population must understand and recognise the importance of restoring the banks of streams. To this end, they need to be made aware of the vegetation to be maintained, so that they can trust the proposed structure.

In this context, a variety of public policies supporting the implementation of NbS[47] can be observed. From a legal point of view, it is important to recognise the variety of public policies for sustainable urban development through the use of NbS, bearing in mind that environmental[48] and urban planning[49] policies have shared competence, i.e. they are common to the federal (e.g. National Environmental Policy), state (e.g. State Environmental Code) and municipal (e.g. Municipal Environmental Policy) spheres. There is therefore a clear need for these policies to involve different authorities and their own legal instruments, such as laws, decrees and resolutions, and to provide for inclusive environmental management.

From a legal point of view, it is important to remember the range of public policies for sustainable urban development through the use of NbS and to bear in mind that environmental and urban planning policies have shared competence, i.e., common to the federal (e.g. National Environmental Policy), state (e.g. State Environmental Code) and municipal (e.g. Municipal Environmental Policy) spheres. In this context, there is a clear need for their operations to involve different authorities and their own legal instruments (such as laws, decrees, resolutions, etc.) and to provide for inclusive environmental management.

Within the **scope of Environmental Law**, whose legal relationship is between man and the environment, through directive, cogent, prohibitive and sanctioning mechanisms, the Federal Constitution, in its provision 225, defines the environment as a legal asset for the common use of society, which needs to be balanced and protected so that it can guarantee the necessary quality of life for the population, in such a way that it directs the action of the Public Power, together with society, towards the duty to preserve and defend this asset. And one of the ways to instrumentalize this constitutional precept is through public policies, which must be carried out at the federal, state and municipal spheres.

At the municipal level, depending on the city and the provisions of the Master Plan, it is possible to observe the development of a municipal environmental policy aimed at preserving the environment through NbS. Some public administration initiatives and decisions include the adoption of NbS (EVERS et al., 2022):

- **Rio de Janeiro**, Rio de Janeiro: Copacabana rain gardens;
- **São Paulo**, São Paulo: the city has passed the mark of 200 rain gardens[50] – Municipal Law No. 17,578/2021;
- **Belo Horizonte**, Minas Gerais: 3 rain gardens implemented and 60 under implementation. There are plans to create linear parks and tree planting in the 2019 master plan – Law No. 11,181 of August 8, 2019;
- **Campinas**, São Paulo: implementation of linear parks, ecological corridors and urban afforestation – Municipal Decrees No. 19,167/15, No. 19,173/16, No. 19,226/16 and Resolution 03/2018;
- **Contagem**, Minas Gerais: rain garden implementation – Project Interct Bio – ICLEI;
- **Fortaleza**, Ceará: implementation of the Raquel de Queiroz linear park – Municipal Decree No. 13,764/2016;
- **Salvador**, Bahia: implementing green roofs – Municipal Decree No. 29,100/2017;
- **Sobral**, Ceará: Pajeú Park, which represents a complete solution to environmental demand with urbanisation, filter garden, wastewater treatment and other NbS solutions – Complementary Law 60/2018;
- **Goiânia**, Goiás: rain garden implementation – Municipal Decree No. 2,887/2019.

The municipal government has taken action at a local level by implementing NbS in sustainable urban policies, as well as through the interaction between master plans, municipal climate action plans and the work of the Environment Secretariats[51].

47 Public policies can be understood as responses to social and environmental needs through the actions of the state, through programmes, actions, laws and other normative acts. The structure of a public policy must consider functional and sequential aspects to serve the common good and fulfill its original function, as well as having legal provisions. In this way, the relationship between the state and society is at the heart of forming public policies and monitoring them vigilantly during their execution and reformulation.

48 Within the scope of environmental law, which establishes a legal relationship between humans and the environment, through directive, cogent, prohibitive and sanctioning mechanisms, the Federal Constitution defines the environment as a legal asset for the common use of society in provision 225. This asset must be balanced and protected to guarantee the necessary quality of life for the population, directing the action of the public power together with society towards preserving and defending this asset. One way to implement this constitutional principle is through public policies, which must be conducted at the federal, state and municipal levels.

49 Regarding urban planning, the aim is state intervention to organise habitable spaces (SILVA, José Afonso da. Direito Urbanístico Brasileiro. 5 ed. São Paulo: Malheiros, 2006, p. 44) and to serve the community while always respecting the legal statute. Article 182 of the Federal Constitution establishes that urban policy should be implemented at a municipal level to safeguard and guarantee social well-being and fulfilthe social function of cities. The City Statute, Law 10,257/2001, regulates articles 182 and 183 of the Federal Constitution by establishing the following: the general guidelines for urban policy, including the guarantee of the right to sustainable cities stands out, in its article 2, item I; the establishment of municipal master plans as instruments for making municipal urban public policies viable, in its article 4, item I; and social participation as a factor in the democratic management of urban development projects, in the same article 2, item II.

50 Information published by São Paulo Municipality on its website.

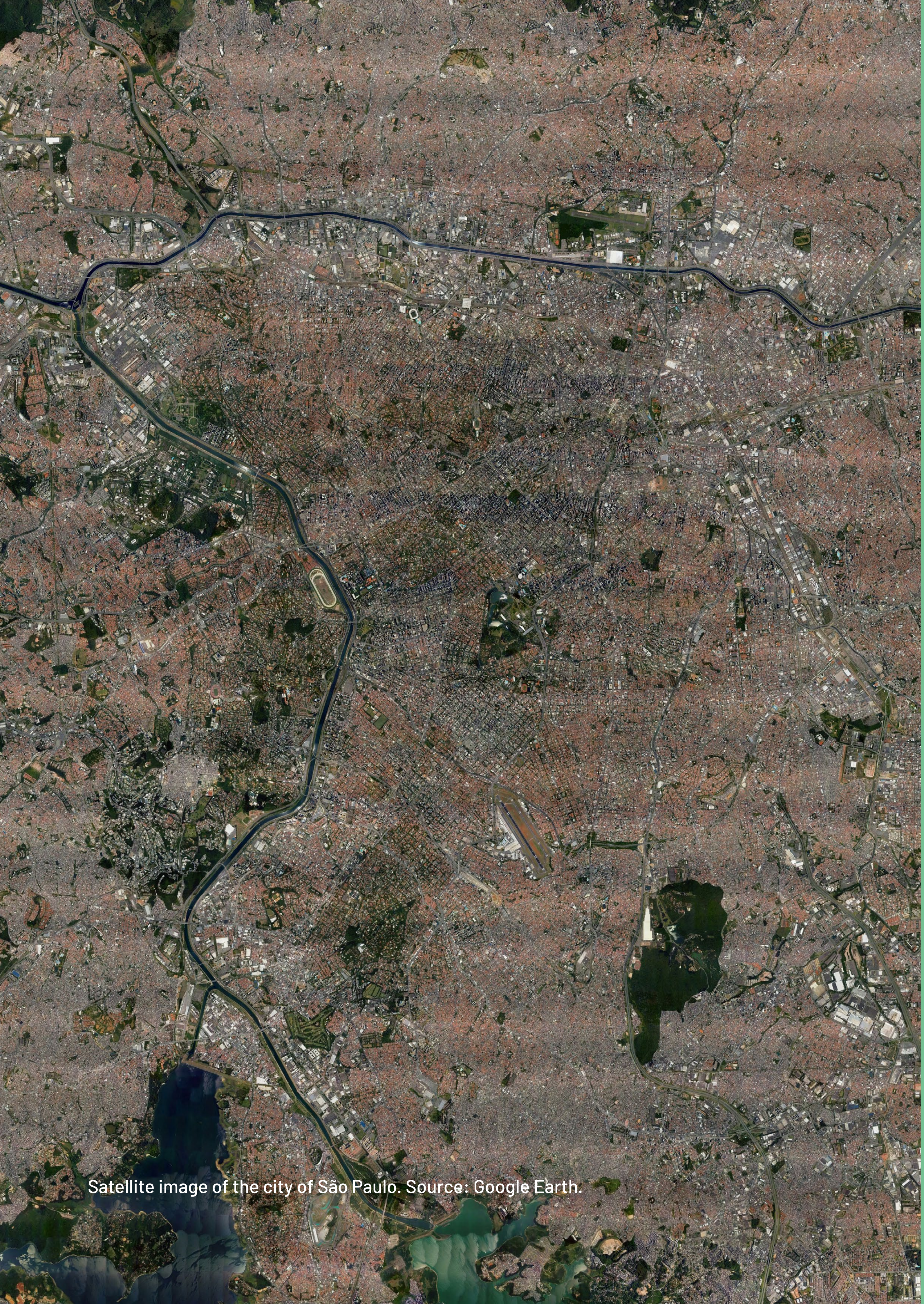
51 The City Statute, Law 10,257/2001, regulates articles 182 and 183 of the Federal Constitution by establishing: the general guidelines for urban policy, for which the guarantee of the right to sustainable cities stands out, in its article 2, item I; the establishment of municipal master plans as instruments for making municipal urban public policies viable, in its article 4, item I; and social participation as a factor in the democratic management of urban development projects, in the same article 2, item II.

