A CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN RESILIENCE

GFDRR
Global Facility for Disaster Reduction and Recovery
WORLD BANK GROUP
GLOBAL PROGRAM ON NATURE-BASED SOLUTIONS FOR CLIMATE RESILIENCE

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Vegetated slopes and upland forests in Sarvelat, Gilan, Iran
Photo by Mojtaba Hoseini on Unsplash

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A dense tree canopy in Hanoi, Vietnam
Photo by Raissa Lara Lütolf on Unsplash

Acknowledgments

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in collaboration with: felixx LANDSCAPE ARCHITECTS & PLANNERS

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A meandering river with a dense riparian forest in Ivanovo Oblast, Russia
Photo by Alexandr Bormotin on Unsplash

Foreword

More than half of the world's population lives in cities, and that number is rising every day. Urban areas are becoming more crowded, corrosively reducing green spaces within cities, and causing loss of biodiversity, and in turn, affecting people's mental and physical well-being and exposure to disaster impacts. At the same time, cities are facing growing climate-related challenges. Climate change and urbanization are exacerbating disaster risks, and these risks are affecting the poor and the vulnerable the most. By protecting natural systems and investing in green infrastructure, cities have the opportunity to build resilience and protect development gains for future generations.

Globally, the interest in nature-based solutions (NBS) or using nature for climate resilience, is growing. Key international agreements, such as the Sendai Framework for Disaster Risk Reduction, the Paris Climate Agreement, and Sustainable Development Goals, underline the importance of NBS as dependable approaches that address climate change. Nature-based solutions also contribute to people's well-being and support biodiversity, as well as remove carbon dioxide from the atmosphere as noted in the Sixth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC), which provides an additional rationale for investment.

The World Bank has a growing portfolio of NBS investments for disaster risk management and climate resilience, which amounted to nearly US$5 billion between 2012 and 2020. In Beira, Mozambique, a 17-hectare, multifunctional urban green park along the Chiveve River was financed by the World Bank to provide various recreational and economic opportunities for residents, while also restoring the river's natural ability to retain water and mitigate floods. In Freetown, Sierra Leone, a community-based reforestation project—to combat deforestation and its accompanying loss of biodiversity, and counter the severity of natural hazards—has created more than 550 jobs to support local economies impacted by the COVID-19 pandemic.

Despite the growing demand for NBS in cities, many people who make planning, financing, and technical decisions for urban resilience building have little knowledge of when and how to build with nature. It creates a need for better guidance, more real-world examples that illustrate how such approaches have worked, and technical assistance to help support more cities identify potentially viable nature-based investments that help cities address resilience challenges.

Thus, this Catalogue of Nature-based Solutions for Urban Resilience was created as a resource for those aiming to shape urban resilience with nature. The Catalogue was jointly launched by the Global Program on Nature-Based Solutions for Climate Resilience and the City Resilience Program, both housed in the Global Facility for Disaster Reduction and Recovery (GFDRR). Developed with a specialized cohort from Felixx Landscape Architects and Planners, Nelen & Schuurmans, Rebel, UNStudio, and UNSense, and a team of experts from the Word Bank, the Catalogue provides good practice examples, design, benefits, and implementation considerations. It gives insight to the suitability of NBS in the urban landscape and their effectiveness for climate resilience.

We hope that this Catalogue will support the identification of potential investments, start policy dialogues on NBS in cities, and inspire any person—policy maker, project developer, development professional, urban planner, engineer, or ecologist—to work with nature to address urban resilience challenges.

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Practice Manager GFDRR
World Bank

A green corridor runs parallel to railway infrastructure in Hanoi, Vietnam
Photo by Hoach Le Dinh on Unsplash

Chapter 01
Introduction

1.1 The Urban Resilience Challenge

Cities worldwide are facing resilience challenges as climate risks interact with urbanization, loss of biodiversity and ecosystem services, poverty, and rising socioeconomic inequality. Extreme precipitation events, flooding, heatwaves, and droughts are causing economic losses, social insecurity, and affecting wellbeing. Over time, urban resilience challenges are expected to grow, driven by processes such as urbanization, land use, and climate change. Whereas climate change is expected to increase the frequency and intensity of some natural hazards, urbanization can also lead to higher exposure of people and assets in cities.

More than half of the global population lives in cities, and more than 70 percent are expected to do so by 2050 (Wijesiri et al. 2020; Nerini et al. 2018). In rapidly urbanizing areas, a significant proportion of urban growth risks to materialize in dense, lower-quality unplanned settlements. In these vulnerable areas, climate impacts are exacerbated—now and into the future—as these settlements are often located in high-risk areas, such as on floodplains or steep slopes (Hallegatte et al. 2017). In addition, poorly maintained infrastructure, such as drainage systems, and impervious surfaces can increase the magnitude of natural hazards, such as flooding and urban heat island effects.

The World Bank has a growing portfolio of investments and analytical engagements in urban resilience. In the past, structural interventions to reduce disaster risk and build climate resilience have largely focused on gray infrastructure. However, gray infrastructure will not always be suitable in cost-effectiveness, resiliency, or sustainability. More than ever, nature-based solutions (NBS) are recognized to have a critical role in addressing resilience challenges urban areas (*box 1-1)*. The need to advance nature-based approaches is endorsed by many international agreements and initiatives such as the Sendai Framework for Disaster Risk Reduction, the Sustainable Development Goals (SDGs), and the Paris Climate Agreement. These agreements support an alignment of environmental and risk management goals to address the burgeoning needs of managing climate risk, to confront environmental degradation, to improve the adaptive capacities of vulnerable communities, and to advance public and private investment in disaster risk prevention and reduction (Reguero et al. 2020).

Box 1-1: Definitions

1. Gray infrastructure *refers to built structures and mechanical equipment, such as reservoirs, embankments, pipes, pumps, water treatment plants, and canals. These engineered solutions are embedded within watersheds or coastal ecosystems whose hydrological and environmental attributes profoundly affect the performance of the gray infrastructure. (World Bank and World Resources Institute. 2019.)*

2. Nature-based solutions (NBS) *is an umbrella term referring to "actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits." (Cohen-Shacham et al. 2016.)*

1.2 Nature-based Solutions

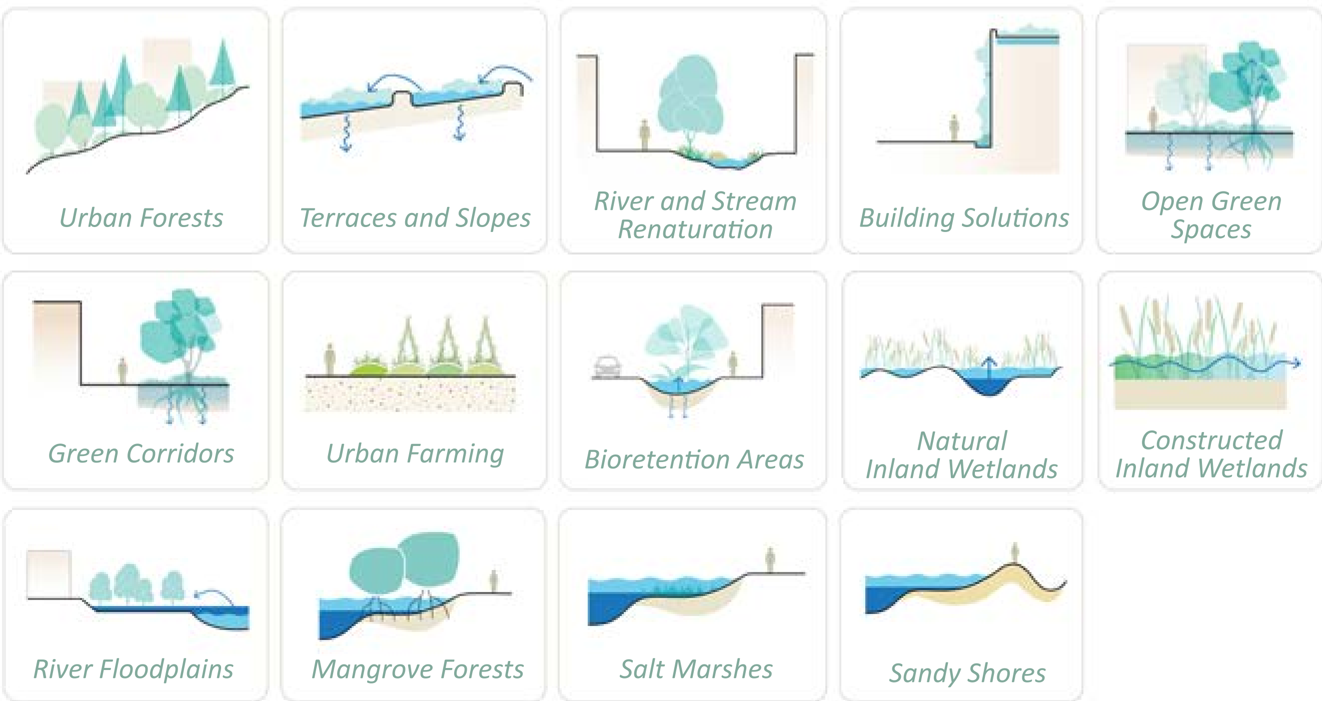
Nature-based solutions are approaches that use nature and natural processes for delivering infrastructure, services, and integrative solutions to meet the rising challenge of urban resilience. These interventions usually go beyond sectoral boundaries and require cross-sectoral partnership. NBS can provide multiple benefits to cities and address different societal challenges, including reducing disaster risk and building climate resilience, while also contributing to restore biodiversity, creating opportunities for recreation, improving human health, water and food security, and supporting community wellbeing and livelihoods.

NBS use a set of structural and non-structural interventions that protect, manage, restore, or create natural or nature-based features. Alongside other benefits, NBS can reduce the impact of natural hazards in cities, such as flooding, erosion, landslides, drought, and extreme heat (Ozment et al. 2019; Sudmeier-Rieux et al. 2021). They can also complement gray infrastructure such as storm drains, embankments, and retaining walls. In many cases, integration of NBS has proven to be cost-effective (Raymond et al. 2017).

Nature-based solutions for urban resilience can be applied across spatial scales and settings in and around cities. Examples include small scale green spaces on buildings, bioswales, and green corridors along streets and water bodies, urban parks and forests within city boundaries, and larger areas with wetlands and forests upstream or along the coast, sheltering cities from flooding and improving availability and quality of water. Figure 1-1 includes an overview of common NBS typologies.

A momentum is growing for NBS as a vehicle for delivering green resilient and inclusive development, especially in the context of economic recovery from the COVID-19 pandemic. Demand and interest from World Bank clients in investing in NBS is steadily rising. Since 2012, the World Bank's portfolio of NBS investment projects contributing to climate resilience is worth nearly 5 billion USD. NBS investments have increased especially sharply in the last three years, 2018–2020, when the total number of NBS-lending projects rose by 35 percent.

Figure 1-1: *Diversity of nature-based solutions for urban application*



1.3 A Catalogue to Support the Identification of Urban NBS Investments

The Catalogue of Nature-based Solutions for Urban Resilience has been developed as a guidance document to support the growing demand for NBS by enabling an initial identification of potential investments in nature-based solutions. Consolidating insights of the performance and benefits of the 14 NBS typologies—hereafter "NBS families"—presented in figure 1-1, intends to support policy makers, project developers, development professionals, urban planners, and engineers with the identification of potential NBS investments, and to start a policy dialogue on NBS in cities.

Two key questions in the initial scoping of nature-based solutions potential are: (i) What are the desired benefits from the NBS? and (ii) Is the NBS suitable at the location? To help answer these two questions, the Catalogue provides: (i) technical descriptions, visualizations, and examples to better assess the potential of NBS in urban areas; (ii) unit costs and benefits' estimates to help assess the economic viability; and (iii) suitability considerations to provide guidance on possible locations for NBS (see also *figure 2-1*). The Catalogue focuses mainly on nature-based solutions for flood and heat risk management in urban areas, but it also provides insights for other social and environmental benefits of NBS.

This Catalogue complements and builds on other knowledge products on NBS developed by the World Bank (Jongman and Ozment 2019; World Bank 2017; Browder et al. 2019) to support the integration of NBS in investment projects. The document represents a selection of prevailing thinking around urban NBS in a quickly evolving and growing field.

The document is structured as follows: Chapter 2 describes generic principles for integrating NBS into urban environments. Chapter 3 provides a reader's guide and holds the Catalogue of the 14 NBS families that include: *Urban Forests, Terraces and Slopes, River and Stream Renaturation, Building Solutions, Open Green Spaces, Green Corridors, Urban Farming, Bioretention Areas, Natural Inland Wetlands, Constructed Inland Wetlands, River Floodplains, Mangrove Forests, Salt Marshes, and Sandy Shores.*

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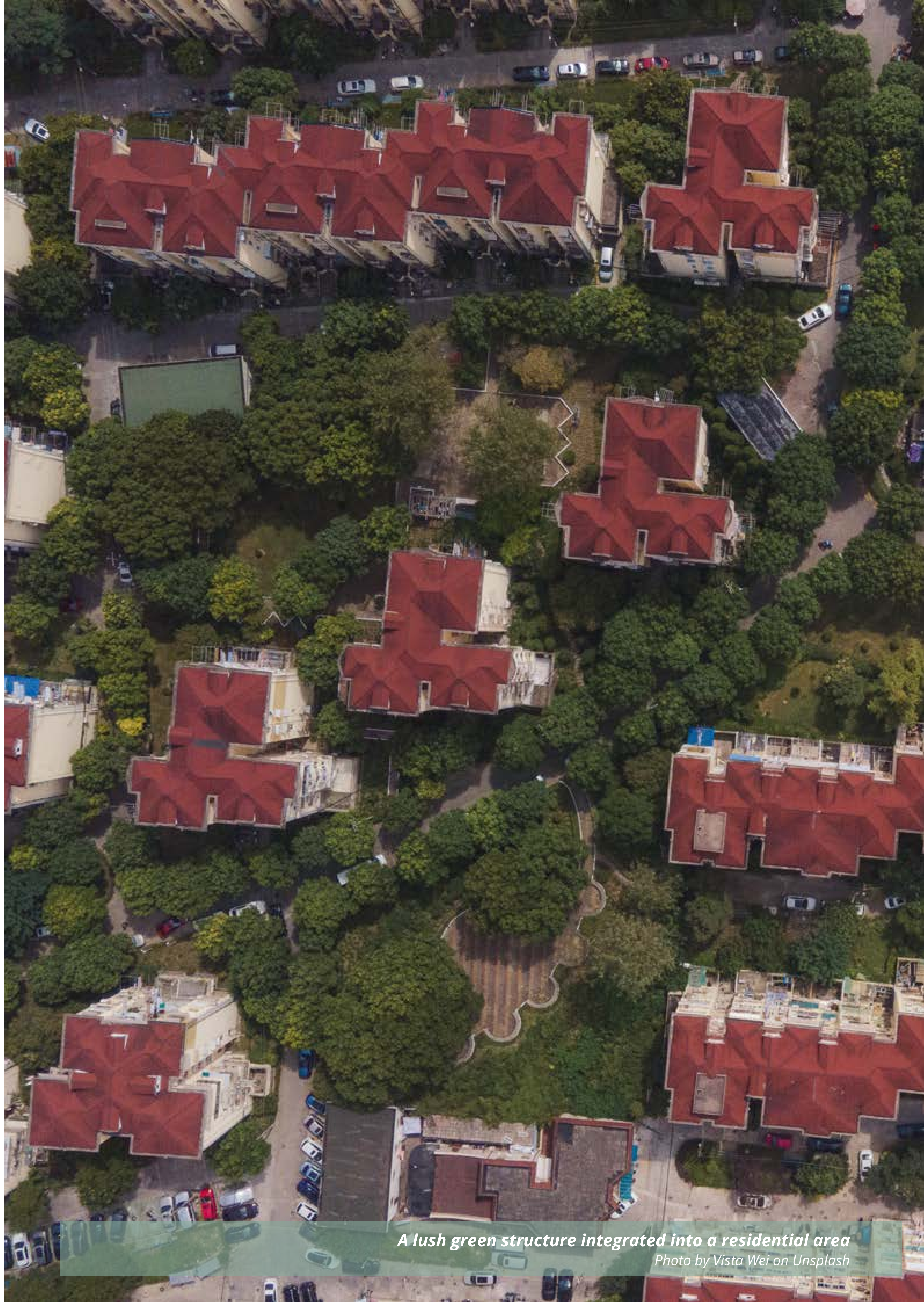


A lush green structure integrated into a residential area
Photo by Vista Wei on Unsplash

An urban park in Nairobi, Kenya
Photo by Zac Wolff on Unsplash

Chapter 02

Integrating Nature-based Solutions for Urban Resilience

The urban landscape is an interconnected system. The built environment functions as a system that modifies the local hydrology and climate, and hence, influences the frequency and intensity of hydrometeorological natural hazards. At the same time, the built environment can often hinder large-scale NBS because of space constraints. Critical considerations can be defined that enable the integration of NBS in the urban landscape. One enlightened approach, for example, would be that project developers and planners follow an approach of "green where possible, gray when needed".

This chapter describes five important principles for the integration of NBS in cities—that hold good for all NBS families in the Catalogue—and that can guide the identification and realization of potential investments in NBS:

1. Assess the functions, benefits, costs, and suitability considerations of NBS
2. Apply an integrated systems approach to NBS for resilience in urban landscapes
3. Consider the principles of ecosystem conservation by adopting a hierarchy of ecosystem-based approaches
4. Consider the integration of NBS across a range of spatial scales
5. Adopt a multistakeholder and interdisciplinary approach

2.1. Assess the Functions, Benefits, Suitability Considerations and Costs of NBS

Assessments on functions, benefits, location suitability, and costs of NBS enable an initial identification of locations of potential investments. It increases understanding of the socioeconomic values of NBS and helps identify locations where environmental, technical, or urban conditions are suitable for NBS *(figure 2-1)*. In the Catalogue, this information is provided for every NBS family.

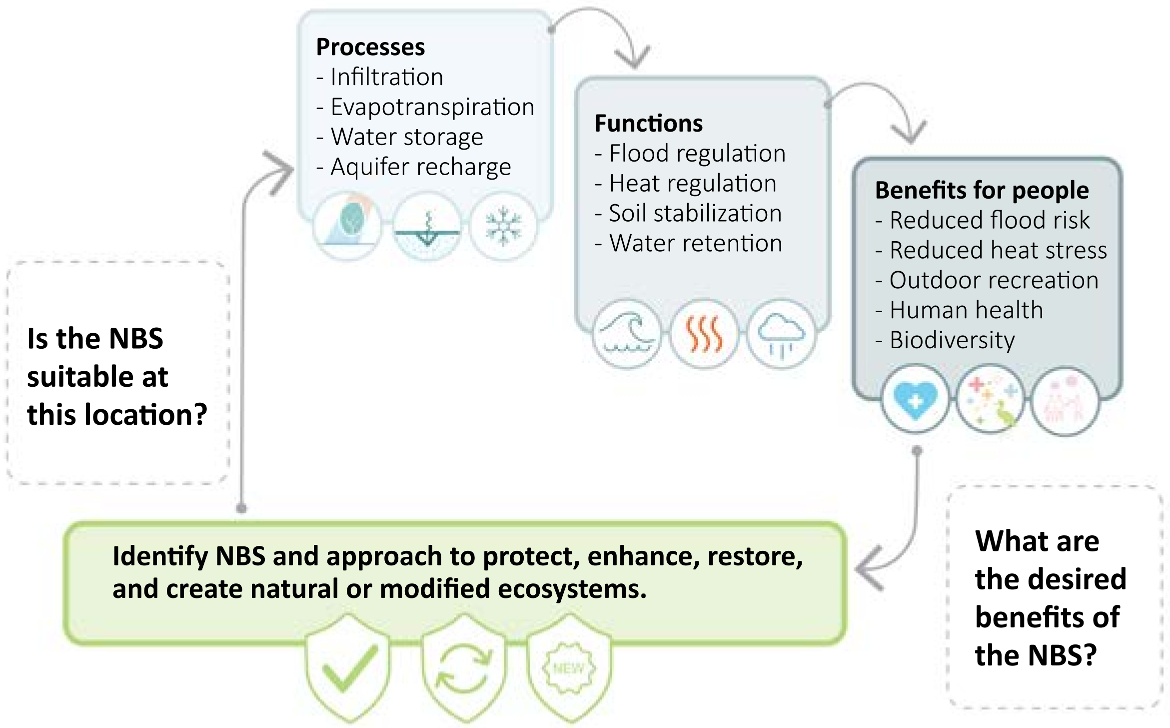
Functions, benefits, and suitability considerations

Each NBS is characterized by a set of processes that defines their functions and the benefits they provide. Processes of NBS may involve stormwater infiltration and evapotranspiration. ‘Functions’ refer to the capacity of NBS to provide benefits to people. For example, NBS can regulate flooding or reduce extreme heat, stabilize soils, or improve water quality. These functions are an important intermediate step for understanding the value, or benefits, of NBS for people. ‘Benefits’ are provided if there are people who directly or indirectly benefit from NBS functions. This, for example, includes reduced flood damages, reduced heat stress, or the use of green space for recreation.

In comparison to gray infrastructure, NBS provide a variety of benefits to society such as flood risk reduction, heat stress reduction, human health, recreation, tourism, and biodiversity. Often, the full suite of benefits that NBS offer represents an important factor in decision making. In the Catalogue, each NBS family includes a visualization of their processes, a section describing its functions, and a section with its benefits described qualitatively *(box 2-1)*.

Considerations on locations of NBS can help in understanding whether an NBS could be suitable at a location in or around a city, which may, for example, depend on the local climate, terrain, available space, or maintenance needs. These location suitability considerations are subdivided in the Catalogue in environmental, technical and urban categories.

Figure 2-1: *A framework to support the first identification of potential investments in NBS*



Note: *The information per NBS family is organized to provide an understanding of the processes, functions, benefits, and location suitability of NBS. The lists in the boxes are examples and not intended to be exhaustive.*

Box 2-1: Benefits assessment is important for identifying project financing

After the scoping phase and identification of NBS (and beyond the scope of this Catalogue), a thorough assessment of the benefits and beneficiaries of NBS is critical for the identification of financing options. The principal sources of funding are based on sustainable revenues derived from tariffs, taxes, or transfers that determine how investment costs are repaid over time, while also supporting project life cycle costs. Governments have traditionally played a key role in providing economic and social infrastructure, both as financier and by establishing the enabling policies and regulations. However, public investments alone are often not sufficient, given the size of investment required to meet future challenges relating to building urban resilience. Valuation of a broad range of benefits can provide opportunities to leverage a wider array of financing options that can help promote the application of nature-based solutions and continuous improvements in the quality of life and urban landscape. Based on the potential benefits and beneficiaries identified, different financing mechanisms and sources can be adopted and leveraged (Wishart et. al. 2021).

Costs

For each NBS type, the Catalogue outlines key cost considerations for the investment and implementation stage, such as land-related costs, NBS construction costs, or longer-term maintenance costs. In addition, examples of unit costs are provided. However, such unit cost estimates should only be taken as indicative, as NBS costs may vary significantly across locations *(box 2-2).* Factors that influence costs include, for example, the approach taken by the project—protection, rehabilitation/restoration, or creation—and numerous other economic, environmental, and project-level labor and material costs.

• Upfront costs

Upfront costs of NBS include costs associated with securing the land upon which the NBS will be installed and costs for planning, installing, and overseeing the effective implementation of NBS measures.

Land-related costs of implementing NBS are dependent on: the extent of land the extent of land area required for the NBS, which is sometimes large; whether land must be purchased to implement the NBS; and, if land must be purchased or otherwise obtained for use; whether the land is held publicly or privately; and the relative value of the land. Land values are driven by the opportunity cost of using the land for NBS versus other purposes—agricultural cultivation; residential or commercial development; open space or recreation—and beneficial uses to which the land could be put. Land-related costs in a Developing Country context are in part generated by necessary engagement and collaboration with multiple stakeholders to secure land acquisition or use, and must consider social safeguards and social inclusion of local communities, especially regarding indigenous peoples and women.

NBS installation or implementation costs are driven by labor and materials needed for the project. The type of NBS and site-specific factors such as local materials, topography, preparatory works required, hydrological conditions, transportation, or access to the correct types of trees and plants to be used.

• Maintenance costs

Maintenance costs are the actions required to maintain a functional NBS, providing the benefits it was designed for. Maintenance costs include routine monitoring or inspection to determine necessary maintenance actions, and implementation of these maintenance activities on a regular basis. NBS maintenance activities may include enforcing area protection avoiding encroachment, removal and disposal of debris and dead plant material; weeding; pruning or thinning; removal of invasive species; replanting; and fertilizing. Effective maintenance actions are critical to NBS project sustainability and success and require upfront planning and long-term funding to realize.

Box 2-2: Key cost-related caveats

Actual project-level NBS costs may differ from the example unit cost estimates provided in the Catalogue for the following reasons:

NBS project costs vary significantly and are highly site- and project-specific. Unit costs will also vary over time with changing land, labor, and materials prices. In addition, economies of scale may be present with larger projects, leading some unit cost estimates to overestimate potential projectwide costs.

Many unit cost estimates in the literature are derived from developed countries, where unit costs may be much higher than in the developing country context due to higher labor and materials costs and other location-specific costs. For example, one source lists the costs of dredging as US\$2/ m^3 in Bangladesh and US\$59/m^3 in *the UK (Aerts 2018). Costs from the developed world may be therefore limited in their ability to represent actual costs in developing countries.*

Unit cost estimates associated with implementing NBS in rural areas may be lower than in urban areas given the higher transaction costs that typically accompany urban projects (for example, municipal zoning and permit or construction requirements; larger numbers and greater density of landowners and fragmented landownership; larger number of stakeholders requiring engagement) and frequently higher costs of labor and materials in urban areas.

Unit cost estimates in the literature vary depending on the components the project included—for example, land acquisition, construction technique, types of materials, maintenance needed—. Some estimates bundle multiple components together, which makes difficult to isolate and compare upfront costs from other longer-term sources of project cost.

2.2. Apply an Integrated Systems Approach to NBS for Resilience in Urban Landscapes

Nature-based solutions aimed to increase urban resilience are often most effective when approached and planned in an integrated or holistic manner, especially in complex urban environments. This means first taking a system-based approach to address resilience and biodiversity challenges, and then, seeking practical ways to integrate NBS into policies plans, programs, and projects.

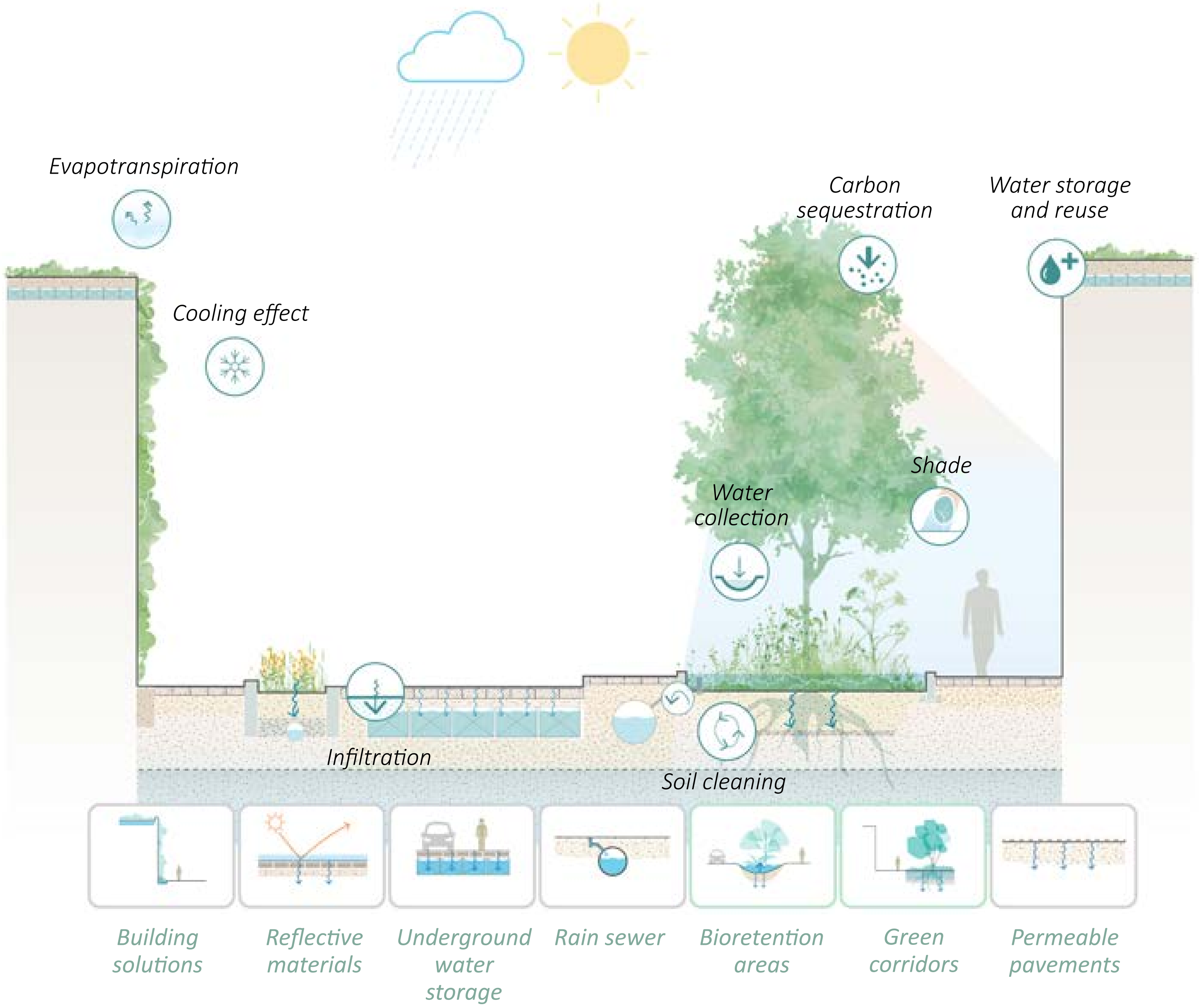
Taking an integrated systems approach also means that NBS should not be designed independently, but rather to complement and strengthen existing risk management interventions. NBS can, for example, augment and complement existing gray infrastructure, gradually increasing the overall capacity of the system, and its efficacy and efficiency on risk reduction and co-benefits to the urban landscape. Such integration is not only necessary at a system level, but should also be considered at a local scale where hybrid solutions—a combination of nature-based features and gray infrastructure elements—may provide the most efficient solution *(figure 2-2).*

Consequently, NBS can be integrated into broader programs, such as risk management plans, plans for designs of structural measures, proactive urban and land use planning, evacuation management, and sustainable maintenance. As most NBS are multifunctional, they can perform a variety of functions at different scales, and respond to several resilience demands, such as managing flooding and extreme heat effects, at different times. For example, the same NBS implemented as part of a larger systems approach can retain, filter, and convey water protecting cities from floods as well as droughts. A hilly area with loose soils, debilitated from water damage and erosion, can benefit from an appropriately designed slope stabilizing NBS, while at the same time retaining runoff and conveying water down to the areas where it is needed (Jha et al. 2012).

With the alarming levels of biodiversity loss, cities also have a responsibility to contribute to global efforts to restore, strengthen, and enhance biodiversity. In practice, this involves ensuring that critical biodiversity areas are protected and effectively managed, and that ecological networks are enhanced to promote the movement of wildlife that is necessary for dispersing, foraging, and maintaining genetic diversity. Planning of ecological networks is therefore critical in cities where NBS can be used to provide supplementary habitat. Optimizing these benefits does, however, require an understanding of the local ecology including temperature, rainfall, soils, and the selection of naturally occurring plant species for their use in NBS projects.

While resilience and biodiversity benefits are key in NBS design, it is often the variety of co-benefits contributing to human wellbeing that supports the value proposition over gray infrastructure alternatives. These include aesthetic benefits that make neighborhoods more attractive to urban residents and cultural benefits including opportunities for relaxation and recreation. The longevity of NBS also requires the support of local communities and as such, warrants a need to integrate local community needs and aspirations into planning to ensure that interventions are supported and maintained in the long term.

Figure 2-2: *Example of a hybrid solution integrating green and gray infrastructure*



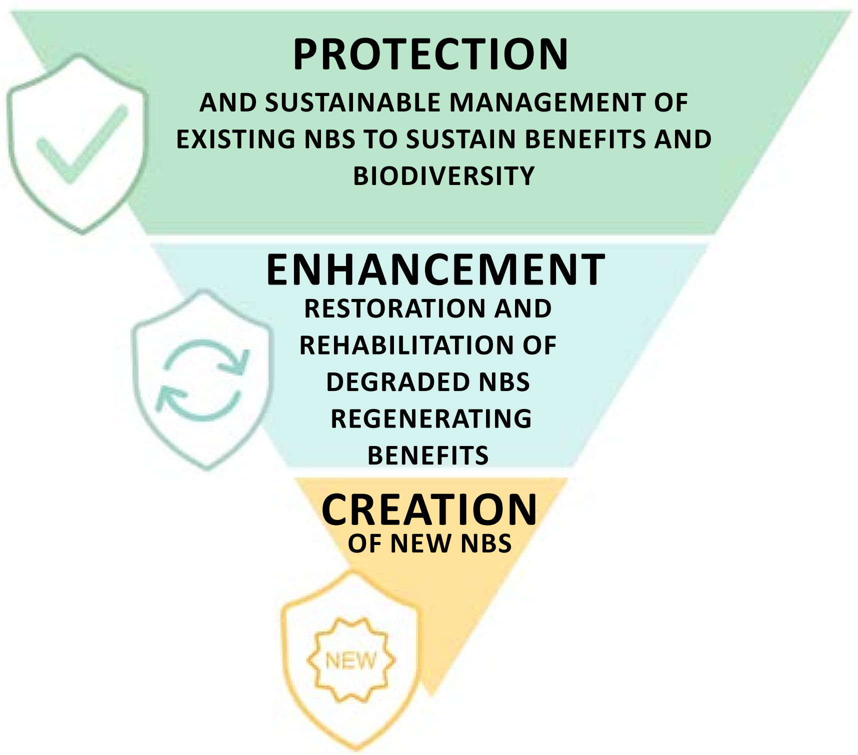
2.3 Consider the Principles of Ecosystem Conservation by adopting a Hierarchy of Ecosystem-based Approaches

Nature-based solutions are an umbrella concept covering a range of ecosystem-based approaches including protection, sustainable management, restoration, and creation of natural or green infrastructure (Cohen-Shacham et al. 2019). These approaches can be considered in a hierarchy, prioritizing the protection of existing ecosystems over enhanced management, rehabilitation and restoration, or the creation of new NBS *(figure 2-3)*. At the same time the three elements—protection, restoration, and creation of new NBS—are complementary and the development of an NBS strategy should assess all elements. Consideration of this hierarchy is particularly relevant when investigating and prioritizing NBS opportunities at a strategic level, such as when screening investment opportunities for a city. However, the three approaches can also be adopted for planning and preparing NBS projects at the neighborhood, city, and river basin scales (see also section 2.4). The Catalogue indicates which of the ecosystem-based approaches can be applied for each NBS family.

Adopting the hierarchy of these three elements supports the need to take a strategic approach to planning. It also emphasizes the importance of evaluating opportunities to strengthen the protection of existing natural infrastructure in a city to maintain functional and biodiversity values. Natural wetlands, grasslands, floodplains, urban forests, and mangroves are all examples of ecosystems in and around urban areas that can be protected to secure existing benefits. This requires their formal integration into zoning schemes and the application of measures to prevent encroachment and degradation.

While protection is critical, untransformed land in urban areas is typically exposed to a broad suite of impacts that can adversely affect the capacity to deliver valuable ecosystem services. The second layer focuses on the restoration and rehabilitation of ecosystems to enhance their performance, functioning, and benefits. Deforestation, for example, can be addressed through active reforestation, while the benefits provided by streams, wetlands, and floodplains can be enhanced through carefully planned rehabilitation and restoration initiatives. In coastal regions, the benefits provided by mangroves, salt marshes, and sandy shores can also be strengthened through restoration efforts. Co-benefits of productive lands can also be enhanced through terracing and appropriate slope stabilization measures, and the implementation of sustainable urban farming methods. Opportunities also exist to enhance and strengthen a broad suite of benefits provided by existing urban green spaces and green corridors through enhanced design, landscaping, and replanting measures. The third layer, creation of new NBS, can be used to mitigate impacts and strengthen urban resilience. This includes new natural or green infrastructure interventions such as green roofs, vegetated facades, constructed wetlands, and bioretention areas. These new NBS can also provide other co-benefits to communities.

Figure 2-3: *A hierarchy of approaches under the nature-based solutions umbrella*



2.4 Consider the Integration of NBS across a Range of Spatial Scales

NBS should be considered at a range of spatial scales. The Catalogue considers NBS at three spatial scales: the river basin scale, the city scale, and the neighborhood scale. The different scales at which the NBS can be implemented are indicated for every NBS family. For example, floodplain restoration that re-establishes natural hydraulic and hydrological connectivity can help manage flood hazards at the river basin scale, whereas bioswales can be planned at the neighborhood level.

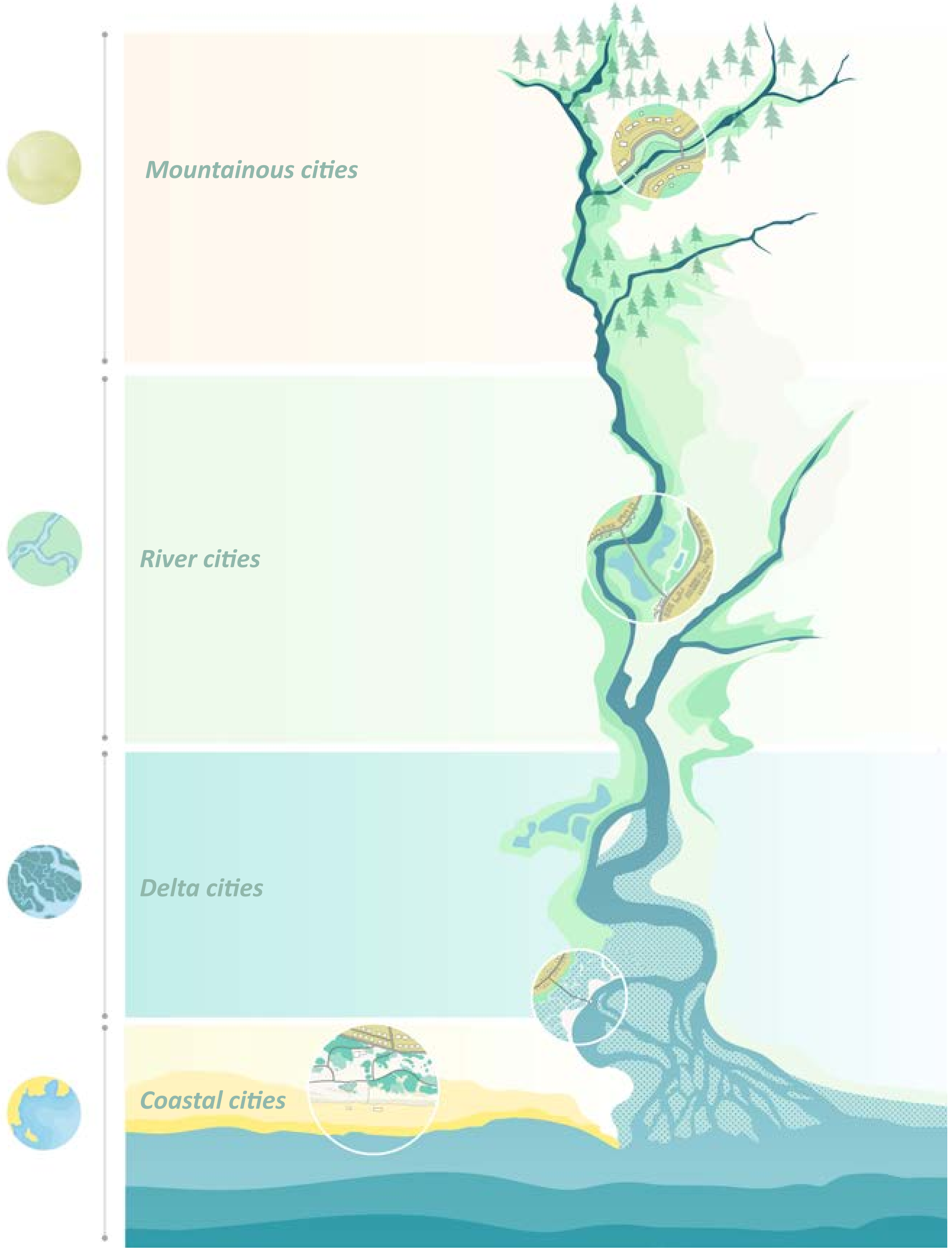
This section describes the difference between these spatial scales for flood resilience problems. Urban areas can be affected by riverine flooding, coastal flooding, and either pluvial or ground water floods or combinations. These floods can be the result of a complex combination of causes, such as meteorological and hydrological extremes, including extreme precipitation, river discharges and storm surges, and failure of flood defenses. NBS can serve to mitigate and adapt to flood risk. They can contribute to flood risk reduction by controlling the flow of water both outside and within urban settlements. Offshore or upstream measures at some distance from the affected city that reduce storm surges or slow down runoff can tackle flooding problems before floods reach the urban areas. For example, in the event of a heavy storm, inland NBS such as forests can hold water upstream, relieving the pressure from the downstream part of the system and thereby protecting the river. At the same time, adaptation measures within the city can be applied to prepare the built environment in towns and cities with their concentrated population centers, buildings and urban infrastructure, and strengthen their resilience (Jha et al. 2012).

The river basin scale

Cities can be located at different positions in a river basin—at the most upstream location in the mountains to the downstream region at the coast. To some degree, their position determines the suitability of NBS types in the city at hand. Cities can be classified by their position in the river basin, along with their main characteristics into (see also *figure 2-4*):

- ***Mountainous cities,*** located at higher elevations, often with steep slopes, are characterized by an extensive network of streams, and are vulnerable to flash floods from stormwater, erosion, and landslides.
- ***River cities,*** located along the large river systems, benefit from fertile soils and access to river trading, but also experience seasonal water-level fluctuations, and are often susceptible to flooding.
- ***Delta cities*** are often flood-prone regions and highly influenced by hydrological dynamics, including dynamics between fresh and brackish water and sedimentation. They are also home to highly productive and nutrient-rich wetland ecosystems and soils.
- ***Coastal cities*** are located along shorelines and benefit from coastal ecosystem services. At the same time, these cities are exposed to the impact of sea level rise, coastal flooding, erosion, and also other threats such as subsidence or saltwater intrusion.

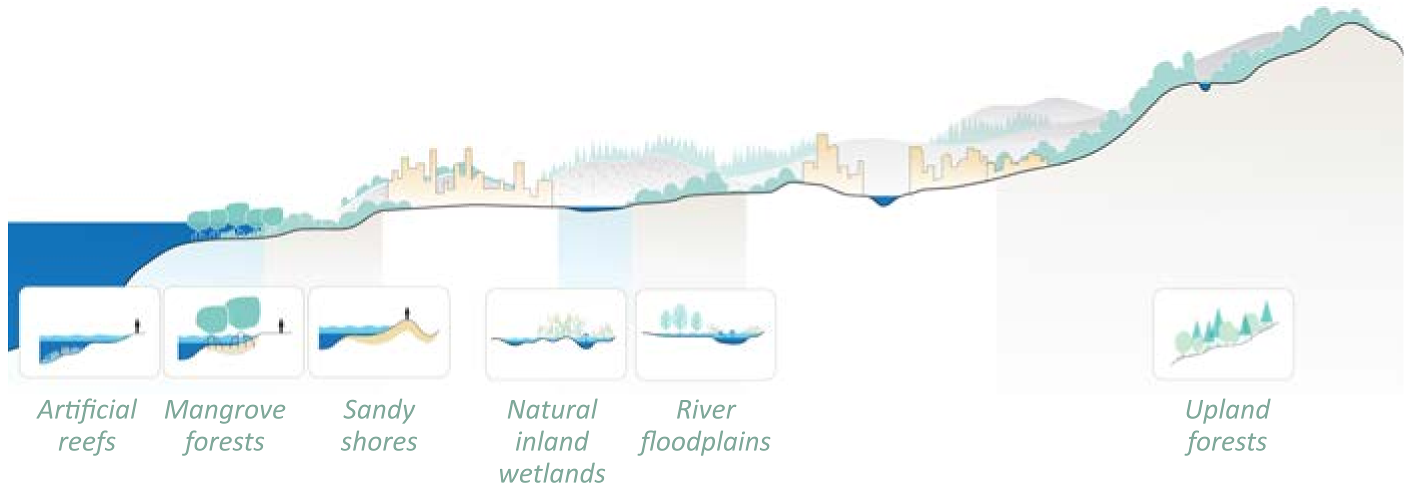
Figure 2-4: *Different types of cities based on their location in the river basin. Suitable NBS can be considered dependent on the characteristics of the city such as the hydrological conditions.*



NBS at the river basin scale recognize the interconnectedness of communities and the importance of integrated catchment management approaches to address flooding and water resource challenges. These include NBS that address the problem near the source, outside of the city, and aim to tackle the problem before it reaches the city. Examples of NBS that benefit cities but which take a broader river basin scale perspective *(figure 2-5)* include:

- Restoration of forest cover in upland areas to intercept and slow floodwater.
- Rehabilitation of river floodplains to enhance storage and reduce flood risks in downstream areas.
- Restoration of mangrove forests outside the city to decrease wave energy and storm surges.