Integrating other secretariats, such as Works and Infrastructure, is an important way to promote interdisciplinary public policies. This can be achieved through legal urban planning instruments aimed at maintaining the urban ecosystem in a balanced and less degraded state. This process involves the participation of civil society through consultations and public meetings.

Different regional needs and characteristics lead to different discussions and paths. Other characteristics impacting the development of public policies include the municipal budget, the population's economic income, the mobilisation of civil society around the issue and the priority areas for conservation, among other characteristics that make up the regional municipality. For this reason, public policies must be created in an integrated and coordinated manner between the country's different federal entities.

In short, it is important to promote municipal public policies that implement NbS by incorporating them into master plans – the main instrument of municipal administrative management – as well as integrating the different secretariats to ensure effective environmental management. NbS are the means most aligned of sustainable development with contemporary urban development objectives, providing a resilient ecosystem supported by an effective legal framework.

Cantareira state park, Pedra Grande view, São Paulo, São Paulo (Luiz Barrionuevo, 2020).



Satellite image of the city of São Paulo. Source: Google Earth.

Project in the city of
São Paulo | SP

Project in the city of São Paulo/SP

DATASHEET:

Saracura Infiltration Area, Anhangabaú Hydrographic Basin
Drainage Notebook for the Anhangabaú Hydrographic Basin, 2021

Authors: Guajava Arquitetura da Paisagem e Urbanismo, responsible for the project, together with the Hydraulics Technology Center Foundation (FCTH) and São Paulo Municipality

The city of São Paulo is involved in several important projects related to the implementation of NbS. Many of these projects are part of the Drainage Notebooks which were developed by the Hydraulics Technology Center Foundation (FCTH) for the Municipal Urban Infrastructure and Works Department (Siurb). These notebooks go beyond simple drainage master plans because, as well as proposing and establishing priority and risk levels for hydraulic works to control flooding, they also present interventions that offer environmental, technological and urbanistic benefits, focusing on sustainable and multidisciplinary urban drainage solutions.

One project that stands out is the Saracura Infiltration Area. Located in the Anhangabaú stream hydrographic basin, the area suffers from frequent flooding near the Saracura estuary. Several factors contribute to the recurrence of these events: high levels of soil sealing, massive canalisation of streams and the age and flow capacity of the drainage infrastructure, which is at risk of collapse.

Although structural measures using reservoirs are necessary in the Anhangabaú basin due to the severity of the problem, obstacles to their construction have been encountered due to the significant impact they would have on the region's transportation system during the construction stage (GONÇALVES et al., 2018). In this context, the Saracura Infiltration Area acts as a decentralised reservoir and infiltration system, which reduces and slows down surface run-off, helping to minimise flooding downstream. In addition, this solution also has the benefit of being simpler to build than conventional structural measures.

In this way, the project, located in the area surroundings Av. Nove de Julho, was designed to slow down rainwater run-off. To this end, a diagnosis was carried out to select the ideal NbS for each section of the project, taking into account its suitability in relation to the slope of the street and the embankment, as well as the type of soil and its permeability.

Once a rainfall event begins, the rainwater runs through the bioswales, located at Eng. Monlevade and Prof. Picarolo streets, with its surface run-off slowed down due to the small barriers inserted in this NbS. Once on Av. Nove de Julho, the water is directed to the rainwater gallery beneath the roadbed.

During periods of extreme rainfall, the surface run-off from the bioswales will be directed into infiltration pits located beneath the sidewalks of the aforementioned streets. These pits are perforated on their side walls and open at the bottom to allow the water to infiltrate the ground. In addition, stones are placed around the pit walls to optimise water infiltration. If it rains again in subsequent days, increasing the degree of soil saturation, an outlet will allow the water to flow between the pits and then into the rainwater gallery on Av. Nove de Julho.

Figure 71 Plan of the Saracura Infiltration Area showing the location of the NbS: bioswales, rain terraces, infiltration pits, rain bed and underground reservoir (Source: São Paulo Municipal Government, FCTH, 2021).

At the same time, the rain terraces, as NbS located on both embankments, act to slow down the surface run-off of rainwater into the valley floor. The slope of the land and a stone containment system following the contour lines are used to contain the water. When the water reaches the maximum level of the terrace, it is directed into bioswales, which carry it to the next rain terrace.

Once on Av. Nove de Julho, the rainwater flows into a watertight reservoir beneath the sidewalks on both sides of the avenue. It then passes through a coarse sand and gravel before being directed to the rainwater system. It should be noted that this reservoir is sealed, since the soil on the valley floor is not ideal for rainwater infiltration. Finally, in the centre of Av. Nove de Julho, there is a rain bed with barriers is inserted to direct and slow down rainwater run-off.

Gonçalves et al. (2018) estimated that a volume of 4,000 m^3 of rainwater could be contained from constructing 7,000 m^3 of NbS. The authors concluded that the project effectively reduces the volume of excess run-off to RT 2, with predicted improvements both in the floodplain upstream of Praça Quatorze Bis and in the results seen in the hydrographs[52].

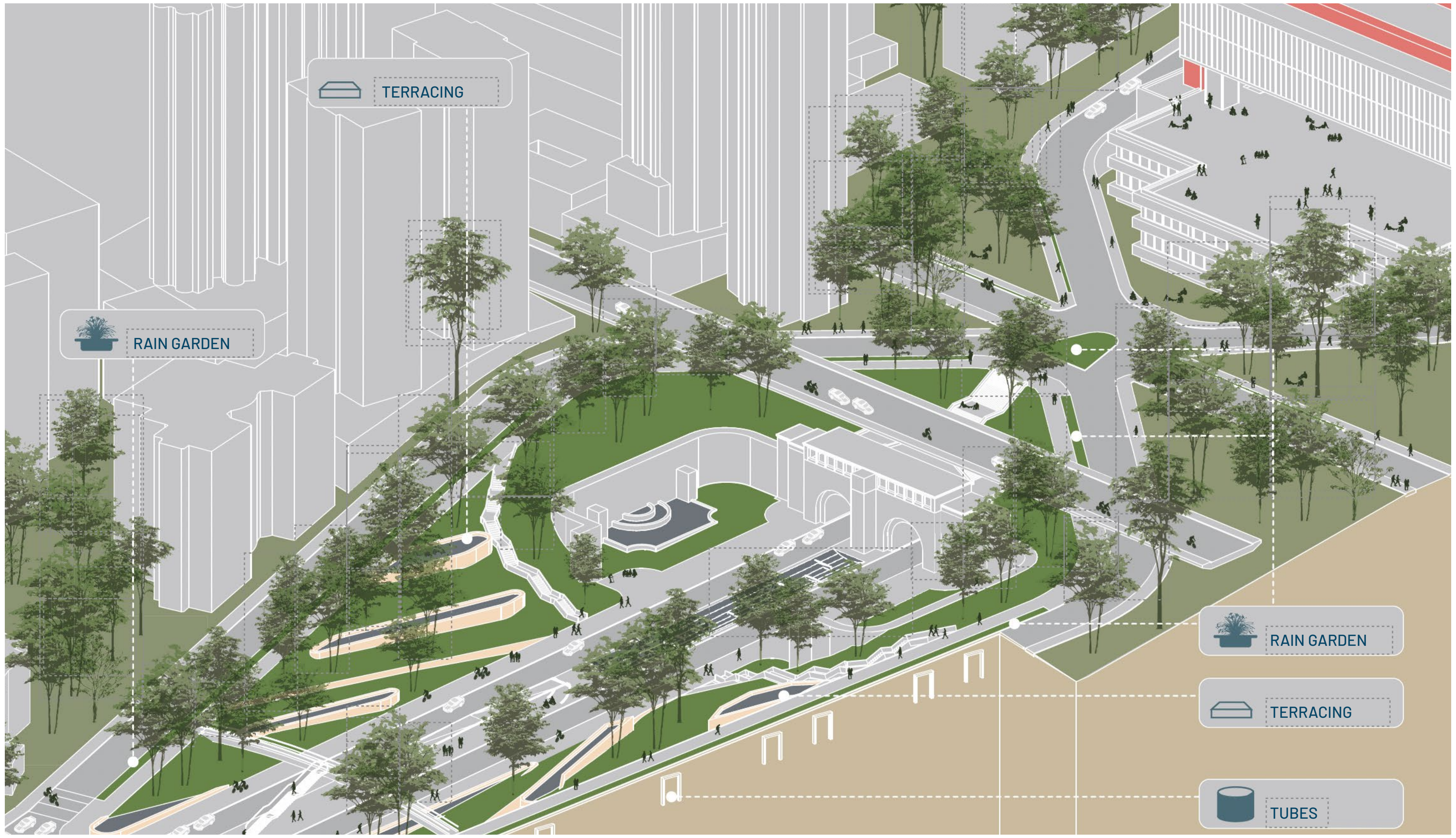


Figure 72 Details of the location of the NbS (Source: São Paulo Municipal Government, FCTH, 2021).

Table - Total accumulated precipitation in the NbS with rainfall of RT 2. For more details of the hydraulic calculations, see Gonçalves (Source: Gonçalves et al., 2018).

DEVICE	LOCATION	QUANTITY	DEPTH (m)	UNIT AREA (m^2)	TOTAL AREA (m^2)	TYPE PCSWMM - METHOD I	VOLUME OF VOIDS (m^2) - METHOD II
Underground reservoirs	Av. Nove de Julho	2	2	600	1,200	Cistern (impermeable device)	1,650
Infiltration well	R. Prof. Picarolo e Eng. Monlevada	23	5	12.25	282	Infiltration trench	1,400
Rain terraces	R. Prof. Picarolo e Eng. Monlevada	9	1	80	720	Infiltration trench	520
Rain bed	Av. Nove de Julho	1	1.3	510	510	Infiltration trench	270
Rain garden	Rotatória da R. Carlos Comenale	1	3	170	170	Rain garden	230
Bioswales	R. Prof. Picarolo e Eng. Monlevada	4	0.4	230	920	Bioswale	–
Total:		**40**		**1,602**	**3,802**		**4,070**

52 The data was calculated from the watershed diagnosis, calibrated from the PCSWMM hydraulic-hydrological model with the fluviometric monitoring data measured at the Av. Nove de Julho station, and from the NbS simulation. For details, see Gonçalves et al., 2018.

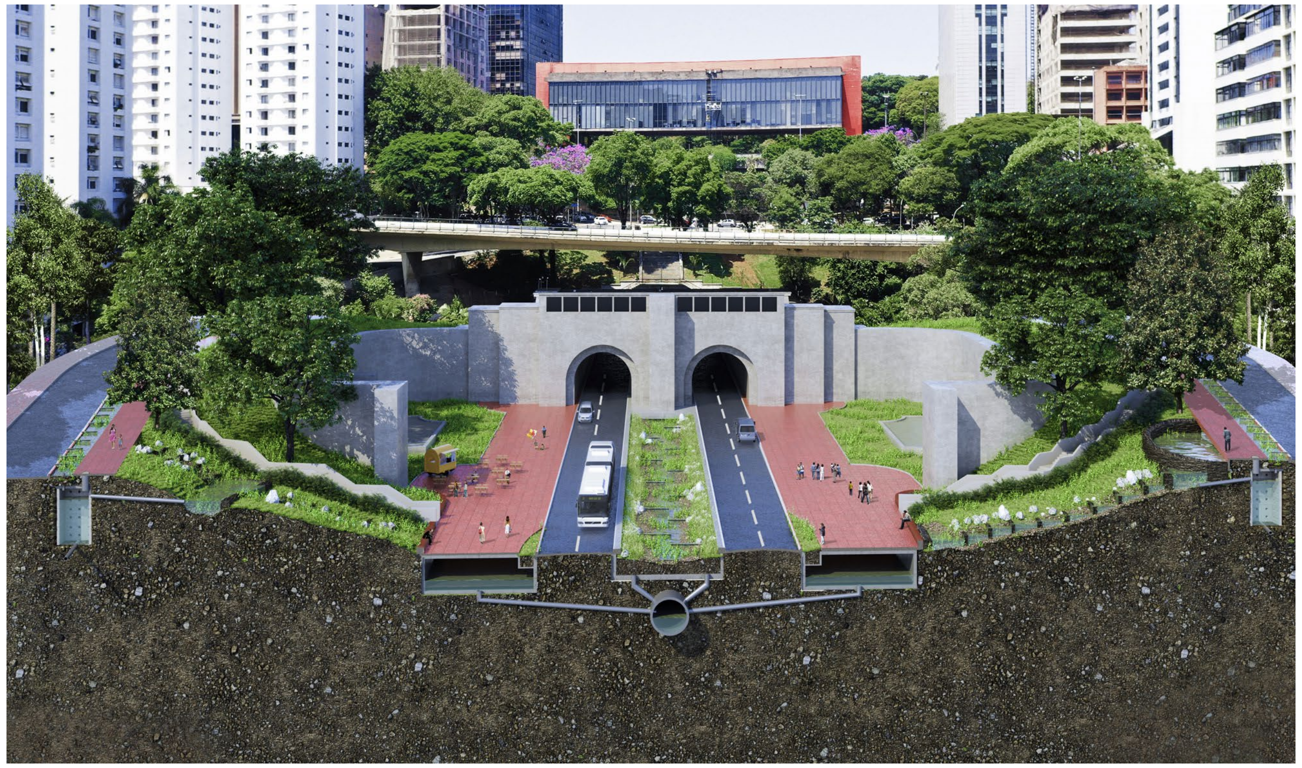


Figure 73 Project cross-section, highlighting the proposal of a new NbS: rain terrace (Source: Prefeitura de São Paulo, FCTH, 2021).