Figure 2-5*: Schematic section of NBS at the river basin scale*

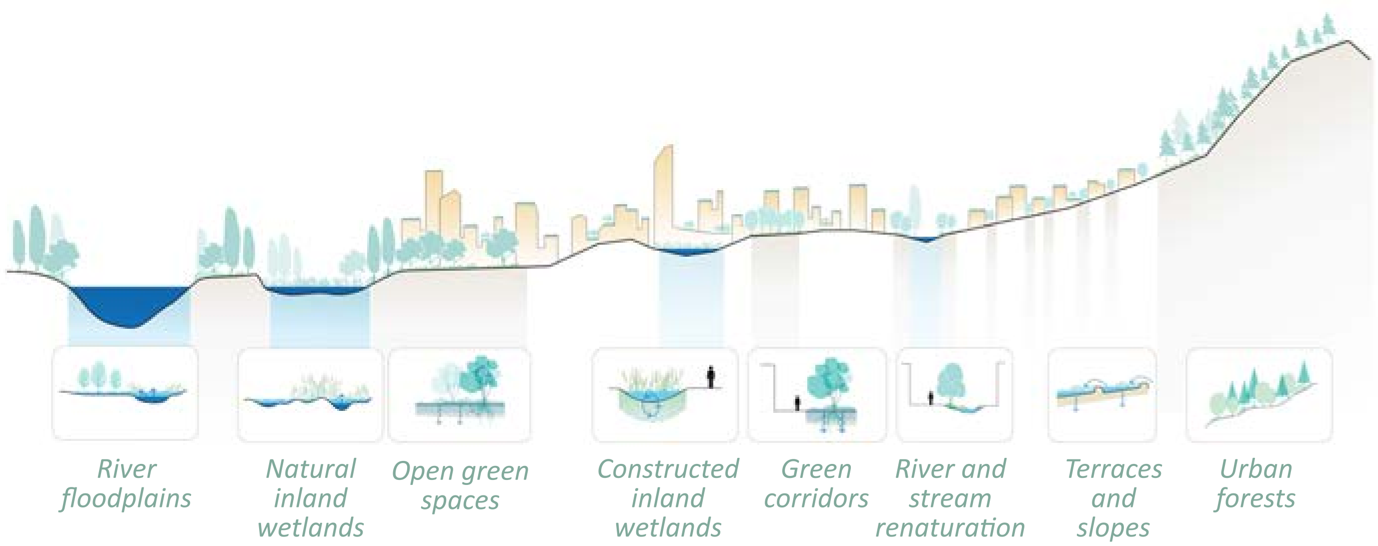


The city scale

NBS at the city scale include measures in a city or town that seek to complement and strengthen urban land use planning and to support disaster risk management. The landscape and ecological structure of the city, together with the unique challenges faced by city residents, determine the suitability and potential of NBS. A broad suite of characteristics can be distinguished that affect the applicability of NBS such as the terrain, climate, hydrology, ecology, and sociology. Some examples of NBS that are typically considered at city level are *(figure 2-6)*:

- Urban forests and terracing on higher elevation levels to delay runoff.
- Creation of constructed wetlands or wetland restoration in lower urban areas to collect and store water runoff.
- Renaturation of existing streams and drainage lines in the city to slow down water flows.
- Increase of open green spaces or parks throughout the city to add infiltration capacity and reduce urban heat.
- Continuity of linear tree canopies and green corridors along roads in the city to reduce urban heat and strengthen biodiversity networks.

Figure 2-6: *Schematic section of NBS at the city scale*



The neighborhood scale

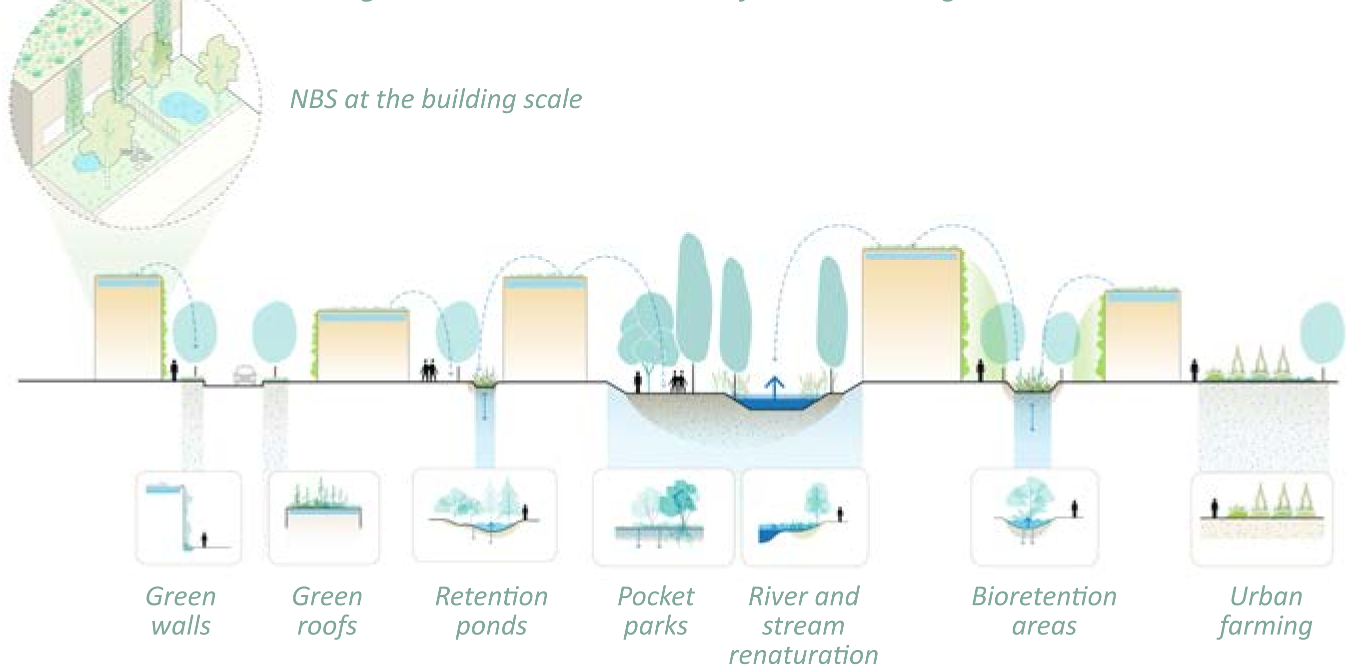
At the neighborhood scale, resilience challenges are addressed at a local level including measures in buildings, streets, and open public spaces (*figure 2-7*). These often smaller-scale interventions can build resilience by increasing stormwater retention capacities and reducing the heat island effect, for example. These NBS can be very effective for local rainwater collection, to mitigate impacts of air, water, and soil contamination, and to reduce heat levels in cities by providing shade. Neighborhoods can be established as functional clusters of resilience. Implementing NBS at the neighborhood level can relieve pressure on existing local infrastructure such as stormwater drains. At the neighborhood level, collaboration between the public and the private domain is key, and NBS implementation can help build alliances between the different stakeholders—governments, private sector, property owners, and communities—. Examples of NBS at the neighborhood scale include:

•NBS integrated into buildings such as green roofs, green facades, private gardens in combination with green streets. Such measures can both regulate temperature and store water.

• Retention basins, rainwater retention ponds, or green water squares to store water.

• Small-scale rainwater catchment and drainage interventions such as bioswales.

Figure 2-7: *Schematic section of NBS at the neighborhood scale*



Box 2-3: Spatial considerations for arid and semi-arid urban contexts

Planning and implementing NBS in arid and semi-arid urban contexts requires several special considerations. Arid and semi-arid landscapes, as well as landscapes with distinct wet and dry seasons, can be particularly challenging environments for plants and trees to thrive which are critical components for several of the NBS. NBS planning for these contexts should integrate detailed analysis of the environmental factors critical for plant and tree survival including sunlight intensity and directness, rainfall patterns, surface water flows, and groundwater levels and access. The planning phase should also include a detailed assessment of indigenous plant and tree species inclusive of their ideal growing conditions such as their tolerances to direct sun and water requirements, which should be incorporated into the implementation and maintenance plans. Sufficient resources should be allocated including financing for watering and general maintenance for prolonged periods post-implementation to ensure the survival and establishment of all plants and trees for the NBS.

2.5 Adopt a Multistakeholder and Interdisciplinary Approach

Integrating NBS into urban resilience strategies requires a collaborative, interdisciplinary, and cross-sectoral approach. This means extensive coordination through project phases—starting from the identification and design to the implementation and operation —and between a variety of actors, including city governments, national governments, ministries, public sector companies, meteorological and planning institutions, civil society, non-government organizations, educational institutions and research centers, and the private sector (Frantzeskaki 2019).

Successful realization of NBS requires interactive development of holistic long-term strategies that balance existing resilience needs with sustainable development (Jha et al. 2012). It also involves an interdisciplinary approach that integrates flood risk management, land use planning, and climate change adaptation strategies. Interdisciplinary teams of urban planners, landscape architects, urbanists, civil engineers, and stakeholders should actively collaborate in the planning and design process of urban resilience projects to provide more comprehensive solutions to urban challenges *(box 2-3)*. This is particularly relevant in urban environments that typically have significant space constraints and that have led to an increase in societal emphasis on the spatial and environmental footprint and impact of interventions in urbanizing areas (Nillesen 2018).

Given their interdisciplinary and cross-sectoral character, NBS projects have the unique capacity and opportunity to catalyze better cross-sectoral collaboration. This could support a shift from fragmented, siloed planning of urban interventions toward a systems-planning approach to achieve urban resilience objectives while using the available resources in an efficient manner.

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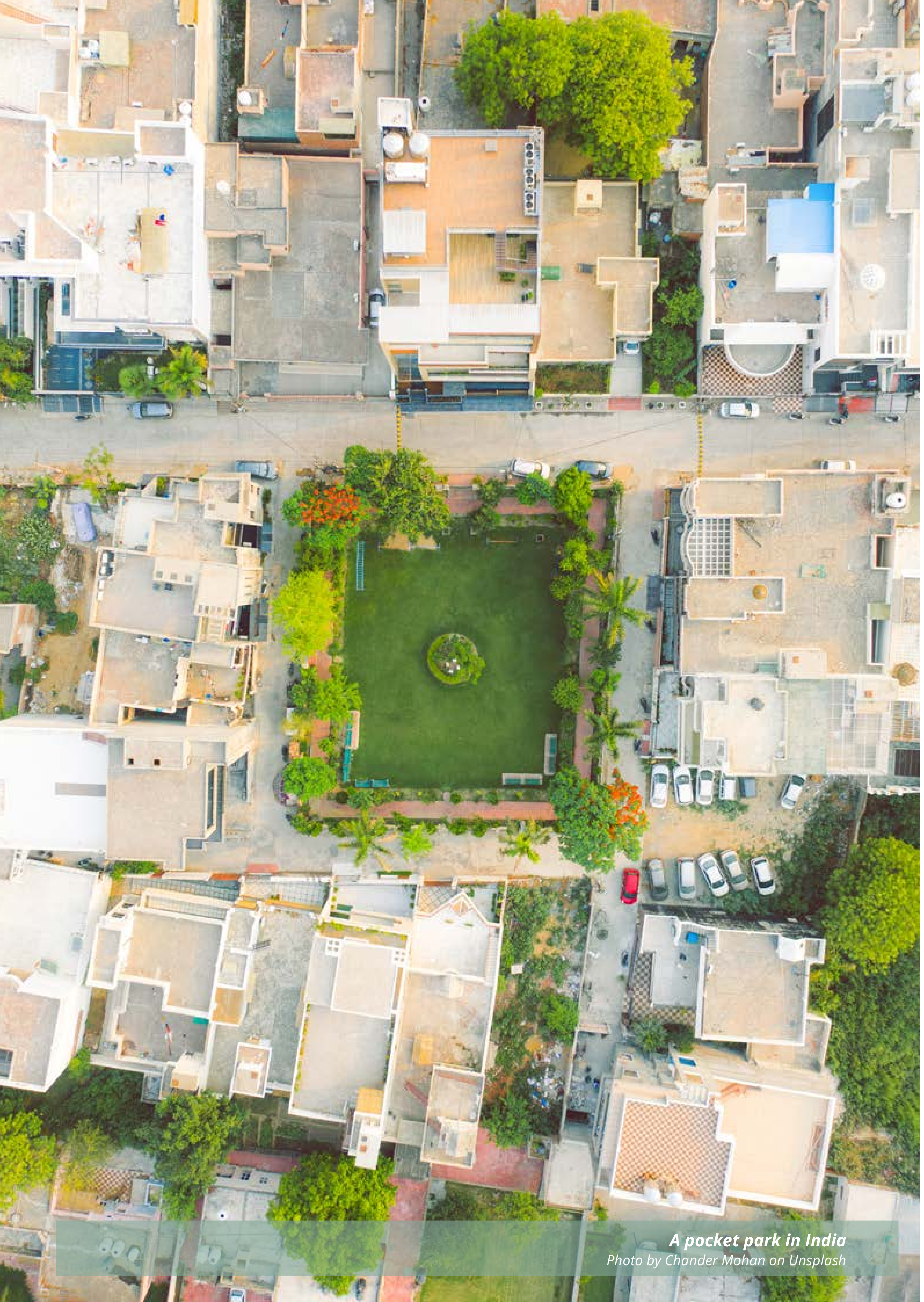
Lush courtyard in Spain
Photo by Alevision.co on Unsplash



A pocket park in India
Photo by Chander Mohan on Unsplash

Chapter 03

THE CATALOGUE

3.1 Reader's Guide

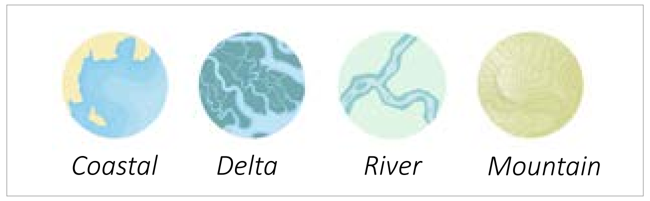
The Catalogue consists of 14 chapters, one for each NBS family. This chapter guides the reader through the different sections by explaining the nature of information included in every section. This can help the reader take the first step to assess possible locations for NBS. Each NBS family chapter consists of following sections:

1. Facts and figures
2. Visualizations
3. Functions
4. Benefits
5. Suitability considerations
6. Costs
7. NBS in practice

FACTS AND FIGURES

Short descriptions
Generic background information about the NBS family.

Type of city
Information about the type of city the NBS can be applied to, with respect to the position of the city into the river basin, including mountainous, river, delta and coastal cities (see also *figure 2-4*).



Scale
The spatial scale at which the NBS can be applied, including the river basin, city, and neighborhood scale.

Approach
How the planning of NBS can be approached through ecosystem-based approaches:
1. Protection of existing ecosystems or NBS;
2. Rehabilitation of degraded ecosystems or NBS;
3. Creation of new NBS.

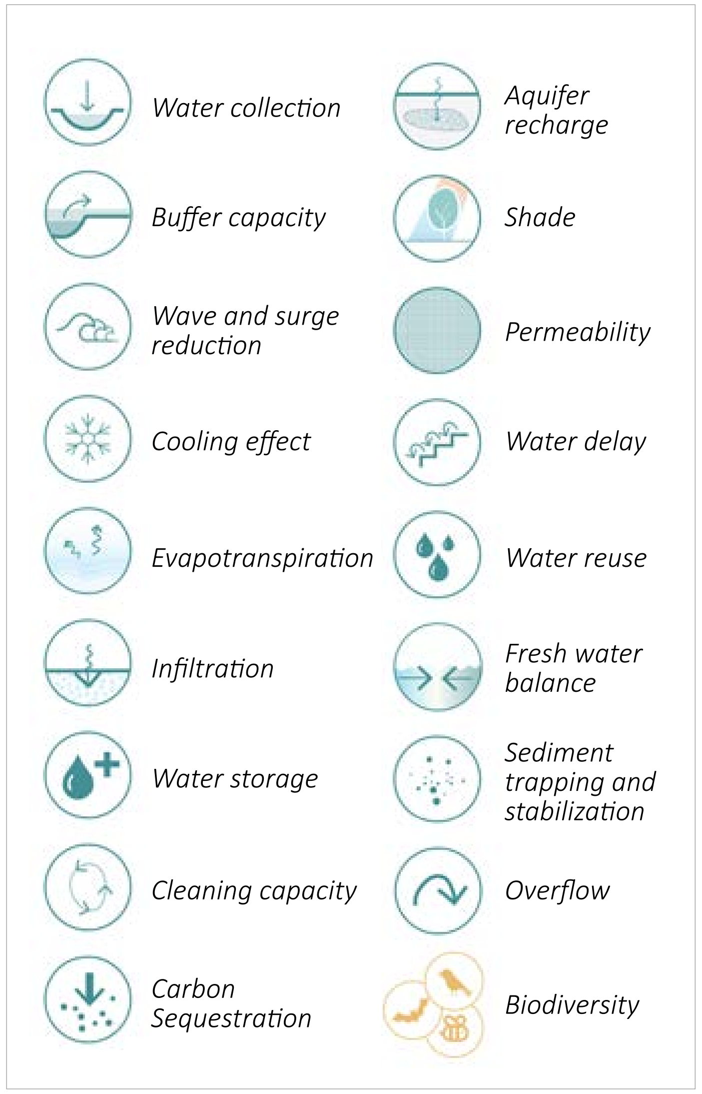
Processes

The technical profile of NBS illustrates processes that are relevant for its resilience functions and benefits *(figure 3-1)*.

The left panel *(figure 3-1)* represents a sample technical profile that is provided for each NBS family. It indicates the characteristic processes of NBS that are considered in this Catalogue, which are individually outlined in the right panel *(figure 3-2)*.

Figure 3-1: *Technical profile NBS processes*

Figure 3-2: *Processes icons*

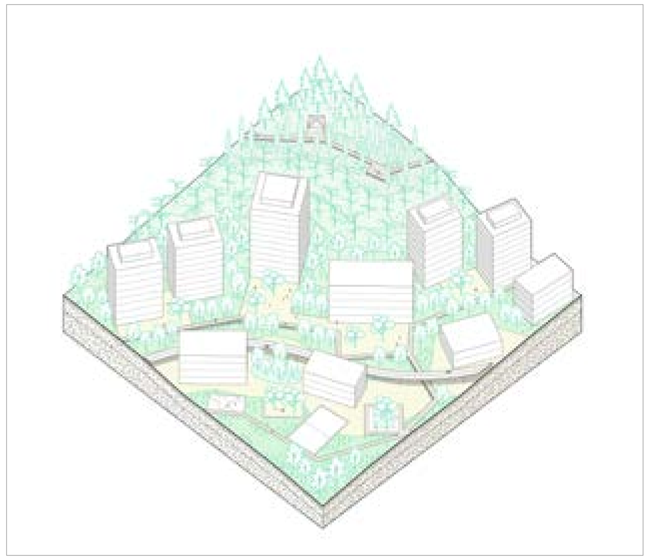


VISUALIZATIONS

This section includes visualizations and landscaping sketches, developed for each NBS family in a uniform style to illustrate certain NBS designs in the urban landscape, including technical and spatial characteristics and environmental qualities. The visualizations also provide insight to how NBS can be seen from a systems perspective and how they are most effective when integrated at different scales. This section includes following visualizations: (i) visualization of the NBS in the urban context; (ii) details of increased benefits for the urban living environment; and (iii) special NBS techniques within the family.

Visualization of the NBS in the urban context

A bird's eye view of the NBS illustrating the urban context and the connection with the built environment, typical topographical profiles and settings, and a representative spatial scale of the NBS in an urban area.

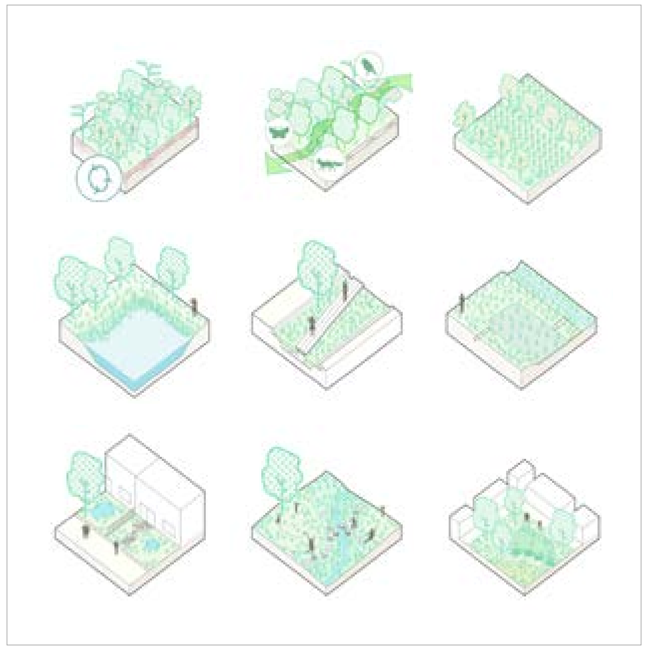


Details of increased benefits for the urban living environment

Highlights of NBS in the built environment and the added values they deliver in enhanced landscape ecology of the city and in daily experience of the living environment of people.

Special techniques for the NBS

Illustrations that zoom in on different specific NBS applications and techniques within the NBS family, including alternative design options and techniques.



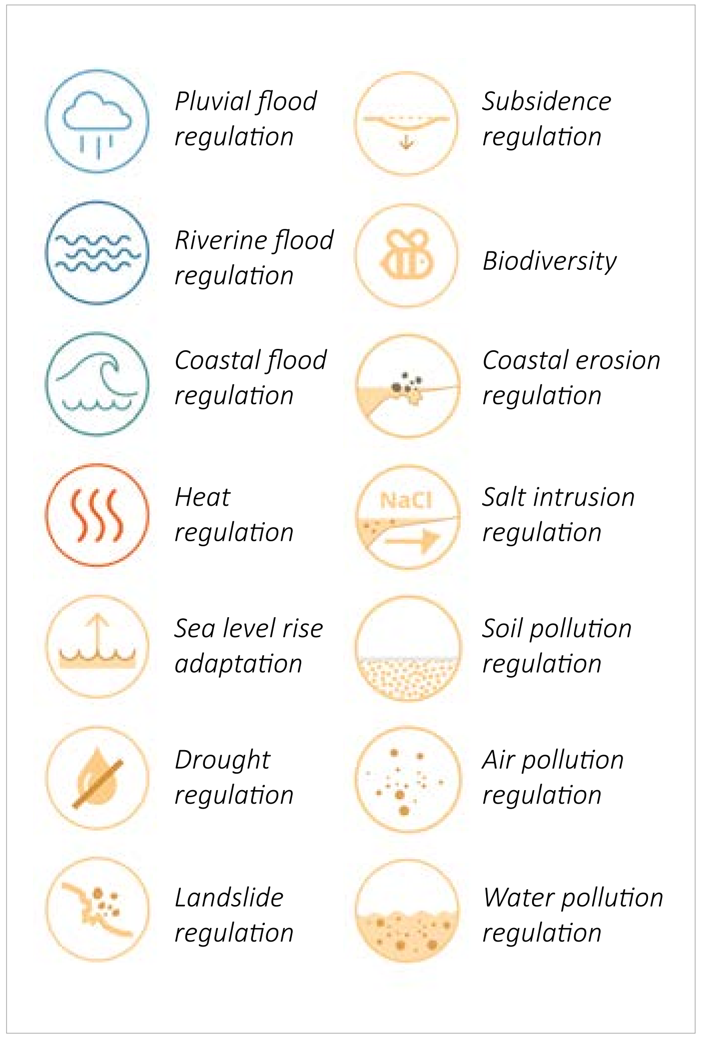
FUNCTIONS

This section describes the functions of each NBS family. Functions refer to the capacity of NBS to provide benefits to people. These functions may describe the regulation of potential natural hazards, such as flooding, extreme heat, drought or erosion. They can also describe the functions underpinning other regulating ecosystems services, such as mitigating pollution, preventing land subsidence or improving water quality.

A chart visualizes the relative importance of NBS functions. The flood and heat regulating functions are described for each NBS family, while the remaining functions are summarized under other functions. The left panel *(figure 3-3)* represents a sample diagram that is provided for each NBS family. The icons that were included in this Catalogue are individually outlined in figure 3-4.

***Figure 3-3:** NBS functions chart*

***Figure 3-4:** Functions icons*

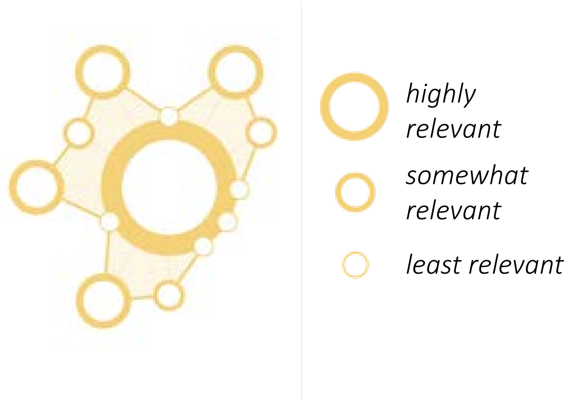


BENEFITS

This section describes multiple ways NBS can deliver social, economic, and environmental benefits. Each NBS family chapter contains a list of selected benefits that are highlighted and explained *(figure 3-6)*. The relative importance of benefits is graphically presented in a radar chart scored qualitatively to distinguish benefits that are considered least relevant, somewhat relevant and highly relevant for each NBS family *(figures 3-5 and 3-7)*.

Figure 3-5: *Radar graph for NBS benefits*

Figure 3-7: *Scale of measurement*



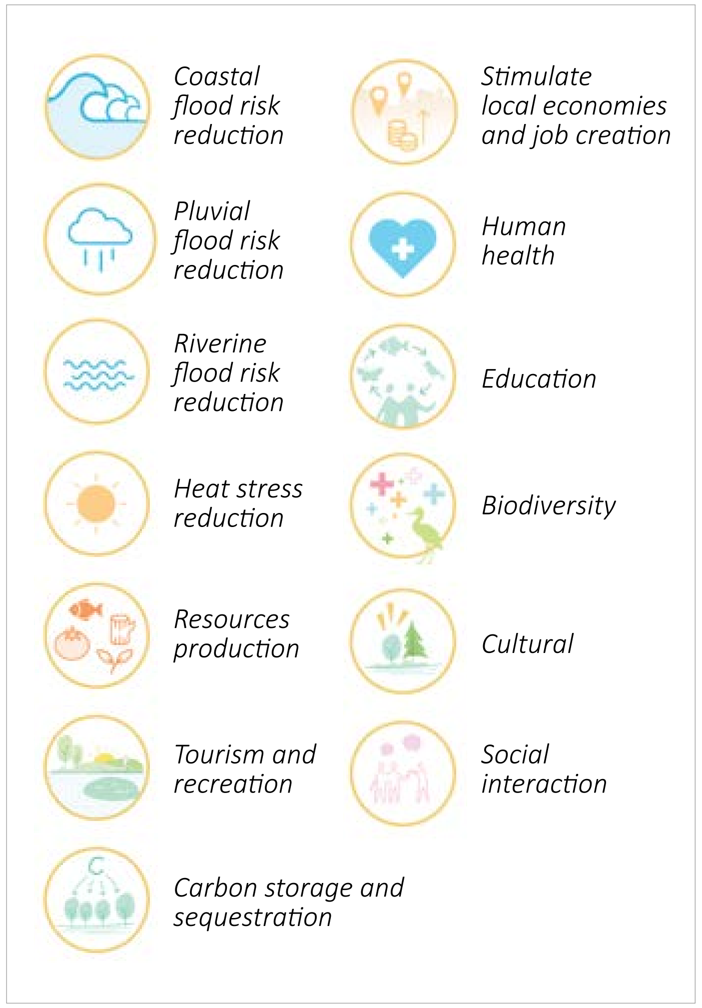


Figure 3-6: *Benefits icons*

SUITABILITY CONSIDERATIONS

This section describes considerations of location suitability of NBS to help understand whether an NBS is suitable at a location in or around a city. Suitability considerations that are relevant for the feasibility and implementation of the NBS family, are subdivided in four categories *(figure 3-8)*:

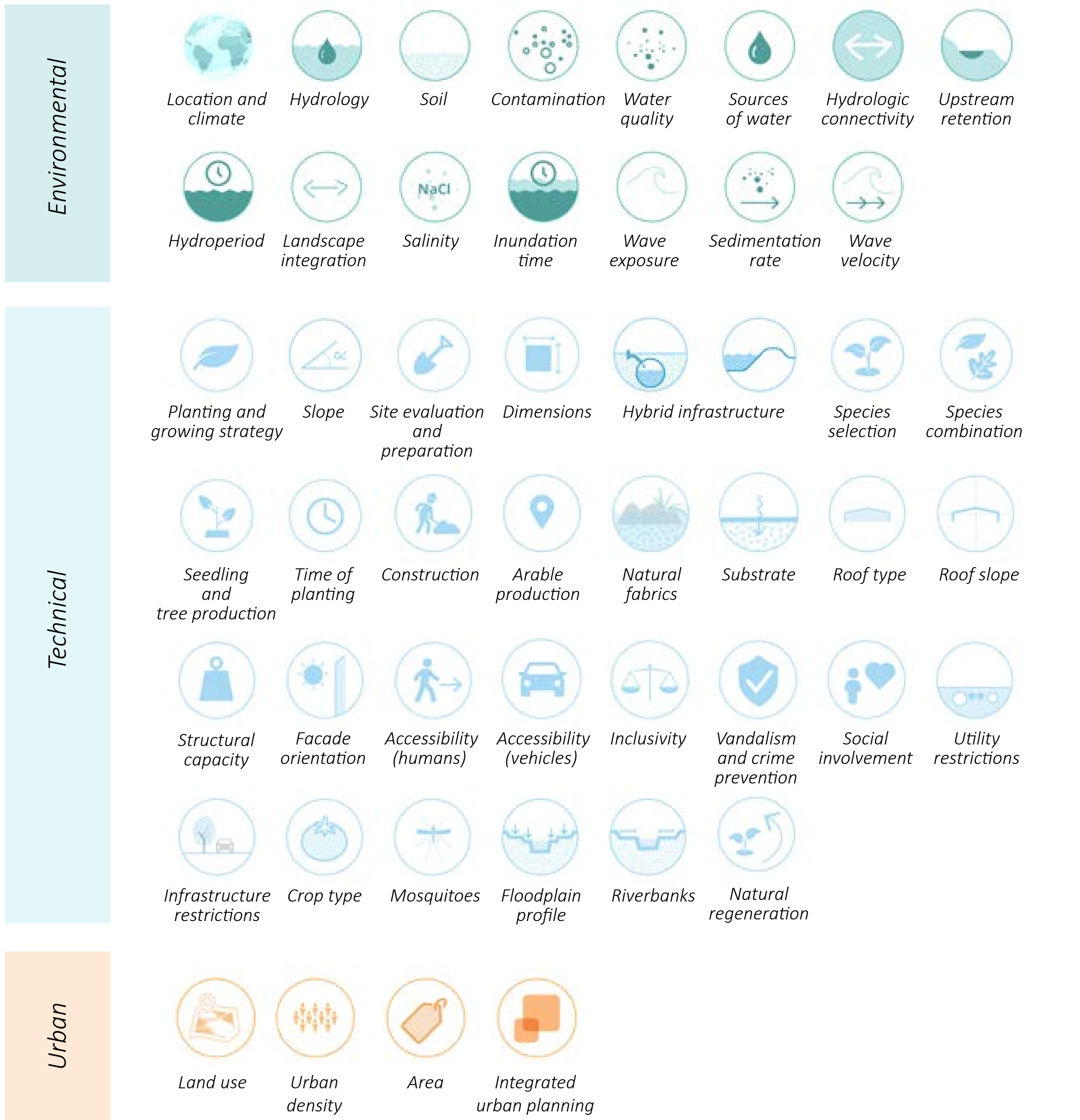
1. Environmental considerations comprise factors such as location and climate, hydrology and soil characteristics.

2. Technical considerations cover a variety of considerations dependent on the NBS, such as effective dimensions, planting and growing strategy, and synergies with gray infrastructure.

3. Urban considerations comprise suitable urban density, preferred land use, the relative size of the required area, and potential for integration with urban agendas. Urban density is rated from low to high based on the number of dwellings and the availability of open space. Area is rated from small to extra-large and is based on the required area of a specific NBS to be effective. Normally, a nature-based solution with small area requirements has potentially high replicability rates, while a nature-based solution with extra-large area requirements is usually site-specific.

4. Maintenance comprises basic guidance on requirements such as intensity of labor, frequency, or special care in the initial stages of development.

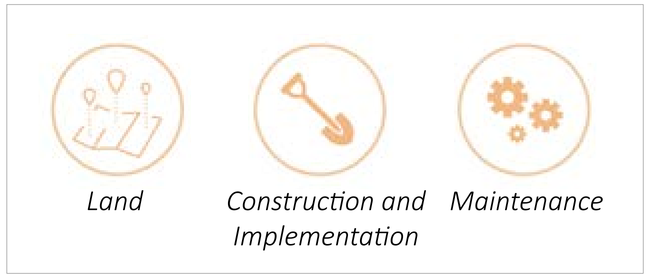
Figure 3-8: *Suitability considerations icons*



COSTS

This section consists of two elements:

1. Cost considerations:
    1. Land;
    2. Construction and implementation;
    3. Maintenance.
2. Unit cost examples from around the globe.



NBS IN PRACTICE

This section provides examples of NBS with global good practices, lessons learned, and guidance for learning how to successfully finance, implement, and maintain NBS. The examples are from existing NBS projects, literature review, and case studies that have identified as good practices throughout the globe.

Every example selected comprises an image, project name, year, location, brief description, benefits, source, website link for detailed information, and key aspects which highlight the significance of the NBS in a specific context (*figure 3-9*).

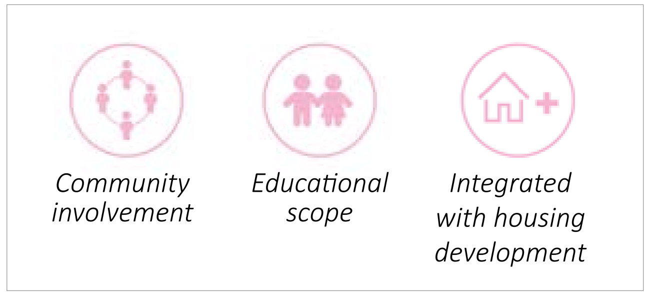


Figure 3-9: *Examples of key aspects of NBS implementation*

A recreational corridor in Seoul, South Korea
Photo by Daniel Bernard on Unsplash

3.2 Urban NBS Families

An urban wetland park in Nugegoda, Sri Lanka
Photo by Shruthimathews on Flickr

URBAN FORESTS

Bojong Genteng, Indonesia
Photo by Vickry Alvian on Unsplash

FACTS AND FIGURES

DESCRIPTION

Urban forests are complex ecosystems with a remarkable capacity for regeneration and resiliency (FAO 2016). Urban forests are located within cities or at the rural–urban interface. In most contexts, urban forests survive and thrive as fragments of the larger regional landscape mosaic, or emerge as pockets of successional outgrowth on vacant or abandoned land. Urban forests adapt to adversity and have the ability to survive in hostile conditions. Varied in size and composition, they demonstrate remarkable resilience under a great deal of stress from pollution, compacted soils, and disrupted hydrological cycles. In addition, urban forests may be subjected to intentional and unintentional abuse from fires, harvesting, logging, encroachment, and adverse chemical impacts. The combination of trees, shrubs and grasses, the complexity of soils, and related biotic and abiotic components give urban forests a strong advantage as rich and vital sources of biodiversity. Multiple mechanisms of adaptation make them one of the most valuable nature-based solutions.

Urban forests have a great potential to mitigate the urban heat island effect and air pollution, and to retain stormwater. They protect rivers by intercepting rainfall, increasing infiltration, and reducing flooding. In addition, they clean soils, sequester carbon, and regulate water cycles through retention, infiltration and evapotranspiration; improve air and water quality; provide critical habitat for a variety of species, and decrease ambient temperatures. Urban forests make positive contribution to the physical, mental, social, and economic wellbeing of urban societies. Their preservation and maintenance are a critical opportunity to make cities and communities resilient to climate change.

Acknowledging that "urban forests can be defined as networks or systems comprising all woodlands, groups of trees, and individual trees located in urban and peri-urban areas; they include, therefore, forests, street trees, trees in parks and gardens, and trees in derelict corners" (UN FAO), the tunneled perspective in this chapter on urban forests focuses only to support cities with this specific NBS family.

TYPE OF CITY

Coastal
Delta
River
Mountain

SCALE

Neighborhood
City
River basin

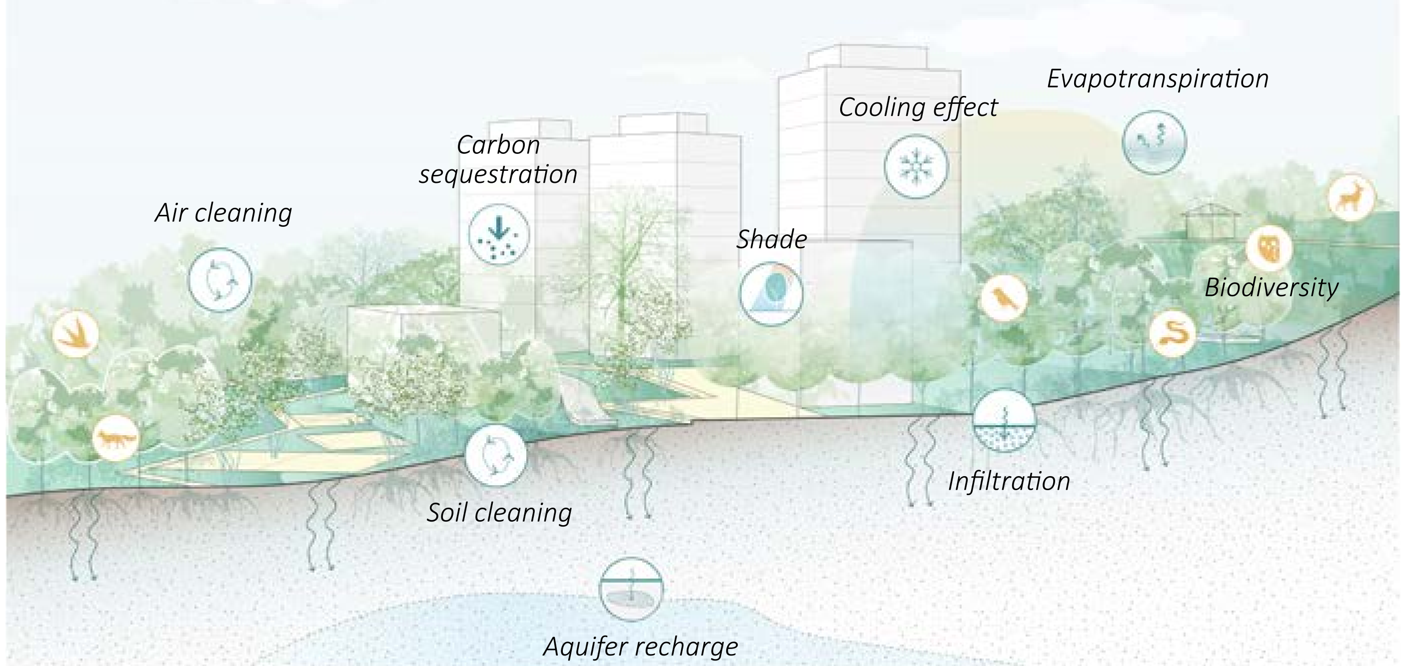
APPROACH

Protect
Conserve existing forest areas.

Rehabilitate, Restore, Enhance
Reforest and manage existing forest areas.

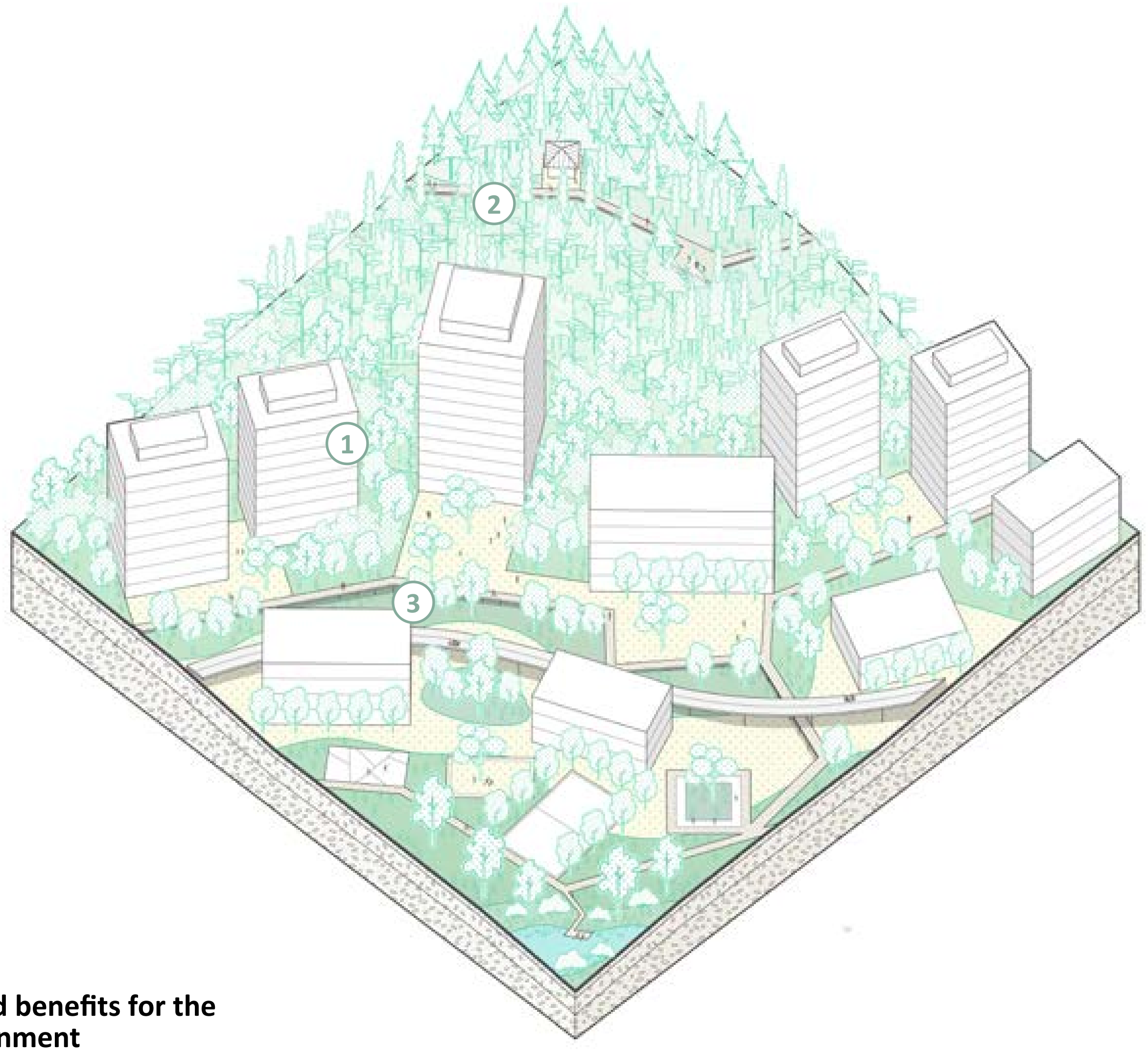
Create
Plant new forest areas.

PROCESSES

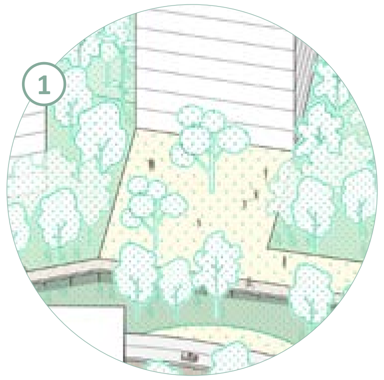


VISUALIZATIONS

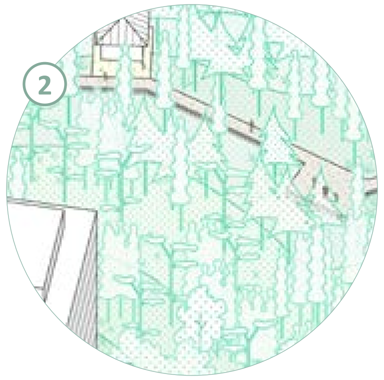
VISUALIZATION OF URBAN FORESTS IN THE URBAN CONTEXT



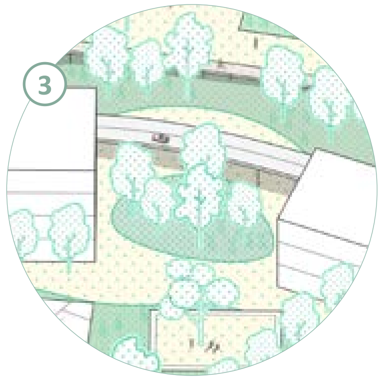
Details of increased benefits for the urban living environment



Urban forests reduce heat by providing shade and evaporative cooling.

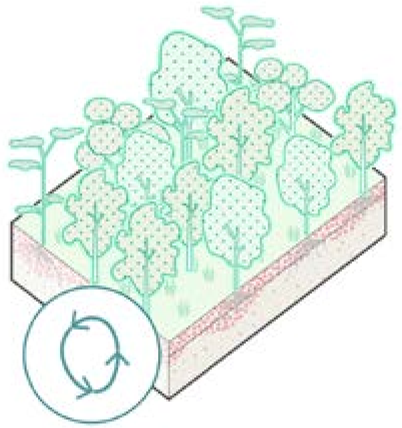


Urban forests provide opportunities for people to retreat from the city and enjoy recreational activities such as walking and cycling.



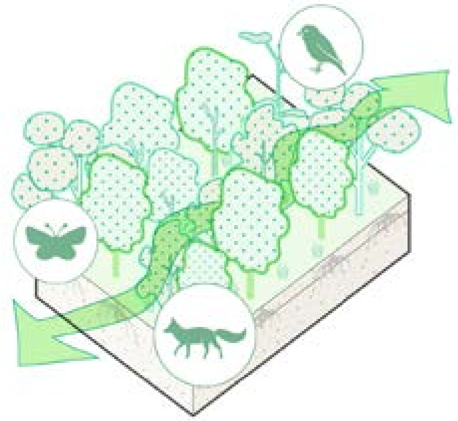
Urban forests should be developed using a suite of native species to optimize biodiversity values.

SPECIAL TECHNIQUES FOR URBAN FORESTS



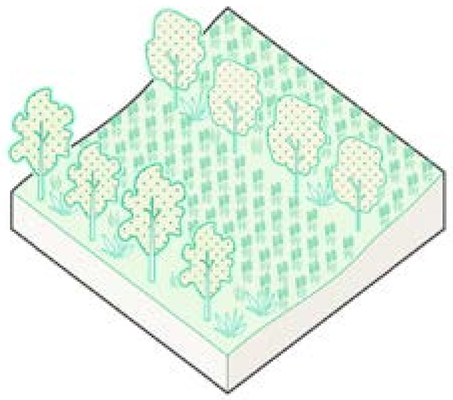
Phytoremediation forest

A phytoremediation forest consists of trees and shrubs with specific metabolic qualities that allow such vegetation to clean polluted soils inclusive of those on landfills and abandoned urban areas. The roots and microorganisms remove, transfer, stabilize, or detoxify contaminants in the soil and groundwater, improve ecological conditions, and help prepare sites for future development.



Ecological forest corridors

Urban forests are often established along drainage lines where additional moisture is available. These forests provide a critical linkage, while screening light and noise effects, allowing safe movement of species in the landscape. Ecological forest corridors can also be established in upland areas to link important habitats. Where possible, these forests should include structural complexity and species diversity to facilitate movement of a broad suite of species.

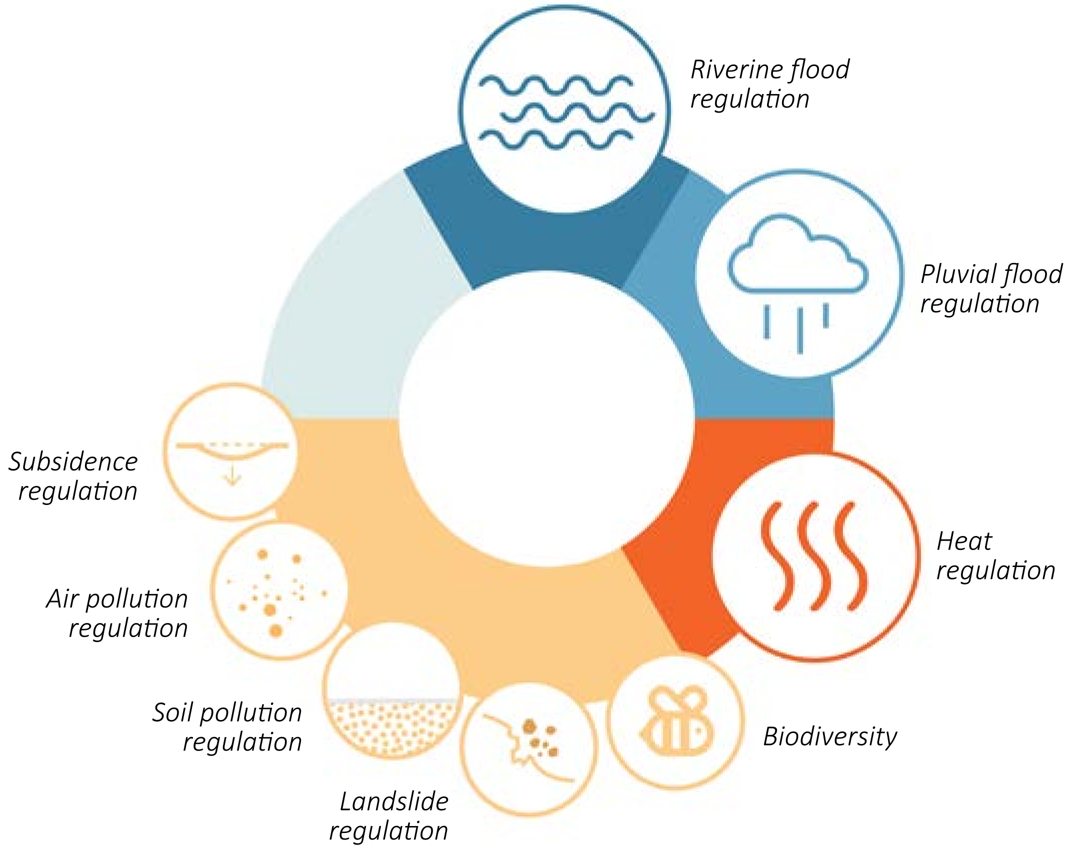


Agroforestry

Agroforestry is a dynamic and ecologically based natural resource management system. Agroforestry integrates trees and wooded patches into farms and productive landscapes, and diversifies and enhances agricultural production. Increased social, economic, and environmental benefits can be derived from any productive area where trees contribute to the productivity of the landscape within and outside cities (FAO 2021a).

FUNCTIONS

The diagram in this section shows relevant functions of urban forests.



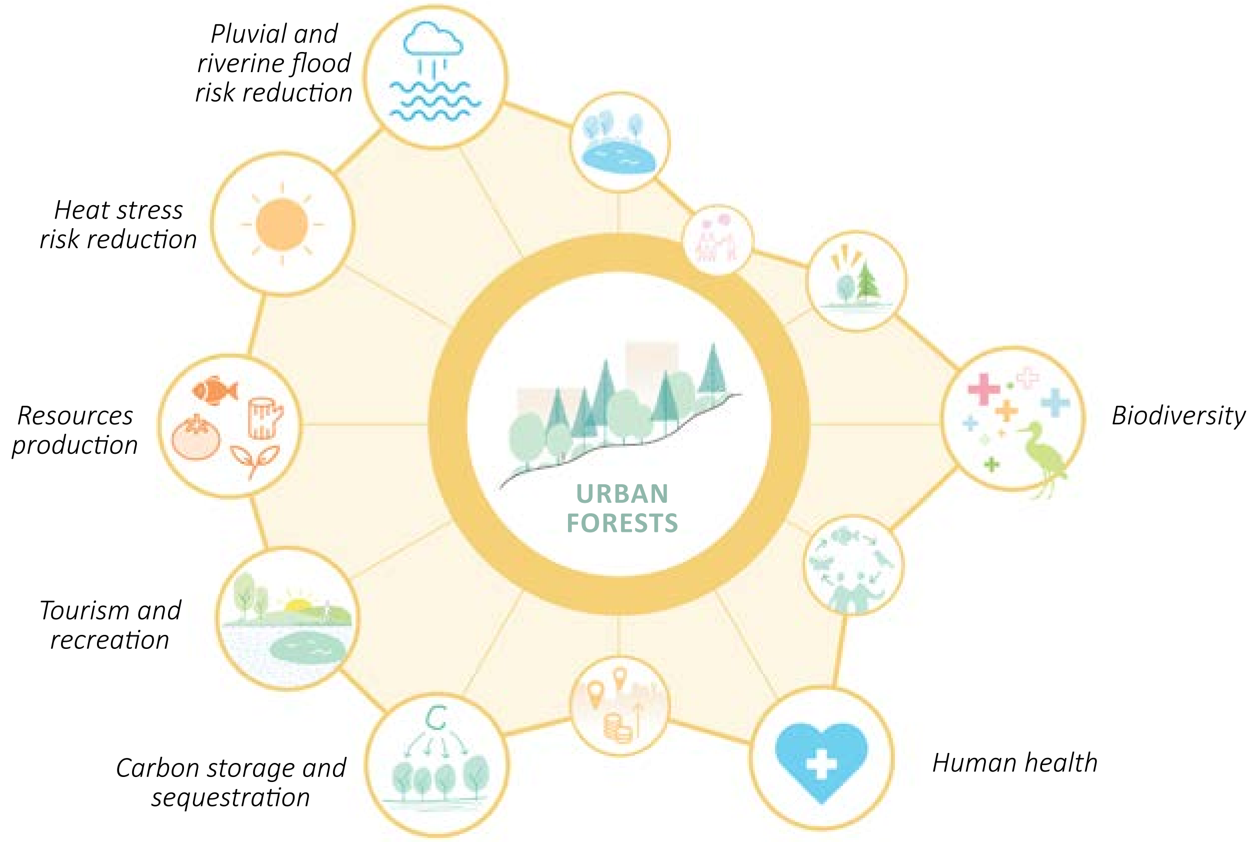
Pluvial and riverine flood regulation: Urban forests absorb and retain significantly more stormwater than paved surfaces. Trees and soils of forested areas intercept precipitation and recycle the water through evapotranspiration, root water uptake, and infiltration (Gehrels et al. 2016). Upland forests with deep soils can intercept and infiltrate rainwater, reducing flood hazards along canals and rivers downstream (Ozment et al. 2019). A review of restoration studies found that 83% of the cases reported a positive relation between infiltration capacity and forest restoration in upland areas (Filoso et al. 2017).

Heat regulation: Urban forests reduce heat island effects by shading building surfaces, deflecting radiation from the sun, and releasing moisture into the atmosphere. Shaded surfaces may be 11–25°C (20–45°F) cooler than peak temperatures of unshaded materials. Evapotranspiration, alone or in combination with shading, can help reduce peak summer temperatures by 1–5°C (2–9°F) (EPA n.d).

Other functions: Tree root systems stabilize soils. This is particularly important in areas with high risk of erosion such as riparian zones and steep slopes. Forested areas reduce soil subsidence, mitigate air and soil pollution, and provide habitat and conduits for the movement and propagation of local fauna (Brockerhoff et al. 2017).

BENEFITS

The diagram in this section shows a sampling of important benefits that urban forests can provide to people.



Pluvial and riverine flood risk reduction: Well-managed and healthy forests can contribute greatly to reducing flood risks in downstream areas. Forests are beneficial to retain stormwater and decrease the amount of water rapidly washing over the streets and public spaces, entering and overwhelming the sewerage systemws. As a result, forests can lower flood heights and flood velocities in surrounding areas, thereby reducing structural damages to properties and infrastructure (Salbitano et al. 2016).

Heat stress risk reduction: Trees reduce heat in the built environment by providing shade and evaporative cooling. Forest areas within the city boundaries reduce solar radiation, by providing shade, and air temperature through evapotranspiration (EPA n.d.). Reducing extreme heat in cities brings a variety of socioeconomic benefits, including reduced mortality (Tan et al. 2010), improved health, reduced energy cost and carbon dioxide emissions (Roxon et al. 2020), and improved productivity of labor (Wong et al. 2017).

Resource production: If managed sustainably, forests can provide a variety of natural resources: fruit and vegetation, animals, biomass and timber, genetic material for all types of biota, fuel, and medicinal plants (Brockerhoff et al. 2017).

Human health: Urban forests offer physical, emotional, and mental health benefits to local communities in different ways, including: increased immune responses (Kuo 2015; Li et al. 2008); benefits for focus and attention (Kaplan 1995); and accelerated rates of recovery from illnesses (Ulrich et al. 1991; Alvarsson et al. 2010). These positive health effects often lead to a reduction in the cost of healthcare and improved productivity (Buckley and Brough 2015).

Tourism and recreation: Urban forests create opportunities for recreational activities such as walking and cycling especially in proximity to residential areas. Urbanization will result in a higher demand for recreation opportunities and increased visitor numbers in urban forests.

Carbon storage and sequestration: Urban forests store and sequester carbon in the above ground vegetation and in the soil, providing climate change mitigation benefits. Stored carbon densities per hectare vary greatly as a result of climatic conditions, soil conditions, and forest management. A recent review of natural regeneration—successional forests, secondary forests, and forest restoration—showed that regeneration delivers significant carbon sequestration benefits estimated at 9.1–18.8 tons CO_2 per ha per year for the first 20 years of growth. With continued biomass growth, these rates can be as high or higher after the first 20 years of forest regeneration. Rates are typically lower in temperate than in tropical regions, suggesting that latitude is an important general driver of biomass growth (Bernal et al. 2018).

Biodiversity: Forests and woodlands support a range of terrestrial and aquatic biodiversity. Wet tropical forest regions are home to the richest diversity of species in the world (Hassan et al. 2005; Lindenmayer 2009; Gibson et al. 2011). Besides the intrinsic value of biodiversity, the species that are part of the forest ecosystem support its tourism and recreation value.

SUITABILITY CONSIDERATIONS

ENVIRONMENTAL

Location and climate: New urban forests can be planted anywhere in the world (FAO 2021b). Forests intended to reduce stormwater runoff can be effective in a broad range of climates and significant results can be achieved within 15 to 20 years after planting. In dry climates, however, afforestation must be implemented with greater care to avoid lowering water tables and reducing soil recharge rates especially during the dry season. In contexts where water is critical to tree growth, artificial irrigation may be required to sustain forest establishment and maintenance.

Soil: Soils provide water and nutrition, and act as a substrate or a medium for the trees to grow (Le et al. 2012). New trees require the substrate to have high mineral and structural quality. The type and composition, depth, acidity, and the degree of compaction are all major substrate considerations. Sandy and loamy soils provide better conditions for new forests given their strong infiltration capacity and aeration of the soil. Soils with a high proportion of clay and compact soils are much less favorable to the establishment of the new roots (Kadam et al. 2020).

TECHNICAL

Slope: The direction of the slope is an important consideration in temperate regions. Slopes are responsible for variations in soil humidity, determining the velocity of stormwater runoff, and the rate of erosion of soils. Unstable soils and steep slopes can be challenging during the initial phase of growth when trees are establishing the roots (Kadam et al. 2020). Once the initial challenge is surpassed, forests thrive and frequently occur on steep slopes where the cost of construction is too prohibitive for urban development.

Site evaluation and preparation: Site preparation may require suppression and removal of weeds, possibly cultivation and fertilization, augmentation of soil structure and composition (Le et al. 2012). In areas without established vegetation, it may be necessary to establish nurse crops of fast-growing species before planting preferred species (FAO 2021b).

Species selection: Identifying the desired type of urban forest and its ultimate objectives are important in supporting the selection of tree species, establishment of a planting and growing strategy, and the implementation of each urban forest. Future mature forest objectives could include carbon sequestration, slope stabilization, heat stress mitigation, flood mitigation, biodiversity enhancement, and other technical factors as well as aesthetics, recreational, and public space uses, costs for implementation and maintenance. Additional objectives may include the provision of livelihood and income generation opportunities for local communities. Species selection can be tailored to the suitability of each identified species option according to each specific site, with local indigenous tree species always being preferable (Le et al. 2012).

Species combination: As a general recommendation, newly established forests should be composed of a mix of local tree and understory species. It is important that forests are not established on untransformed land that already supports indigenous vegetation as such areas contribute to the conservation of other non-forest species and ecosystems. When forests are established, a mix of species should be used that mimics natural forest habitat in the region. Such forests are more typically productive and resilient and offer higher levels of ecosystem services (Le et al. 2012).

Seedling and tree production: Global urban forestry best practices are shifting to include—and in some cases require—the planting of larger saplings and trees rather than conventional seedling planting. Some cities have mandated a mix of size, age, planting distribution, species variety, and other requirements including, for example, that urban trees must be at least 1.5 to 3.0 meters tall at the time of planting for seedling, sapling, or tree production. The growing, formative pruning, and establishment of seedlings, saplings, and young trees in a nursery is the primary way of establishing planting stock in many parts of the world, although local communities may also be trained in growing indigenous seedlings (Douwes et al. 2015). The availability of a nursery or other sources that can produce quality trees, following a good seedling preparation process, is therefore critical for forest establishment (Evans and Turnbull 2004). Easily cultivated seedlings are not always the most desirable, and incentives, financial or otherwise, should be used to encourage the growing of desirable species to desirable sizes and parameters.

Planting and growing strategy: Humans, free-range livestock, and land management practices in urban settings can subject seedlings or young trees to additional removal, destruction, and browsing challenges, which require a sustainable planting and growing strategy. Planting on deforested or degraded sites requires sturdy plants from the nursery, which are well-watered before planting (FAO 2021b). Planting in urban settings—especially for urban forests with intended human uses and in areas with gray infrastructure—often requires additional considerations of seedling or tree sizes, pre-planting, formative pruning, and root management, proximity of planting to gray infrastructure, and identification of other growing and planting parameters to ensure the most sustainable planting initiative.

Time of planting: To survive, the seedlings must be planted at the right time of the year (Nawir and Rumboko 2007). In most parts of the world that means the beginning of the rainy season. Tree planting can extend into the middle of the season as long as newly planted trees receive adequate amount of moisture during the first months while they develop their root systems (Le et al. 2012).

URBAN

Land use: Suitable land uses for urban forests: Afforestation of degraded natural forest areas, alluvial sites along streams, rivers, and water bodies, steep slopes at risk of soil erosion and landslides, non-productive agricultural sites, and no longer productive industrial wood plantations (FAO 2021b).

Urban density: Urban forests are suitable for low to medium density urban areas.

Area: Small to extra-large. Whereas regional afforestation programs are ideally planned at a landscape or city scale, small forests also offer biodiversity and other benefits .

Integrated urban planning: New forests can become an integral component of conservation zones, slope stabilization measures, and the development of green areas and public parks.

MAINTENANCE

For up to five years after establishment, tree seedlings may require watering or irrigation and need to be protected from weeds competing for light, moisture, and nutrients, and from grazing wild and domestic animals. Pruning and cutting may also be required. In seasonally dry climates where fire poses a significant risk, an effective fire prevention program is essential. Dead seedlings should be replaced early in the next rainy season, ideally with seedlings of a similar size to those surviving nearby (FAO 2021b) Silvicultural treatments applied at the establishment and early growth phase are particularly important to forest establishment (Le et al. 2012).

COSTS

COST CONSIDERATIONS

Land

Access to or ownership of land is required for urban forests.

Land on which urban forests may be located may be public or private.

Land required for urban forests may span a spectrum of small to large parcels. Larger urban forest areas may require engagement and cooperation with multiple landowners and stakeholders and can raise transaction costs.

Example land-related costs:

- Acquisition costs
- Land use (for example, payments to landowners) costs
- Land protection costs, including managing and controlling access
- Community resettlement costs

Construction and implementation

Urban forest implementation costs include tree inventory, securing necessary government permits, site preparation (for example, draining, cleaning, weeding and invasive species removal), and reforestation (tree purchase, planting, watering, and pruning as required).

Maintenance

The cost of forest maintenance can vary widely depending on the location of the urban forest, forest condition, and its age (newly planted versus conserved mature forests) and species composition of trees.

Urban forest maintenance costs may include:

- Training and capacity building
- Monitoring and additional inventory
- Replanting, depending on tree mortality
- Pruning or thinning
- Invasive species removal
- Tree disposal
- Tree or forest litter management

UNIT COST EXAMPLES THROUGHOUT THE GLOBE

- *Planting and 40-year maintenance costs for urban trees in different cities of Colorado, US, were found to vary from **US$100–$570 per tree.** (McHale et al. 2007).*
- *Watershed reforestation from European cost data: **US$2207/ha (US$185–US$5,546/ha)** (Ayres et al. 2014).*
- *Capital costs of afforestation (planting, establishment, financing) from a UK study: **US$15,780–US$18,700/ha** (Cambridge Econometrics 2020).*
- *Tree reforestation costs: **US$2,400–US$3,500/ha** (Strassburg and Latawiec 2014).*
- *A study in Ghana estimated **~US$8,000/year** cost of forest area within an urban university (Dumenu 2013).*
- *Operational costs of afforestation (for example, maintenance, invasive species and pest control, labor expenses) from a UK study: **US$3,600–US$3,700/ha** (Cambridge Econometrics 2020)*
- *U.S. cities spend **US$13–US$65 annually** per tree (McPherson et al. 2005)*

Brasov, Romania
Photo by Maria Teneva on Unsplash

NBS IN PRACTICE

The projects in this section highlight good practices and lessons learned in four urban forest projects, drawn from a growing number of case studies around the globe.

Photo by World Bank

Community involvement | Private and public scope | Environmental stewardship for sustainability

Project #1: *Freetown the Tree Town Campaign, 2020–23*
Location: *Freetown, Sierra Leone*
Description: *Within and surrounding the urban space around the capital, Freetown, trees have given way to buildings, a bleak testament to ongoing deforestation and environmental degradation in Sierra Leone. The Freetown Municipality began a one million tree-planting campaign in 2020. In addition to diverse native tree species with extended canopies and strong roots, private compound and community-based trees include mango trees to provide additional fruit harvesting community benefits. Educational workshops, community-based stewardship, planting and growing models establish ownership and value in the campaign at the community level. "This isn't just about planting trees. It's about growing trees, and it's about ensuring that each one of us is part of the process," says Yvonne Aki-Sawyerr, Mayor of Freetown. "A million trees is our city's small contribution to increasing the much-needed global carbon sink."*

Benefits
Education, Health, Biodiversity, Employment.
Source
Freetown City Council
https://www.betterplace.org/en/projects/82290-tree-planting-campaign-in-sierra-leone

Photo by World Bank

Government leadership | Participatory process | Knowledge development for future application

Project #2: *Shandong Ecological Afforestation Project, 2010–16*
Location: *Shandong, China*
Description: *Counties of the Shandong Province initiated the revegetation of degraded mountainous areas through the planting of trees and shrubs on highly degraded hillsides with a shallow soil cover. The main goal was to protect agricultural land, improve productivity, and stabilize a newly created alluvial plain near the mouth of the Yellow River. A protective layer of vegetation was established along the roads, the canals, and in areas designated for afforestation. The initiative aimed to strengthen project management capacity of the local and provincial governments. Participants received technical assistance, learn to monitor and evaluate the results, and took part in study tours.*

Benefits
Governance, Education.
Source
World Bank
https://www.worldbank.org/en/results/2017/07/26/china-afforestation-project-in-shandong-improves-environment-and-farmers-incomes

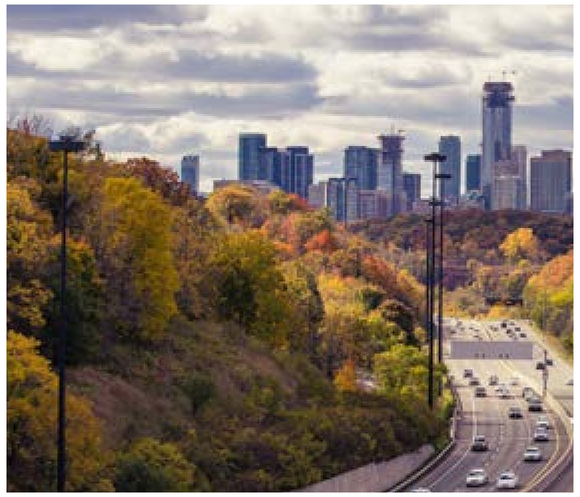


Photo by Matthew Henry on Unsplash

Equitable distribution | Increase awareness | Promote environmental stewardship

Project #3: *Toronto Strategic Forest Management Plan, 2012–22*
Location: *Toronto, Canada*
Description: *The City of Toronto recognizes the value of urban forests and aims to increase its tree canopy cover to 40 percent. The City's focus is on maximizing the potential ecological, social, and economic benefits of urban trees. The Urban Forestry branch of the Parks, Forestry and Recreation division maintains over four million trees on public property and works with local groups and residents to expand and improve the urban forest throughout the city. Since 2013, the city has been planting approximately 100,000 trees on public lands—parks, streets, ravines—per year, with ambitions to increase that to 300,000 trees per year through new private–public partnerships with private landowners.*

Benefits
Governance, Health, Biodiversity.
Source
City of Toronto, Urban Forestry
https://www.toronto.ca/data/parks/pdf/trees/sustaining-expanding-urban-forest-management-plan.pdf

Photo by Fieke Damen / Felixx Landscape Architects and Planners

Community involvement | Educational scope | Integrated with housing development

Project #4: *Urban Food Forest Rijnvliet, 2017 to date*
Location: *Utrecht, The Netherlands*
Description: *Residents of the Rijksstraatweg and the Metaalkathedraal areas proposed the concept of a food forest in the new urban development of Rijnvliet in 2017. The municipality developed a public space for this purpose—the edible residential area. All plantings were chosen for their value to nature, with strong preferences for edible plants and trees, even in the private residential gardens. The municipality has also accorded Rijnvliet a central food forest of 15,000 m*^{2}*, dedicated space built on seven multiple layers that form an integrated ecosystem. A neighborhood orchard for recreational activities and play areas for children is also in planning. Residents, the school, and the municipality regularly discuss fresh ideas to implement.*

Benefits
Community, Food, Biodiversity, Awareness.
Source
Felixx Landscape Architects, The Zwarte Hond, AE Food Forestry Development and Utrecht Municipality.
https://www.utrecht.nl/wonen-en-leven/bouwen/bouwprojecten/leidsche-rijn/buurten/rijnvliet/de-eetbare-woonbuurt/
https://www.felixx.nl/projects/urban-food-forest-rijnvliet-utrecht.html

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TERRACES AND SLOPES

Bali, Indonesia
Photo by Guille Álvarez on Unsplash

FACTS AND FIGURES

DESCRIPTION

Civilizations across the globe have been building landscape terraces to stabilize slopes for centuries and protect urbanized areas with steep slopes and loose soils, often exposed to a variety of hazards. These may include hydrometeorological hazards, such as floods, cyclones, and droughts, as well as gravitational hazards, like landslides and mudslides. Such gravitational hazards can cause disruption of transportation networks, loss of property and agriculture, sedimentation and pollution of the water bodies, blocked streets and infrastructure, and clogged stormwater systems. During a landslide, fast-moving debris can cause extensive damage.

Many typologies and technical approaches for terracing exist, tailored to specific conditions and geographical characteristics of a location. Terracing technology is often developed to enable and to prevent land degradation and erosion simultaneously. To date, it is an efficient solution to control erosion and it provides additional advantages for agriculture, such as added soil depth and the possibility of managing water levels. Modern technology including geogrids, textiles, membranes, and barriers evolved to augment and enhance terracing practices tested over time. Bioengineered substrates and reinforcement materials have been developed to provide better growing medium for trees, shrubs, and herbaceous species that enhance the stability of the slopes. Other tools are available to electronically monitor and control water levels and check water and soil quality and nutrient content.

TYPE OF CITY

Coastal
Delta
River
Mountain

SCALE

Neighborhood
City
River basin

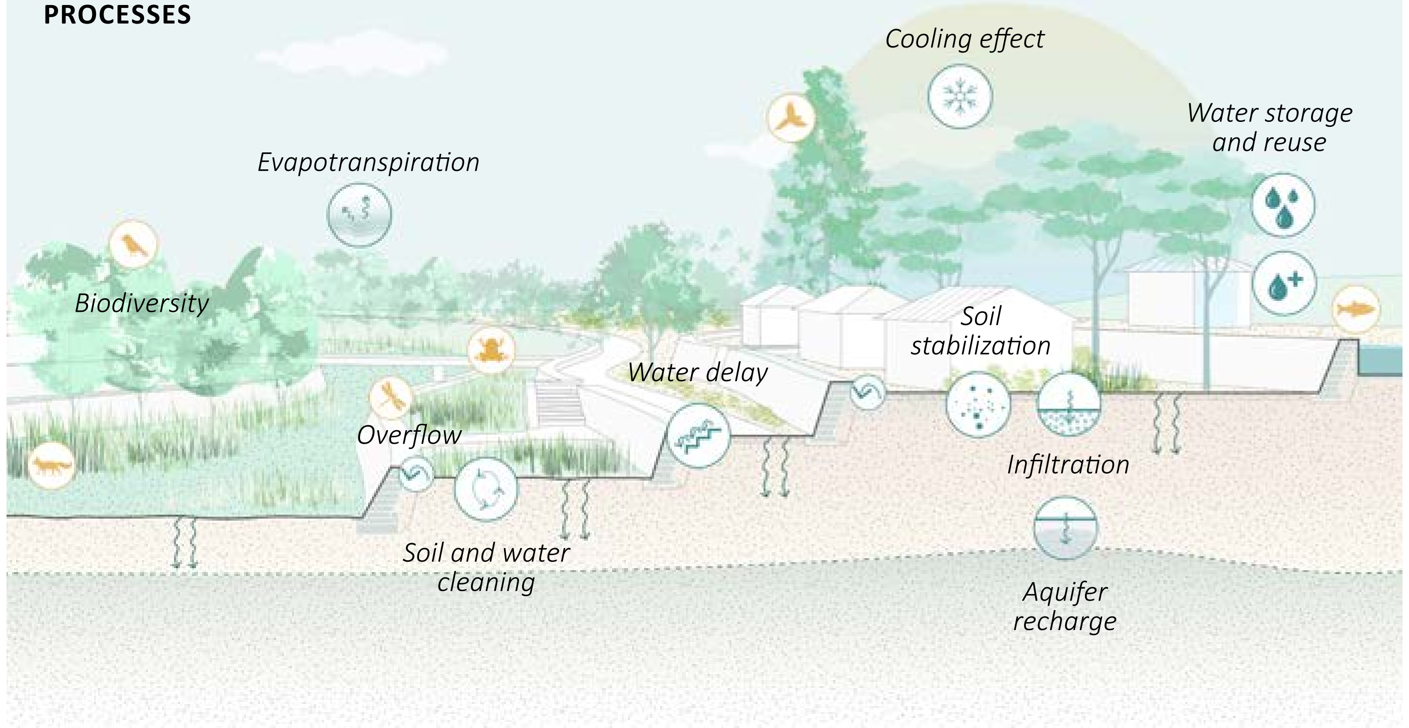
APPROACH

Protect
Preserve existing terrace systems.

Rehabilitate, Restore, Enhance
Restore existing terraces. Apply modern landscape technologies, including membranes and geo-textiles.

Create
Design new terraces with built-in long-term sustainability criteria.

PROCESSES

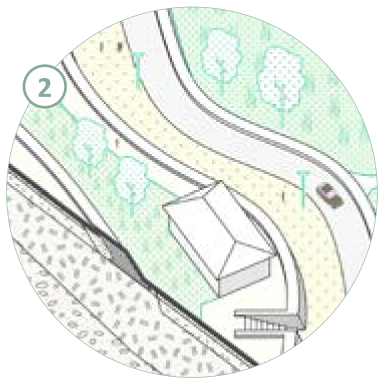


VISUALIZATIONS

VISUALIZATION OF TERRACES AND SLOPES IN THE URBAN CONTEXT

Details of increased benefits for the urban living environment

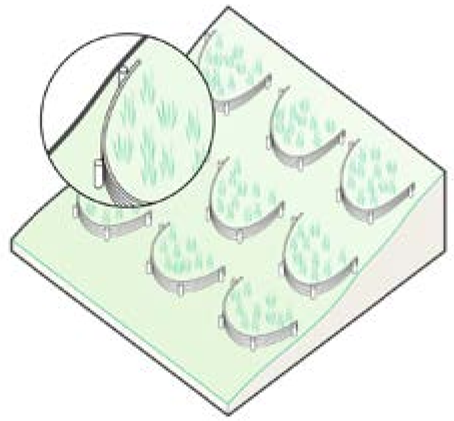
Terraces stabilize areas affected by flooding and landslides, while creating safe spaces for recreation and other uses.



The design of terraces continues centuries-old tradition, passing technical knowledge and cultural traditions, integrating new technologies and preserving local customs.

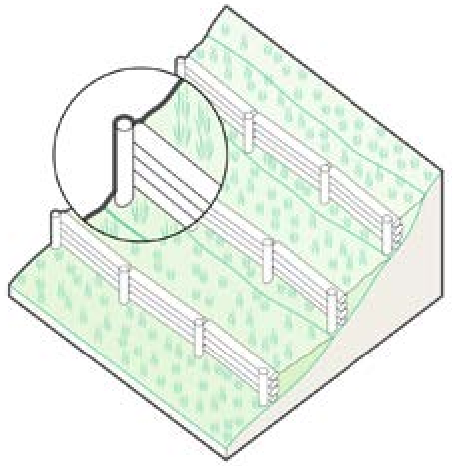
Terraces are entirely man-made landscapes that rely on a continuous commitment of people for their upkeep. They have symbolic meaning and represent a cultural practice that binds people to their natural context.

SPECIAL TECHNIQUES FOR TERRACES AND SLOPES



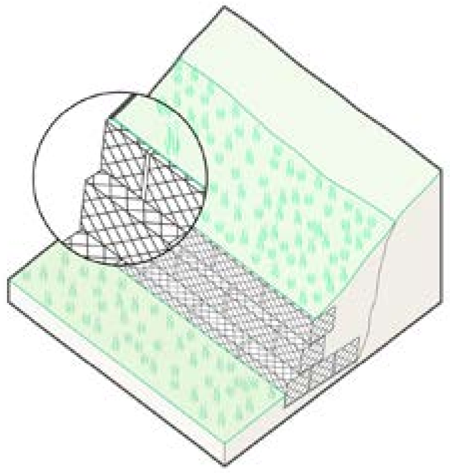
Living smiles

A living smile is a natural porous fence made of flexible plant cuttings, installed to drain a terrace of the excess water, simultaneously capturing and retaining suspended sediment, which is incorporated into the existing soil. Additional sediment increases the volume and structure of the existing soil, enhancing its quality as a growth medium. As a landscape technology, the living smile protects terraces from losing too much soil during heavy storms and protects plant roots from being exposed (Polster 2008).



Wattle fences

A wattle fence is made of sturdy wooden posts driven vertically into the soil with pliable young shoots woven horizontally in between. Traditionally made of willows or similar young trees, it is an ancient technology that is affordable, quick, and easily applied. Wattle fences are installed as vertical breaks perpendicular to the slope to reduce the impact of rolling materials during a storm. They also act as short retaining walls to reduce the angle of a slope and help vegetation establish. The cuttings sprout and grow, reinforcing the overall structure (Polster 2008).

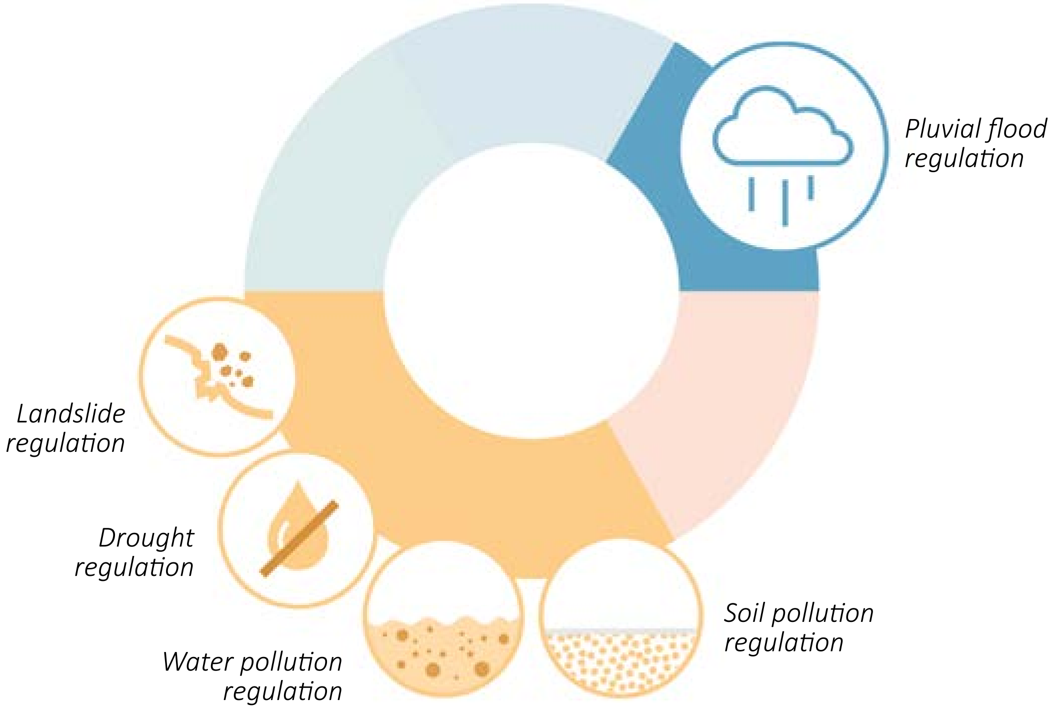


Vegetated gabions

Vegetated gabions are rectangular baskets made of heavily galvanized steel or another durable, corrosion resistant wire mesh, filled with stones. Gabions can be reinforced with geotextiles and filled with earth. They are used to reinforce and protect the slopes from fast-moving stormwater. By virtue of their initially porous structure, gabions capture and incorporate some of the flowing debris and sediment into their structure, which becomes a growth medium for plants that colonize and reinforce the gabions (Polster 2008).

FUNCTIONS

The diagram in this section shows relevant functions of terraces and slopes.



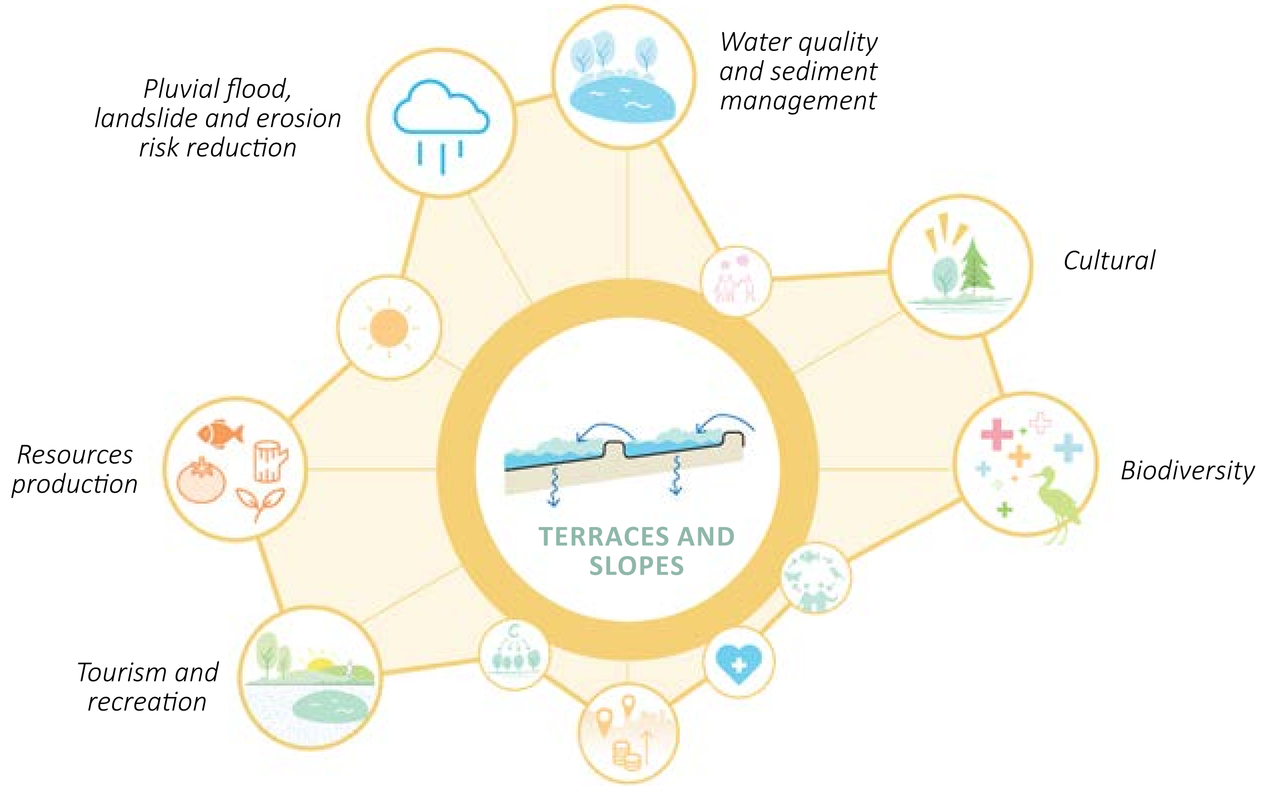
Pluvial flood regulation, erosion and landslide control: Traditionally, landscape terracing has been used in regions with steep topography and poor soils to increase the size of arable land and stabilize soils simultaneously (Berčič and Ažman-Momirski 2020). Terraces conserve water and soil by keeping them in place. They have the ability to capture and store stormwater and slowly release the excess. The detention function of terraces is of increasing importance as more extreme precipitation events are occurring as a result of climate change. Terraces can be managed to improve their detention and infiltration capacity (Eekhout et al. 2018).

A study conducted in India demonstrated the efficacy of terraces in reducing runoff and soil loss by more than 80% compared to unterraced slopes (Díaz et al. 2019). In addition, a Canadian study found that terracing reduced runoff of seasonal rainfall by 25% (NWRM n.d.). The traditional terracing in Veneto, Italy, reported a 50% increase in stormwater storage capacity by the terraces (NWRM n.d.).

Other functions: Terraces improve soil and water quality. Water quality increases due to improved buffering and filtering, thereby reducing groundwater and river pollution, and providing an extra supply of water to face periods of drought (Díaz et al. 2019).

BENEFITS

The diagram in this section shows a sampling of benefits that terraces and slopes can provide to people.



Pluvial flood, landslide, and erosion risk reduction: Terracing transforms the overall length of a slope into a series of short, relatively level steps. Since each step is positioned perpendicular to the flow of water, it absorbs a certain amount and drains the excess to the next step down (Díaz et al. 2019). This way, much of the soil and its nutrient content is preserved in situ and the overall system not only reduces the risk of flooding downstream, but minimizes the amount of suspended soil in the stormwater runoff, and protects infrastructures like irrigation channels, reservoirs, street drainage, the sewerage system from being damaged and clogged by the sediment (Sandor and Eash 1995). Hence, proper functioning terraces avoid structural damages from pluvial flooding to the agricultural and irrigation infrastructure as well as to properties downstream. Besides reducing flood risk, terraces reduce landslide risk.

Resource production: Terrace farming ensures food security and increases crop yield 2.5 times by conserving water and soil (Haas et al. 1996; Hammad et al. 2004). In some instances, the production is not limited to the crops. Rice paddies for example, provide habitat for various edible aquatic animals. Terraces capture and clean stormwater, which can be reused for additional purposes.