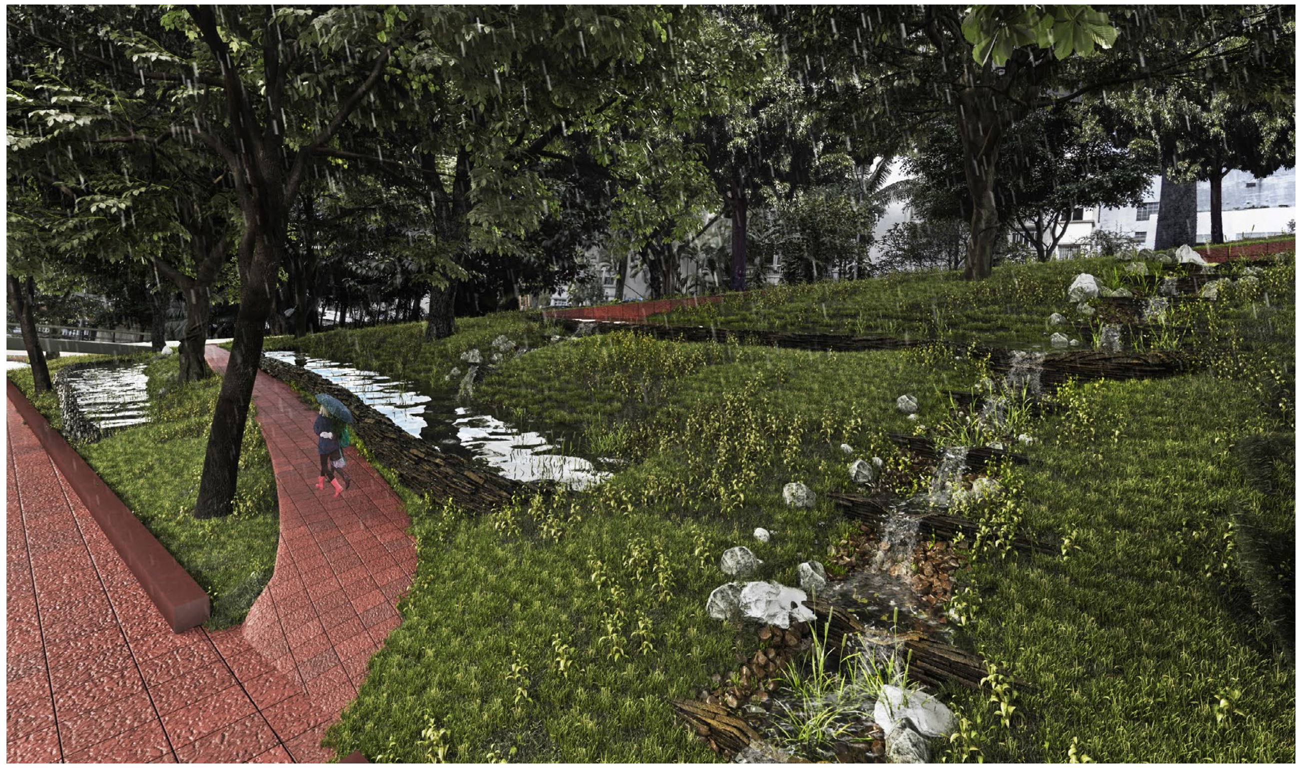


Figure 74 Perspective of the NbS, focusing on the rain terrace and bioswales (Source: Prefeitura de São Paulo, FCTH, 2021).

To promote the educational aspect of the project, paths have been added to the embankment to show the public how the model works. The site is also an important tourist attraction in São Paulo, with the Assis Chateaubriand São Paulo Art Museum (MASP) – designed by the architect Lina Bo Bardi – among its surroundings. Under the museum, where an antiques fair is held on Sundays, visitors can contemplate the proposed infiltration model. Another highlight is the Nove de Julho viewpoint, which currently houses a café that attracts many tourists seeking a view of the valley.

Figure 75 Saracura Infiltration Area showing the location of the NbS: bioswales, rain terraces, infiltration pits, rain bed and underground reservoir.

These NbS combine retention and infiltration measures, sized appropriately to provide flood abatement. Once a rainfall event has started, the rainwater runs through the bioswales located on Eng. Monlevade and Prof. Picarolo streets, where it slows down due to small barriers inserted in this NbS. The surface run-off from the bioswales will then be directed to infiltration pits located under the sidewalks and also to the bioswales on the embankments, which will conduct some of this run-off to the rain terraces.

To allow the water to infiltrate the soil, the infiltration pits are perforated on their side walls and are open at the bottom. Stones are also placed around the walls to enhance water infiltration. An outlet allows the water to flow through the pits to the rainwater gallery on Av. Nove de Julho, as well as to the terracing on the embankments.

The rain terraces, NbS located on both embankments of Av. Nove de Julho, were designed to slow down surface run-off.

The slope of the land is used to contain the water, along with a stone containment that follows the contour lines, outlining the rain terraces. When the water reaches the maximum level of a terrace, it is directed to Bioswales that take it to the next rain terrace. Once on Av. Nove de Julho, the rainwater goes to a watertight reservoir under the sidewalks on both sides of the avenue. It then passes through a filter made of coarse sand and gravel and is directed to the rainwater system. It should be noted that this reservoir is sealed, as the valley floor soil is not ideal for rainwater infiltration.

Finally, at the centre of Av. Nove de Julho, there is a rain bed with barriers is inserted to direct and slow down rainwater run-off.

To promote the educational aspect of the project, paths have been added to the embankment to show the public how the model works[53].

53 More detailed information is available in a video at: https://www.youtube.com/watch?v=pvHbSSmWyB8&t=4s.

Satellite image of the city of Belo Horizonte. Source: Google Earth.

Project in the city of

Belo Horizonte | MG

Project in the city of Belo Horizonte/MG

DATASHEET:

Lagoa do Nado rain garden
Initiative: INTERACT-BIO Project implemented by ICLEI (International Council for Environmental Initiatives), Local Governments for Sustainability and the Ministry of the Environment, Nature Conservation and Nuclear Safety of the German Government and Belo Horizonte Municipal Government.

Authors: Landscape Architecture – Guajava Arquitetura da Paisagem e Urbanismo and professors Paulo Pellegrino and Silvio Motta; Civil Engineering – Geasa Engenharia

The city of Belo Horizonte is often cited as a reference point for NbS due to its innovative initiatives and practices in the field of sustainable management of water and environmental resources. These initiatives demonstrate the social, economic and environmental benefits of integrating NbS strategies into urban planning.

One of his most iconic projects is the rain garden at Lagoa do Nado Park. Located in the north of the city, the park covers an area of approximately 300,000 m^2 and plays an important role in providing leisure facilities preserving the environment for the local population.

The choice of Lagoa do Nado Park was strategic in both technical and social terms: it is an area prone to recurrent flooding during extreme rainfall events, and it is a popular place, which increases awareness of this NbS among the local population.