Tourism and recreation: Terraces are part of the cultural identity of many regions. They contribute to the scenic beauty of landscapes that attract tourists and inspire cultural production in the form of photography, painting, and film. In some regions that are appreciated for their exceptional beauty and historic significance, terraces generate additional revenue from tourism, including income from local restaurants, hotels, and hospitality services (Díaz et al. 2019).

Biodiversity: Cultivated terraces maintain high levels of soil moisture and nutrient content. The plants, unless they grow in the gabions, may be perceived as a threat, yet terraces can safely provide habitat for certain birds. In the Mediterranean region, for example, birds build nests on the terraces of rain-fed arboreal crops and vineyard terraces shelter endangered spiders (Tokuoka and Hashigoe 2015).

Cultural: Terraces represent cultural practices dating back millennia. They are some of the most spectacular and enduring achievements of human civilization recognized by UNESCO. (Díaz et al. 2019). As an agricultural practice, terraces help preserve ancient methods and practices passed from generation to generation. As such, they are both physical artifacts and part of the intangible cultural heritage.

Water quality and sediment management: Considered highly effective techniques for erosion control, terraces trap sediment at each level of the steps where it becomes incorporated as the growing medium for the crops. They also capture and infiltrate large volumes of water and incrementally discharge the excess water so that it gets filtered by several terraces. Terracing is considered as a powerful water-harvesting technique (Rashid et al. 2016). In temperate climates, terraces work to conserve water, and facilitate groundwater recharge (Liu et al. 2004).

SUITABILITY CONSIDERATIONS

ENVIRONMENTAL

Location and climate: Terraces can be found almost everywhere in the world, but they are very different in use, size, shape, and construction. They can be used as a land management instrument to prevent erosion and mudslides, but are more commonly used in combination with agriculture. Terraced barley, wheat, and rice paddies for example, are abundant in southeast Asia, and South America where rains are frequent and there is usually an excess of water. In the drier climates of Africa and in the Mediterranean region, terraces are built for vineyards, olive groves, and orchards as well as to grow cork oaks and other crops (Berčič and Ažman-Momirski 2020).

Hydrology and soil: Terraces are built perpendicular to the flow of water to reduce erosion, retain soil and moisture, create space for the crops, and generate a favorable microclimate to increase crop yield. The dynamic nature of terrace water-and-soil cycles helps maintain long-term soil fertility and requires areas with relatively deep soils, sites that are not dissected by gullies, and not too stony (FAO 1990). Different types of structural design for terraces can be applied in variety of conditions: For example, level bench terraces are generally used in areas with medium rainfall and highly permeable soils. Most of the stormwater falling on these terraces is absorbed; the excess water is drained out. Outward sloping bench terraces or orchard-type bench terraces are typical of the low-rainfall areas with moderately permeable soil. Inward sloping bench terraces are typically constructed in areas with heavy rainfall and less permeable soils. A large portion of the rainwater is drained off through a drainage channel located on the inner side of the side of the terrace (Mesfin 2016).

Arable production: Terrace farming improves soil fertility and land productivity and decreases the amount of horizontal surface required to meet the local demand for crops. Terraces are therefore suitable for any hilly area with dense population, food shortages, and high unemployment rates; and areas where traditional local crops require plentiful irrigation or permanent water levels, such as rice and taro (Mesfin 2016).

TECHNICAL

Slope: The optimal slope and the ideal distance between terraces on slopes with different gradients and the analysis of existing practices can yield valuable information on what works in each region (Doreen and Rey 2004). Although a 50% slope is usually considered a threshold for making terraces (Green 1978), in Nepal terraces are made on slopes exceeding this limit, and cultivation is practised up to a 100% slope using contour terracing (Shrestha et al. 2004).

Construction: Terrace construction is a labor-intensive land management practice. In any region, terracing must be done gradually at a regular pace, maintaining a careful balance between the cut and fill of soils (FAO 1990).

Several construction methods are available:

- Manual labor; the terrace must be built when the soil is neither too dry nor too wet.
- Construction using farmyard working animals and specialized tools.
- Mechanized construction.

It is essential to design and maintain the proper slope for the individual terrace; secure proper installation of the drainage channels along the inner side of the terrace; identify the need for secure proper installation of any geotechnical membranes, living smiles, wattle fences, and gabions; and secure correct installation of electronic equipment for monitoring water level, chemicals, and temperature.

Dimensions: The size of a terrace is defined by drainage requirements and method of agricultural cultivation, among other variables. Its length is limited to the size and shape of the lot. In humid tropical climates, a maximum of 100 meters in one direction is recommended for proper drainage. Nonmechanized cultivation limits the width to 2.5–5 meters; mechanized increases the width to 3.5–8 meters where depth of soil is not a limit (Mesfin 2016).

URBAN

Land use: Suitable land uses for terraces are peri-urban green areas, agricultural areas, slopes, and green areas.

Urban density: Terrace construction is suitable for low to medium density urban areas.

Area: Medium to large. Terraces are nature-based solutions typically designed for application at a medium to large scale.

Integrated urban planning: Terraces can be an integral component of slope stabilization works, local food production, development of green areas and public parks, and reforestation programs.

MAINTENANCE

Terraces require regular care and maintenance. A small, neglected break can result in significant damage. Regular monitoring and maintenance should be carried out after heavy storms and harvests, especially in the first two or three years after construction or restoration (FAO 1990). The use of monitoring equipment can reduce the number of inspections and expedite the delivery of maintenance when it is needed.

COSTS

COST CONSIDERATIONS

Land

Access to or ownership of land is required for terraces in urban areas.

Land on which terraces may be located may be public or private.

Land required for terraces may range from small to large, requiring different levels of engagement with landowners and stakeholders depending on the project area, and affecting transaction costs.

Example land-related costs:

- Acquisition costs
- Land use (e.g., payments to landowners) costs
- Land protection costs, including managing and controlling access
- Community resettlement costs

Construction and implementation

Terrace construction costs will be impacted by soil conditions, the degree and consistency of the slope to be terraced, the length of terraces required, the material terraces are constructed from, and whether the terrace will be parallel or contour, level or graded.

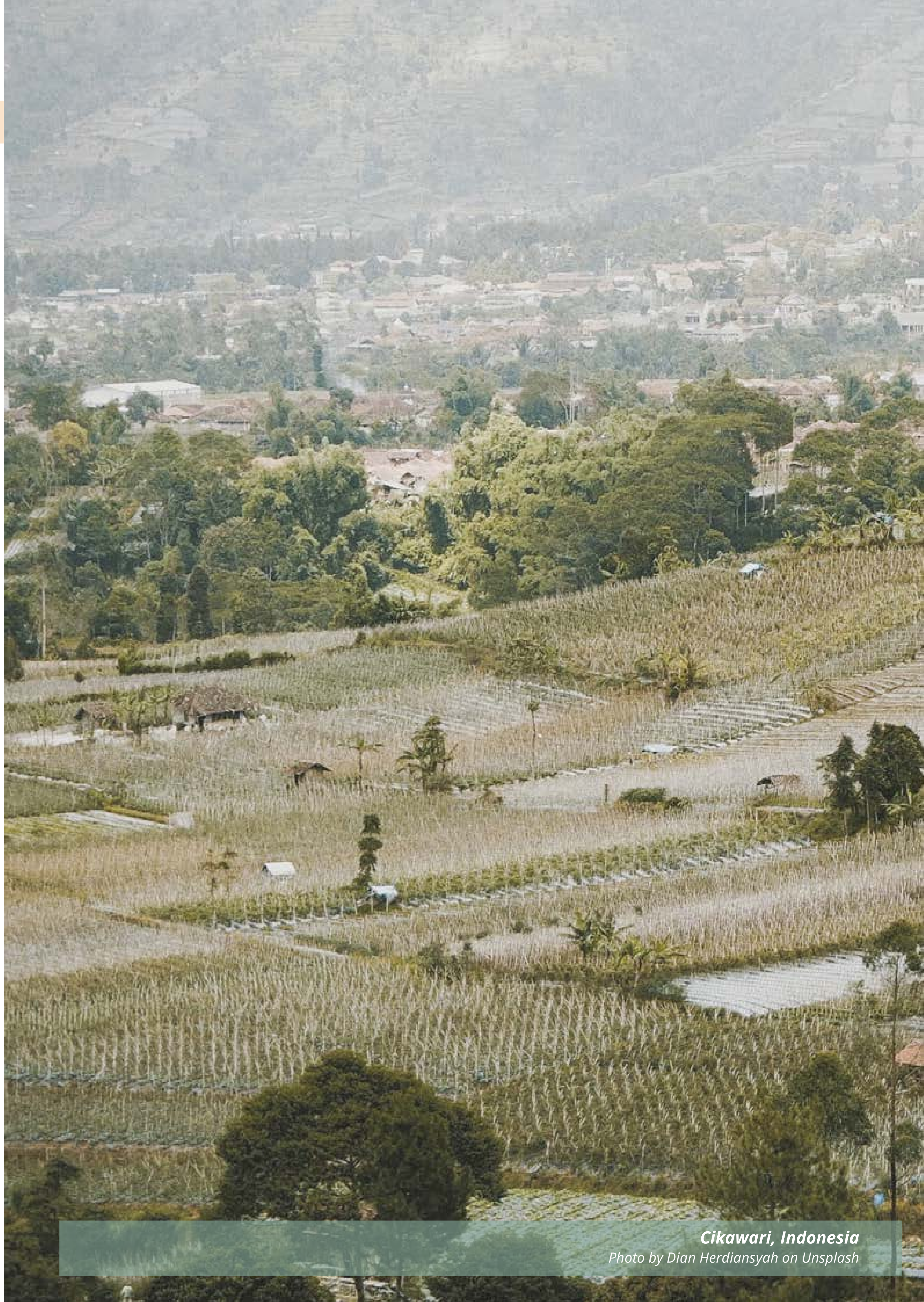
Costs of terrace construction include machinery (e.g., bulldozers, terrace plows); labor (equipment operators; managers); materials (e.g., materials to make gabions, support terrace edges, and others); and mobilization equipment to move soil.

Maintenance

The costs of terrace maintenance depend on the terrace typology, the local context, labor, and material costs.

UNIT COST EXAMPLES THROUGHOUT THE GLOBE

- *A European study estimates the cost for new terracing using heavy machinery at* ***US$1,080 ha/year*** *(Khulman et al. 2010).*
- *The U.S. Natural Resources Conservation Service (NRCS) provides a range of cost estimates for terraces from* ***US$2.3–US$4.92/m*** *of terrace.*
- *In India, the total cost of construction and the first two years of maintenance has been estimated at* ***US$1,600/ha****, including preparation of the plants in the nursery and transplantation and manual harvesting (Mishra and Rai 2011).*
- *A European study estimates the cost of terrace maintenance at* ***US$242 ha/year*** *(Khulman et al. 2010).*



Cikawari, Indonesia
Photo by Dian Herdiansyah on Unsplash

NBS IN PRACTICE

The four projects in this section highlight best practices and lessons learned in terracing and slopes in rural areas, drawn from growing experience in implementing NBS throughout the globe.

Photo by Momo on Flickr

Example of a fruitful partnership | *Physical and economic transformation of agriculture* | *Project principles widely adopted and replicated*

Project #1: *Loess Plateau Watershed Rehabilitation Project, 1994–2002*
Location: *China*
Description: *Home to more than 50 million people, the Loess Plateau in China's northwest takes its name from the dry powdery wind-blown soil. Centuries of overuse and overgrazing led to one of the highest soil erosion rates in the world and widespread poverty. Two projects over 12 years set out to restore China's heavily degraded Loess Plateau in the early 1990s through one of the world's largest erosion control programs with the goal of returning this poor part of China to an area of sustainable agricultural production. Terraces have reduced labor inputs and so, allowed farmers to pursue new income-earning activities. The physical and economic transformation of the Loess Plateau offers the clearest demonstration of what can be achieved through close partnership with the government, good policies, technical support, and active consultation and participation of the people.*
Benefits
Income, Food, Water Quality and Sedimentation Management.
Source
World Bank
https://web.worldbank.org/archive/website00819C/WEB/PDF/CHINA_LO.PDF

Photo by Azilem-yongbi on Unsplash

Community-based land use and zoning plans | *Continuity of cultural traditions and ecological knowledge* | *Generations of small-scale farmers working as a community*

Project #2: *Ifugao Rice Terraces, Ongoing*
Location: *Cordilleras, Philippines*
Description: *Built 2,000 years ago and maintained from generation to generation, the Ifugao Rice Terraces represent an enduring illustration of an ancient civilization that surpassed various challenges and setbacks posed by modernization. The terraces illustrate a persistence of cultural traditions, remarkable continuity, and endurance. The maintenance of the living rice terraces reflects a primarily cooperative approach of the whole community. It is based on detailed knowledge of the rich diversity of biological resources of the Ifugao agroecosystem, a finely tuned annual system respecting lunar cycles, zoning and planning, extensive soil conservation, mastery of a most complex pest control regime based on the processing of a variety of herbs, accompanied by religious rituals.*

Benefits
Culture, Education, Economy.
Source
World Heritage Conservation
https://whc.unesco.org/en/list/722/

Photo by Simon Allen on Unsplash

Support to promote agricultural transition | *Partnership with international research institutes* | *Building and promoting capacity to access climate finance*

Project #3: *Lesotho Climate-Smart Agriculture Investment Plan, 2012–20*
Location: *Lesotho*
Description: *The Kingdom of Lesotho is a small mountainous country in South Africa. Its agriculture is based entirely on the mountain terraces. In addition to raising crops, most households own livestock and cattle, indispensable to the cultivation of the terraces. When not grazing on summer cattle posts, away from the village, livestock is kept at night in special enclosures, known as kraals, adjacent to the farmers' houses. The cattle and the terrace agriculture are part of the same agricultural ecosystem that sustains life in Lesotho. Long-term success of its communities depends on careful land management to preserve the delicate balance between the grazing and the crop-producing land.*
Benefits
Economic resiliency, Culture.
Source
World Bank
http://documents1.worldbank.org/curated/en/847551575647928833/pdf/Lesotho-Climate-Smart-Agriculture-Investment-Plan-Opportunities-for-Transitioning-to-More-Productive-Climate-Resilient-and-Low-Carbon-Agriculture.pdf

Photo by Manasse Nshimiyimana / Green Cover Initiative RWANDA

External funding | *Community leadership in execution and maintenance* | *Boost local economy and livelihoods*

Project #4: *Radical Terraces, 1970s to date*
Location: *Amaterasi y'indinganire, Rwanda*
Description: *Unique to Rwanda, radical terracing is a terracing method of cut and fill that results in reverse-slope bench terraces with regularly shaped risers stabilized by grass or trees. Radical terraces consolidate land to create permanent agriculture on the very steep slopes. Their objective is to improve the livelihood of the farmers; restore and enhance environmental resilience by reducing the amount of soil being washed off, and improving the rates of stormwater retention and infiltration. When making the terrace, the farmers isolate and preserve nutrient-rich topsoil from the slope and incorporate it back into the reverse-slope bench. With help from external funding, 70% of land users have implemented radical terracing.*

Benefits
Social, Education, Economy.
Source
FAO
http://www.fao.org/3/a-au298e.pdf

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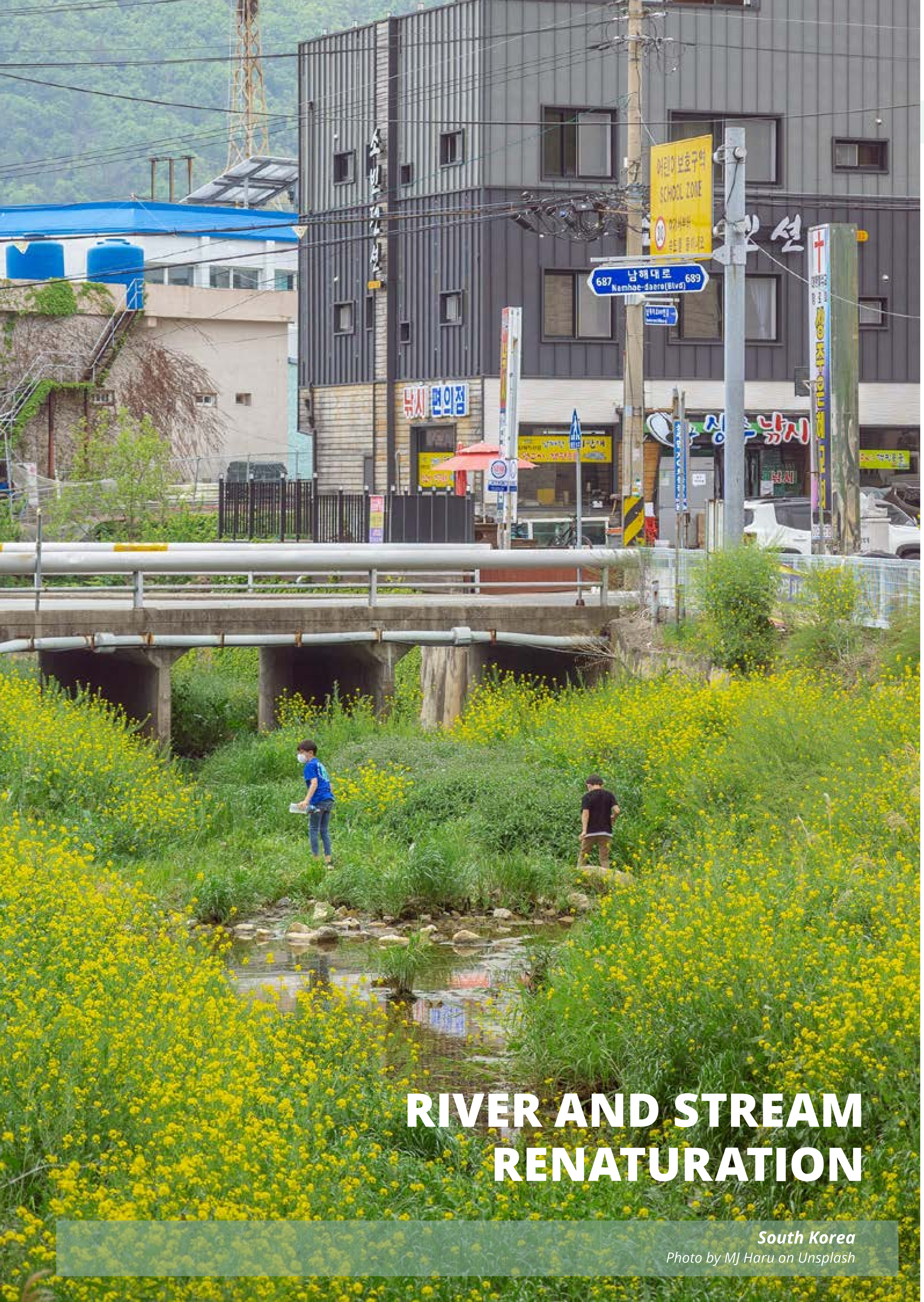
Puthucode, Kerala, India
Photo by Aboodi Vesakaran on Unsplash



RIVER AND STREAM RENATURATION

South Korea
Photo by MJ Haru on Unsplash

FACTS AND FIGURES

DESCRIPTION

In many urbanized areas around the world, rivers and streams became completely denaturalized. Construction of embankments, culverting, and filling in of tributaries became a normal practice in industrialized societies to create space for development. Globally, flood risk along rivers and streams steadily increased as a result of these ongoing economic developments in flood prone areas, in addition to the increased likelihood of extreme weather events owing to climate change.

Increasing flood risk and the societal appreciation of ecosystem services and biodiversity have led to a paradigm shift in management of rivers and streams in urbanized areas, making the case for their renaturation and restoration. Several nature-based solutions have been developed to restore the natural dynamics of these watercourses. Renaturation—stream daylighting, reestablishment of riparian corridors, removal of concrete embankments, and river or stream bed and bank revegetation—are gaining momentum. Where possible, cities are more frequently reinstalling riparian corridors and other measures for renaturation, giving additional room for the rivers to flow. "Don't fight the water, work with it," is becoming entrenched in urban planning and drives river and stream renaturation projects.

TYPE OF CITY

Coastal
Delta
River
Mountain

SCALE

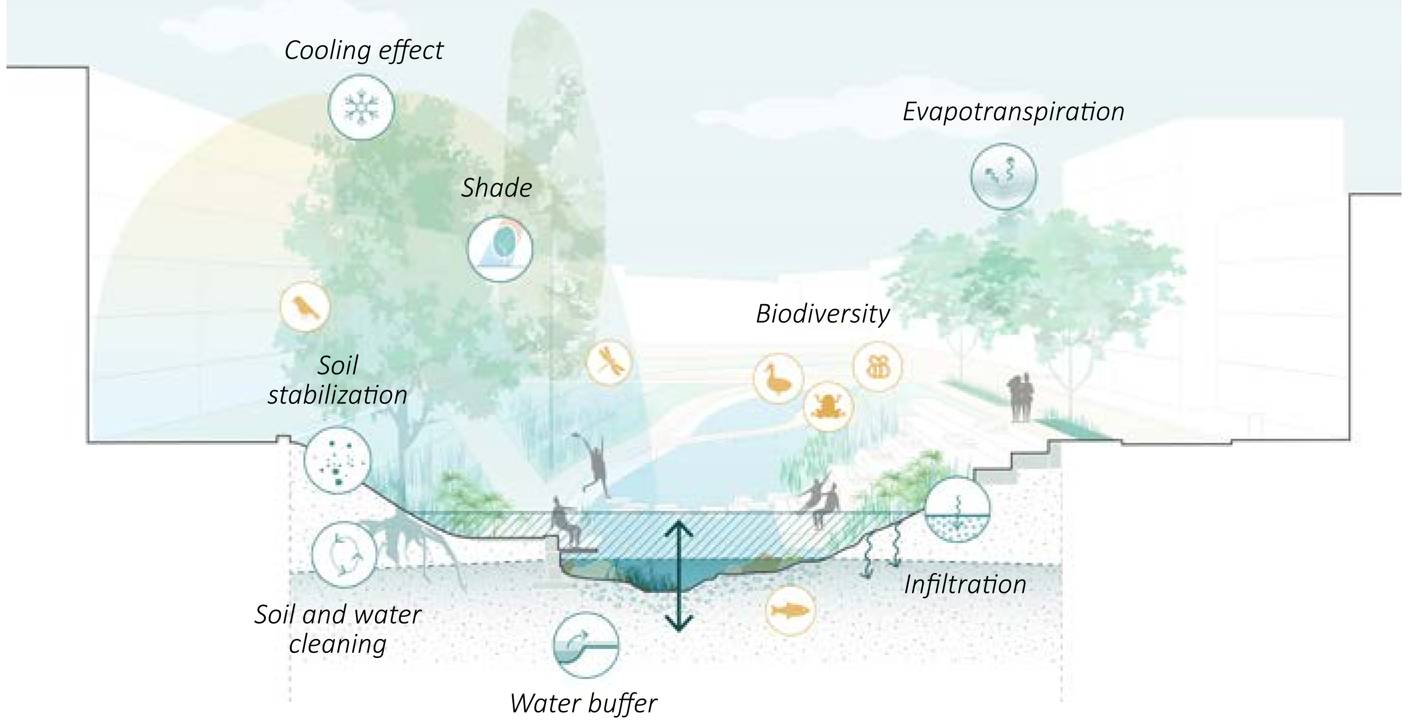
Neighborhood
City
River basin

APPROACH

Protect
Preserve the tree structure along rivers and streams.
Preserve and protect existing watercourses and hydrological systems of rivers.

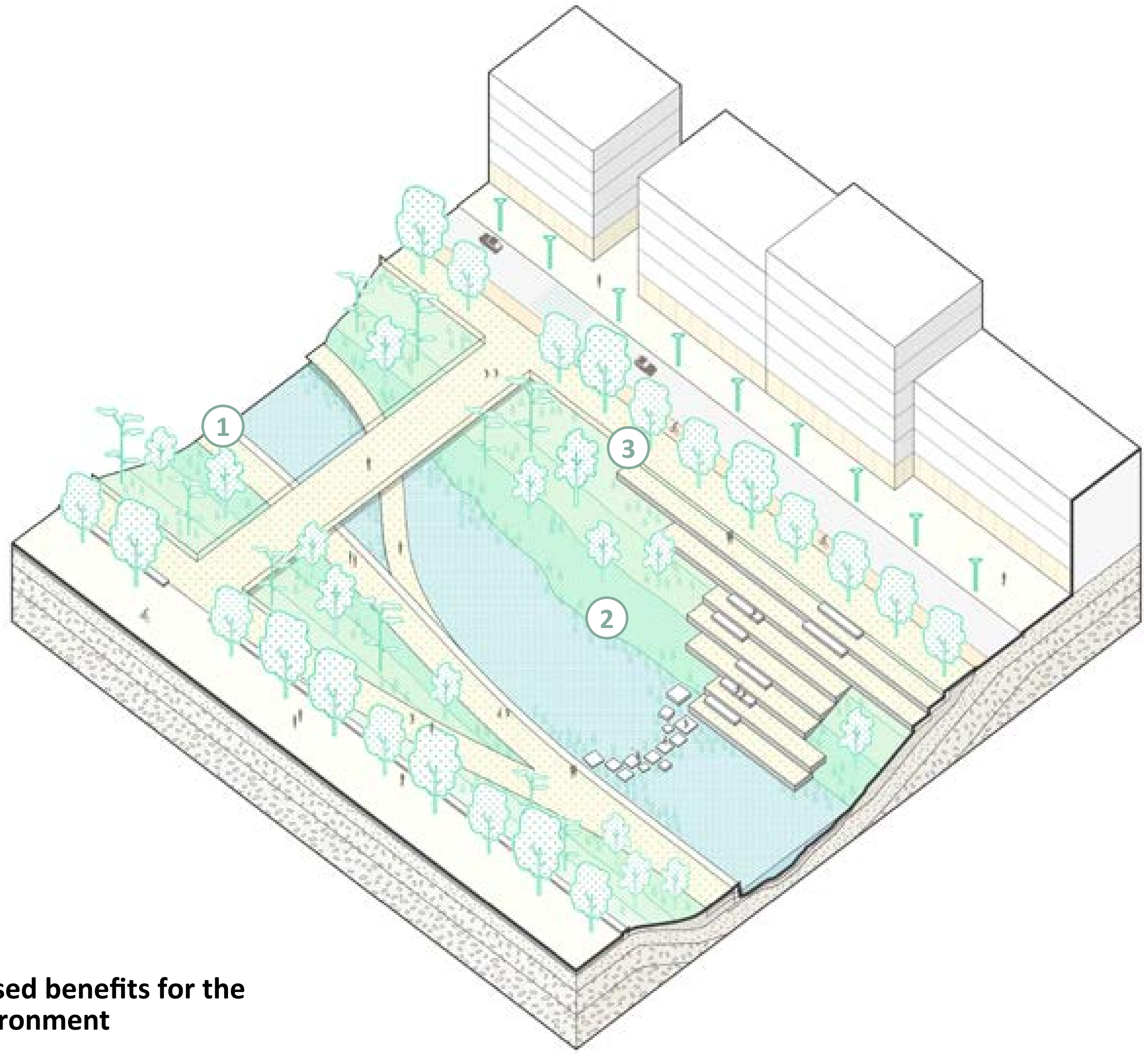
Rehabilitate, Restore, Enhance
Replant riverbanks.
Daylight streams and tributaries.
Rehabilitate rivers and stream to restore natural dynamic processes.

PROCESSES

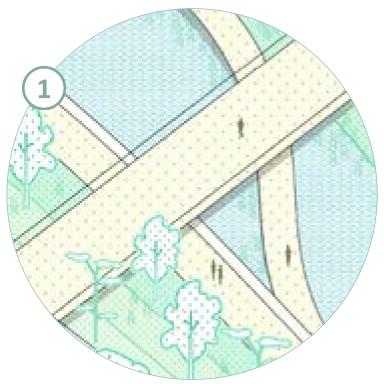


VISUALIZATIONS

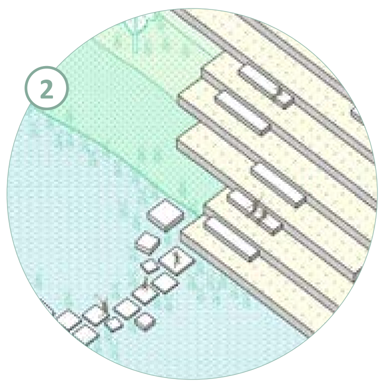
VISUALIZATION OF RIVER AND STREAM RENATURATION IN THE URBAN CONTEXT



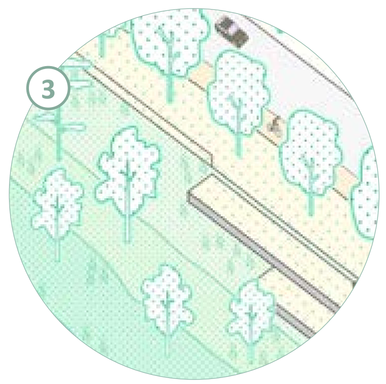
Details of increased benefits for the urban living environment



River renaturation establishes a meaningful relationship between the city and its river. The new public space provides recreational and cultural benefits, contributing to the city's identity.

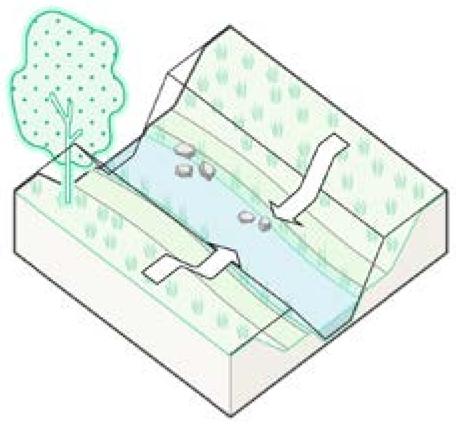


Stream renaturation returns streams to communities. It makes water a visible, valuable, and enjoyable part of daily life; an asset that protects and invigorates.



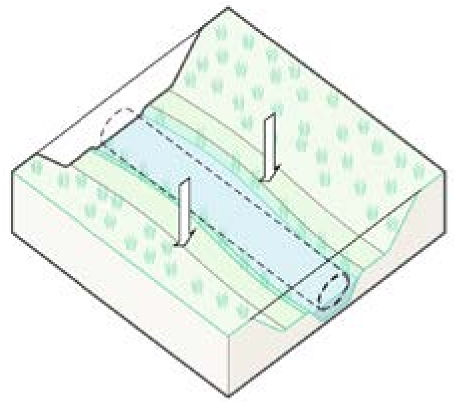
People experience the river and its riparian corridor as one landscape, full of opportunities, recreation, and education, a year-round source of discovery.

SPECIAL TECHNIQUES FOR RIVER AND STREAM RENATURATION



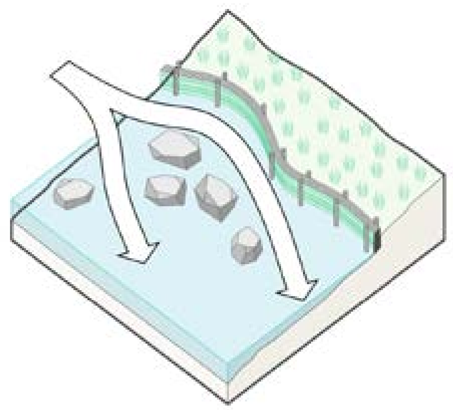
Bank and bed renaturation

The riverbank is an interface of aquatic and terrestrial ecosystems, an area protecting cities from riverine floods and often an important social place with recreational and cultural value. Its renaturation design should also safeguard ecological functions and flood control. Riverbank and bed renaturation aim to restore the natural dynamic of the river, which may mean restoring its shape, creating physical structures to direct the flow of water, and provide habitat for aquatic species.



Stream daylighting

Small streams provide a wide array of benefits to communities, such as nutrient and pollution removal, groundwater recharge, and flood mitigation. In some urban areas, streams were previously enclosed by concrete pipes or simply filled in. This could lead to floods, soil subsidence, and consequently to severe damages such as building collapses. Daylighting is a technique to remove layers of concrete and recreate the natural shape and dynamic of streams, resulting in increased wildlife and aquatic habitat, and better regulated stormwater runoff treatment and intake (Eisenbert and Polcher 2020).

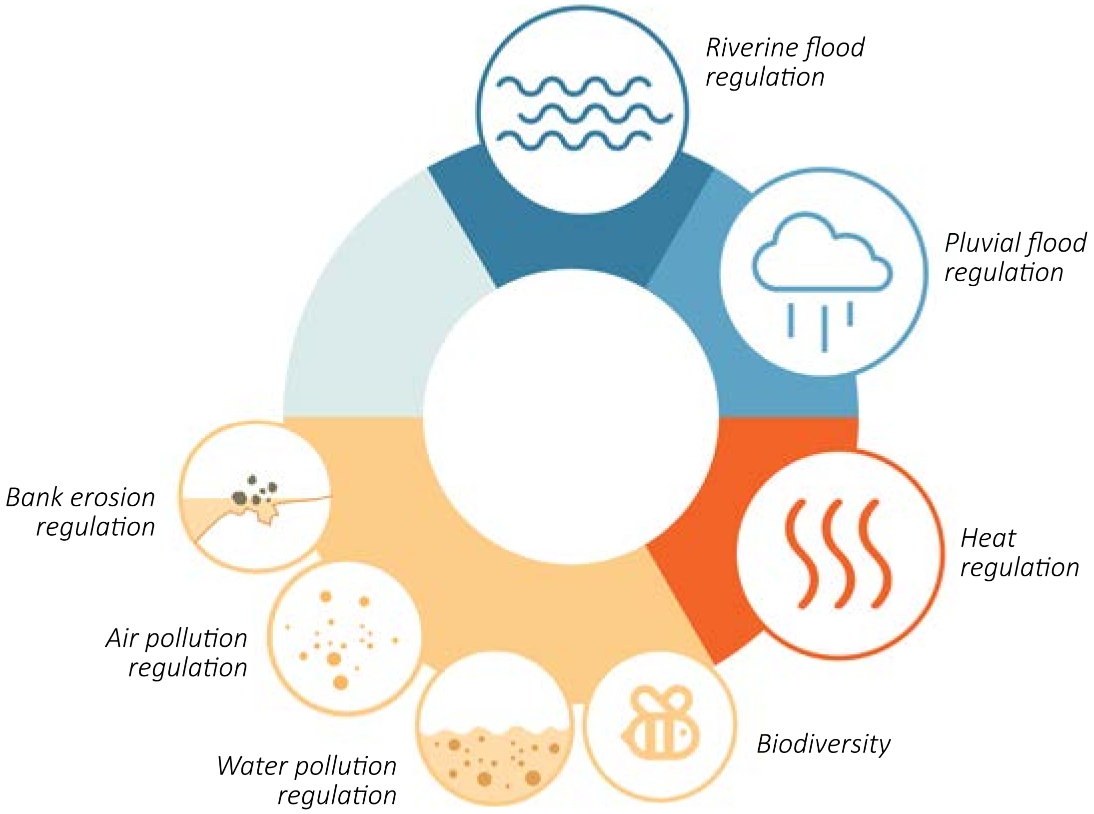


Bioengineering techniques

Renaturation relies on several bioengineering techniques to recreate the natural course of a river and connect it to its landscape for floodplain and riparian corridor revegetation, riverbank stabilization, and restoration of the riverbed. The natural river dynamic rests on the use of plants, rocks, and other natural elements, as well as geotextiles and membranes to create ecologically rich and structurally stable environment mimicking natural conditions, while providing space for recreation (Eisenbert and Polcher 2020).

FUNCTIONS

The diagram in this section shows relevant functions of river and stream renaturation.



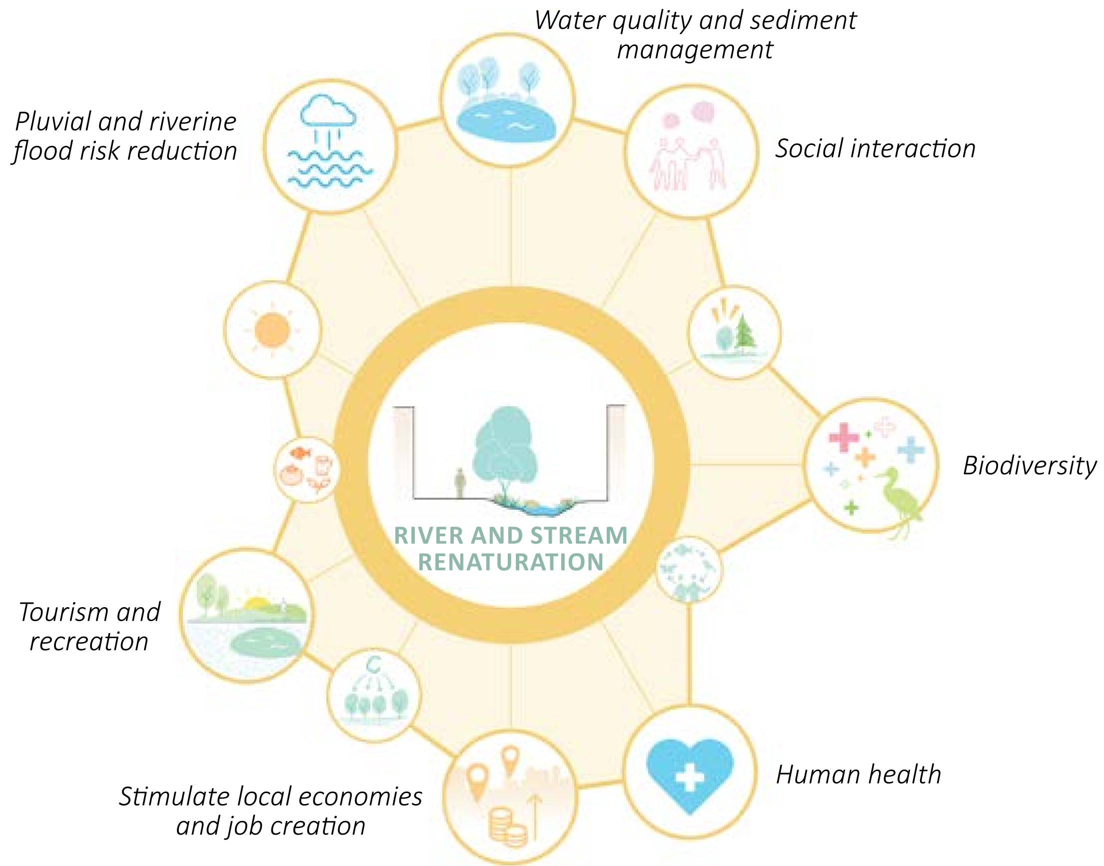
Pluvial and riverine flood regulation: River and stream renaturation can help slow the river flow and thus, reduce river floods by creating water retention and infiltration capacity in the river system (Ozment et al. 2019). If natural functions are preserved or restored—such as a river's meandering path or vegetated riparian areas—a variation of flow and sediment movement leads to a reduction of the peak discharge (Soar and Thorne 2001). Stream restoration, when applied to an urban watershed, can be complemented by other NBS for stormwater management throughout the river basin to also reduce the magnitude of local pluvial flood hazard.

Heat regulation: Some specific forms of river and stream renaturation—such as restored riparian corridors including trees—stabilize water temperature and reduce ambient temperatures in adjacent neighborhoods. Such canopy-rich NBS are specifically effective for reducing extreme heat in high density urban areas or riparian areas used for recreation (Hathway and Sharples 2012).

Other functions: River and stream renaturation can decrease pollution of water, soil, and air, stabilize soils and reduce soil erosion, and offset the loss of biodiversity by becoming critical conduits for the movement and propagation of biota (NWRM n.d.).

BENEFITS

The diagram in this section shows a sampling of benefits that river and stream renaturation can provide to people.



Pluvial and riverine flood risk reduction: River and stream renaturation projects can be effective as part of a large-scale urban water management strategy, in which a typical objective is to protect cities from floods by increasing the capacity of waterbodies to hold excessive amounts of stormwater. Such projects increase volumetric capacity and restore the natural hydrodynamics of the watercourses together with their river banks, riparian corridors, buffer zones, and floodplains where possible (NWRM n.d.). As a result, river and stream renaturation projects can lower flood height and flood velocity in surrounding areas and thereby reduce structural damages to properties and infrastructure.

Tourism and recreation: Stream and river renaturation create new recreational and tourism opportunities, from fishing and boating to walking and bird watching, attracting urban dwellers to the waterfront. In some contexts, formal sports and recreation areas can be integrated into buffer zones (NWRM n.d.).

Stimulate local economies and job creation: Stream and river renaturation in cities enhance flood safety, leading to the rise of property values in areas close to renaturated areas and potentially enable land value capture. Also, renaturation projects increase the number of recreants and tourists, and thereby bring opportunities for local entrepreneurs contributing to urban economic growth.

Human health: Rivers and riparian areas are uniquely suited for active recreation, and as areas for contemplation and reflection pastime. These activities enhance the human experience in cities and deliver important public health benefits. Studies have specifically shown that visiting rivers, lakes, and other waterbodies increases the sense of wellbeing (Helliwell et al. 2020). Renaturation projects created with safe spaces and that promote active exercise, kayaking, walking, and biking, contribute to mental and physical health (D'Haese et al. 2015). These positive health effects often lead to a reduction in the cost of healthcare and improved productivity (Buckley and Brough 2015).

Biodiversity: River, stream, and riparian corridor restoration projects are excellent ways to enhance biodiversity. The corridors provide food, shelter, nesting, and breeding areas for wildlife, and serve as safe conduits for the movement of biota within the city and to the larger patches in the regional landscape mosaic.

Social interaction: Daylighting and reshaping of hidden and artificially straightened watercourses result in attractive new green and blue areas with plenty of opportunities for social interaction. These urban spaces can, for example, be enlivened with simple footpaths and are good locations for cultural events to highlight the connection between the people and the river.

Water quality and sediment management: River and stream renaturation stabilizes riverbanks, prevents soil erosion, and reduces runoff. A riparian zone, for example, protects water quality by capturing sediments and pollutants and prevents stormwater runoff from streets entering and contaminating a watercourse (NWRM n.d.). This may reduce adverse health effects of water pollution and reduce water treatment costs for the city and downstream areas.

SUITABILITY CONSIDERATIONS

ENVIRONMENTAL

Location and climate: River and stream renaturation projects can be initiated anywhere river systems have been altered by development. They are particularly important in flood prone areas; areas characterized by high levels of impervious surface and runoff; and areas with vulnerable structures on top of culverted streams (NWRM n.d.).

Hydrology: The effectiveness of river and stream renaturation interventions depends on the hydrological conditions of a river system and the performance targets of the full suite of benefits. Seasonal flow characteristics and the capacity of the river to accommodate high discharge levels should be modeled to understand the capacity of the restored watercourse to retain floods and to inform bed and bank stabilization measures. Good hydrological and hydraulic models can be used to support the restoration of the natural dynamics of the river basin, evaluate appropriate renaturation techniques at targeted sites, and simulate the potential impact of climate change and planned future developments such as new urban development, construction of dams, or new wastewater outfalls. These variables may change the quantity and timing of water flowing through the river as well as the potential consequences of flooding events along the catchment.

Soil: Soil characteristics of the riverbed, the banks, and the floodplain need to be examined when designing a renaturation project. Riverbank and floodplain soils must have enough structure to keep plant roots in place during inundation. They must also have the right acidity and enough moisture to sustain the plants during droughts. Bank soils should be erosion resistant and can be reinforced by plants, geotextiles, membranes, and gabions, if needed. In some contexts, silt-laden riverbeds may require dredging to maintain the capacity and biodiversity values of the river (DEP 2006).

TECHNICAL

Slope: Riverbank and floodplain slopes intercept and assimilate pollutants from lateral stormwater inputs. They also provide additional storage space for floodwaters that help protect the city in case the river overflows. Slopes also support riparian habitat that helps maintain temperature regime, sustain aquatic life, and serve as essential movement corridors for terrestrial biota. The slopes should maintain stability, so protection and stabilization are key elements to be considered when planning river and stream renaturation projects.

Dimensions: The dimensions of a river renaturation project depend on the availability of land, the size of the stream or a river, and the goals of the project. The restoration of a riparian corridor and a buffer zone may extend tens of meters on both sides of the river (NWRM n.d.). Although wider buffer zones provide greater benefits (DEP 2006), this is rarely possible in the urban context. The most frequently approved minimum dimensions for buffers providing water quality and habitat maintenance are 10–30 meters (2030 palette 2020). A range of factors need to be considered when delineating a buffer zone such as flood risks, the profile of the banks, risks of pollution from adjacent land uses, and the need to generate other benefits such as recreation and cultural value.

Planting and growing strategy: As part of the riverine ecosystem, plants have several roles. They help reduce soil erosion and stabilize banks, enhance the quality and functions of riparian corridors and buffer zones, and provide an aesthetic identity for the waterfront. Where possible, native plants should be selected for river and stream renaturation. Trees that can tolerate a high water table, provide strong shade, enhance habitat value for wildlife, and provide good cover for roving animals, should be used for riparian corridors (DEP 2006). The selection should fit soil profiles and hydrology in different zones.

Natural fabrics: River and stream renaturation may use a combination of geotextiles and other technologies with natural elements such as stones, wood logs, and fascine mattresses for bed and bank protection and to control water movement along the stream (Eisenberg and Polcher 2020).

URBAN

Land use: Multifunctional use, such as recreation, should be encouraged where possible as part of river and stream renaturation projects to enhance the provision of benefits.

Urban density: River or stream renaturation projects can be implemented in both low and high urban density areas.

Area: Medium to extra-large. River and stream renaturation is a nature-based solution appropriate for a neighborhood, district, city and river basin scale.

Integrated urban planning: River and stream renaturation can be integrated into ecoconservation, water management, and the development or restoration of green areas or public parks.

MAINTENANCE

River and stream renaturation projects are particularly susceptible to damage during the first two to four years after implementation (DEP 2006). Regular inspections should follow the progress of revegetation and check for any signs of erosion. Once vegetation is successfully established, maintenance frequency can be reduced, although regular control of invasive species, mowing, and monitoring for pests and diseases are recommended. Additional monitoring and maintenance are required during the first few years after inundation, and after any additional restoration efforts (DEP 2006).

COSTS

COST CONSIDERATIONS

Land

Access to or ownership of land is required in riparian urban areas.

Land on which river and stream renaturation is conducted may be public or private.

Land required in riparian areas may overlap with multiple landowners where renaturation work is required on longer lengths along a waterway, and may increase transaction costs associated with engagement of numerous landowners and stakeholders.

Example land-related costs:

- Acquisition costs
- Land use (e.g., payments to landowners) costs
- Land protection costs, including managing and controlling access

Construction and implementation

Depending on project design, river and stream renaturation costs may include protection or conservation of land adjacent to watercourses; removal of impervious surfaces and barriers (e.g., concrete); and revegetation of land adjacent to the watercourse.

Maintenance

Maintenance costs for river widening include clearing weeds/vegetation; removing obstructions, dirt, and silt; and repairing riverbanks. These maintenance activities can be conducted manually or mechanically.

UNIT COST EXAMPLES THROUGHOUT THE GLOBE

- *Removal of riverbed or bank fixation from European cost data: **US$1.80–US$1,426/m** of restored watercourse (Ayres et al. 2014).*
- *Nature-based "Soft Bank" protection and water buffering (e.g., brush mattresses, revegetation, geotextiles); costs reflect smaller rural river branches in Europe: **US$54,000–US$978,000/km** (Ayres et al. 2014).*
- *Restoration of natural watercourse from European cost data: **US$18–US$1,188/m** of river stretch recovered (Ayres et al. 2014).*
- *Manual maintenance activity costs: **US$5,730–US$51,311/km** of river per year (Aerts 2018).*
- *Mechanical maintenance activity costs: **US$1,680–US$17,096/km** of river per year (Aerts 2018).*

Thailand
Photo by James Zwadlo on Unsplash

NBS IN PRACTICE

The four projects in this section highlight good practices and lessons learned in river and stream renaturation, drawn from selected case studies around the globe.

Photo by Jimmy Tan on Flickr

Paradigm shift for traditional flood infrastructure

Long-term initiative to transform country's water bodies

Residents changed view and ownership toward the river park

Project #1: *Bishan–Ang Mo Kio Park, 2009–12*
Location: *Singapore*
Description: *Bishan–-Ang Mo Kio Park was designed as an ambitious water management and park project, with a focus on recreation and social interaction. It is one of the largest and most successful parks in Southeast Asia. To realize the park, an old concrete canal was stripped of concrete and naturalized into a 3-kilometer long meandering river with open lawns and gently sloping grassy banks on both sides. The park offers many amenities, picnic areas, walkways, and cycle routes. It also includes allotment gardens where residents can rent and raise planter beds. A designated butterfly habitat area, and other areas with emphasis on biodiversity complement active recreation areas.*

Benefits
Social, Health, Heat Stress and Flood Risk Reduction.
Source
Ramboll Studio Dreiseitl
https://www.asla.org/2016awards/169669.html

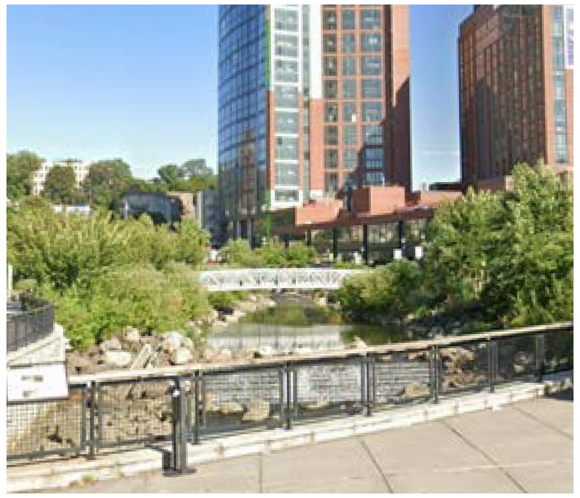


Photo by Google Earth

Environmental organizations initiated the process by public discussion

Grant funded, which provided opportunity to leverage other funding sources

The project sparked for downtown revitalization project

Project #2: *Saw Mill River Daylighting Project, 2001–12*
Location: *Yonkers, NY, USA*
Description: *The Saw Mill River in Yonkers was kept underground in the 1920s after the industry together with residents had turned it into a polluted sewer. It remained buried until 2001 when the Groundwork Hudson Valley—an environmental NGO focused on improving the physical and social environment of urban communities—began to investigate a possibility of recovering the river and securing funding for the project. The Saw Mill River Coalition established the project, and conducted the initial research and public outreach. As a result of these community efforts, a section of the river, previously hidden by a large parking lot, was daylighted and naturalized. The project was so successful that more sections of the Saw Mill River in Yonkers are now being daylighted. Yonkers demonstrates that daylighting can be good for the environment, community, economy, and the municipal budget.*

Benefits
Recreation, Biodiversity, Social and Urban Revitalization.
Source
Saw Mill River Coalition, Groundwork Hudson Valley.
https://www.americanrivers.org/wp-content/uploads/2016/05/AmericanRivers_daylighting-streams-report.pdf

Photo by Brian Kusler on Flickr

Innovative governance and interagency coordination

Sustainable pedestrian-oriented public space

Public engagement with residents, local merchants, and entrepreneurs

Project #3: *Cheonggyecheon, 2002–05*
Location: *Seoul, South Korea*
Description: *The Seoul Metropolitan Government dismantled a 10-lane roadway and the 4-lane elevated highway that carried over 170,000 vehicles daily, and daylighted the ancient Cheonggyecheon Stream to create a major arterial public space in 2005. The transformed street encourages the use of public transit, and offers a new environmentally sustainable, pedestrian-oriented green corridor. The project contributed to a 15.1% increase in bus ridership and a 3.3% increase in subway ridership between 2003 and 2008. The revitalized street attracts 64,000 visitors daily. The daylighting of the river brought immense social value to the city and its residents. Twenty-one new bridges were constructed to extend public amenities for the pedestrians and connect adjacent neighborhoods to each other and the recreational spaces in the middle.*
Benefits
Tourism, Health and Wellbeing, Heat Stress and Flood Risk Reduction.
Source
Seoul Metropolitan Government
https://globaldesigningcities.org/publication/global-street-design-guide/streets/special-conditions/elevated-structure-removal/case-study-cheonggyecheon-seoul-korea/

Photo by Scott Meltzer

Restoration and rehabilitation approach

Guidelines to assess city standards for other restoration projects

Raising the sensibility for ecologically oriented actions by villagers

Project #4: *Restoration of Small Water Bodies (SWBR), 2009–12*
Location: *Beijing, China*
Description: *In 2012, Beijing implemented a 30–50 km^2 restoration of Small Water Bodies to improve flood control and the ecology of the river, the riparian zones, and the floodplain. Instead of resorting to the traditional practice of building dams, the project team chose to enlarge the space of the river. The project improved hydromorphological conditions, the longitudinal and lateral continuity, and the green areas on both sides of the river. The restoration created additional environmental, recreational, and scenic value for the communities. Guidelines to assess the biological and hydromorphological status of rivers were developed, along with plans to introduce them as standards for the city.*

Benefits
Biodiversity, Health, Heat Stress and Flood Risk Reduction.
Source
Beijing Park and Forest Department of International Cooperation
https://www.sciencedirect.com/science/article/pii/S209563391500009X

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Strassbourg, France
Photo by Reiseuhu on Unsplash

BUILDING SOLUTIONS

Singapore
Photo by Chuttersnap on Unsplash

FACTS AND FIGURES

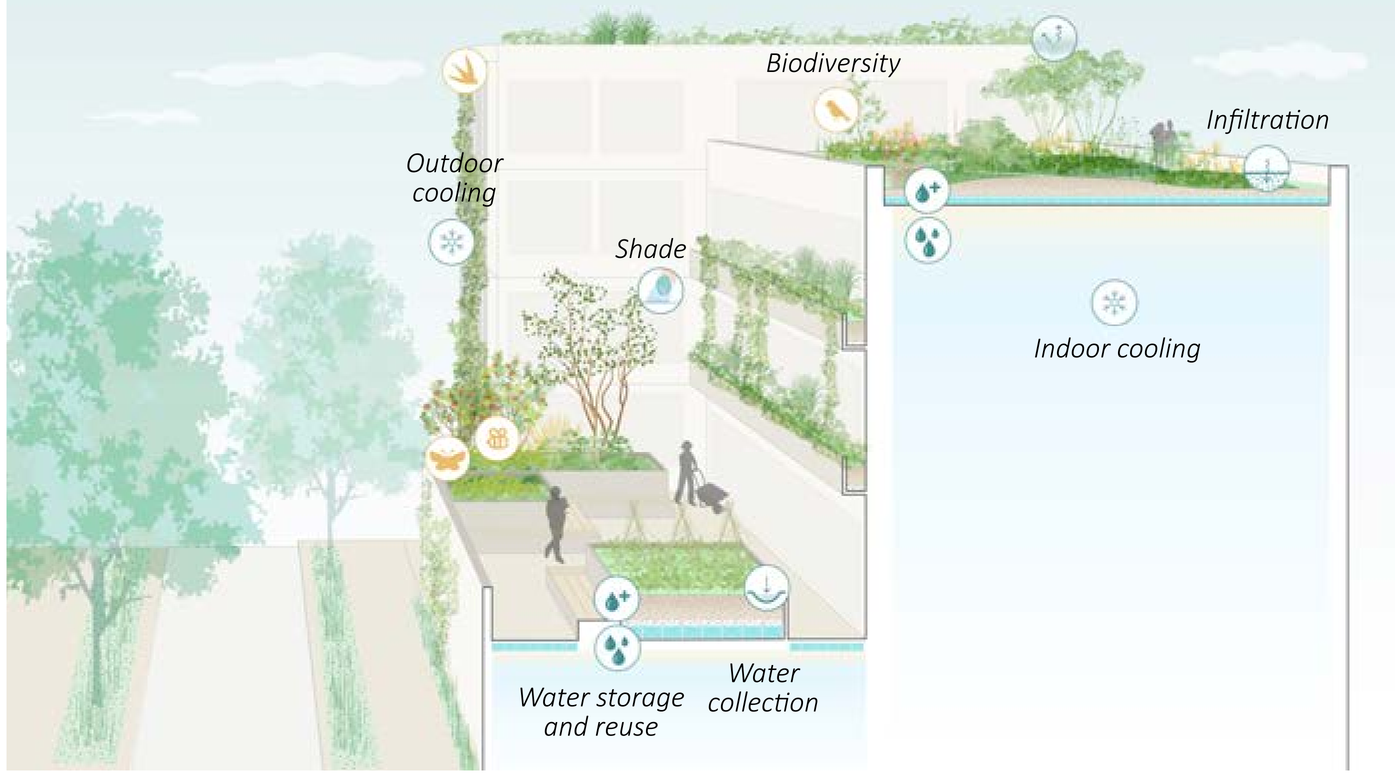
DESCRIPTION

Interest in nature-based solutions in buildings has increased considerably in the recent years. These solutions include adding green surfaces to building roofs and facades, creating opportunities to capture, store, and reuse stormwater, improve air quality, and reduce temperatures. They provide urban flooding and heat reduction benefits, and at the same time they can reduce costs by enhancing efficiency of climate control systems in buildings. Green roofs and facades may also improve property values and marketability of a building, especially in urban areas with little green space, and accommodate additional space for human use and urban functions associated with food production.

Materials and technologies that support and monitor the growth of mosses, sedums, herbs, and low-growing grasses—common choices for green roofs—are entering the market. Research and innovation increasingly focus on the potential of productive rooftop gardens that also provide food, educational, recreational, and biodiversity benefits. Growing evidence on the safety and efficiency of building solutions and their ability to increase the R–value—a measure of the resistance of a material to the heat flow—of the roofing system, is promoting new applications that can result in energy cost savings and reduce the urban heat island effect, greenhouse gas emissions and the carbon footprint of the building.

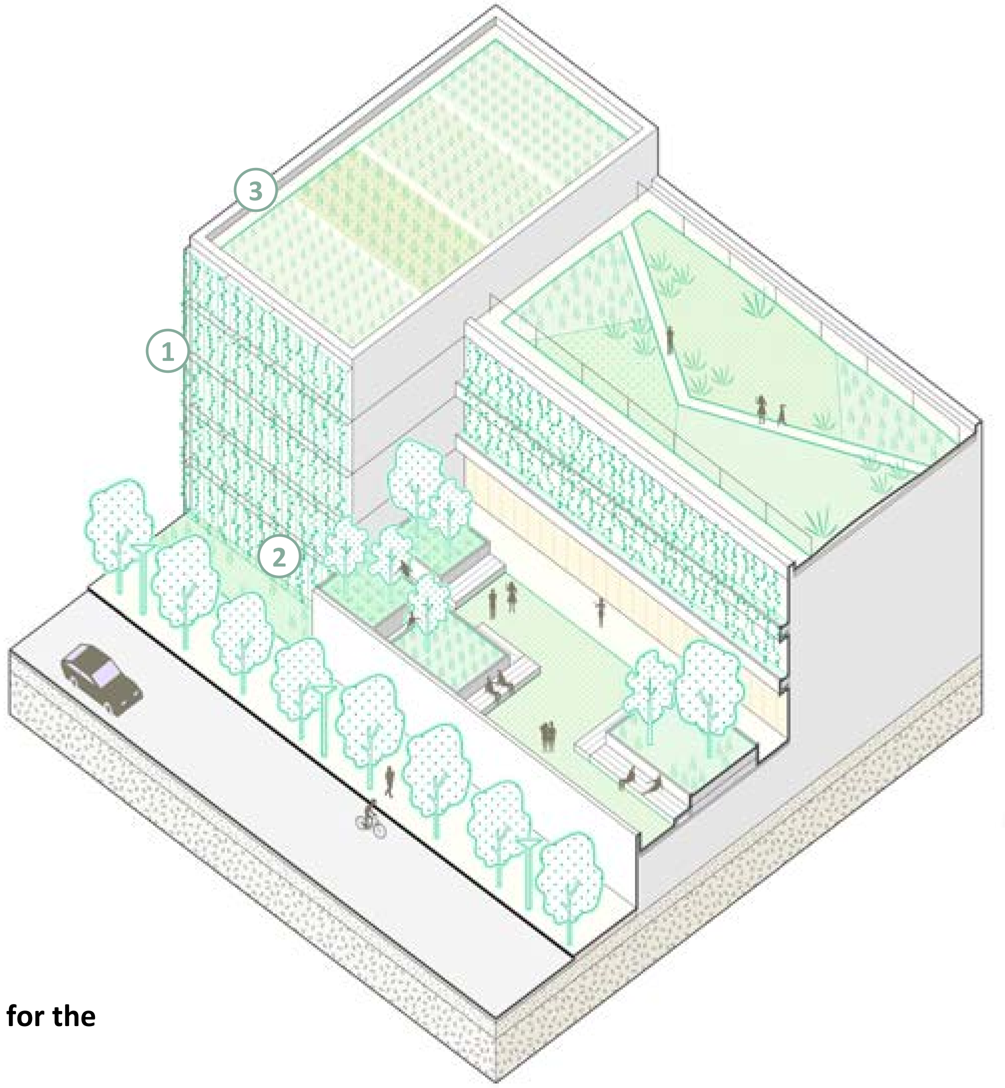
TYPE OF CITY	SCALE	APPROACH
Coastal, Delta, River, Mountain	Neighborhood City River basin	Create Construction of new green roofs and green facades on new buildings or existing buildings (renovation).

PROCESSES

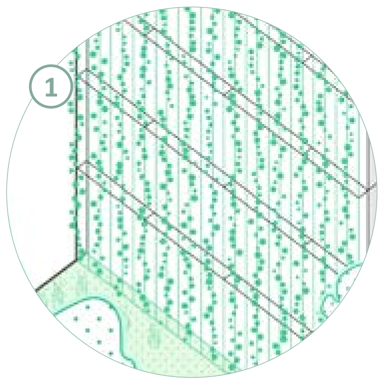


VISUALIZATIONS

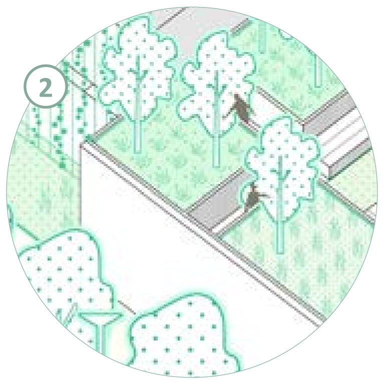
VISUALIZATION OF BUILDING SOLUTIONS IN THE URBAN CONTEXT



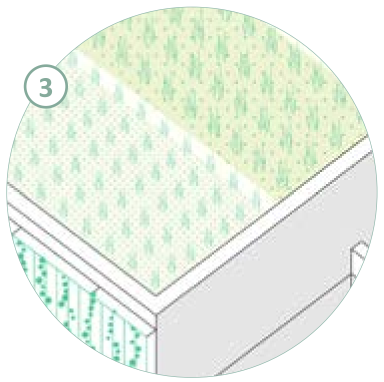
Details of increased benefits for the urban living environment



Application of nature-based solutions at the scale of buildings signals the urgency of urban adaptation to climate change, and enhances the built identity.

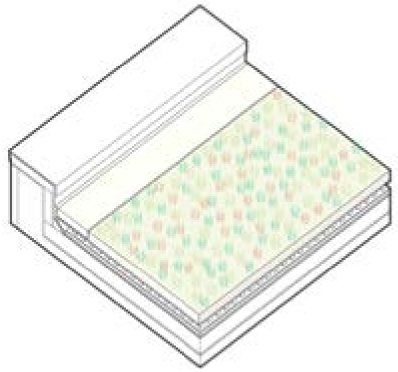


A green roof serves as communal space that brings neighbors and coworkers together, enriches social interaction, and increases community trust.



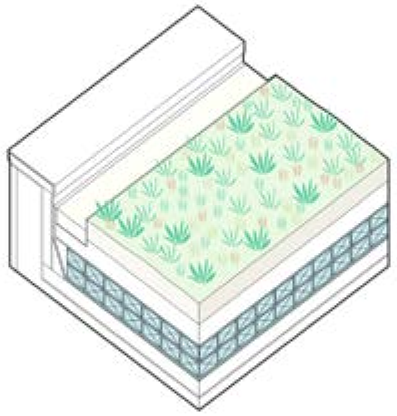
Rooftop gardens offer additional usable space in dense urban environments; provide opportunities to grow flowers and vegetables, exercise, work, and rest.

SPECIAL TECHNIQUES FOR GREEN ROOFS AND GREEN FACADES



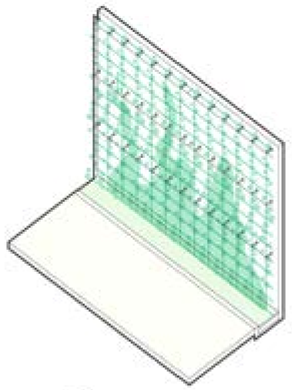
Extensive green roofs

Extensive green roofs consist of several horizontal layers—bioengineered growth medium; membranes to support and control plant roots; buffers to collect, filter, store, reuse, or discharge water, as well as structural and insulation layers. Performance criteria based on desired plant typology and the quantity of water determine the thickness and the composition of the layered structure. The roofs are normally not accessible to the public and have drought resistant plants that can withstand variations in temperature and sun exposure (Eisenberg and Polcher 2020).



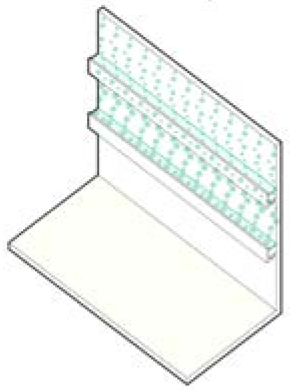
Intensive green roofs

The structure of intensive green roofs has a thicker substrate layer supporting higher variety of vegetation. In addition to water management and cooling, they provide amenities to building residents—opportunities for gardening, exercise, sunbathing, relaxation, and socializing. Intensive green roofs have good returns on investment of lowering building energy bills. They provide habitats for attractive species, birds, bees, and other pollinators. Installation and maintenance come with a higher price tag than extensive green roofs (Eisenberg and Polcher 2020). Rooftop gardens are a special type of intensive green roofs, which serve as a productive garden for urban farming. Rooftop gardens require higher investments and a robust structural capacity of the roof to support the higher installation and, maintenance, but offer higher use and accessibility to people. A special type of smart green roofs is constructed with a system of crates located under the vegetation layer that stores rainwater. The crate system can be dynamically controlled and drained at a later preferred time. In return, the stored rainwater can be used for irrigation (Dakdoctors.com).



Ground-based green facades

Ground-based green facades are a type of green wall with climbing plants rooted in ground planters. The climbing or self-clinging plants, with adhesive pads as part of their anatomy, can grow directly on the wall or on a special frame connected to the wall. The plants extract water and nutrients from soil at ground level and can grow very tall, and adjust to climate fluctuations and different lighting conditions. Many flowering and evergreen species can add aesthetic experience to exterior walls, cool, and freshen the air (Eisenberg and Polcher 2020).

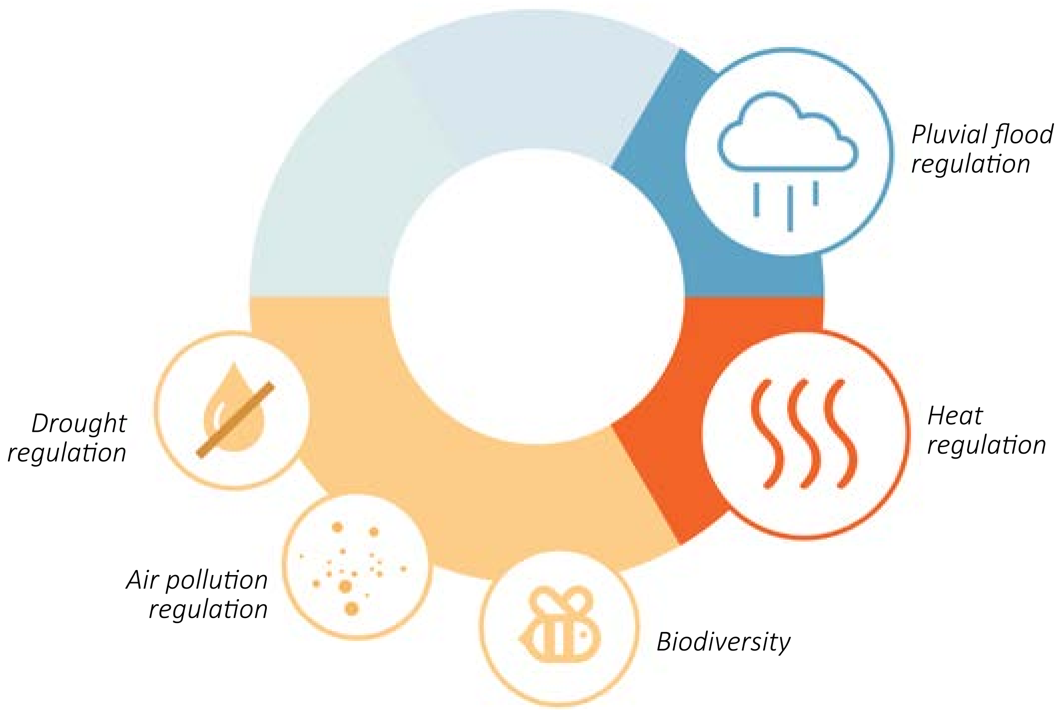


Facade-bounded greening

Facade-bounded greening is a type of green wall using technology for irrigation and special substrates for reducing the weight of green facades (Eisenberg and Polcher 2020). They are more expensive than ground-based greening and require higher use of resources in construction and maintenance. Facade-bounded greening allows for a combination of 10–15 plant species, most often mosses and perennials, and grows fast and uniform. The thin layer of soil inhibits their suitability in cold, temperate regions (Iwaszuk et al. 2019).

FUNCTIONS

The diagram in this section shows relevant functions of building solutions.



Pluvial flood regulation: Green roofs capture and store rainwater in the soil and in the roof construction and thus, reduce peak stormwater load on stormwater and sewerage systems. Standards capacities range depending on the type of green roof (see section Special Techniques), varying from 20–50 l/m² for extensive green roofs to 30–160 l/m² for intensive green roofs (Eisenberg and Polcher 2020).

Heat regulation: The vegetation layer of a green roof and a green facade absorbs solar radiation through photosynthesis; protects the heat transmission into the building; and provides shade if trees are planted. It reduces building temperature and cools the surrounding air (Gehrels et al. 2016). Several studies demonstrate that green roof temperatures can be 16–22°C (60.8–71.6°F) lower than that of conventional roofs (EPA n.d.). When transforming 80–90% of the roofs in a city to green roofs, they may reduce the average ambient temperature between 0.3°C and 3°C (32.5°F and 37.4° F) (Santamoursi 2014). Research conducted in Lagos , Nigeria, showed that a green facade reduces internal air temperatures by an average of 2.3°C (36.14°F) (Akinwolemiswa et al. 2018), and reduces the temperature of the facade itself between 2°C and 10°C (35.6°F and 50°F) compared to the natural stone (Eisenberg and Polcher 2020).

Other functions: Green roofs and green facades mitigate the loss of urban biodiversity, reduce air pollution, and can reduce drought impacts by promoting the reuse of water stored in roofs (Eisenberg and Polcher 2020).

BENEFITS

The diagram in this section shows a sampling of important benefits that building solutions can provide to people.

Pluvial flood risk reduction: Green roofs effectively capture, store, and recycle rainwater, reducing the amount of water running off to impervious surfaces and ending up in the sewer system during a storm. Most cities have combined sewer and stormwater systems designed with lower capacity than required today. As a result, sewers and stormwater management systems are easily overwhelmed, streets and properties get flooded, and significant amounts of untreated discharge end up in rivers. Widespread application of green roofs can reduce the damage from pluvial floods, protect property, and reduce the pollution—and water treatment costs—of surface water and in urban rivers (Hop and Hiemstra 2012).

Heat stress risk reduction: Sufficiently irrigated, green roofs and facades have a strong cooling effect on their surroundings. They improve air quality; intercept, absorb and reflect solar radiation, reducing the amount of solar radiation reaching the wall surface; reduce the thermal load on buildings and the requirement for air conditioning (Hop and Hiemstra 2012). Decreased ambient temperatures and reduced use of air conditioning help mitigate urban heat island effect being even slightly more effective at cooling the city at night (Bowler et al. 2010). Reducing extreme heat in cities brings a variety of socioeconomic benefits, including reduced mortality (Tan et al. 2010), improved health, reduced energy cost and CO_2 emissions (Roxon et al. 2020), and improved productivity of labor (Wong et al. 2017).

Resource production: Like any form of local agriculture, rooftop food production increases food supply. Rooftops can accommodate small agricultural businesses and reduce the distance food must travel from the producer to the consumer. Also, rooftop agricultural entrepreneurship can create much needed low skill and part-time jobs, and engage local communities on cooperative production (Bade et al. 2011).

Human health: Urban green has a positive environmental and psychological affect. Green walls provide cooling and shade. Green roofs can be used for exercise, gardening, and social interaction—all positive factors in public health (Gehrels et al. 2016).

Education: Roof gardens are important sources of information about the environment. They can serve as classrooms for local schools, an observation and testing ground for students interested in nature, biology, and the environment (Hop and Hiemstra 2012; Sheweka and Magdy 2011).

Biodiversity: Green roofs and green walls enhance urban biodiversity. They provide food and shelter for different species, and safe hiding and nesting places. Up to a certain height, roofs attract pollinator species and can become productive areas for flowers, honey, herbs, and specialty products, local pollen, fruit, and berries (Cañero and Redondo 2010).

Social interaction: Green roofs are great places for communities to meet and can become attractive places for intergenerational activities, social interaction, and collaboration (Marissing 2008).

Water quality and sediment management: The layered structure of most green roofs and facades facilitates sediment capture and water filtration. As a result, stormwater processed by green roofs and walls is relatively clean and can be safely reused in many applications (Hop and Hiemstra 2012), reducing the demand for treated water.

SUITABILITY CONSIDERATIONS

ENVIRONMENTAL

Location and climate: Green building solutions heavily depend on the ability of vegetation to survive, succeed, and deliver benefits. In temperate climatic conditions, the capacity of green roofs and facades to manage urban stormwater are based primarily on the quality of the installation, availability of right kinds of substrate soils, membranes, and crates. In arid or semi-arid climates, drought-resistant plants need care and freshwater irrigation. In arid climates, economic viability of building solutions will be more challenging as a result of high irrigation costs (Akhter et al. 2018).

TECHNICAL

Roof type: Green roofs can be installed on most roof surfaces. Certain roof materials, such as exposed chemically treated wood and uncoated galvanized metal, may not be appropriate for green roof tops due to potential pollutants leaching from these materials in the wet conditions and contaminating the planting substrate (Clark et al. 2010).

Roof slope: A green roof water storage volume is at its maximum on a relatively flat roof (1% or 2%). However, some inclination is needed to promote drainage and prevent ponding and saturation. A slope of up to 7% is most efficient for rainwater retention. Green roofs can be installed on rooftops with slopes up to 30% if structural interventions like baffles, grids, or strips are used to hold the growing medium that is the substrate on which the vegetation grows, often a mixture containing organic matter (DDOE 2013).

Substrate:

- *Green roofs:* A recommended composition of the growing media for green roofs, provided in a study (DDOE 2013), is 80% lightweight material, no more than 20% of organic matter—normally well-aged compost. Media used in a green roof should have a maximum moisture capacity between 30% and 40% (DEP 2006). The thickness of the layer depends on the type of roof, ranging from 5–15 cm for intensive roofs to 15–48 cm for extensive roofs. Tree planting requires extra depths of the substrate (Eisenberg and Polcher 2020).
- *Green facades:* Regular planting soil is the common choice in basic ground-based facades, although more complex green facades with weight restrictions must consider the use of light soils similar to green roofs.

Structural capacity of the roof: The structural capacity of existing roofs must be considered to support the weight of a green roof and the additional volume of water.

- *Extensive green roofs:* 20 kg/m² to 190 kg/m².
- *Intensive roofs and rooftop gardens:* 190 kg/m² to 680 kg/m² (Eisenberg and Polcher 2020).

Facade orientation: All facade surfaces are potentially usable. The choice of plants should directly correspond to the amount of sunlight they will receive throughout the day depending on the façade orientation. (Eisenberg and Polcher 2020).

Accessibility: Roof access must be provided during the installation for the delivery of materials, and for regular maintenance of the roofs (DDOE 2013). Public access to intensive roofs must be properly monitored with the right set of safety measures put in place.

Dimensions:

- *Green roofs:* A study shows that the entire contributing drainage area to a green roof, including the green roof itself, must be no more than 25% larger than the area of the green roof (DDOE 2013).
- *Green facades:* A facade or wall of almost any size can be used to create a green wall; a minimum amount of space is required on the ground for planting and to remain healthy (Iwaszuk et al. 2019).

URBAN

Land use: Suitable land uses for green roofs and facades are a variety of buildings—residential, public, commercial, and office buildings, convention centers, and major utility structures.

Urban density: Green building solutions can be applied at any density from low to high.

Area: Small to medium. Green roofs and facades are applied at the building scale.

Integrated urban planning: Green building solutions can be an integral component of the roof and facade renovation or part of new building construction.

MAINTENANCE

Green roofs: Green roofs require semi-annual inspections to ensure water outlets are clear of (dead and living) plants and debris. Extensive green roofs require minimal maintenance while an intensive green roof requires regular garden maintenance including pruning, cleaning and removal of debris, soil amendment, and nourishment.

Green facades: Ground-based facades require inspections during the first months after installation to ensure plant growth and direction. Subsequently annual inspection can be sufficient (Iwaszuk et al. 2019).

COSTS

COST CONSIDERATIONS

Land

Access to or ownership of land is required, potentially through collaboration and engagement with building owners.

Construction and implementation

The cost of green roof installation varies widely depending on the types of building solutions, the complexity of the installation roof, and material and labor costs at the site location.

Maintenance

Maintenance costs on green roofs or facades will be a function of the type of roof as well as of the local climate and weather. Frequent inspection of green roofs and facades is necessary to conduct necessary maintenance, such as clearing dead plants, weeding, pruning, and fertilizing. Intensive green roofs are generally more expensive than extensive green roofs.

UNIT COST EXAMPLES THROUGHOUT THE GLOBE

Construction and implementation

Example green roof costs:

- *Extensive green roofs*: ***US$60–US$270/m^2 (US$60,000–US$2,700,000/ha)*** *(Iwaszuk et al. 2019).*
- *Intensive green roofs*: *>* ***US$180/$m^2$ (US$1,800,000/ha)*** *(Iwaszuk et al. 2019).*
- *Extensive green roofs cost roughly* ***US$6–US$8*** *per square foot less than semi-intensive green roofs. Smaller green roofs cost more per square foot than larger green roofs. Extensive green roofs cost* ***US$10.30–US$12.50*** *more per square foot than a black roof; semi-intensive green roofs cost* ***US$16.20–US$19.70*** *more per square foot than black roofs (U.S. GSA 2011).*

Example green facade costs:

- *Ground-based façade*: ***US$35–US$55/m^2 (US$350,000–US$550,000/ha)*** *(Perini and Rosasco 2013).*
- *Façade-bounded*: ***US$480–US$1450/m^2 (US$,800,000–$14,500,000/ha)*** *(Perini and Rosasco 2013).*

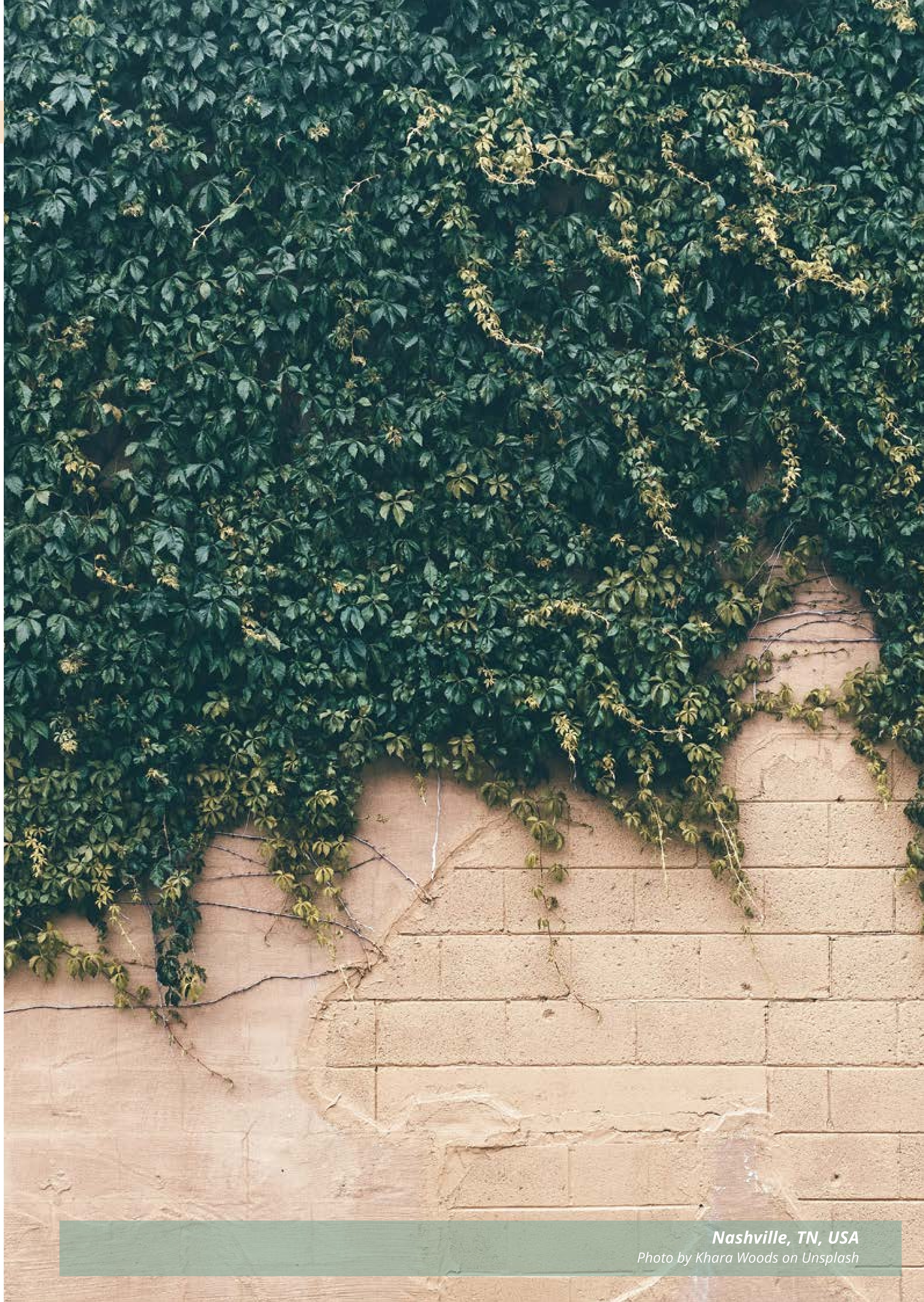
Maintenance

Example green roof costs:

- *Extensive green roofs*: ***US$0.60–US$3.50/m^2/year (US$6,000–US$35,000/ha)*** *(Iwaszuk et al. 2019).*
- *Intensive green roofs*: ***US$4.20–US$18.00/m^2/year (US$42,000–US$180,000/ha/year)*** *(Iwaszuk et al. 2019).*

Example green facade costs:

- *Green facades require annual pruning estimated at* ***US$3.40/$m^2$ (US$34,000/ha)*** *and long-term cladding renovation estimated at* ***US$1,480/$m^2$ (US$14,800,000/ha)*** *(Perini and Rosasco 2013).*



Nashville, TN, USA
Photo by Khara Woods on Unsplash

NBS IN PRACTICE

The four projects in this section highlight good practices and lessons learned in building solutions, drawn from the growing practice of integrating NBS in building solutions around the globe.

Photo by Doaa211 on Wikimedia Commons

Government initiative in collaboration with local stakeholders

Scope for education and promotion of healthy lifestyle

Women empowerment and knowledge transmission

Project #1: *Greening Cairo's roofs, 2001–03*
Location: *Cairo, Egypt*
Description: *The objective of the Cairo and Alexandria Green Roof program was to offer low-income suburban families a possibility of growing their own food and to create income-generating opportunities. The program was wholeheartedly embraced by local women, who began to produce fresh vegetables and use the roofs for social gatherings in a safe, semiprivate setting. FAO initially trained 48 families in the use of hydroponics systems and green techniques, eliminating use of pesticides. Since then the project has become an urban and peri-urban horticulture model.*

Benefits
Environmental, Climate, Micro-economy, Gender Empowerment.
Source
FAO Regional Office for Near East and North Africa
https://www.researchgate.net/publication/269873380_Green_Roofs_in_Cairo_A_Holistic_Approach_for_Healthy_Productive_Cities

Photo by OKI Hiroyuki

Icon and showcase for new eco-building typology for educational centers

Learning experience for children about agriculture and nature

Money saving and showcase for building energy efficiency

Project #2: *Farming Kindergarten, 2013–15*
Location: *Biên Hòa, Dong Nai, Vietnam*
Description: *Architects in 2013 conceived a new kindergarten building as a continuous productive green roof supplying fresh produce, providing a food-growing experience to children. The building is located next to a shoe factory and serves about 500 children of the factory workers. The contemporary design of the kindergarten provides a large playground and an innovative combination of developmentally important activities: growing food and hands-on learning. The kindergarten projects aim to preserve a better understanding of the natural processes, and to make it more fun for early learners to spend time outdoors.*

Benefits
Health, Education.
Source
Vo Trong Nghia Architects
https://www.archdaily.com/566580/farming-kindergarten-vo-trong-nghia-architects

https://worldarchitecture.org/architecture-projects/hfnfc/farming-kidergarten-project-pages.html

Photo by Alejandro Arango / El Equipo Mazzanti

Integrated with park and neighborhood renewal plan

Scope for equity, publicness, social connection, and crime reduction

Design oriented: Launched as idea competition

Project #3: *Bicentenario Park, 2007–16*
Location: *Bogotá, Colombia*
Description: *Bicentenario Park was conceived as a revitalization project in downtown Bogotá and inaugurated in 2016. It is a reinforced concrete bridge that adapts to the topography of the terrain and meets a vast number of urban technicisms and norms of the city. In order to transform this bridge into a green public space of 4,600 m^2, a series of extensive and intensive green roofs were designed, resulting in eight small vegetated squares. A wide variety of native and adapted plants were selected by the Botanical Garden of Bogotá. The new Parque Bicentenario restoration has become a healing factor in the division between the south and north sectors of Bogotá.*

Benefits
Heat Stress Reduction, Equity, Recreation, Social Interaction.
Source
Bogotá city, El Equipo Mazzanti
https://www.greenroofs.com/projects/parque-bicentenario-bogota/

https://www.archdaily.co/co/898371/parque-bicentenario-un-proyecto-que-ayuda-a-coser-una-herida-urbana-en-bogota

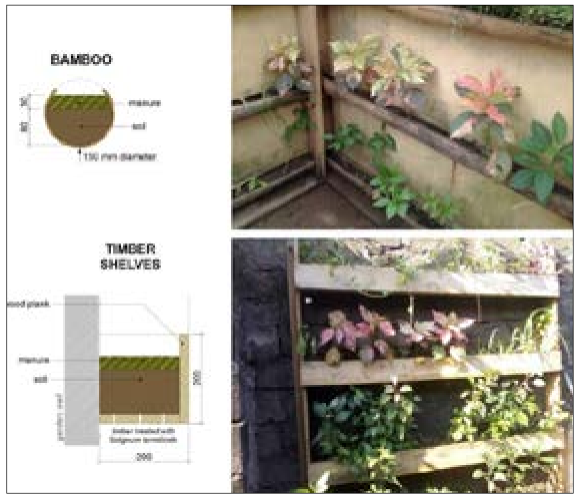


Photo by Oluwafeyikemi H. Akinwolemiwa and Clarice Bleil de Souza

Community involvement and empowerment

Participatory process between local communities and knowledge institutions

Knowledge development for future application

Project #4: *Building community-driven vertical greening systems for people living on less than £1 a day: a case study in Nigeria (VGS), 2014–16*
Location: *Lagos, Nigeria*
Description: *Low-income residents of Lagos installed an interior vertical greening system (VGS) prototype to grow produce, herbs and cool the immediate environment. VGS is a compact, affordable, low-tech passive technology. Yet, even in this challenging environment it can be effective and popular. Community engagement surveys showed that VGSs reduce internal air temperature by an average of 2.3°C (36.14°F). Many users pointed out the benefits of being able to grow medicinal plants, such as bitter leaves to treat diabetes, plants to treat malaria, as well as pumpkin leaves for general consumption. With the right kind of community entrepreneurship, VGSs can evolve into a viable commercial product and become a source of income for the community.*

Benefits
Health, Education, Economy.
Source
Oluwafeyikemi H. Akinwolemiwa
https://www.sciencedirect.com/science/article/pii/S0360132318300349

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OPEN GREEN SPACES

Lima, Peru
Photo by Dan Gold on Unsplash

FACTS AND FIGURES

DESCRIPTION

The successful protection, creation, and development of open green spaces is one of the key elements required to achieve sustainable urban development. Parks, unpaved, and biologically active green areas of every size can help cities adapt to climate change by cooling and enhancing the quality of air, providing shade, and offsetting the urban heat island effect. Unpaved areas can also absorb and attenuate the velocity of stormwater, reduce the amount of water entering the sewerage system, and minimize stormwater and sewage discharge, contributing to urban flood risk management. These values can be enhanced through targeted interventions to improve infiltration, reduce runoff, and increase water retention. However, they must be designed with clear performance objectives and also resonate with users to encourage a sense of collective ownership and stewardship. Accessible open green spaces of all scales are highly valuable to quality of life and public health benefits for urban communities as they attract social and physical activity. Whereas many open green spaces can provide habitat for species, some parks also serve as critical refugia for biodiversity in an otherwise highly transformed urban context.