The rain garden was designed to collect rainwater from the urbanised areas around the park. It retains, infiltrates and treats run-off water, minimising the risk of flooding downstream. Water percolates through the system in a series of small basins, which temporarily detain it before it gradually infiltrates into the ground or is directed into the park's existing pond.

As well as fulfilling its main function of managing rainwater, the rain garden in Lagoa do Nado Park also has other benefits. It improves water quality by filtering and treating the water using the materials and plants present in the garden. In addition, the project enhances the park's aesthetic and landscaping, integrating harmoniously into the environment and providing visitors with a pleasant space.

The rain garden at Lagoa do Nado Park is a successful example of how Nature-based Solutions can be implemented in urban areas to address rainwater management issues. It demonstrates the importance of integrating nature into urban planning to promote environmental sustainability and provide benefits for both the environment and the local community.

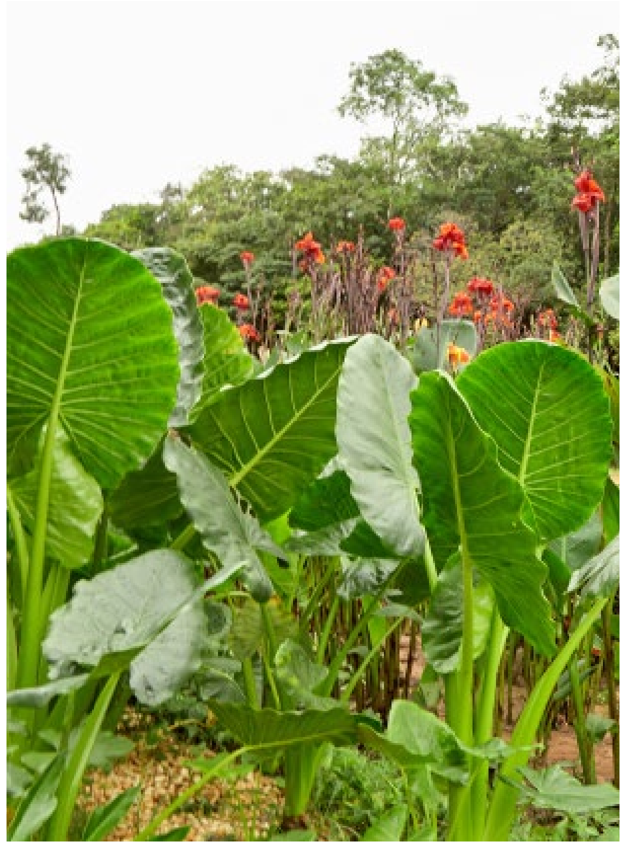
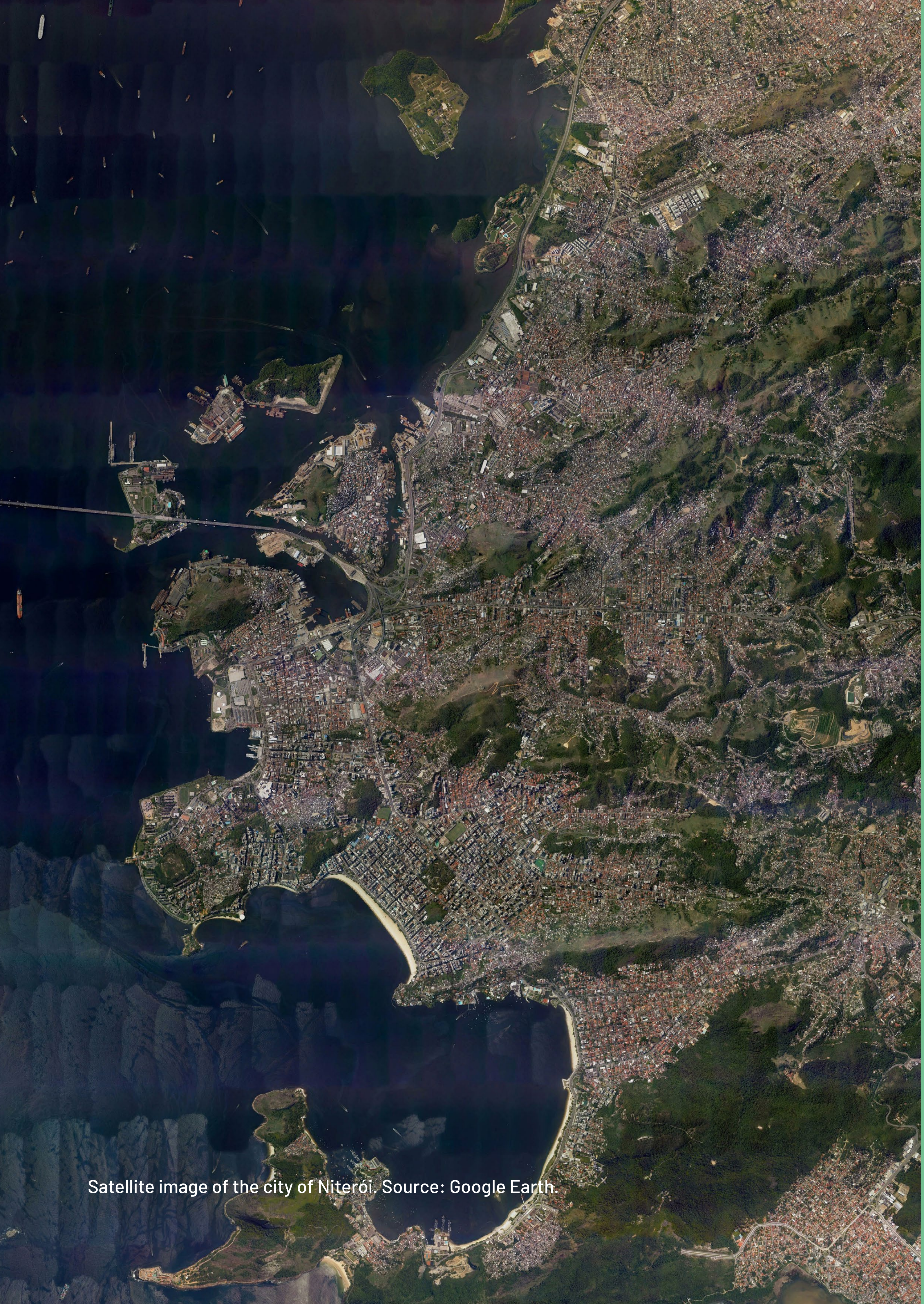


Figure 76 Photos of the rain garden in an integrated NbS system implemented in Parque Municipal Lagoa do Nado, Belo Horizonte/MG (Landscape Architecture Project by Guajava Arquitetura da Paisagem e Urbanismo, Paulo Pellegrino, and Silvio Motta; photo: Nereu Jr, 2021).



Satellite image of the city of Niterói. Source: Google Earth.

Project in the city of Niterói | RJ

Project in the city of Niterói/RJ

TECHNICAL DATA:

Piratininga Shoreline Park
Initiative: Niterói Municipal Government, Sustainable Ocean Region Program – PRO Sustentável

Authors: Niterói Municipal Government, Sustainable Ocean Region Program - Consórcio Ilhas de Piratininga (Phytorestore, Embyá Paisagens e Ecossistemas, Kaan Architecten, Village Construções)

Piratininga Riverside Park (POP) is a 680 km^2 public park built on the banks of Piratininga Lagoon. It was designed to offer the population an environment that prioritises and brings people closer to the natural world, even in an urban context. This fosters a sense of belonging to the space. The project is part of the Sustainable Oceanic Region Programme, which includes the following hubs based on territorial location: Piratininga Lagoon Hub; Jacaré Sustainable Neighborhood Hub; Beaches Hub; Itaipu-Piratininga Lagoon System Recovery Hub; Conservation Units Strengthening Hub; Bicycle System Hub, coordinated by the Niterói Bicycle Program; and the Paving and Drainage Hub, under the responsibility of EMUSA (NITERÓI CITY HALL, 2023).

POP was planned to protect and restore the ecosystems of Piratininga Lagoon and its surroundings, restore the environmental quality of its waters, and provide facilities for leisure, recreation, contemplation, culture, and environmental education. POP faces several development challenges, including the direct discharge of sewage, sediments, and contamination from diffuse pollution and solid waste reaching Piratininga Lagoon via the Cafubá, Arrozal, and Jacaré rivers.

Three constructed wetland systems were installed approximately 3 km from Piratininga Lagoon to treat the waters flowing into it from the small urban watersheds of the Cafubá, Arrozal, and Jacaré rivers (the latter of which is already undergoing renaturalisation works). Despite the Oceanic Region in Niterói having a sewage collection network channelled to two WWTPs, there are many illegal connections.

Each wetland system consists of a spillway (a large tank, averaging about 600 m^2) that receives water at the mouth of each river, a sedimentation basin, and macrophyte gardens for phytoremediation covering an area of approximately 35,000 m^2.

Water from the spillway is directed to a sedimentation basin which is designed to allow sediment to settle before the water is sent to the filter gardens. Thus, the sedimentation basins minimise diffuse pollution flowing into Piratininga Lagoon via the contaminated rivers, retaining various elements that contribute to the lagoon's siltation.

The basins require periodic maintenance, including access for vehicles and equipment to carry out maintenance work. The phytoremediation process of the waters is carried out in the macrophyte gardens. Twelve strips of macrophytes were planted in each of the three gardens, totalling approximately 12,000 m^2.

The macrophyte species absorb nutrients from organic matter through their roots and perform evapotranspiration, creating an environment within the gardens in which bacteria can break down pollutant particles (NITERÓI CITY HALL, 2023).

Figure 77 Illustrative images of the Parque Orla Piratininga project (Source: Embyá, 2019).

The filtering system was installed to assess water quality after all filtration stages and ensure proper functioning, preventing any more contaminated water with organic loads from irregular domestic sewage discharges from being released into Piratininga Lagoon. After all filtration stages from the sedimentation basin to the filter gardens, the water is released into Piratininga Lagoon. Each system was therefore installed at the mouth of a river to facilitate the treatment of effluents and sludge, making use of vegetation as a key component of the system.

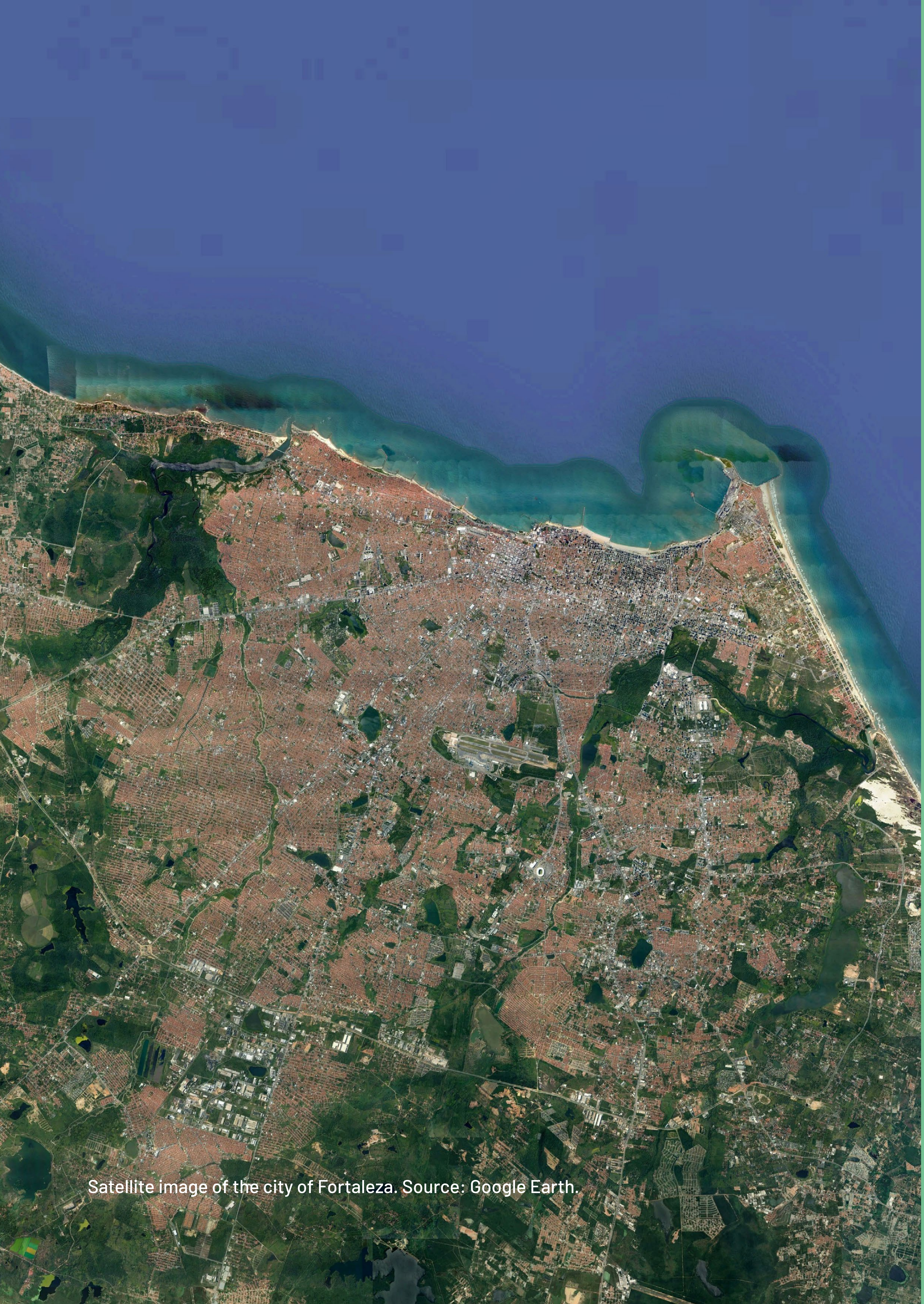
In addition to the constructed wetlands comprising spillways, sedimentation basins, and macrophyte gardens for phytoremediation, POP has 3,300 metres of bioswales acting as bioretention systems to control pollutants, increase soil infiltration, and retain water volumes. This contributes to the mitigation of flooding. These infrastructures function as drainage systems and are constructed with gravel, sand, drainage pipes, and vegetation that facilitate the drainage of stormwater.

The completed Cafubá system was the first to be planted in September 2022, in accordance with the specifications of the executive project. From the beginning of planting, maintenance actions were necessary, including desilting of the spillway, suppressing brachiarias between the gardens, adjusting the water levels in the gardens, removing vegetation that could not withstand the variation in water levels in the gardens, and removing species that emerged more quickly than expected. Monitoring conducted each month at the final exit of the filter gardens demonstrates the efficacy of water treatment and the success of the Nature-based Solutions technique.