Green spaces vary significantly in spatial extent and properties, and may include both private and public lands. They range from gardens in neighborhoods to large city parks connected to the surrounding landscape. Such a variation in their characteristics also means that they provide a broad spectrum of social and environmental values.

TYPE OF CITY

Coastal
Delta
River
Mountain

SCALE

Neighborhood
City
River basin

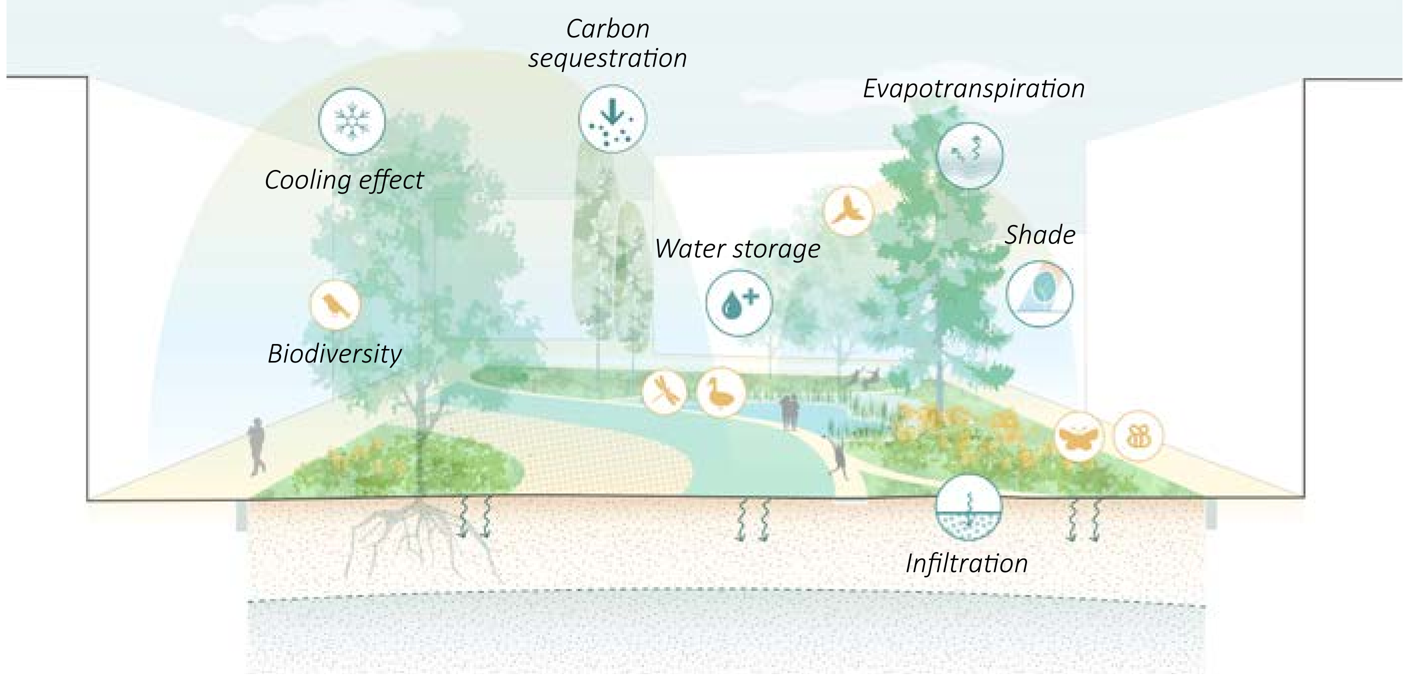
APPROACH

Protect
Protect existing open green spaces.

Rehabilitate, Restore, Enhance
Upgrade or renovation existing green spaces.
Allow temporal use of undefined areas as green spaces.

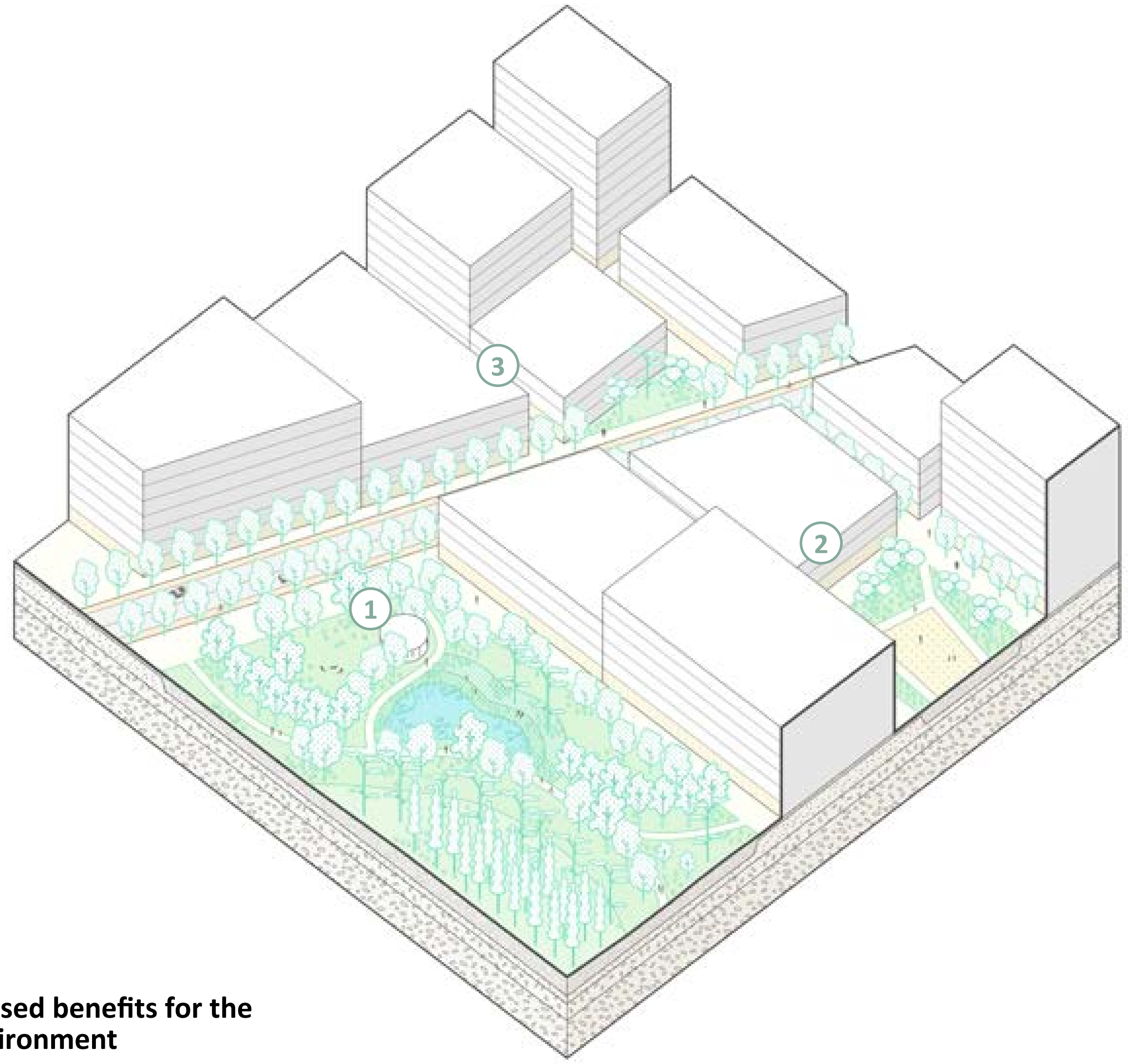
Create
Construct new open green spaces.

PROCESSES

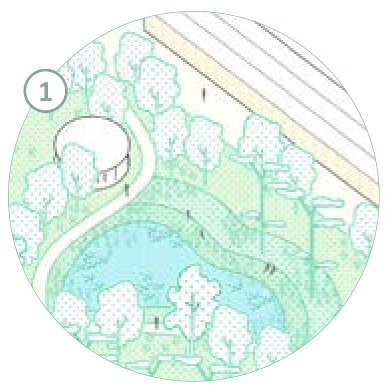


VISUALIZATIONS

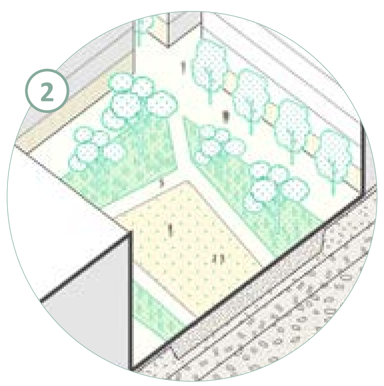
VISUALIZATION OF OPEN GREEN SPACES IN THE URBAN CONTEXT



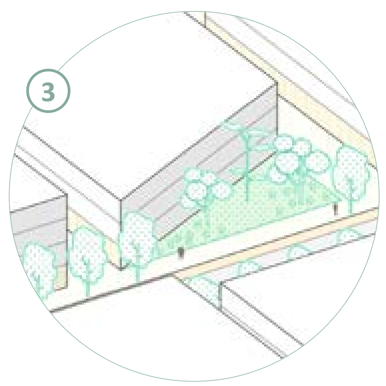
Details of increased benefits for the urban living environment



Open green spaces provide refugia for wildlife, recreational and cultural programs, and amenities for urban communities.

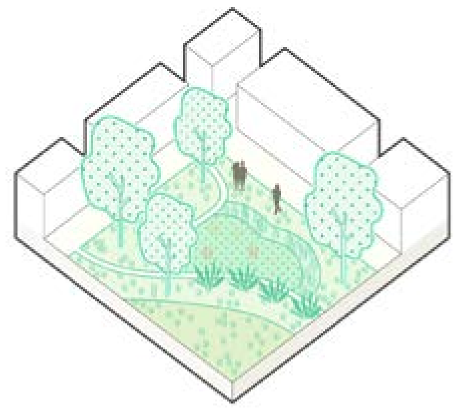


In tropical and subtropical regions, green spaces offer areas for cooling, making it safer and more pleasant to spend time outdoors.



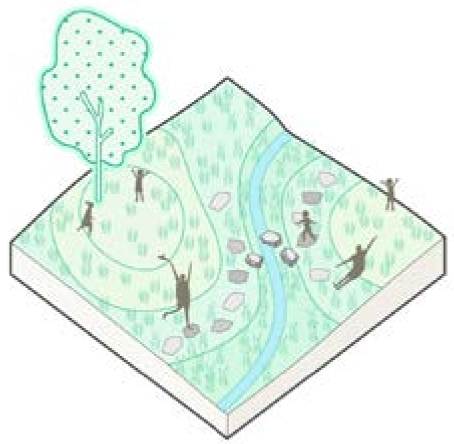
Accessible green spaces of all scales close to residential and commercial areas are highly valuable to quality of life and public health benefits.

SPECIAL TECHNIQUES FOR OPEN GREEN SPACES



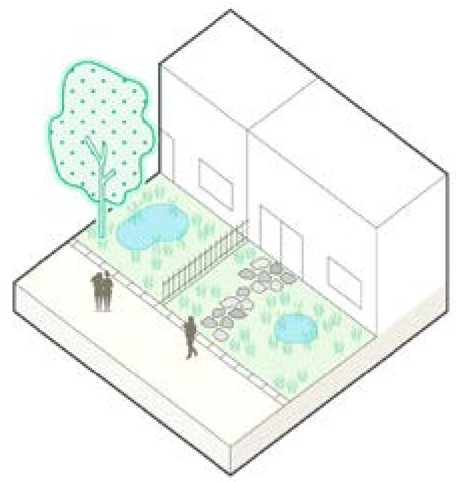
Pocket parks

Pocket parks are relatively small open spaces distributed throughout the urban fabric. Pocket parks serve the immediate population of a neighborhood and provide a wide variety of small-scale recreation possibilities, such as playgrounds, dog parks, workout stations, water fountains, vegetable and flower planters, and other props for neighborhood recreation. Pocket parks can also appear on vacant lots through community initiative.



Natural playgrounds

Playgrounds with trees, flowers, rocks, and water features help children develop development skills, such as sensory, tactile perceptions, creativity, and appreciation for nature (Kahn and Kellert 2002). Playgrounds encourage social and physical activity for all ages. Ponds and other blue–green infrastructure in playgrounds can provide educational opportunities to children, green retreats of recreation, and enjoyment to others, while contributing to stormwater management.

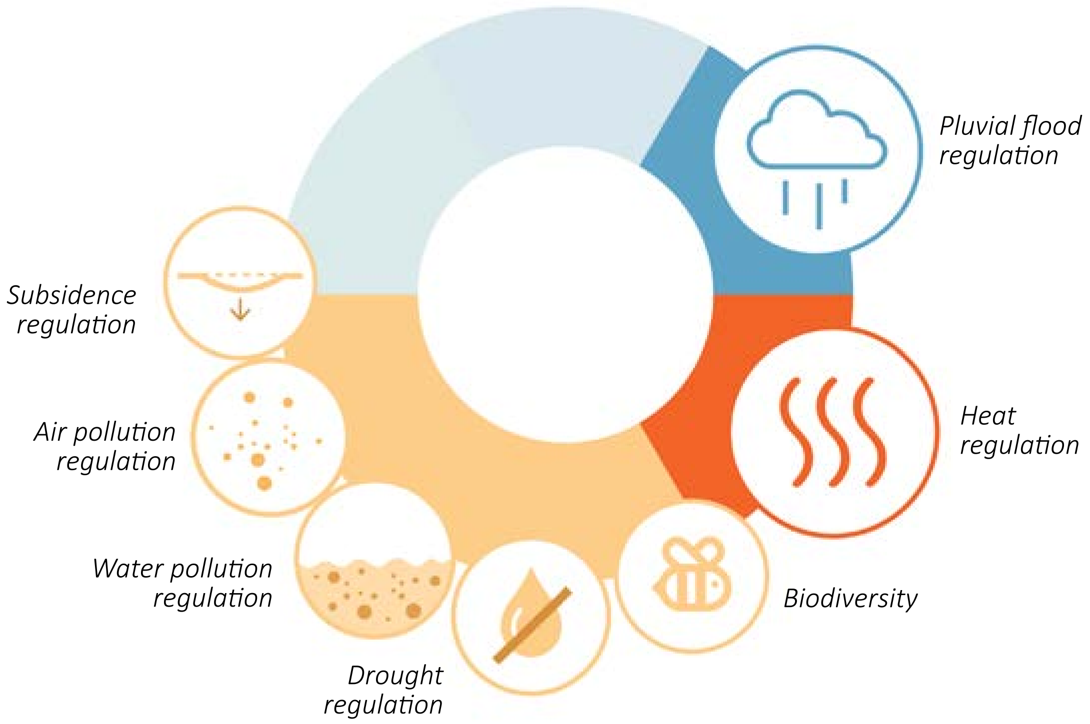


Climate-proof residential gardens

Residential gardens can have a large cumulative impact in stormwater reduction if they are integrated into larger green infrastructure networks. Each garden manages stormwater from buildings, roofs, and courtyards, capturing and recycling stormwater. The vegetation also helps mitigate heat, while trees, bushes, and other vegetation provide habitat. Residents can also use gardens for growing vegetables and recreational uses (see also Urban Farming).

FUNCTIONS

The diagram in this section shows relevant functions of open green spaces.



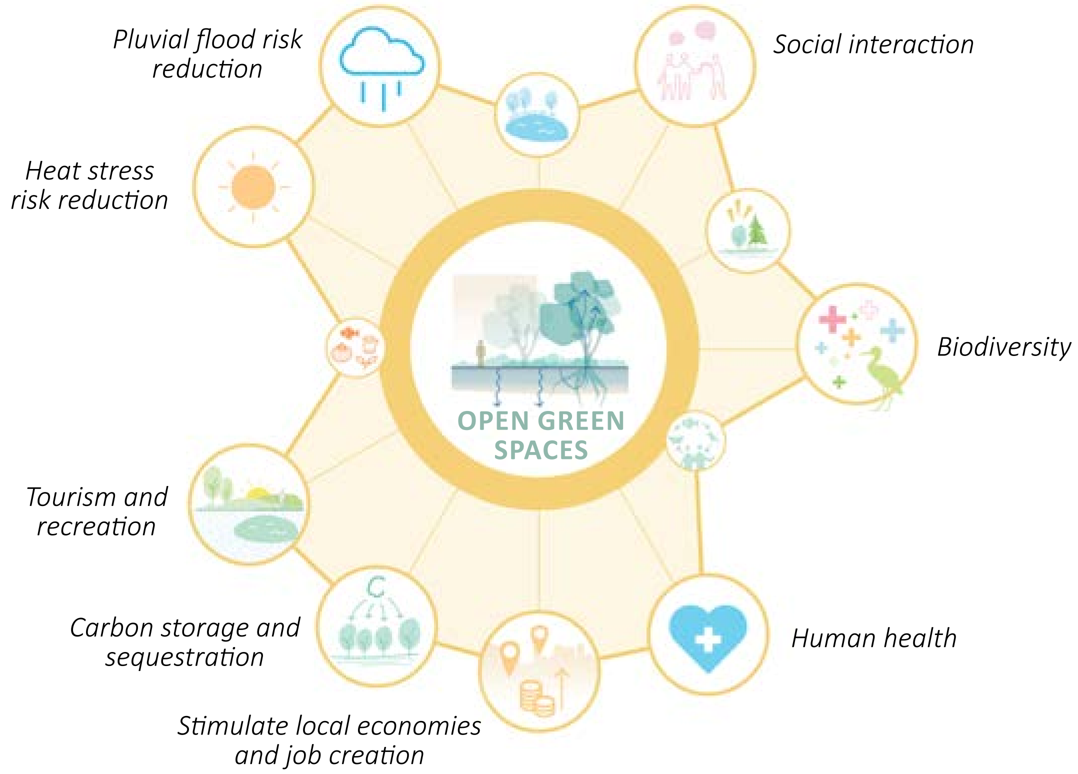
Pluvial flood regulation: Open green spaces help manage stormwater and mitigate floods. Trees, gardens, and lawns intercept and absorb rainwater through soil infiltration and evapotranspiration, also helping to recharge aquifers. The capacity of green spaces to reduce flooding depends on the extent of the park relative to the catchment area, the topography, type and density of vegetation, and soil characteristics. Lakes, ponds and other water detention zones in parks can add (temporary) water storage capacities to the system and thereby reduce stormwater peak flows.

Heat regulation: Urban green spaces reduce heat by providing shade and evaporative cooling (Gehrels et al. 2016). By some estimates, large park areas of more than 10 hectares can reduce temperatures by 1°C or 2°C (33.8 or 35.6°F) within 350 meters of the park boundary (Aram et al. 2019). Small parks can maintain air temperatures lower than the surrounding built areas by as much as 3°C (37.4°F) (Singerland 2012).

Other functions: Open green spaces reduce subsidence, build resistance against drought, remove pollutants from air, water, and soil, and support biodiversity by providing nourishment and habitat for flora and fauna (Eisenberg and Polcher 2020).

BENEFITS

The diagram in this section shows a sampling of important benefits that open green spaces can provide to people.



Pluvial flood risk reduction: Open green spaces reduce the impact of storms and can decrease potential damage to buildings and infrastructure. To achieve a greater cumulative effect, a series of green open spaces should be planned as a coherent blue–green infrastructure network that can absorb, infiltrate, and store large volumes of stormwater and reduce the velocity of stormwater flow in large parts of the city. (Gehrels et al. 2016).

Heat stress risk reduction: Urban green spaces reduce heat stress by providing shade and evaporative cooling (Gehrels et al. 2016). Green spaces and urban planting help keep thermal comfort and reduce the incidence of heat-related illnesses (Howe and Boden 2007); increase productivity (Seppanen et al.2004); and reduce the accumulation of heat inside buildings.

Tourism and recreation: Green open spaces attract social and physical activity (Wan and Shen 2015). They bring people together for relaxation, recreational activities, and sports (Halprin 1981; Wendel et al. 2012). Parks increase the prestige, economic success, and the livability of a city (Woolley 2003).

Carbon storage and sequestration: Open green spaces and urban parks store carbon in soil and vegetation, mitigating climate change. An example from a region with a temperate climate indicates that carbon density in an urban park is approximately 130 tons of CO_2 per ha, of which approximately 75% is stored below ground (Linden et al. 2020). The contribution of open green spaces and urban parks to carbon sequestration will vary significantly based on the habitat structure and growth rates of plants associated with the corridor. Where dominated by grassy areas, rates are likely to be in the region of 0.5 to 5 tons of CO_2 per ha per year whereas this could increase to well above 5 tons of CO_2 per ha per year for forest-dominated corridors.

Stimulate local economies and job creation: Parks and open green spaces enhance the reputation of a city and attract tourism. Parks can also host cultural events, becoming an asset. They may increase property values and tax revenue (Dunnett et al. 2002; Wendel 2011).

Human health: Urban green spaces have a positive effect on mental wellbeing and physical health. The mitigation of pollution and urban heat island effect leads to fewer respiratory problems and reduces the number of lethal outcomes of heat exposure among the elderly. Lower temperatures in urban green spaces allow people to exercise during hot days, and increase physical wellbeing of people. Parks can improve mental health and reduce stress levels, and offer getaways from the crowds of a city (Kaplan and Kaplan 1982).

Biodiversity: Open spaces can serve to protect critical remnant habitat. Urban greenery is essential to the survival of many species and preservation of biodiversity. These benefits can be strengthened by proactively integrating key biodiversity areas in the open space network of a city. For optimal environmental performance, this requires a comprehensive network of green patches and corridors that provides food and habitat for biota and facilitates its movement across the landscape (De la Barrerra et al. 2016; Dunnett et al. 2002).

Social interaction: Parks and green open spaces give distinct identity to a neighborhood or a city, giving residents a shared sense of belonging to a larger and more complex social context (Yilmaz and Mumcu 2016). This sense of community has been proven beneficial to the individual physical and mental wellbeing and has a strong set of public health as well as economic benefits (Bertram and Rehdanz 2015).

SUITABILITY CONSIDERATIONS

ENVIRONMENTAL

Location and climate: Open green spaces are valuable in every climate zone. Their contribution to stormwater management will be the greatest in geographical regions with frequent heavy precipitation. Their ability to provide shade and reduce temperatures is most valuable in dry, hot areas. In dry climates, establishing and sustaining open green spaces throughout the year requires greater care to avoid lowering the water tables, reducing soil recharge rates, and to ensure sufficient water is available for plant survival.

Soil: Soils and plants should be chosen simultaneously to enhance performance for stormwater management. Soils should have a relatively dense structure with a good infiltration capacity and depth to sustain plant growth. Loose soils are at risk of being eroded, but solid, clay soils will not absorb enough water, and could accelerate stormwater runoff. The right combination of soils will allow water to percolate but will retain the nutrients necessary for plant growth. Clay soils or areas with high groundwater levels require open water bodies to contribute to stormwater management (Gehrels et al. 2016).

TECHNICAL

Planting and growing strategy: The choice of planting in an open green space site depends on climate and lighting conditions, the size, its soils, and available water resources. Preference should be given to resilient native species. In addition, other factors for choosing the plants include climate mitigation potential, water management and phytoremediation capacities, aesthetic value, and contribution to urban wildlife habitat.

Dimensions: Parks of any size provide multiple cultural and recreational benefits. The urban context, availability of land, and its performative criteria for resilience objectives—such as urban flooding, heat, or biodiversity—will determine the area of a park (City of Gold Coast 2018):

- *Small local and pocket parks* range from 250–4,000 m^2 and serve the immediate neighborhood within a 400-meter radius or 5-minute walking distance. They can provide limited recreational opportunities and accommodate short visits.
- *Medium size district parks* range from 2–4 hectares and can serve several neighborhoods within a 400–800-meter distance. These often support a wider variety of informal recreational uses and include community facilities.
- *Large city parks* of 10–20 hectares cater the recreational needs of the residents within a 1–5 km radius as well as visitors and tourists. City parks can attract people from across the city and the region.

Inclusivity: The design or upgrading of public parks and open green spaces should follow the principles of universal design that facilitate physical accessibility for people of every age and of all levels of physical ability (City of Gold Coast 2018). To secure equitable access, communities of different social and ethnic backgrounds should be able to engage in cultural practices and enjoy the benefits of nature and fresh air equally.

Vandalism and crime prevention: The work on open green spaces should follow well-tested design guidelines for vandalism and crime prevention. Environmental urban design elements offer opportunities to prevent vandalism and crime. Planting, pathway and spatial arrangement of built elements, lighting, and way-finding graphics should promote visibility and passive surveillance. In crime-prone areas, tree canopies can be trimmed to allow maximum crossview, and time restrictions may be imposed on park use (City of Gold Coast 2018).

Social involvement: The identity of a park should resonate with its users and respond to their cultural preferences and needs while delivering on its environmental performance. When the performative aspects of the parks are made visible and understandable, users will value its ecosystem services and play an important role in protecting the park (City of Gold Coast 2018).

URBAN

Land use: Suitable land uses for green open spaces are parks, gardens, squares, streets, outdoor sports facilities, and vacant lots that can receive greenery.

Urban density: Suitable urban density for open green spaces ranges from low to high.

Area: Small to large. Open green spaces are nature-based solutions that can be designed for application at a neighborhood, district, or city scale.

Integrated urban planning: Green open spaces can be integrated into several urban programs—environmental conservation, parks, green infrastructure, new developments and regeneration; and vacant lot reclamation.

MAINTENANCE

An open green space is an important public asset that is aimed to serve all members of society without financial profit. The return of investment can come from climate mitigation and public health benefits. Maintenance of parks and open spaces should be planned for, funded, and systematically performed. Local stewardship and volunteer support can help with the upkeep, but maintenance can be systematically ensured by city taxes financing and creating job opportunities for local low-skill employment.

COSTS

COST CONSIDERATIONS

Land

Access to or ownership of land is required for open green space in urban areas.

Land on which open green space may be located may be public or private.

Land required for open green space may be relatively large in scale—though urban open green spaces vary widely in size—and may result in transaction costs associated with landowners and other stakeholder engagement.

Example land-related costs:

- Acquisition costs
- Land use (e.g., payments to landowners) costs
- Land protection costs, including managing and controlling access
- Community resettlement costs

Construction and implementation

Urban open green space costs are a function of labor, site preparation, design, and construction costs. Costs associated with managing and controlling access may also be included.

Maintenance

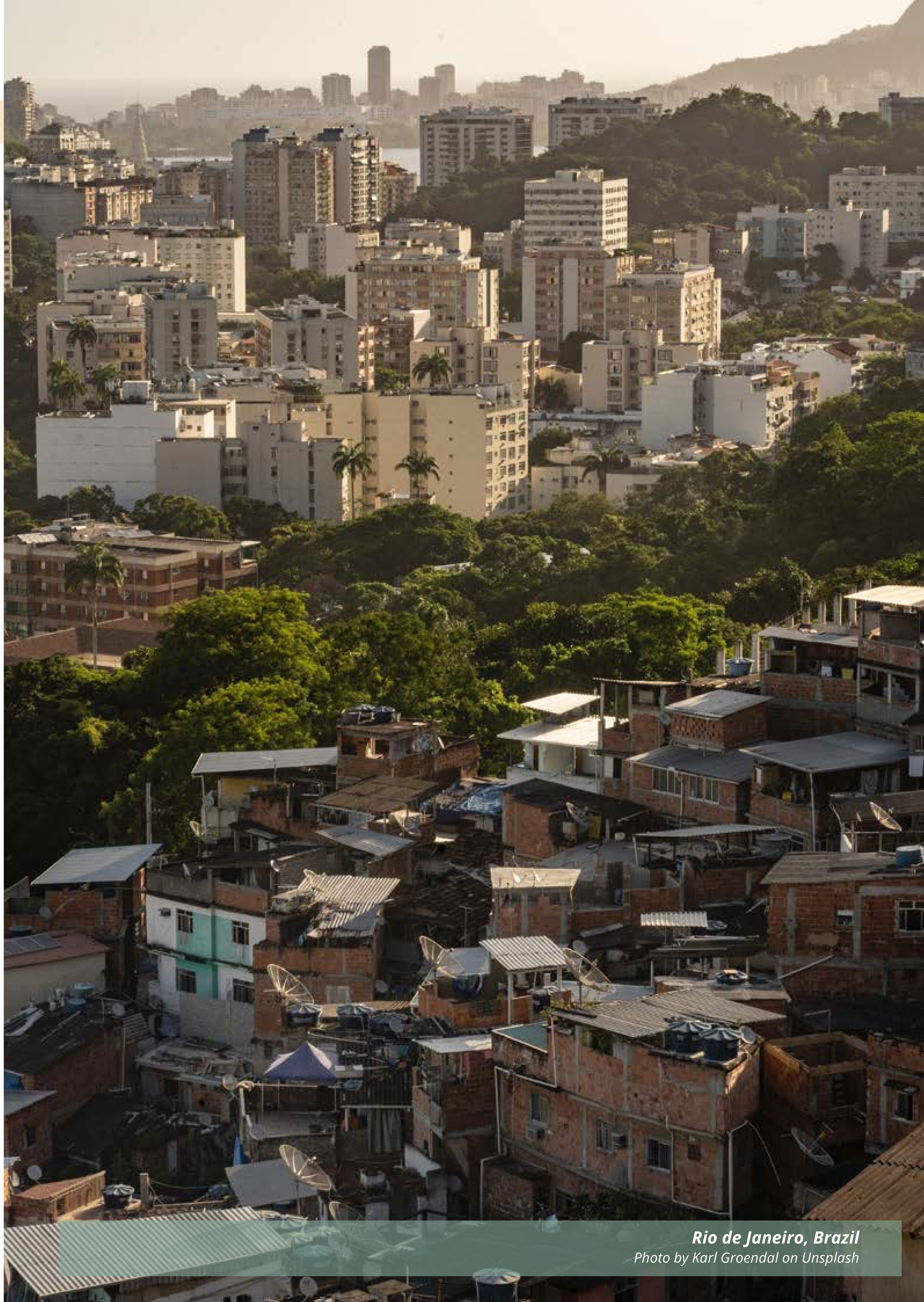
Maintenance costs for urban open green spaces vary depending on open space design, use, type of vegetation, and local climatic conditions.

UNIT COST EXAMPLES THROUGHOUT THE GLOBE

A study of European parks provided the following estimates for capital costs:

- *High-cost intensive use urban parks*: ***> US$270/m² (US$2,700,000/ha)***.
- *Medium cost urban parks*: ***US$135–US$270/m² (US$1,350,000–US$2,700,000/ha)***.
- *Low-cost parks*: ***US$68–US$270/m² (US$680,000–US$2,700,000/ha)***.
- *Very low-cost parks*: ***< US$68/m² (US$680,000/ha)*** *(Holden 2007).*

- *Estimates of maintenance costs in the United Kingdom vary between* ***US$0.4–$2/m²/year (US$4,000–US$20,000/ha/year)*** *(Tempesta 2015).*



Rio de Janeiro, Brazil
Photo by Karl Groendal on Unsplash

NBS IN PRACTICE

The four projects in this section highlight good practices and lessons learned in creating open green spaces from international experiences.

Photo by Saúl Ortega on Flickr

Private donation from local stakeholders

Equity promotion through playing and learning

Linked to cultural amenities, offering interdisciplinary activities

Project #1: *Julio Mario Santo Domingo Library Park, Completed 2010*
Location: *Bogotá, Colombia*
Description: *The Santo Domingo Library and gardens, set in 55,000 m² space, offer extraordinary benefits to the population of the northern districts of Bogotá—Usaquen and Suba. The restoration in 2010 involved conserving many existing plants while adding new ones. The gardens create an excellent education space and contain many rediscovered indigenous plants that are endangered, reviving a process of ecological restoration. The project demonstrates how important a healthy, green space can be to the mental wellbeing and physical health of urban dwellers*

Benefits
Education, Biodiversity, Health.
Source
Diana Wiesner and Daniel Bermúdez.
http://landezine.com/index.php/2013/06/julio-mario-santo-domingo-library-park-by-diana-wiesner-arquitectura-y-paisaje/

https://www.researchgate.net/publication/307751026_Julio_Mario_Santodomingo_Library's_Public_Space

Photo by BunBn on Wikimedia Commons

Urban green and natural icon

Design oriented: Launched as an international idea competition

Integrated in educational and cultural institution

Project #2: *Chulalongkorn Centenary Park, 2012–17*
Location: *Bangkok, Thailand*
Description: *The Chulalongkorn Centenary Park in Bangkok is the first critical piece of green infrastructure for the city, designed to mitigate detrimental ecological issues. It has added a much-needed outdoor public space to the gray city in 2017. Its green roof is the largest in the country, and the park's filtration system treats water from neighboring areas. It has become a showcase for ecological and social impacts of landscape architecture in dense urban areas. Its site area spans 48,000 m² and is 1.3 kilometers in length, and it sits in the campus area of Chulalongkorn University.*

Benefits
Pollutants Reduction, Biodiversity, Tourism, Social Interaction.
Source
LandProcess, Kotchakorn Voraakhom
www.nparks.gov.sg/-/media/cuge/ebook/citygreen/cg16/cg16_05.pdf

https://worldlandscapearchitect.com/chulalongkorn-centenary-park-green-infrastructure-for-the-city-of-bangkok/#.YWV7s_lBxPY

Photo by Ninara on Flickr

Gender and youth empowerment

Comprehensive task of neighborhood recovery

Community involvement in project management and expansion

Project #3: *Kibera Public Space Project, 2006 to date*
Location: *Lindi Village, Nairobi, Kenya*
Description: *Located at a busy river crossing, the project was previously subject to periodic destructive floods, and lacked basic sanitation and amenities to youth. The Kibera Public Space project, designed by KDI with local residents in 2006, developed programs that would meet some of the physical, social, and economic needs of its residents, and provide activities for the youth. The result was a network of productive public spaces, with various hubs of cultural exchange, economic activity, and environmental remediation. Today, resident-managed programs, many led by women and youth, maintain these sites, help residents build new skills, and generate income. The network continues to expand and improve environmental and social resilience across the settlement.*

Benefits
Education, Gender Empowerment.
Source
Kounkuey Design Initiative (KDI)
https://www.kounkuey.org/projects/kibera_public_space_project_network

Photo by Google Earth

Renewal of common residential areas and building trust through design

Community involvement in project design and execution

Active space between private and public properties

Project #4: *Common-Unity, Completed 2016*
Location: *San Pablo Xalpa, Azcapotzalco, Mexico City*
Description: *Common-Unity is a public space rehabilitation project for San Pablo Xalpa Housing Unit in Azcapotzalco, Mexico City. The unit was previously divided into sectors. Walls, fences, and barriers led to a fragmentation of spaces that did not allow the community to benefit from public spaces. The project transformed such a divided space into a neighborhood space. The recovered public space became an extension of each apartment. The strategy was a big success: people contributed to the design and an increasing number of people decided to remove their fences*

Benefits
Heat Stress Risk Reduction, Social Interaction, Health and wellbeing.
Source
Rozana Montiel, Estudio de Arquitectura
https://www.archdaily.com/892388/common-unity-rozana-montiel-estudio-de-arquitectura

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Dnipropetrovsk, Ukraine
Photo by Artiom Vallat on Unsplash

GREEN CORRIDORS

Jakarta, Indonesia
Photo by Fawazlul Rizqi on Unsplash

FACTS AND FIGURES

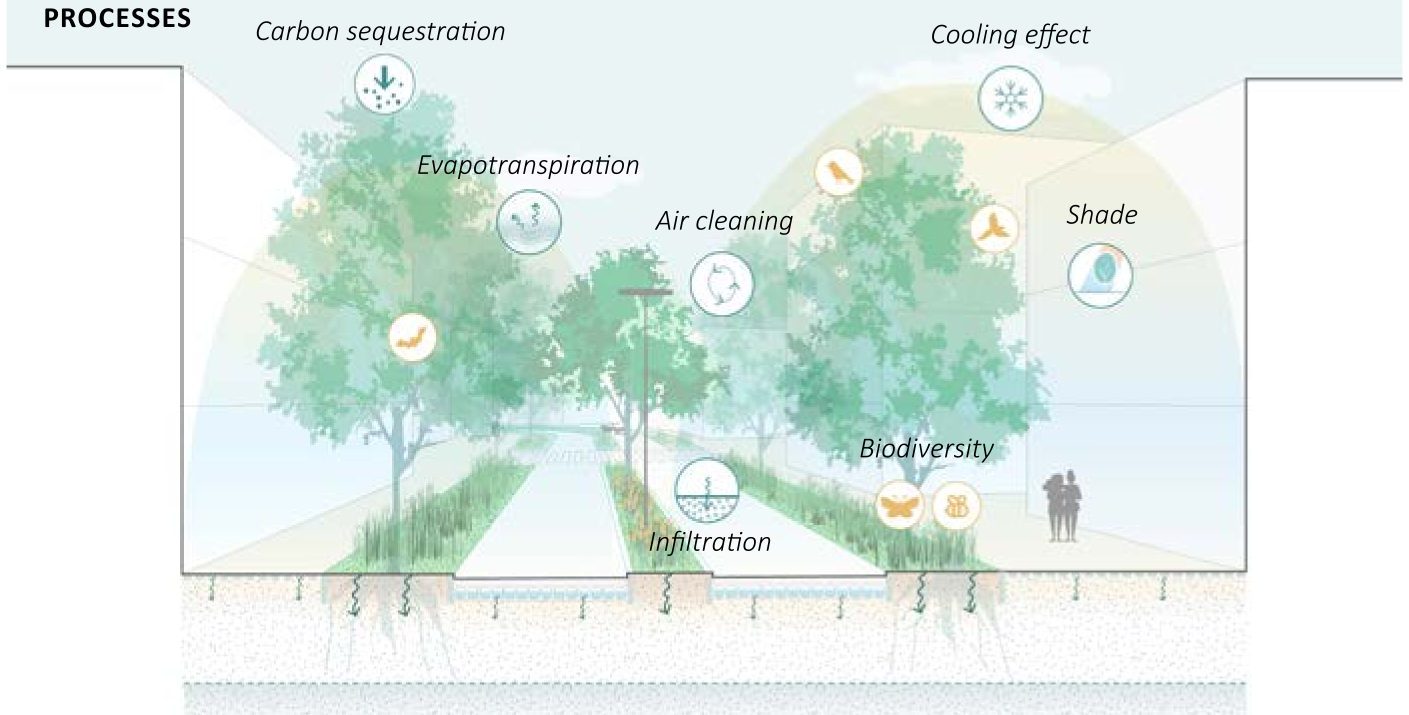
DESCRIPTION

Green corridors, also known as linear natural infrastructure, are an essential part of the urban landscape ecology. These strips of trees, plants, or vegetation can be found at a range of scales, and typically connect green spaces in a city, creating a green urban infrastructure network. Green corridors complement green spaces in a city, protect natural habitat, and typically contain the most valuable animal species urban habitat. The corridors allow biota to move, survive, and propagate.

Highly fragmented urban landscapes, where distances between green spaces are large and corridors are insufficient or absent, reduce the landscape's potential to mitigate flood risks through enhanced interception and infiltration. In many cities, the ratio of paved to biologically active surfaces that can absorb, store, and recirculate water is out of balance, and the stormwater drainage and sewer system cannot handle the growing amounts of precipitation. As a result, damaging floods and river pollution can occur. Cities can mitigate this problem by establishing more green corridors and connecting them into a green urban infrastructure network, which would lessen the load on the drainage and sewerage systems, and ultimately protect the urban living environment from flooding and polluted water discharges. With growing awareness of the importance of green corridors, cities are being proactive in designing interconnected green spaces, with both large scale as well as smaller scale interventions in neighborhoods and buildings. Riparian corridors can often be found as prominent corridors in cities. They act as important dispersal corridors for climate-induced species and they provide microclimatic refugia from warming (Krosby et al. 2018). Smaller scale interventions include green streets, green avenues, and gardens, providing microcorridors and stepping stones that better support biodiversity values and ecosystem services.

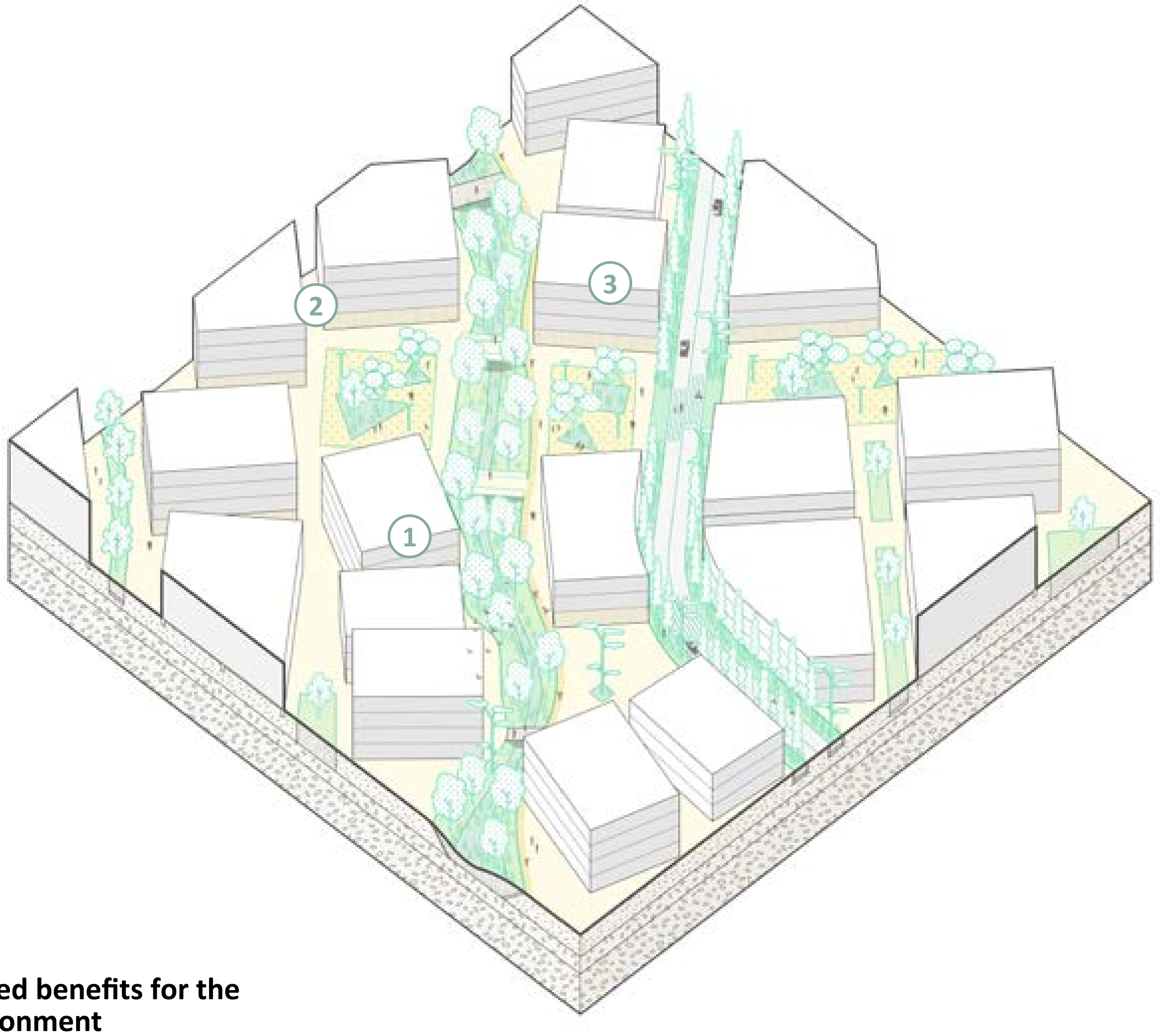
TYPE OF CITY	SCALE	APPROACH
Coastal, Delta, River, Mountain	Neighborhood, City, River basin	**Protect**: Preserve natural corridors, particularly drainage lines. Preserve the existing tree structure. **Rehabilitate, Restore, Enhance**: Integrate existing elements of green infrastructure into a connected system. Upgrade of individual elements. **Create**: Expand the existing tree structure and the connective green structure of the city.