By the time this catalogue was completed, the following had been implemented: the Cafubá system's filter gardens with planted macrophytes; the structure of the filter gardens in the Rio Arrozal and Rio Jacaré systems, but without planting; and bioswales along the stretch from Camboatá to Tibau island. Although the park's construction is not yet complete with all its systems operational, it is possible to identify environmental and social benefits. In terms of environmental benefits, the following can be noted: reduction of diffuse water pollution; habitats for native bees and other identified insects (such as butterflies and dragonflies); retention of surface run-off water in which aids the mitigation of flooding; increase in native flora biodiversity and local ecosystems; and valorisation of the park's surroundings through the changes made. Notably, the constructed wetland systems have become natural nurseries for birds and support amphibians, reptiles, and mammals in just one year of operation.

Figure 78 Parque Orla do Piratininga, Niterói (Photos: Dionê Maria Marinho Castro, 2023).

Figure 79 Parque Orla do Piratininga, Niterói (Photos: Dionê Maria Marinho Castro, 2023).


Satellite image of the city of Fortaleza. Source: Google Earth.

Project in the city of
Fortaleza | CE

Project in the city of Fortaleza/CE

DATASHEET:

Rachel de Queiroz Park
Initiative: Fortaleza Municipal Government, Fortaleza Sustainable City Program (FCS)

Authors: Landscape Architecture – Architectus S/S

The Rachel de Queiroz Park is part of the Fortaleza Sustainable City Programme, which is in turn part of the municipality's environmental policy[54].

According to the Fortaleza Municipal Government (2023), the aim of the municipal programme is to promote the integration of the natural and built environments in the city of Fortaleza, positively impacting the population's environmental health and urban safety. Thus, by investing in urban and environmental infrastructure, the capacity of municipal management is strengthened.

The requalification of the park is one of the programme's objectives. Rachel de Queiroz Park covers 200 hectares and passes through 8 neighbourhoods. The programme of works includes leisure facilities, crossings, cleaning, dredging and the restoration of the riparian forest and river, with effluent treatment through the implementation of Nature-based Solutions. The park has been divided into 19 sections, 6 of which have already been completed by the first half of 2022.

The sixth and final section is particularly worth highlighting as it is located in a flooded municipal conservation area. Prior to the interventions, this area was derelict, used as an illegal dumping ground for waste and sewage, causing various social and environmental problems. The Raquel de Queiroz Park project adopted drainage as the structuring axis for this section, taking into account its flooded/swampy nature.

To improve the water quality of the Cachoeirinha Creek - which runs through the park's terrain and has a history of frequent flooding due to the conventional rainwater drainage system being overloaded - the wetlands technique was used to filter through microorganisms attached to the soil surface and plant roots.

Even shortly after completing the works on this section, many benefits were identified in the social, environmental and economic spheres, such as: improved conditions for the development of local fauna and flora; interaction between the population and the new landscape; leisure options for the population; water depollution; and mitigation of the occurrence of flooding in the terrain and its surroundings.

Solutions that are planned to serve multiple functions and cover various needs tend to become extremely important infrastructure in different areas. This helps both the population who will enjoy the area, and the municipality, which will save on future recurring maintenance costs for cleaning water and mitigating flood damage.

54 Details of the Municipal Program are available at: https://urbanismoemeioambiente.fortaleza.ce.gov.br/infocidade/362-programa-fortaleza-cidade-sustentavel.

Figure 80 Rachel de Queiroz Park, section 6 before the interventions (Source: Archdaily, 2022).

Figure 81 Rachel de Queiroz Park (Source: Archdaily, 2022).

Satellite image of the city of Londrina. Source: Google Earth.

Project in the city of

Londrina | PR

Project in the city of Londrina/PR

FICHA TÉCNICA:

Revitalization of the source of Lake Cabrinha

Initiative: INTERACT-BIO Project implemented by ICLEI (International Council for Environmental Initiatives), Local Governments for Sustainability and the Ministry for the Environment, Nature Conservation and Nuclear Safety of the German Government and Belo Horizonte City Hall.

Authors: Landscape Architecture – Guajava Arquitetura da Paisagem e Urbanismo and professors Paulo Pellegrino and Silvio Motta; Civil Engineering – Geasa Engenharia

The project to revitalise the source of Lake Cabrinha was designed using Nature-based Solutions (NbS). It was developed as part of the INTERACT-Bio project, which is run by ICLEI South America. In Brazil, in addition to Belo Horizonte, Campinas and Londrina were the other two cities chosen to implement this initiative, promoted in partnership with the international organization ICLEI – Local Governments for Sustainability and the German Ministry for the Environment, Nature Conservation and Nuclear Safety.

Starting in October 2021, the project involved rearranging basalt rocks that had been placed in Cabrinha Lake by the Municipal Traffic and Urbanisation Company, as well as recovering its margins by planting of riparian and rhizomatous vegetation to form a containment barrier and reduce the speed of rainwater.

The stones were arranged to form small, staggered pools, with the first pool being deeper than the subsequent ones, using the step pool technique explained in this catalogue. This helps to mitigate the risk of flooding and landslides, as well as controlling diffuse pollution before it reaches the lake.

Throughout the process, the project team collaborated with the municipality to engage in meaningful dialogue with the local population and academic groups. The private sector was also involved, with companies and suppliers of materials and services in the region facilitating the implementation of the project and expanding knowledge of NbS practices in the engineering and architecture market, transforming these practices into scalable solutions.

Another notable project initiative was the promotion of environmental education work, aimed at raising public awareness and encouraging engagement in the maintaining and preserving the interventions, and in understanding the importance of the NbS.

As these examples show, it can be seen that there are several challenges in Brazil regarding the choice and approval of projects, the correct execution and maintenance of various NbS, as well as the lack of incentives and legislation to support environmental education and the replication of solutions.

However, these projects provide an overview of the application of NbS in the country and aim to encourage the use of these solutions to achieve an efficient balance between urban services, sustainability, and to reduce potential disaster risks arising from climate change and environmental degradation.

Figure 82 Lago Cabrinha, Londrina/PR (Landscape Architecture Project by Guajava Arquitetura da Paisagem e Urbanismo, Paulo Pellegrino, and Silvio Motta; photo: Meridiano Filmes, 2022).

Satellite image of the city of Sobral. Source: Google Earth

Project in the city of
Sobral | CE

Project in the city of Sobral/CE

DATASHEET:

Filtering Gardens of Riacho Pajeú, in Sobral, Ceará
Initiative: Sobral Municipal Government, through the Socio-environmental Development Program of Sobral (Prodesol), with funding from the Development Bank of Latin America and the Caribbean (CAF).

Authors: Conceptualization - Secretariat of Urbanism, Housing, and Environment (Seuma), Infrastructure Secretariat (Seinfra), and Environmental Agency (AMA). Design - Hidrobotânica Ambiental

The municipality of Sobral is located in the northern region of the state of Ceará, 232 km from the state capital, Fortaleza. The urban centre originated from a village built on the banks of the Acaraú River, which is the city's main waterway and an important element of the landscape, culture, and economy. However, in recent decades, rapid urban growth and the delayed expansion of urban infrastructure have unfortunately led to the degradation of this river and other water resources in the city.

One of the waterways that feed the Acaraú River is the Riacho Pajeú. Originally, it was an intermittent flow stream that became perennial over time due to the improper discharge of effluents and grey water along its course. It crosses four populous neighbourhoods in Sobral, reaching more than 50,000 people, and two urban parks — Pajeú Park and City Park.