PROCESSES

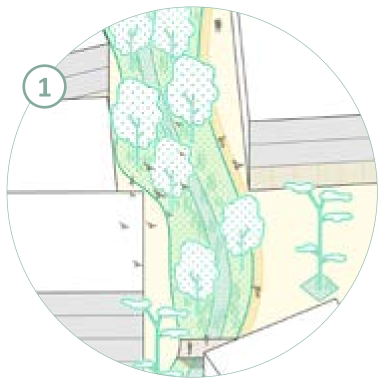


VISUALIZATIONS

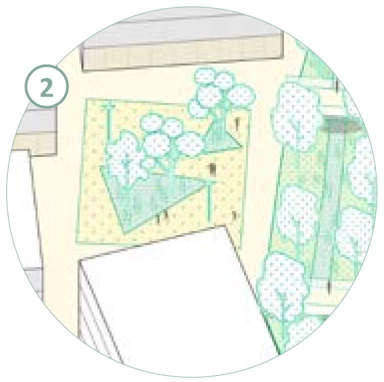
VISUALIZATION OF GREEN CORRIDORS IN THE URBAN CONTEXT



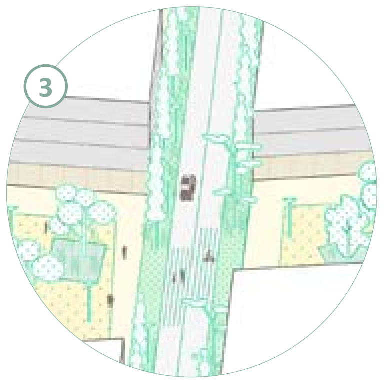
Details of increased benefits for the urban living environment



Maintaining buffers along drainage lines improves water quality and provides critical habitat linkages for wildlife.

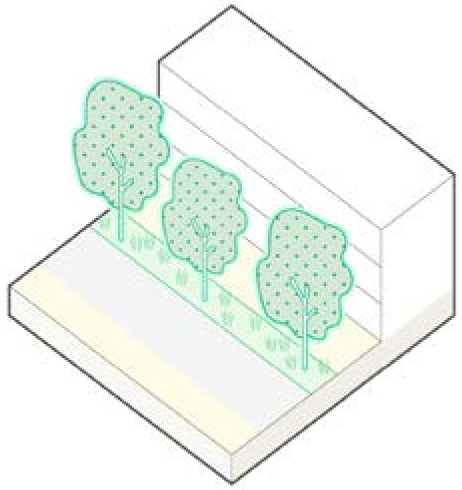


Stepping stones for biodiversity are provided when the design of parks and gardens seek to complement existing corridors.



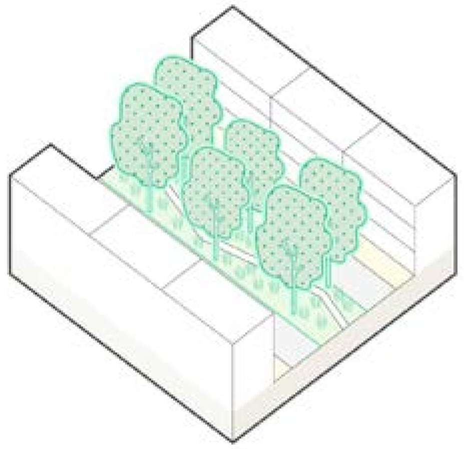
Maintaining green verges and establishing trees alongside roadways enhance aesthetics, reduces heat, and provides shade for pedestrians.

SPECIAL TECHNIQUES FOR GREEN CORRIDORS



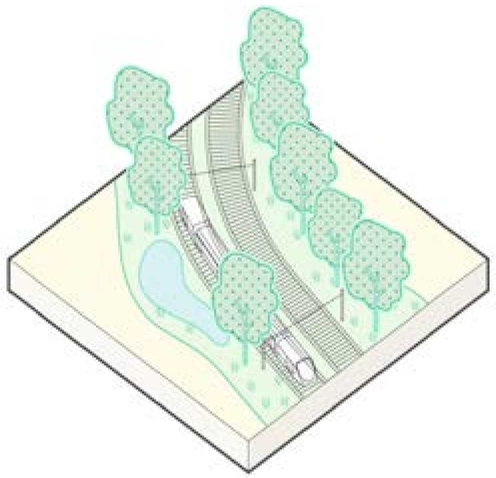
Street tree canopies

Streets with large tree canopies enhance the image of a city, increase its competitiveness, deliver economic and environmental benefits. Some cities are famous for a particular type of tree and attract seasonal tourism based on the tree-blooming schedule. Tree canopies circulate rainwater, create local microclimate, absorb pollution, provide shade, and attenuate heat. Heat reduction translates into lower cooling bills for buildings. Cooler streets with large tree canopies promote walking and social interaction and generate more retail and hospitality revenue.



Green avenues

Green avenues and boulevards are among the most attractive urban typologies, historically proven to improve business, increase property taxes and enhance the prestige and desirability of cities. Functioning as environmental corridors from the start, they are instrumental in climate adaptation. An unpaved, vegetated medium can be integrated into the green infrastructure network for climate adaptation and help prevent floods. Continuous tree canopy efficiently mitigates urban heat, provides shade and shelter for small species, and promotes walking.

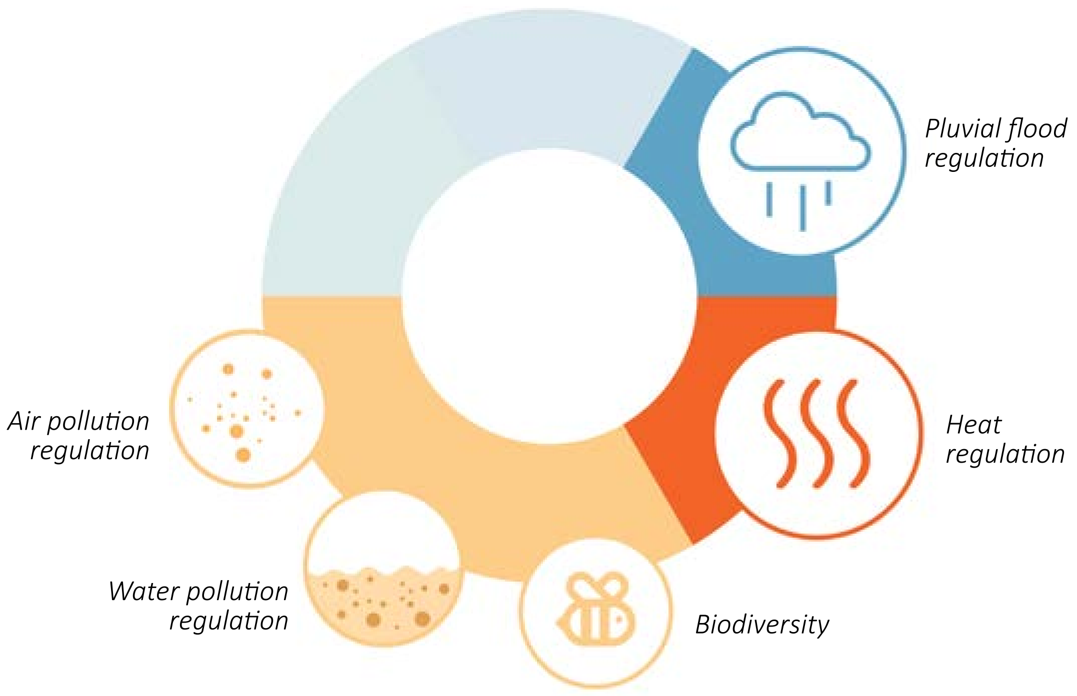


Urban green corridors

The most efficient way to create a green corridor is to plant deciduous trees as large canopies. Trees can be placed along the streets, open train tracks, and other transportation and infrastructure corridors, in open and derelict spaces. Green corridors should be designed for multiple functions such as new bike paths, walking, and jogging routes, in addition to water management areas. Green corridors can help establish better landscape connectivity across the city and improve ecosystem functions (NWC 2016).

FUNCTIONS

The diagram in this section shows relevant functions of green corridors.



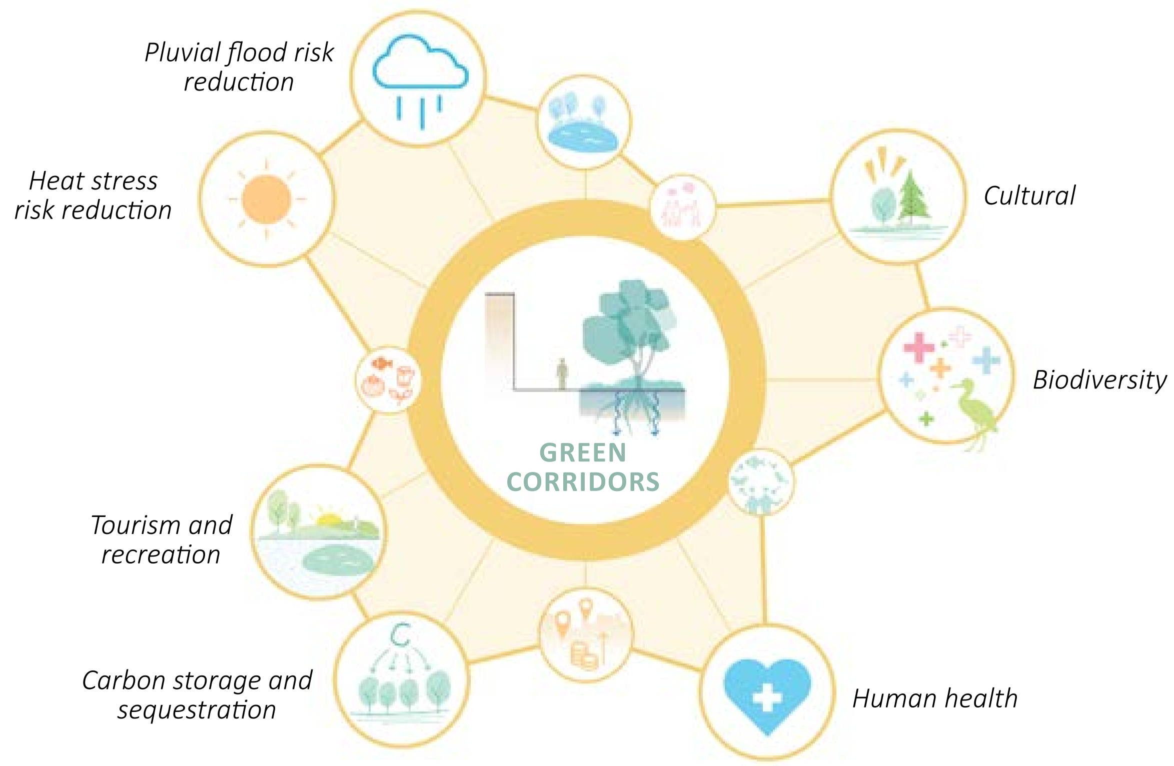
Pluvial flood regulation: As part of a green space network in a city, green corridors can help manage stormwater and mitigate floods through interception of rainwater, evapotranspiration, root water uptake, and soil infiltration (Gehrels et al. 2016). The integration of green corridors as part of road drainage and streetscapes can also serve to promote infiltration and decelerate flows, while a range of opportunities exist to integrate them into existing drainage networks. Their effective reach then expands from purely natural elements to being part of the existing gray infrastructure network of a city.

Heat regulation: The potential for green corridors to regulate heat depends largely on the height and density of tree canopies present within the corridor. A tree canopy reduces the temperature in the shade by 1–5°C (33.8–41°F) compared to an open area, and by 11–17°C (51.8–62.8°F) compared to a parking lot. A 10% increase in the tree canopy cover reduces the maximum midday air temperature by about 1°C (33.8°F) (2030 Palette 2020). The cooling efficiency of trees depends on the foliage color, density, thickness, and texture. Darker and denser greenery provides shade and reduces temperatures more effectively (Lin and Lin 2010).

Other functions: Green corridors improve water and air quality, reduce noise, and offset the loss of biodiversity in urban environments (Eisenberg and Polcher 2018).

BENEFITS

The diagram in this section shows a sampling of important benefits that green corridors can provide to people.



Heat stress risk reduction: Trees in green corridors reduce temperatures in urban areas by creating shade and through evapotranspiration. They reduce the amount of heat reflected off the buildings and pavement (2030 Palette 2020). The quality of tree canopy, its size, density, leaf color, and the distance between the trees determine its effectiveness. A continuous tree corridor will have a greater cumulative heat mitigation effect than a set of individual trees (DDOE 2012).

Pluvial flood risk reduction: Trees in green corridors increase the interception of rainwater in urban environments, reducing risks of local floods and peak loads of stormwater in the sewerage system.

Tourism and recreation: Green corridors are important for recreation and attracting tourists to a city. Greenery makes summer tourism in hot climates more pleasant because of their ability to reduce temperatures in the city. Green corridors promote alternative mobility and safe recreation, provide different ways of experiencing the city, and attract people to the outdoors (Sullivan et al. 2004).

Carbon storage and sequestration: Linear green corridors, such as street trees store and sequester carbon. For example, an empirical study of Beijing street trees found very high heterogeneity carbon density rates between different corridors (Tang et al. 2016). This study estimated the average aboveground carbon density of urban street trees at 13.9 ± 0.7 tons CO_2 per ha. The contribution of green corridors to carbon sequestration will vary significantly based on the habitat structure and growth rates of plants associated with the corridor. Where dominated by grassy areas, rates are likely to be in the region of 0.5 to 5 tons CO_2 per ha per year whereas this could increase to well above 5 tons CO_2 per ha per year for forest-dominated corridors; and found an average sequestration rate of 0.5 ± 0.3 tons CO_2 per ha per year (Bernal et al. 2018).

Human health: Tree canopies reduce peak temperatures and make street life more tolerable on hot summer days (Gehrels et al. 2016). The shade reduces the amount of harmful UV radiation reaching pedestrians; it reduces wind speeds and air pollution. Green corridors work as buffers and shield people from the noise and pollution of large-scale infrastructure. They invite people to participate in year-round sports and physical activities, encourage biking, and complement public parks in their ability to reduce stress and promote a sense of wellbeing. Pedestrians experience better thermal comfort and find the heat more bearable (Gehrels et al. 2016). The presence of tree canopies within walking distance from residential buildings, can reduce mortality in elderly individuals (Takano et al. 2002).

Biodiversity: The spatial arrangement of street trees and green corridors define levels of biodiversity in cities. Green corridors sustain biodiversity by connecting different patches of green within the city and to the larger habitats in the region. In smaller habitats, they facilitate movement of biota between different patches and natural colonization of new areas. Landscape connectivity is vital for biodiversity. Street trees provide habitat for birds, squirrels, and smaller species. They are also stepping stones that allow species to jump from one relatively safe area to another until they reach a larger and safer landscape habitat patch (Vollaard et al. 2018).

Cultural: Together with architecture, street trees and green corridors enhance urban identity and raise the prestige of different areas. Several cities celebrate trees by organizing festivals and other cultural events around their blooming schedule (Yilmaz and Mumcu 2016).

SUITABILITY CONSIDERATIONS

ENVIRONMENTAL

Location and climate: Plants for green corridors should be selected according to the hardiness zone, soil type, sunlight and rain data, frost schedules, and other factors that affect the success of trees and vegetation. Local data can be gathered to check what trees have done well in the area, what plant diseases have occurred, and what weather changes are most pronounced. In semi-arid and arid climates, special considerations regarding water needs, irrigation, and the impacts of establishing green corridors on water tables and soil recharge rates should be evaluated prior to implementation.

Hydrology: Matching new urban trees and plants with the right soils should strike a delicate balance. They should get proper irrigation for their growth, but they should not be water logged if inundated by a flood. The soils should be layered to provide proper drainage, yet retain nutrients. For urban tree propagation, many climate-appropriate technologies introduce structural elements, filters, membranes, and irrigation mechanisms to secure growth and health of urban trees. Given the costs and vulnerability of urban trees, it is important to make use of these technologies (Eisenberg and Polcher 2018).

Soil: Soils in urban areas are frequently compacted, nutrient deficient, have high levels of acidity or alkalinity, and may be contaminated by salt and other ice-melting compounds, or be polluted by industrial or other human activity. Local soil tests are therefore typically required to inform any soil augmentation necessary to support selected vegetation and fulfill their pH value, drainage, and structural requirements (Forest Research n.d.).

TECHNICAL

Slope: Planting methods for green corridors with slopes steeper than 3:1 involve creating a level planting space on the slope. A terrace can be dug into the slope in the shape of a step (DDOE 2012).

Species selection: When developing green corridors, plant species should be selected that support and enhance important benefits. This may range from tree selection to optimize carbon sequestration and heat reduction benefits to the selection of plant species that add to aesthetic values or which provide habitat or food for important wildlife.

Dimensions: Urban trees along linear infrastructure, such as roads, require an appropriately sized three-dimensional space to establish their roots securely. A tree pit and a grate must keep an appropriate amount of unpaved surface around the tree to allow water to percolate; and to the extent possible, keep debris and pollutants out of the tree pit. The depth of the roots, the height, and the size of the canopy must be considered (DDOE 2012), along with the distance between the trees. Root space should ideally be 12 m^3 with a minimum depth of 1.5 meters (Eisenberg and Polcher 2018) although this is not always achievable in an urban context. The space between the edge of the tree pit and the street curb or a building should be least 1.8 meters to allow more space for the roots (DDOE 2012).

Utility restrictions: Trees in green corridors can interfere with the street level and underground utilities. In areas with overhead power lines, trees should be selected to maintain an acceptable distance between the top of the trees and the wires. Appropriate clearance must also be established and preserved between the underground utility lines and the tree roots (Gilman 1994).

Infrastructure restrictions: A clearance must be established to protect the green corridors from built infrastructure, and to ensure that trees are not interfering with roads, train tracks, gas mains, and other elements of urban infrastructure (Eisenberg and Polcher 2018). Tree species must be durable and able to withstand ground vibration, air and water pollution, and other aggravations of urban conditions. The trees must be periodically trimmed to preserve the right distance from infrastructure for the long term.

URBAN

Land use: Infrastructure networks, residential streets, and major infrastructure including rail tracks and highways are suitable land uses for linear green corridors.

Urban density: Suitable urban density for linear green corridors ranges from low to high.

Area: Small to large. Linear green corridors are nature-based solutions suitable for application at neighborhood, district, and city scale.

Integrated urban planning: Linear green corridors can be planted as part of street improvement programs, transformation of underused infrastructure and open spaces, and as part of new urban development.

MAINTENANCE

Maintenance requirements vary considerably across habitats and should be carefully considered when planning new green corridors. Irrigation requirements vary considerably depending on plant types, the soils, and prevailing climatic conditions. Young trees typically require regular watering until the root structure is firmly established (Gilman 1994). In high traffic areas, trees should be trimmed to at least 2.5–3 meters from the ground so as not to interfere with the passage of cars and pedestrians. Trees that produce too much fruit, nuts, or leaf litter should not be planted along streetscapes unless included in street maintenance budgets. Formative pruning is usually not needed for newly planted trees but may be beneficial for the tree structure.

COSTS

COST CONSIDERATIONS

Land

Access to or ownership of land is required for green corridor development.

Land on which green corridors may be located may be public or private.

Land area required for green corridors will vary from smaller to larger areas, raising transaction costs if engagement and collaboration with multiple landowners and stakeholders is necessary

Example land-related costs:

- Acquisition costs
- Land use (e.g., payments to landowners) costs
- Land protection costs, including managing and controlling access
- Community resettlement costs

Construction and implementation

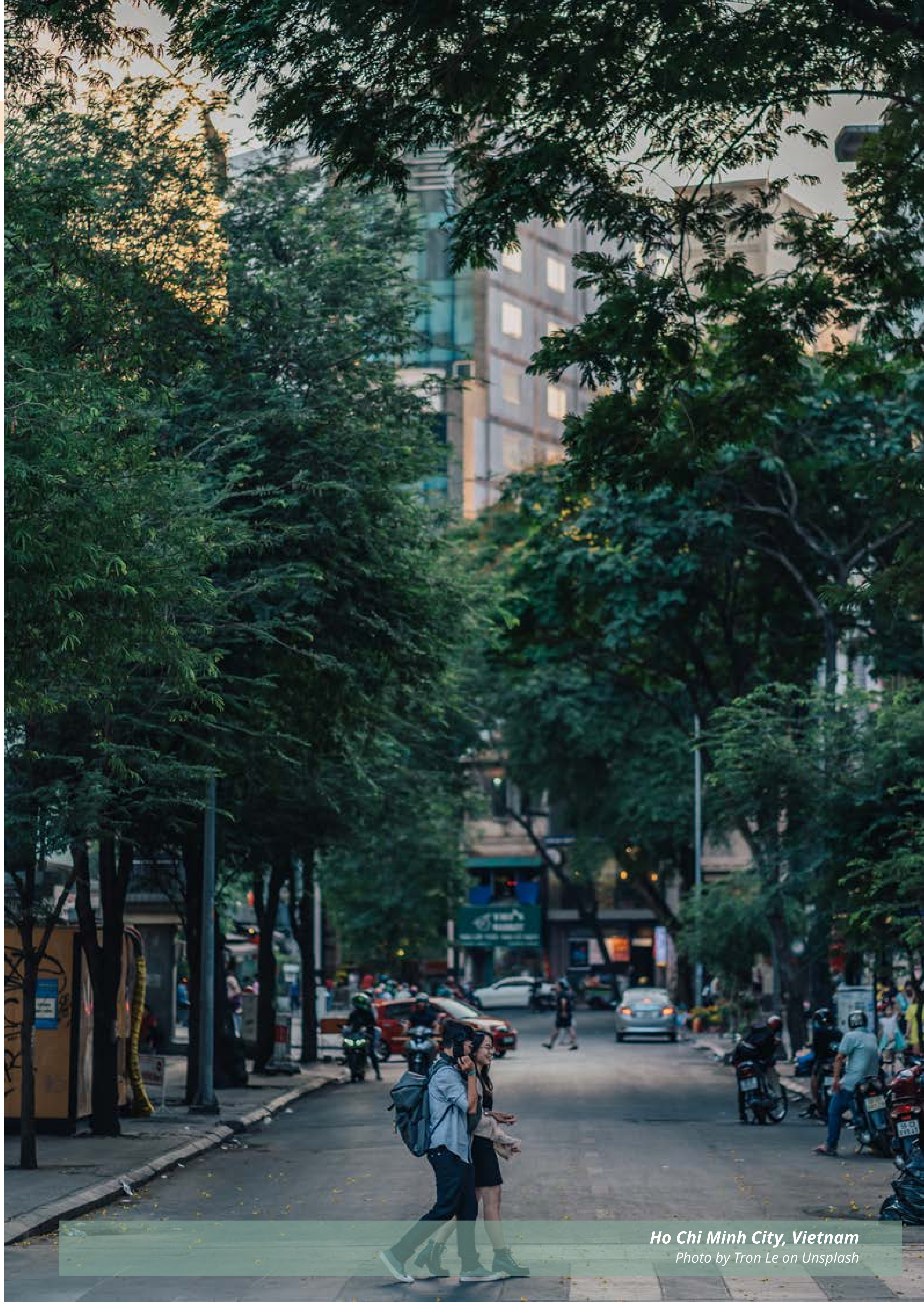
Costs associated with protecting, restoring, or creating urban green corridors will depend on the size of the green corridor, site conditions, the type and size of trees and other vegetation required to be planted, and underlying labor and material costs.

Maintenance

Maintenance of green corridors depend on the type and size of trees or vegetation, the complexity of planting, local climatic conditions, and labor costs.

UNIT COST EXAMPLES THROUGHOUT THE GLOBE

- *Installation costs for street trees cost between **US$6,680–US$11,666** over a 50-year time period, depending on the method of delivery and installation, watering, anchoring, the aeration system, and the tree grille (GBU 2019).*
- *Maintenance costs for street trees range from **US$547–US$2,252** per tree over a 50-year time period, including inspection, leaf clearing, and pruning (GBU 2019).*



Ho Chi Minh City, Vietnam
Photo by Tron Le on Unsplash

NBS IN PRACTICE

The four projects in this section highlight good practices and lessons learned about green corridors, drawn from the growing popularity of NBS throughout the globe.

Photo by Alberto Cabello on Flickr

Sustainable stewardship and urban development

International recognition and city icon

Long time restoration strategy of peri-urban areas

Project #1: *The Green Belt of Vitoria-Gasteiz, 1990s to 2008*
Location: *Vitoria-Gasteiz, Spain*
Description: *The Green Belt is a group of peri-urban parks of high ecological and landscape value, strategically linked by ecorecreational corridors. It is a result of an ambitious environmental restoration project initiated in the early 1990s around the outlying areas of Vitoria-Gasteiz with the objective of creating a large, green area for recreational use around the city. It offers many different environments with a wealth of natural features. Woods, rivers, wetlands, meadows, fields, groves, and hedgerows are some of the varied ecosystems that coexist. Some of these ecosystems, such as the restored wetlands of Salburuaor and the River Zadorra ecosystem, have won recognition at international level for their high environmental value.*

Benefits
Health, Equity, Environmental Sustainability.
Source
Vitoria-Gasteiz Municipal Council
https://www.researchgate.net/publication/259121417_The_Green_Belt_of_Vitoria-Gasteiz_A_successful_practice_for_sustainable_urban_planning

Photo by Karl Fjellstrom / Far East Mobility

District renewal strategy and promotion of mixed-use urban program

Priority of pedestrian mobility and green infrastructure

Boost economy and real estate value

Project #2: *Liuyun Xiaoqu District Project, 2000–10*
Location: *Hangzhou, China*
Description: *Changes in land ownership schemes in Liuyun Xiaoqu district allowed for a redevelopment of public space and the creation of the first green corridors for pedestrians, within densely populated urban blocks. Initially, owners of the ground-floor apartments were able to make a living by converting their premises to commercial uses—at first for local shops and later for designer clothes retail and cafes. The ground floor conversions occurred in waves, eventually converting nearly all the ground floors to commercial use, turning the area into an open, mixed-use neighborhood. With much of the area now being used for commercial purposes, its narrow pedestrian passages were opened to public access. The municipality then improved utilities and infrastructure, pedestrian areas, and key landscaping features including tree maintenance and replanting, that created shaded public spaces.*

Benefits
Economy, Health and Wellbeing, Heat Stress Risk Reduction.
Source
Far East Mobility, Hangzhou Municipality
https://www.fareast.mobi/en/bestpractices/liuyun

Photo by Google Earth

Showcase for coexistence of infrastructure and social interaction

Design oriented: Launched as an international idea competition

Active participatory process with neighbors

Project #3: *Cuernavaca Ferrocarril Linear Park, 2016–20 (Phase 1)*
Location: *Mexico City, Mexico*
Description: *Located at the heart of Mexico City, the project consists of an active urban forest of 4.5 km in length, which crosses 22 districts and buildings. This green corridor is an active, programmed, and sustainable connector of spaces. It created spaces that contribute to the spirit of community and it has promoted a sense of ownership of public space by people. It also achieves high social value by strengthening identity and memory of the history of the place, by creating a sustainable and high quality environment for people to linger and use at their own leisure.*

Benefits
Education, Culture, Biodiversity, Health, Community.
Source
Gaeta Springall Architects
https://mooool.com/en/linear-park-ferrocarril-de-cuernavaca-by-gaeta-springall-arquitectos.html

Photo by Thomas Timlen on Flickr

Symbol for sustainable development of public space

Long term vision, framework and design strategies to guide progressive implementation

Launched as an international competition for masterplan development

Project #4: *The Rail Corridor Project, 2015–21*
Location: *Singapore*
Description: *The closure of Keratapi Tanah Melayu (KTM) railway in 2011, bisecting Singapore released 24 km of continuous land spanning the entire nation. In the face of population growth and urbanization, Singapore made the bold decision to transform the 100-hectare site into public space to provide benefit to its people and the environment.*
The design included the creation of 8 themed stretches and 10 activity nodes, dedicated to different sports or leisure activities.
The project reinvented hidden space within Singapore to inspire movement and new ways of experiencing the environment. It allows people to enjoy the interactions between city, nature, land, water, community and art, as well as enjoy heritage sites. The Rail Corridor has become a green, vibrant and healthy space to engage residents and visitors with Singapore's natural and built heritage.

Benefits
Education, Historic Value, Health and Sports, Heat Stress Risk Reduction.
Source
Tan See Nin, Urban Redevelopment Authority
https://www.csc.gov.sg/articles/co-creating-the-rail-corridor's-future

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George Town, Malaysia
Photo by elCarito on Unsplash

China
Photo by ZHIDA LI on Unsplash

FACTS AND FIGURES

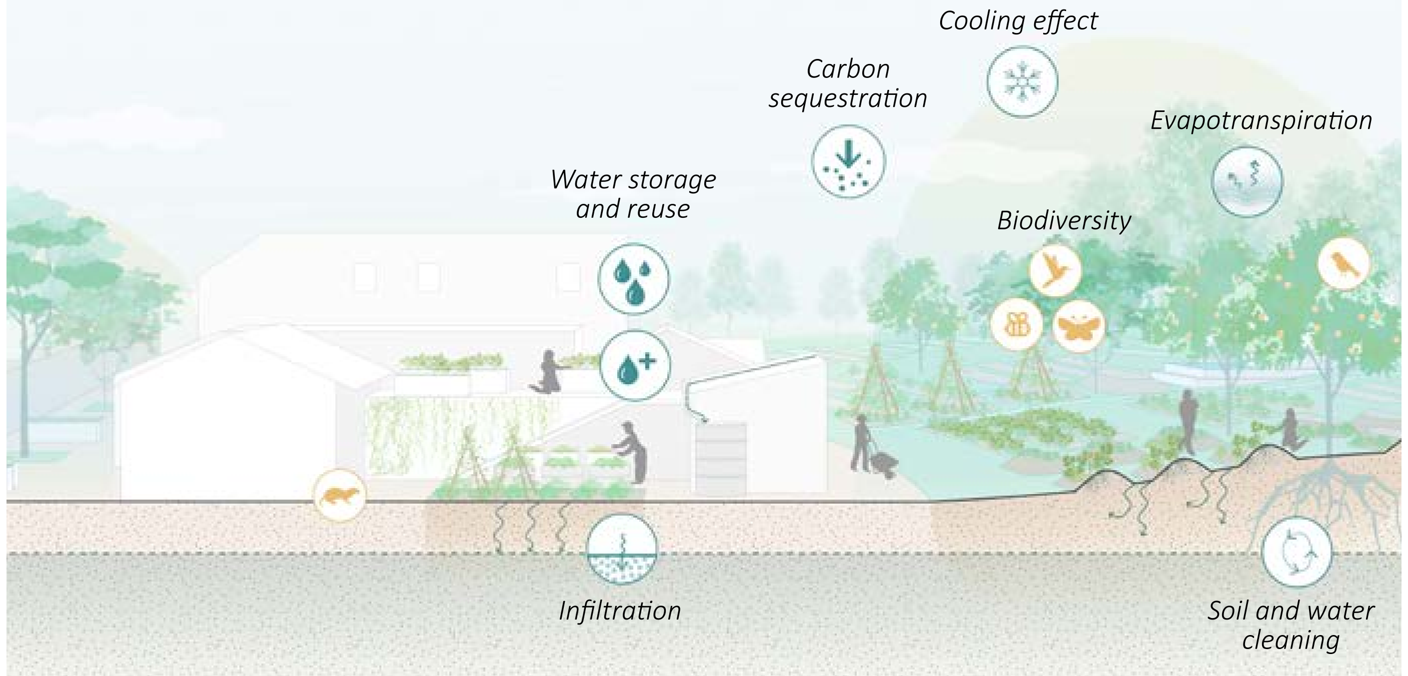
DESCRIPTION

Urban farming is a way for people to grow crops for personal consumption or to sell locally and beyond. Urban agriculture can be defined as the growing of plants or animals within and around cities and associated activities such as producing and delivering inputs as well as processing and marketing of agricultural products (FAO 2011). The most important incentive for urban farming is to increase food security for urban livelihoods. In many parts of the world, it helps build resilient food systems. In addition to contributing to food security, urban farming provides multiple benefits. It supports climate change adaptation and mitigation, biodiversity and ecosystem services, sustainable agricultural, resource efficiency, urban regeneration, land management, public health, social cohesion, and economic growth (Artmann and Sartison 2018).

Urban farming comprises a variety of activities—aquaculture, livestock, plants, and food production. Agro-ecosystems as well as forests, industrial rooftop gardens, residential and community gardens, containers on balconies, vacant land, edible landscaping, vertical edible green infrastructure, and marine and freshwater systems are suitable spaces for urban food products (Grewal et al. 2012; Haberman et al. 2014; Lovel 2010; Russo et al. 2017). As a result of rapid urban development peri-urban agriculture is under threat, but at the same time food demand in cities is increasing. To secure this, accomplishing sustainable agriculture is key. However, without proper management, urban farming could pollute the environment or create additional risks, and can come in direct conflict with real estate and infrastructure development pressures. It can also compete with valuable open space for conservation and place increasing pressure on remaining natural ecosystems. This means the economic contribution of urban farming, social equity, and the need to balance food production with conservation efforts need to be understood and integrated into policies and designs. When managed and planned well, urban farming as an NBS, can play an important role in sustainable urban development and help urban residents to reconnect with nature, reclaim public spaces, recover from disasters, and gain income (Artmann and Sartison 2018).

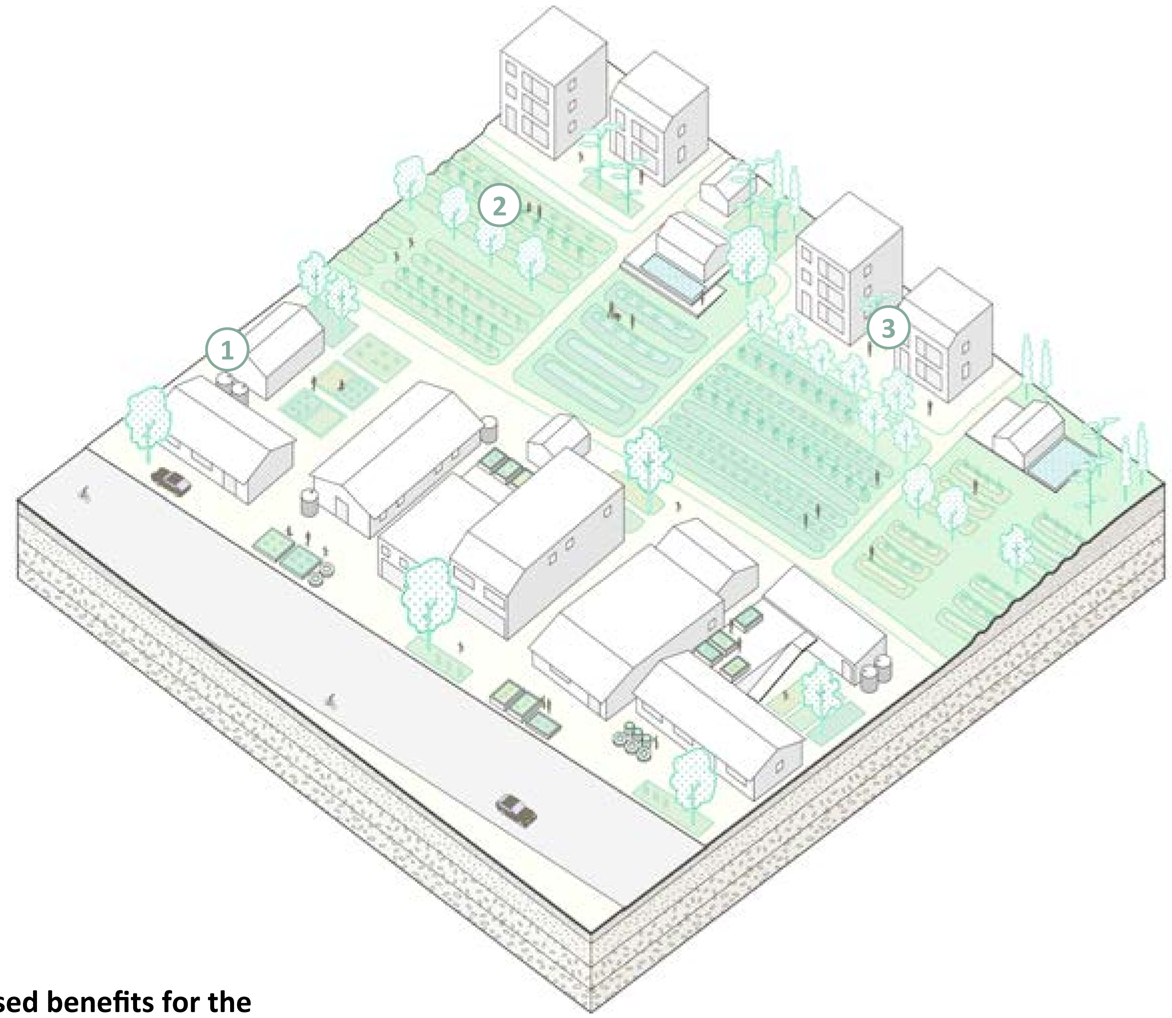
TYPE OF CITY	SCALE	APPROACH
Coastal, Delta, River, Mountain	Neighborhood, City, River basin	**Protect**: Protect prevalent urban farming practice and local food supply networks. **Rehabilitate, Restore, Enhance**: Allow temporal use of unzoned areas for urban farming. **Create**: Create new areas for urban farming.

PROCESSES

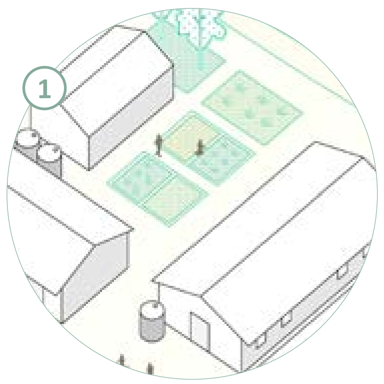


VISUALIZATIONS

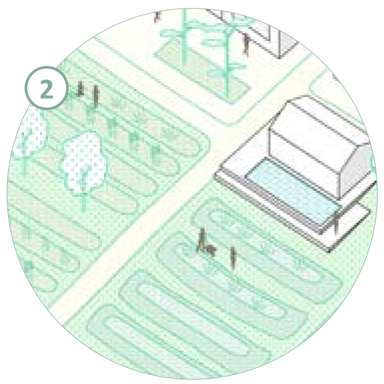
VISUALIZATION OF URBAN FARMING IN THE URBAN CONTEXT



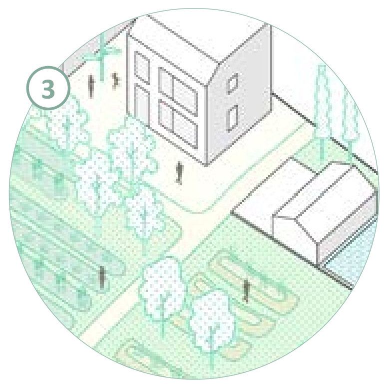
Details of increased benefits for the urban living environment



Outdoor urban farming can produce local food; reduce urban waste stream by absorbing compost; and reduce stormwater runoff by infiltrating and storing water.

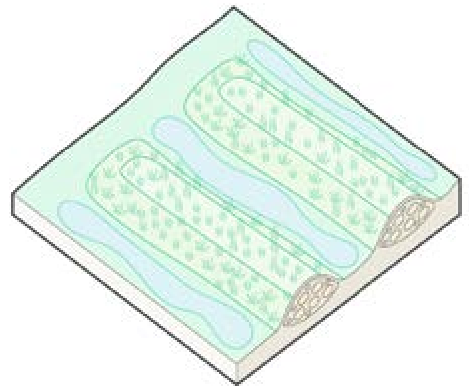


Farming creates strong urban identity and prevents soil erosion, mudslides, and other hazardous effects of loose soils in areas with complex terrains, while increasing social cohesion.



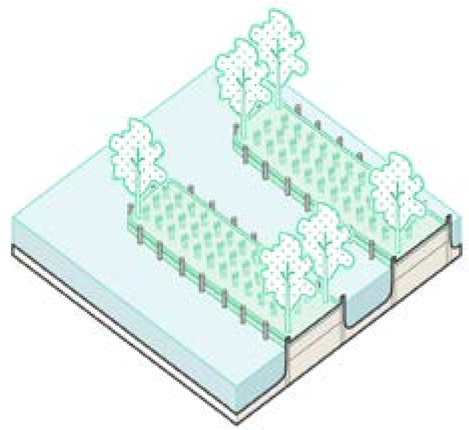
Farming can take place in vacant lots, on rooftops, and high potential agricultural land. It delivers multiple ecosystem service benefits, creates local employment and a beneficial sense of community belonging.

SPECIAL TECHNIQUES FOR URBAN FARMING



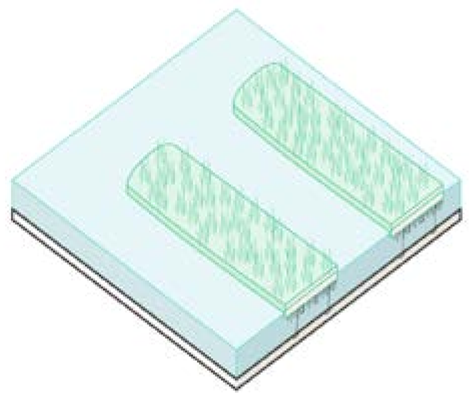
Raised beds

Raised bed farming is a low-cost technique in urban areas where soil pollution can be a threat. Raised beds can be built to any size, using any noncorrosive material, as long as the structure provides good drainage. Raised beds have many advantages: in temperate regions with cold winters, the beds warm up quicker than the barren ground in the spring, thereby extending the growing season. In areas with limited sun, beds can be tilted to maximize the exposure for plant growth. In cold months beds can be covered or converted into greenhouses.



Amphibious farming

Inspired by the ancient Aztec way of farming called *chinampas*, amphibious farming uses artificial islands built in water. The islands are secured in place by driving wooden stakes into a lakebed and establishing a perimeter with woven reed fences. Amphibious farming areas create a grid, with large enough canals between the island crop beds for a small boat to move through. Planting beds use compost produced in situ as the growing medium.

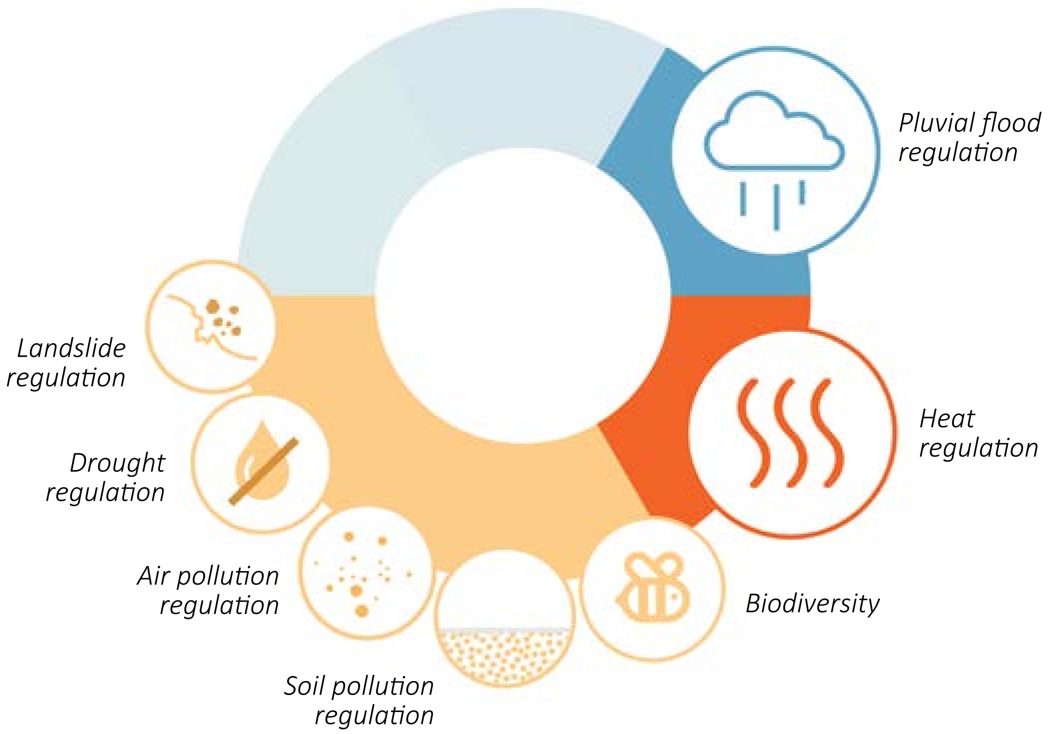


Floating farming

Floating agriculture is a way of utilizing inundated areas for food production. The method creates buoyant beds filled with compost from decomposing vegetation, which becomes a growing substrate for crops. The beds float on the surface of the water, creating additional areas of land suitable for agriculture. Floating cultivation can be up to 10 times more productive than traditionally farmed land but are not suitable in waterbodies that experience high flow velocities (CTCN n.d.; Haq et al. 2004).