Due to the improper discharge of effluents and grey water along its course, the Pajeú flows into the Acaraú River with a high concentration of organic matter. Through biochemical processes, this reduces the water's oxygen content and affects the local fauna and flora. Additionally, these processes produce greenhouse gases and unpleasant odours. Thus, the Riacho has become a potential pollutant of the Acaraú.

Despite the Pajeú catchment area having a sewage collection system that directs effluents to treatment stations, numerous households are not properly connected to the network and/or have illegal connections that discharge their effluents and grey water directly into the regional stormwater network, thereby contributing to pollution of the stream.

The waters that reach the stream via the stormwater drainage network have a high concentration of pollutants, which can be measured by various parameters, including Biochemical Oxygen Demand (BOD). According to a 2018 study, the BOD values of the Riacho Pajeú were 110 times higher than those recommended by the National Environmental Council (CONAMA).

To address water pollution, various interventions are necessary, the most traditional of which are expanding the sewage collection and treatment network and combatting illegal connections to the urban stormwater network — interventions also implemented by Sobral.

In 2018, faced with the challenge of improving the environmental quality of this water resource in Sobral, City Hall began planning the Filtering Gardens project of Riacho Pajeú, with the goal of providing an ecological, aesthetic, and economical alternative for depolluting the stream and soil.

Figure 83 Filtering Gardens of Riacho Pajeú, Sobral (Source: Prefeitura Municipal de Sobral, 2023).

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The project involves implementing wetlands, known in Brazil as constructed wetland systems and natural wetland systems, which use bio-phytoremediation to depollute the water body.

Constructed wetland systems are excavated areas of natural terrain and/or landfills that are water-proofed and filled with porous substrate to form a constructed wetland into which plant species are introduced. Through the porous medium filling the wetland, the effluent slowly travels its entire length, allowing the transformation of existing organic and inorganic elements. In addition to removing the chemical elements transformed into minerals by microorganisms from the medium, plants return oxygen to the aquatic environment and promote the desired treatment of grey water through biochemical processes. Natural wetland systems use naturally flooded areas for effluent treatment by implementing interventions that improve and/or increase the natural capacity of these areas to perform the necessary biochemical processes for water treatment.

In this context, 12,000 m^2 of filtering gardens were constructed, covering 1.19 km in total. This involved excavation, waterproofing, and construction work, as well as the planting of specific vegetation for filtering and effluent treatment. As water levels travel through the Filtering Gardens of Riacho Pajeú by gravity, the process is cheaper and easier to maintain, as pumping it not required.

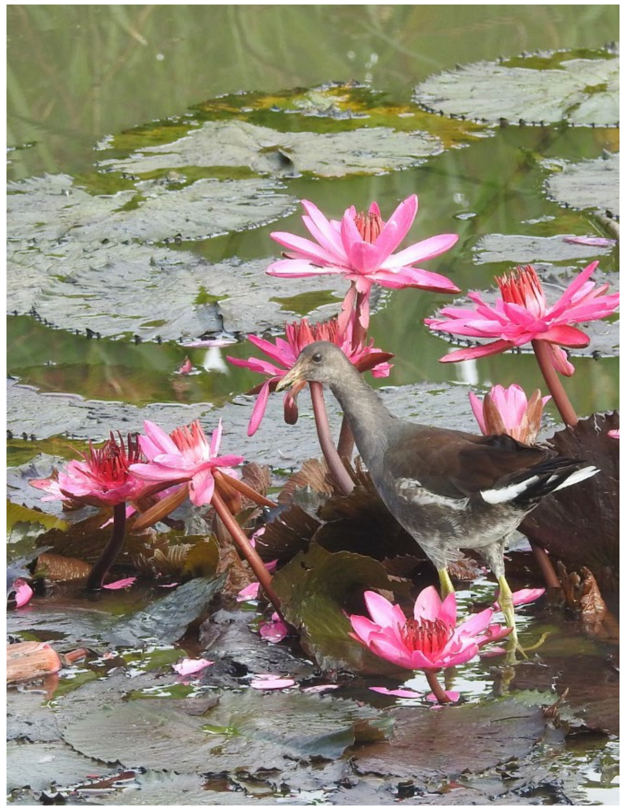
The project was conceptualised by Sobral City Hall through the Secretariat of Urbanism, Housing, and the Environment (Seuma), and designed by the Hidrobotânica Ambiental office. The Infrastructure Secretariat (Seinfra) was responsible for execution. It was realised through Loan Agreement – CFA 10569, signed between the Sobral City Hall and the Development Bank of Latin America and the Caribbean (CAF), as part of the Socio-environmental Development Programme of Sobral (Prodesol). At the time, the implementation costs were around R$ 2.3 million. The operation and maintenance of the Filtering Gardens is carried out by the Municipal Environmental Agency (AMA), which systematically performs cleaning, pruning, planting, and maintenance services, as well as collecting water samples for monthly laboratory evaluation.

Once the construction was complete, the Filtering Gardens underwent a phase of densification and diversification of vegetation in both the constructed tanks and in the natural wetlands of the Riacho Pajeú riverbed. As a result, by the end of 2020, the year of its installation, cleaner and odourless water was flowing out of the 14 constructed tanks.

In addition to the improvement in water quality observed, the solution also benefited the recovery of local fauna, transforming the streambed and park areas into a habitats for animals. The vegetated tanks are home to many birds that use the project space as part of their habitat. The presence of wildlife indicates that the gardens are well integrated into the natural ecosystem.

Alongside the implementation of the Filtering Gardens, interventions also took place in the parks crossed by the stream. These included the renovation and requalification of the City Park and the construction of Pajeú Park. This has improved urban quality in the region in a broad and connected

Figure 84 Samples collected before and after treatment (Source: Prefeitura Municipal de Sobral).



way. The parks received courts for sports courts, kiosks, playgrounds, urban furniture, bike lanes, and marked bike paths. The City Park was even equipped with a BMX track.

From a social perspective, the residents of Sobral, particularly those living near the City Park and Pajeú Park, have embraced and utilised the parks for sports and leisure activities. Educational activities are developed in the park area through visitors, schools, and universities, with the aim of exchanging experiences and developing potential research and extension projects.

The Filtering Gardens' planning and construction process promoted significant learning for the technical staff of the various secretariats involved in the project, as they began executing and operationalising a new technology implemented in Sobral's public areas.

Figure 85 Population and visitors at the Filtering Gardens of Riacho Pajeú (Source: Prefeitura Municipal de Sobral, 2023).


Mangal das Garças ecological park in Belém, Pará, landscape architect: Rosa Kliass (Photo: J Brarymi, 2022)

Closing remarks

This catalogue presents a method for selecting NbS in public open spaces. It brings together technical information, application examples and the ecosystem services provided, as well as the challenges of implementing them.

NbS play an important role in urban development, aligning with the contemporary objectives for resilient, sustainable and biophilic cities. It is important to remember that plans and projects for the urban environment must consider its complexity and socio-environmental characteristics, incorporating and connecting NbS alongside other ecosystem elements and processes, such as urban afforestation from an infrastructural and systemic perspective.

Societal participation in the formative process of a socio-environmentally focused culture is always a major factor in the success of the implemented plans and projects. This is a right of the population and contributes to the creation of more imaginative and responsive public open spaces.

Finally, it is hoped that this material can contribute to the training of public managers and other actors interested in promoting sustainable development for cities, bringing together information that will help decision-making, increase the resilience of the urban environment and provide society with efficient, nature-inspired solutions and with social, environmental and economic benefits.

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