FUNCTIONS

The diagram in this section shows relevant functions of urban farming.



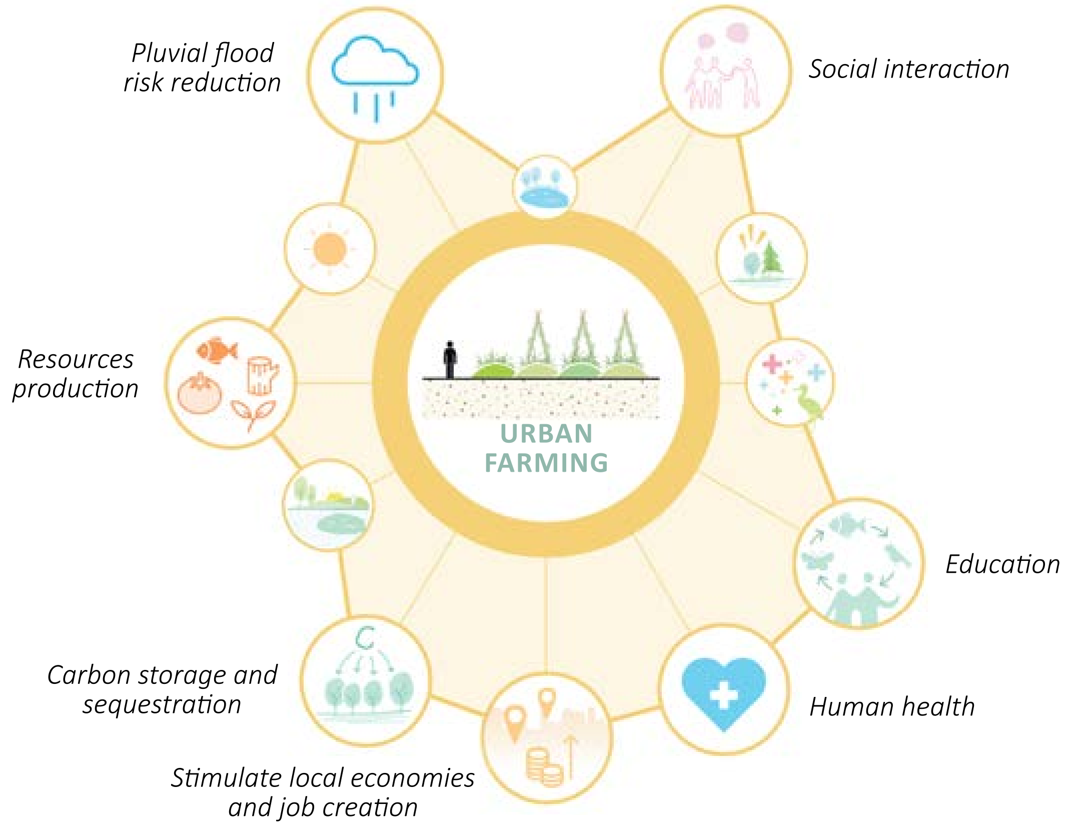
Pluvial flood regulation: Outdoor urban farms increase the amount of pervious surface, and can capture, store, and infiltrate rainwater, reducing runoff (Aerts et al. 2016). Farming soils often have high levels of organic content and a structure that allows water to percolate deeper into the ground. Adding more organic content can increase their water retention and storage capacity, allowing the soils to act as natural sponges. Farms can also include ponds and rain collectors to store additional water.

Heat regulation: Urban agricultural areas, especially orchards, reduce urban heat by creating shade and have an ameliorating effect on the immediate local climate, and in the case of arid climates, increased humidity (Smit et al. 1996).

Other functions: Urban farms clean air, water, and soil, and offset drought by storing water. In areas where development is not possible, such as steep slopes, floodplains, and areas with no bedrock and unstable soils, farming can be used to stabilize soils and prevent mudslides (Smit et al. 1996). Compost can be produced and collected locally, reducing waste (Olson and Gulliver 2011). Urban farms may increase biodiversity in the surrounding areas.

BENEFITS

The diagram in this section shows a sampling of important benefits that urban farming can provide to people.



Pluvial flood risk reduction: Urban farming changes the ratio between paved and unpaved surface in the city reducing the amount of stormwater runoff that ends up in storm drains. During heavy storms, that means protecting urban rivers from untreated runoff. Open-soil farming stores and infiltrates rainwater, as its rich organic soils act as sponges, soaking up rainwater (Aerts et al. 2016).

Resources production: Provision of food, in particular vegetable crops, fruit, spices, and poultry, is the primary benefit of urban farming (Aerts et al. 2016).

Carbon storage and sequestration: The carbon sequestration potential of urban agriculture is largely dependent on the degree to which trees are combined within the agricultural landscape. While removal potential varies considerably, average biomass accumulation for agroforestry is estimated between those of planted forests and naturally regenerated forests (10.8–15.6 tons CO_2 per ha per year for the first 20 years of growth), which could be expected given agroforestry activities typically involve lower planting densities. Removal factors after 20 years, however, are very low, with growth rates in the 20–60-year period below 0.1 tons CO_2 per ha per year (Bernal et al. 2018). Empirical studies investigating the potential of urban agriculture found that food grown in cities can reduce greenhouse gas emissions in different ways, for instance by reducing food mileage (Lee et al. 2015), growing vegetables in residential gardens (Cleveland et al. 2017) or using soilless crops (Llorach-Massana et al 2017).

Stimulate local economies and job creation: Urban farming can be an important part of local economies. An urban farm can become a source of additional nutrition from fresh produce, vegetables, and fruit and a decent source of protein from fish and other products of aquaculture. In some places farms can contribute to food security and create job opportunities (Agbonlahor et al. 2007).

Human health: Farming improves social wellbeing and nutritional health (Hallett et al. 2016) and has a wide range of physiological and psychological benefits.

Education: Urban agriculture creates a better understanding of the value and the meaning of food, which provides opportunities to educate children. Participation in farming helps children learn and gain better understanding of the natural environment, while adults can gain new skills, such as learning about nutritional values of crops they grow (Smit 1996).

Social interaction: Localized agriculture has a very high value of social land use. Community initiatives in urban farming have proven successful to empower social cohesion between different generations and groups, as urban farming can build stronger communities and create a spirit of cooperation. Such communal farming can foster social support networks that are proven to be essential to human wellbeing. Consequently, urban farms create better neighborhoods, with less crime and vandalism (Ober Allen et al. 2008; Bradley and Galt 2014). Farms become community centers where also other social development strategies can be developed (Teig et al. 2009, Smit 1996).

SUITABILITY CONSIDERATIONS

ENVIRONMENTAL

Location and climate: Urban farming can be implemented in urban environments where climate is appropriate for outdoor agriculture. Warmer temperatures and elevated levels of carbon dioxide in urban environments have the potential to extend the growing season and improve crop productivity (Hallet et al. 2016; Wagstaff and Wortman 2015). In dry climates, urban farming considerations should include the evaluation of water requirements, with preferences identified for crops tolerant to arid conditions or requiring limited water use.

Hydrology: Access to water is critical for urban farming. For individual low-income farmers, an irrigation system can be a major expense (Dumitrescu 2013). The use of potable water for irrigation is highly controversial, and in many places very costly. Rainwater is the best alternative, particularly if its quality can be monitored. Rainwater can be captured from precipitation and reused for irrigation when needed. Storage containers can be designed to purify the water too. Raised bed agriculture is a good way to optimize the quantity of water needed and create ideal moisture conditions for the crops. Alluvial plains often offered suitable moisture conditions and soils for urban agriculture.

Soil: Urban farming requires soil preparation to provide good conditions for plant growth. Soils must have the right mineral content, compacted soils must be tilled to improve aeration and drainage, and organic content must be augmented to provide fair nutrition to the plants and ensure water retention. Alluvial soils are highly suitable for agriculture. Sandy urban soils are unsuitable for agriculture production unless soil enrichment is performed.

Contamination: Contamination is a major issue in urban farming. Soil, water, and air pollution in cities can affect crop production, and worker and consumer safety (Agrawal et al. 2003; Mapanda et al. 2005). Avoiding cultivation in these contexts is an option to mitigate the risk of contamination, especially in former industrial areas or nearby factories (Pandey and Pandey 2009), on lands irrigated with water, or on soil contaminated industrial or mining wastes (Mapanda et al. 2005).

TECHNICAL

Dimensions: Small plots for urban farming generally range between 0.01–3 hectares (Zeunert and Waterman 2018; Kaufman and Bailkey 2000). Usually, farms smaller than 1 hectare are organized by individuals or small cooperatives; commercial farms generally require much more space. Production capacity is dependent on the type of crops and local conditions. Bed dimensions are based on how far a person, tending to the plants, can reach—so beds are usually about 1 to 1.2 meters wide by 2 to 2.5 meters long (Dumitrescu 2013).

Crop type: Urban farming includes vegetable and fruit tree cultivation, as well as other specialized crops (e.g., medicinal and ornamentals), wood production, small-scale animal husbandry, beekeeping, and aquaculture consisting of combined fish and plant culture (Orsini et al. 2013).

Accessibility: Generally, farmers need to access markets for trade and to sell their goods (Thapa and Murayama 2008). Urban farms producing enough surplus typically benefit from proximity to markets. This minimizes transportation costs, keeps produce in top condition, maximizes economic benefits for the producer and delivers optimal nutritional content to the consumers (Thapa and Murayama 2008). In addition, areas for urban farming require easy accessibility to roads for transportation and logistics operations.

URBAN

Land use: Urban farming often exploits unused resources in the city—wastewater, solid waste, vacant lots, bodies of water, slopes, and rooftops. It puts idle land to productive use, maintains the land in good condition and generates income from temporarily available land. It is also compatible with open space, parks, sports, universities, roadsides, and floodplains (Smit et al. 1996).

Urban density: Suitable urban density for urban farming ranges from low to medium.

Area: Small to medium. Urban farming is a nature-based solution typically planned and designed for application at a neighborhood, district or city scale.

Integrated urban planning: Urban farming can be an integral component of the transformation of underused spaces, multifunctional green areas, and food programs.

COSTS

COST CONSIDERATIONS

Land

Access to or ownership of land is required for urban farming.

Land on which urban farms may be located may be public or private.

Land area required for urban farms may range from small areas for community gardens to larger agricultural operations either within or adjacent to urban areas.

Example land-related costs:

- Acquisition costs
- Land use (e.g., payments to landowners) costs
- Land protection costs, including managing and controlling access.

Construction and implementation

Costs of urban farming vary by location, labor and land costs; whether land must be acquired or secured for use to develop an urban farm; and the extent of site preparation needed, such as enclosures or others.

Maintenance

Maintenance costs of urban farming include traditional farming activities over a growing season, including weeding, fertilizing, watering, and harvesting.

UNIT COST EXAMPLES THROUGHOUT THE GLOBE

- *Urban farming costs in the U.S. is estimated at* ***US$46.71/m²/year (US$467,100/ha/year),*** *including personnel, location plans, environmental assessment, site preparation, growing structures, and labor for one year. The cost does not include land acquisition or the costs of remediation (USDA 2016).*

Addis Ababa, Ethiopia
Photo by Eyoel Kahssay on Unsplash

NBS IN PRACTICE

The four projects in this section highlight good practices and lessons learned in urban farming, drawn from the growing popularity of NBS throughout the globe.

Photo by Hernán García Crespo on Flickr

Preservation of cultural knowledge and agricultural heritage

Local community empowerment

Boost of local economies and tourism

Project #1: *Floating farms, ongoing*
Location: *Xochimilco, Mexico City*
Description: *Waterborne chinampa farming system—sometimes called floating gardens—is a form of ancient raised bed agriculture that continues to be successfully used by small farmers today. Chinampas are long and narrow floating garden beds separated by canals. The garden lot is built of layers of woven wetland reed mats, stacked on top of each other while alternating directions of a weave, and interlaced with mud and thick mats of decaying vegetation. The layered bed accumulates additional highly fertile fluvial sediment and makes for an exceptionally productive growth medium. The benefit of a chinampa system is that the water in the canals provides a consistent passive source of irrigation that allows for efficient and reliable agricultural practice.*

Benefits
History and Identity, Education, Economy.
Source
Mexico City, FAO, Authority of the world natural and cultural heritage zone in Xochimilco, Tlahuac, and Milpa Alta
https://www.fao.org/3/I9159EN/i9159en.pdf
https://www.fao.org/giahs/giahsaroundtheworld/designated-sites/latin-america-and-the-caribbean/chinampa-system-mexico/en/

Photo by Zeria N. Banda / World Bank

Commercialization of agriculture value chain

Partnership between agro-businesses and smallholder farmers

Coordinated investments by clusters of production

Project #2: *Agricultural Sector Wide Approach (ASWAp) 2011–15*
Location: *Lilongwe, Malawi*
Description: *Medium-scale farms have become a major force in Malawi's agricultural sector. Malawi's most recent official agricultural survey indicates that urban farms account for over a quarter of all land under cultivation in Malawi. Millions of urban Africans cultivate vegetables and fruit trees in home gardens, both for their families and for sale. Urban agriculture is playing a critical role in generating extra income for some of the more disadvantaged groups, especially low-income, female-headed households, and low-skilled populations. In Malawi, 700,000 urban residents practice home gardening to meet their food needs and earn extra income.*

Benefits
Economy, Health, Education, Social.
Source
World Bank
http://documents1.worldbank.org/curated/en/627721490623342886/text/ITM00184-P158434-03-27-2017-1490623340300.txt

Photo by Ninara on Flickr

Households largely involved in urban farming

Collaboration of local community in research surveys

Woman empowerment.

Project #3: *Kibera's vertical farms, 1980s to date*
Location: *Kibera, Nairobi, Kenya*
Description: *Urban agriculture in Nairobi is practiced in backyard farms, on open spaces under power lines, along roadsides, railway lines and riverbanks as well as on institutional land. In the mid 1980s, when the urban population reached one million mark, 20% of Nairobi households were growing crops and 17% kept livestock within the city limits. It is estimated that 30% of households in Nairobi are involved in urban farming. Social value is created by the promotion of value-chain development and direct producer–consumer marketing. Family time and labor spent on urban agriculture depends on the size of land, intensity of the practice, and number of livestock. In the peri-urban transition areas, most labor for vegetable production is provided by women.*

Benefits
Economy, Gender Empowerment, Education.
Source
African Studies Centre, Leiden, Netherlands
http://documents1.worldbank.org/curated/en/434431468331834592/pdf/807590NWP0UDS00Box0379817B00PUBLIC0.pdf

Photo by Renzo Salvador on Unsplash

Definition of metropolitan urban agriculture program

Development of infrastructure to reuse treated water for irrigation

Boost local economy and job creation

Project #4: *Chacrita Productiva, 2011–14*
Location: *Lima, Peru*
Description: *Lima's population growth and economic development is driving unprecedented demand for a greater variety and higher quality of food. On a small scale, urban agriculture is carried out in small spaces—patios, flower pots, small public spaces—ranging from 1 m^2 to 10,000 m^2 . The crops grown in these areas are mostly used for home consumption. Only natural fertilizers are used in production.*

Benefits
Economy, Health, Education, Recreation.
Source
FAO
http://www.fao.org/ag/agp/greenercities/en/ggclac/lima.html

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BIORETENTION AREAS

Menomonee Valley, Milwaukee, WI, USA
Photo by Aaron Volkening on Flickr

FACTS AND FIGURES

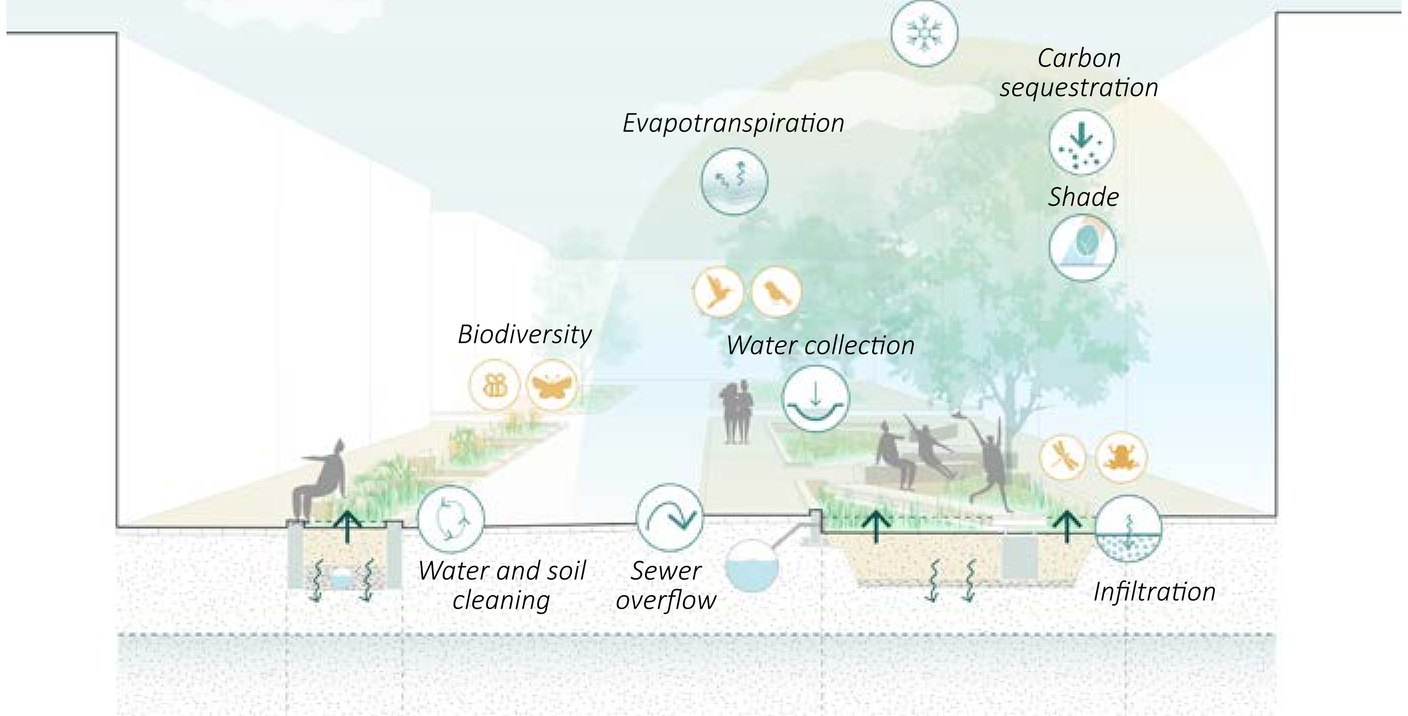
DESCRIPTION

Bioretention is a nature-based solution used to augment traditional gray stormwater and sewerage infrastructure. Bioretention areas are typically designed as shallow vegetated depressions that can intercept, infiltrate, divert, change volume and velocity, and treat stormwater flow. The type of soils, the depth of the landform, and the type of vegetation determine the efficiency and treatment capacity of a bioretention area. Bioretention areas can be particularly valuable in older cities with combined sewerage systems or with limited extent of pervious surfaces and a large volume of contaminated runoff. Well-designed, installed, and maintained bioretention areas can add measurable capacity to stormwater management systems. Correctly selected plants remove pollutants from stormwater and facilitate water table and aquifer recharge.

Bioretention areas can be adapted to a variety of urban environments. It can take many forms and shapes for different functions and contexts. Bioretention basins, vegetated swales, rain gardens, retention ponds, infiltration trenches, and detention ponds are some examples of bioretention systems. Depending on the stormwater volume to be collected, a water retention area can be either dry or wet. When bioretention systems are systematically planned and implemented, they can add to the richness of urban green infrastructure, enhance biodiversity, and deliver aesthetic, recreational, educational, and quality of life benefits.

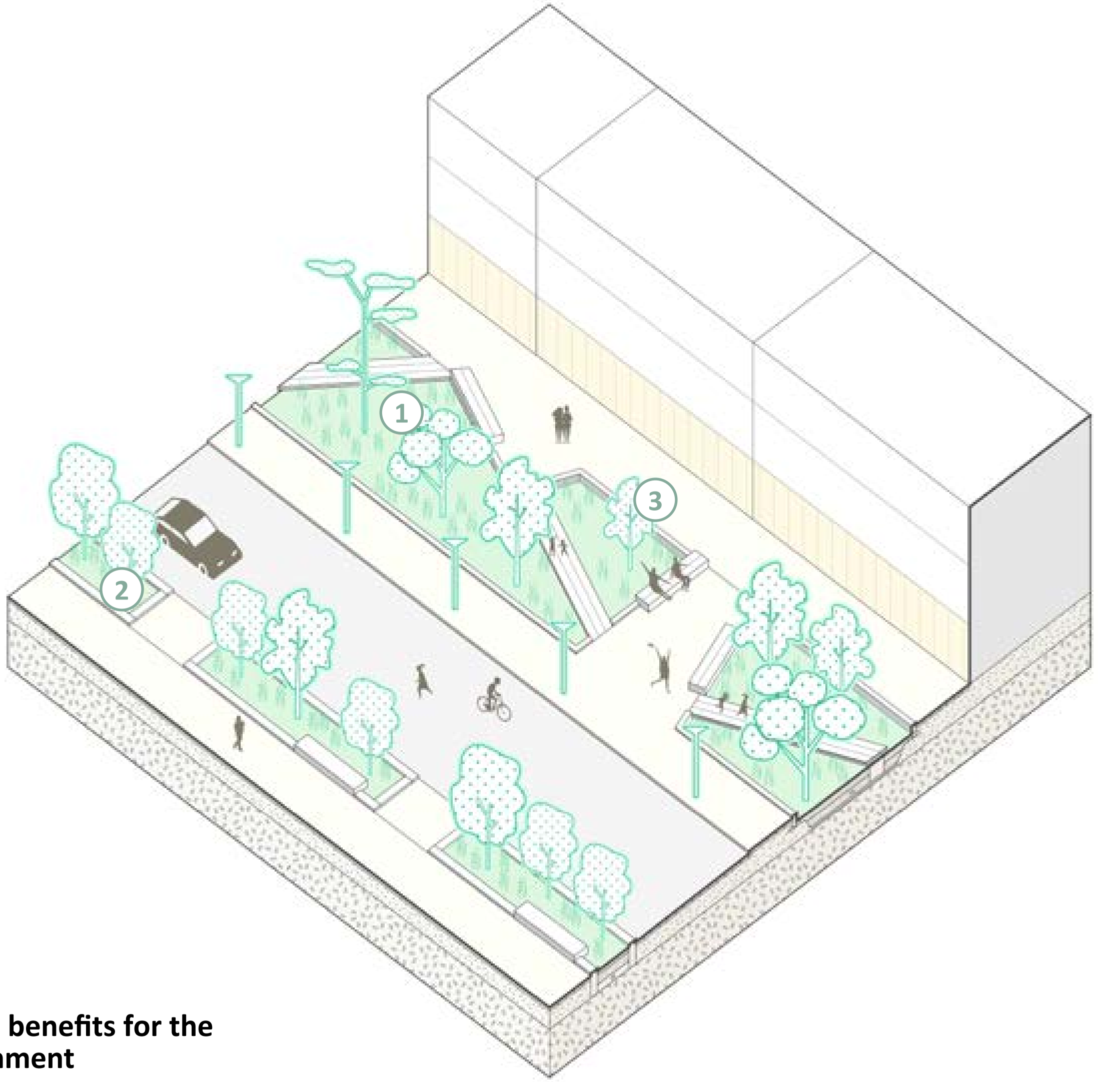
TYPE OF CITY	SCALE	APPROACH
Coastal, Delta, River, Mountain	Neighborhood, City, River basin	**Rehabilitate, Restore, Enhance** Upgrade of existing roadside drainage Installation of green strips along streets and public spaces. **Create** Construct new bioretention areas.

PROCESSES



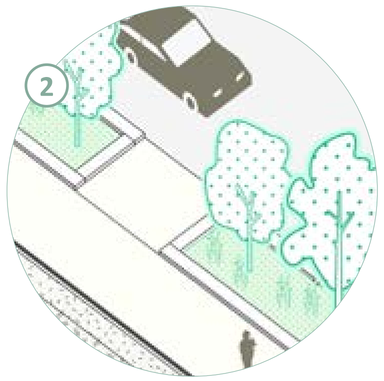
VISUALIZATIONS

VISUALIZATION OF BIORETENTION AREAS IN THE URBAN CONTEXT



Details of increased benefits for the urban living environment

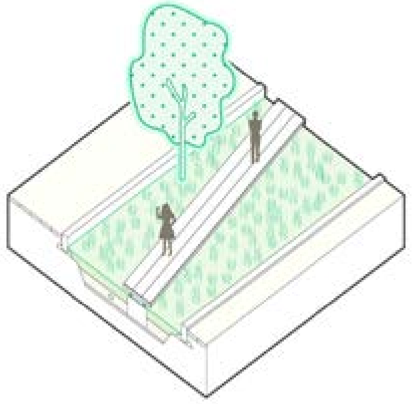
Bioretention areas create natural and ecological spaces for local residents to recreate.



Introduction of bioretention areas into streetscape reduces the dominance of cars and gray infrastructure, bringing nature into public spaces.

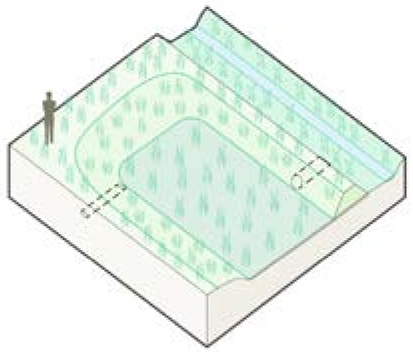
Linear bioretention areas improve the transition between public and private spaces in cities.

SPECIAL TECHNIQUES FOR BIORETENTION AREAS



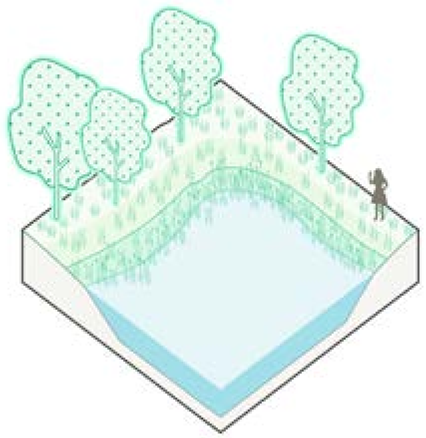
Bioswales and rain gardens

Bioswales and rain gardens are shallow, densely vegetated ground depressions, with a variety of trees, shrubs, and grasses to collect stormwater from adjacent impervious surfaces. During storms, they become flooded and facilitate ground infiltration and cleaning of stormwater simultaneously (EPA 2006). During dry seasons, swales and rain gardens contribute to the quality of public areas. Bioswales are common in streets and other linear infrastructure; rain gardens are common in parks, squares, and private gardens.



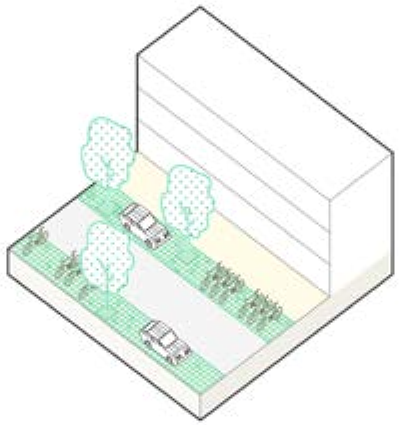
Detention pond

Detention ponds are deeper and less biologically diverse bioretention areas than bioswales and rain gardens. Bioretention systems capture and temporally store stormwater during periods of heavy rain (Eisenberg and Polcher 2020). Detention ponds can be completely filled up with water during storms; they infiltrate much of it into the ground; and discharge the overflow into the sewer system. The remainder of the time they remain dry. Detention ponds can provide attractive scenic elements in public areas, around playgrounds and sport fields.



Retention pond

Retention ponds are bioretention areas characterized by a permanent body of water and vegetated edges. Unlike detention ponds, they are permanently filled with water. Retention ponds collect stormwater from the surrounding areas; add storage capacity and ease the pressure on the surface water treatment and sewerage systems. Retention ponds offer the added benefit of storing water for further reuse during drought conditions, while simultaneously providing habitat and enriching the diversity of public green spaces (Iwaszuk et al. 2019).

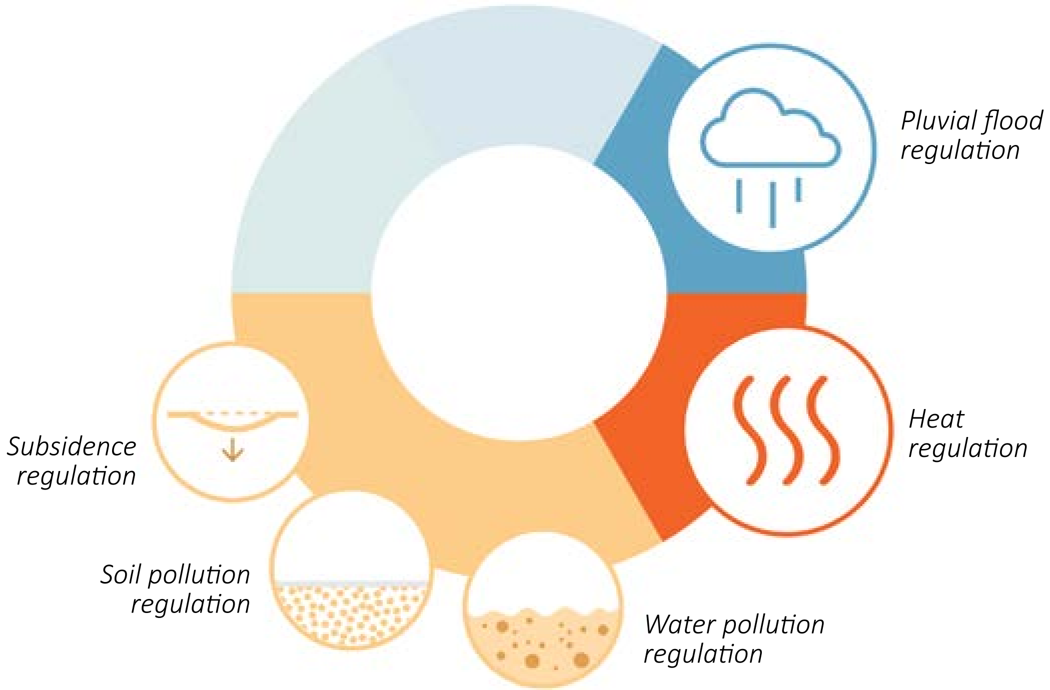


Permeable pavements

Permeable pavements are alternatives to traditional pavements, such as pervious asphalt, pervious concrete, interlocking pavers, and plastic grid pavers, and are especially effective during less intense storms (LIDC 2007) for reducing surface runoff. They infiltrate, treat, and store rainwater and reduce runoff by allowing rain and snowmelt to seep to underlying layers. They generally consist of a surface pavement layer, an underlying stone aggregate reservoir layer, and a filter layer or fabric installed at the bottom. Permeable pavements can be used at commercial, institutional, and residential sites in spaces that are traditionally impervious, such as pedestrian walkways, driveways, bike lanes, parking lots, and low-volume roadways. They are unsuitable for high-volume or high-speed roadways and avoided at spill sites as they clog the pavement (WRI and WBG 2019).

FUNCTIONS

The diagram in this section shows relevant functions of bioretention areas.



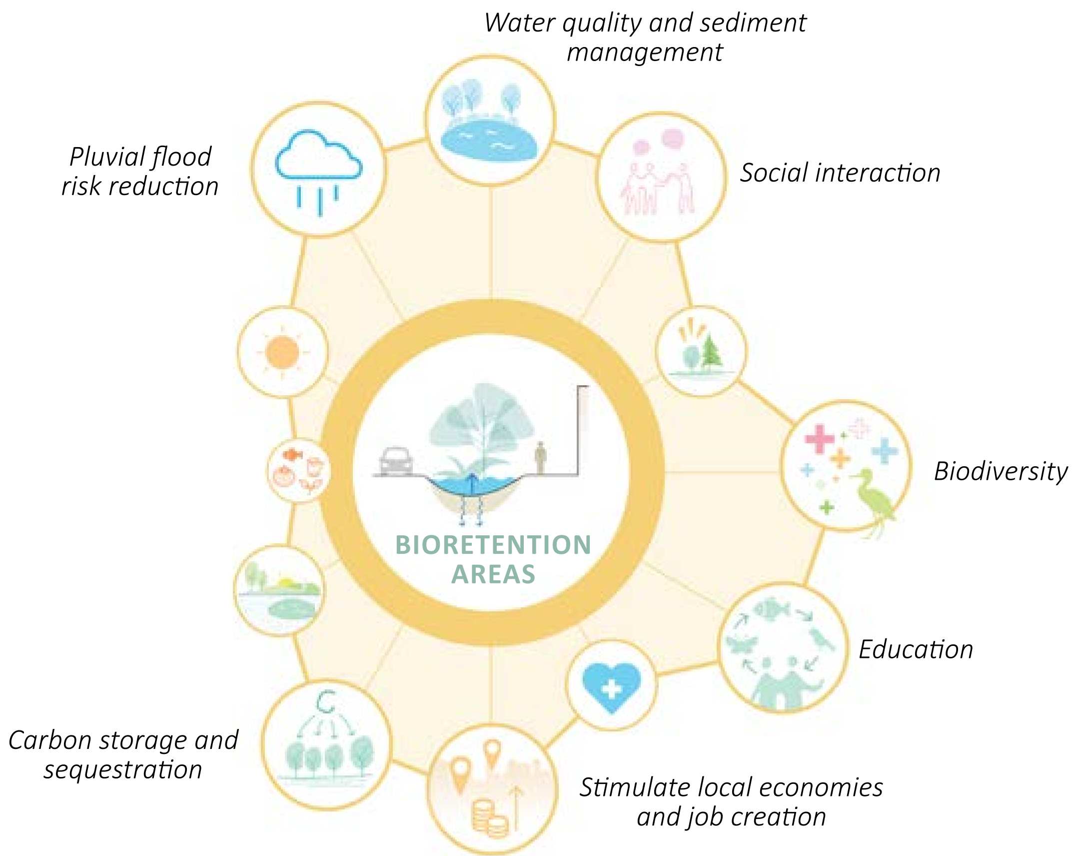
Pluvial flood regulation: Bioretention areas reduce pluvial flooding and mitigate peak water loads on the sewerage and stormwater systems by collecting, infiltrating, and storing stormwater. Literature acknowledges that the effectiveness of bioretention NBS greatly depends on their design and the frequency and the magnitude of rainfall, and on their ability to increase storage capacity using existing open spaces (Ruangpan et al. 2020). Rain gardens are more effective in dealing with small discharge of rainwater (Ishimatsu et al. 2017), while bioswales are better suited for flood reduction during heavier and shorter rainfall (Zölch et al. 2017). Several studies of bioretention basins in the city of Calgary, Canada, demonstrated up to 90% reduction of runoff volume (Khan et al. 2013), and peak flow reduction of up to 41.65% in Hai He Basin, China, (Huang et al. 2014).

Heat regulation: Bioretention areas reduce heat by lowering surface and air temperatures through vegetative evapotranspiration.

Other functions: Bioretention areas are effective in removing pollutants from water and soil (Kennen and Kirkwood 2015). They can remove organic pollutants, nitrogen contamination and heavy metals from stormwater (LIDC 2007). Water reabsorbed by the ground also helps stabilize and prevent soil subsidence.

BENEFITS

The diagram in this section shows a sampling of important benefits that bioretention areas can provide to people.



Pluvial flood risk reduction: Bioretention systems are generally designed to reduce pluvial floods by slowing and attenuating stormwater. These systems are typically designed to address stormwater locally at the source and therefore, generally serving only a small catchment area. A suite of these small-scale interventions applied throughout the catchment however contribute to reducing the effects of larger floods in downstream areas.

Carbon storage and sequestration: Depending on the design, the materials and the species used, bioretention areas sequester and store carbon. According to an estimate by the European Commission, the average carbon sequestration rate is 12.5 kg carbon/m^2 (EC 2020b).

Stimulate local economies and job creation: Bioretention areas improve the image and market value of real estate and improve economic development opportunities. Bioretention areas can generate green jobs and increase productivity among employees in locations with access to these areas (Kim and Song 2019).

Education: Bioretention areas increase recreational and educational opportunities, by raising awareness of environmental issues and providing opportunities for interacting with nature in an urban environment (Kim and Song 2019).

Biodiversity: Bioretention areas provide important habitats; support biodiversity by improving ecological connectivity, providing food and pollination, preserving terrestrial and semiaquatic habitats, and linking the urban environment to the surrounding countryside (Kim and Song 2019).

Social interaction: Bioretention areas provide benefits to improve quality of life. They also create opportunities for recreation in public spaces and create informal social gathering spaces (Kim and Song 2019). These systems can be used to engage the public in their planning and maintenance to build stronger community cohesion. Designs can combine bioretention areas with traffic control and regulation measures, which can improve the safety and spontaneous use of public spaces.

Water quality and sediment management: Bioretention areas are typically designed to capture and treat the first flush of stormwater runoff–the initial wave of runoff that carries the highest amount of pollutants. While effectiveness varies, some bioretention areas have been shown to remove up to 90% of heavy metals from stormwater, organic pollutants, and nitrogen contamination (Kennen and Kirkwood 2015).

SUITABILITY CONSIDERATIONS

ENVIRONMENTAL

Location and climate: A bioretention area is considered an on-site stormwater management solution. Its design should factor in the major differences between temperate countries and tropics, including variations in the amount and pattern of rainfall and stormwater runoff, nutrients concentration, and land use (Goh et al. 2019).

Hydrology: Understanding hydrological conditions is critical to the design of bioretention areas. Bioretention areas should always remain above the water table to ensure that groundwater does not intersect the filter bed and reduce infiltration capacity. Unless an impermeable liner is installed, a distance of at least 0.6 meters should be maintained between the bottom of the excavated bioretention area and the seasonally high ground water table (DDOE 2012).

Soil: Soil for bioretention areas typically include mixed soils or engineered media. High infiltration rates of the media are key. To ensure drainage capacities, well-draining soils are often considered during the design. The underlying soils typically have low infiltration rates and as such, underdrains can be part of the design (DDOE 2012; MSW 2018).

Water quality: Depending on the type of soil and plants, bioretention areas can effectively collect polluted stormwater runoff by removing, trapping, and degrading organic contaminants, converting nitrogen contaminants into gas and returning them to the atmosphere, capturing and immobilizing inorganic contaminants (Kennen and Kirkwood 2015).

TECHNICAL

Slope: Bioretention areas perform the best with contributing slopes greater than 1% but less than 5% (DDOE 2012).

Substrate: The substrate should comprise a loamy soil capable of providing infiltration and supporting a healthy vegetative cover. The soil can be improved with composted organic material. A secondary filtration layer, composed of sand, gravel, or similar drainage material, is often placed below the substrate to enhance the infiltration and water cleaning process (DEP 2006).

Dimensions: Bioretention surface area should be sized at approximately 3% to 6% of the contributing drainage area depending on the extent of impervious surfaces. The depth of the pond depends on the amount of stormwater to be treated. Bioretention areas work best with small contributing drainage areas that facilitate an even distribution of stormwater flow over the filter bed (DDOE 2012).

Planting and growing strategy: Selection of appropriate plant species is essential for the effective functioning of the bioretention areas. Native floodplain species tolerant of variability in soil saturation and inundation and resilient to environmental stress are often best suited to the variable environmental conditions. However, consideration must also be given to changes in plants and soils, which may vary from areas of regular inundation to areas that are seldom saturated.

Hybrid infrastructure: Bioretention areas can be effectively combined and connected with sewer systems through an overflow outlet or through underdrains that connect to the sewer system. By attenuating runoff, bioretention areas relieve the pressure of runoff and contribute to storm water management—integrating green and gray.

URBAN

Land use: Residential, commercial, and industrial streets and infrastructure networks, urban parks of various types, squares, gardens, parking areas, and private gardens are all suitable land uses for bioretention areas.

Urban density: Suitable urban density for bioretention areas ranges from low to medium.

Area: Small to medium. Bioretention areas are nature-based solutions typically designed for application at a neighborhood or district scale.

Integrated urban planning: Bioretention areas can be implemented as part of a street renewal, sewerage system upgrade and capacity expansion, local green initiatives, and stormwater drainage installation for new development areas.

MAINTENANCE

Bioretention systems require intensive and regular maintenance to avoid clogging with sediments. The basins should be inspected monthly to identify further maintenance requirements; litter and plant debris should be removed, and eroded areas should be restored (Iwaszuk et al. 2019).

COSTS

COST CONSIDERATIONS

Land

Access to or ownership of land is required for bioretention areas.

Land on which bioretention areas may be located may be public or private.

Land area required for bioretention areas will vary from smaller to larger areas, raising transaction costs if engagement and collaboration with multiple landowners and stakeholders is necessary.

Example land-related costs:

- Acquisition costs
- Land use (e.g., payments to landowners) costs
- Land protection costs, including managing and controlling access

Construction and implementation

Costs of bioretention areas are a function of the type of bioretention solution installed, the complexity of installation, initial site conditions and characteristics, and labor and material costs. Potential bioretention solutions range from low-cost investments (e.g., detention ponds) to more expensive bioretention solutions (e.g., bioretention basins).

Maintenance

Maintenance costs of bioretention areas are also a function of the type and complexity of bioretention solution installed, the types of trees and vegetation planted, and local climatic conditions. Maintenance activities may include debris removal, weeding, and pruning.

UNIT COST EXAMPLES THROUGHOUT THE GLOBE

Construction and implementation

- *Detention ponds*: ***US$60/$m^2$ (US$600,000/ha)***.
- *Infiltration trenches*: ***US$74/$m^2$ (US$740,000/ha)***.
- *Vegetated bioswales*: ***US$371/$m^2$ (US$3,710,000/ha)***.
- *Public rain gardens*: ***US$501/$m^2$ (US$5,010,000/ha)***.
- *Bioretention basin*: ***US$534/$m^2$ (US$5,340,000/ha)*** *(Costs estimated from global sources in Ruangpan et al. 2020).*

Maintenance

- *Annual operation and maintenance costs as a percentage of construction costs range from* ***0.5 – 10%*** *for all sustainable drainage systems (SUDS) components, including bioretention, in a United Kingdom study, or an annual cost range in the range of* ***US$0.1–US$2/m^2/year (US$1,000–US$20,000/ha/year)*** *(FCERM and EA 2021).*
- *Detention basin*: ***US$0.14–US$0.40/m^2 (US$1,400–US$4,000/ha)*** *of detention basin area annually;* ***US$345–US$1,379*** *per basin* ***(US$3,450,000–US$13,790,000/ha)*** *(cost from the UK).*
- *Infiltration trenches*: ***US$0.3–US$1.4/m^2 (US$3,000–US$14,000/ha)*** *of filter surface area annually (cost from the UK).*
- *Infiltration basin*: ***US$0.14–US$0.41/m^2 (US$1,400–US$1,400/ha)*** *of basin area annually (cost from the UK) (FCERM and EA 2021).*

Milwaukee, WI, USA
Photo by Aaron Volkening on Unsplash

NBS IN PRACTICE

The four projects in this section highlight good practices and lessons learned in bioretention areas, drawn from the growing experience in implementing NBS throughout the globe.

Photo by Google Earth

Showcase for climate-proof public space

Integrated in neighborhood renewal program

Participatory process with local communities

Project #1: *St. Kjeld's neighbourhood: Tåsinge Plads, 2013–15*
Location: *Copenhagen, Denmark*
Description: *The bioretention project is part of 'The Climate Neighborhood' project, in the St. Kjeld's neighborhood, launched as a neighborhood renewal program. The bioretention area was sloped to collect rainwater at the bottom, where it seeps into the ground instead of being directed to the drains. Water from the streets collects in waterbeds, which are filled with mould that filters the water. This climate adaption creates capacity in the drains to prevent flooding. The entire St. Kjeld's neighborhood is a showcase for ground-breaking climate adaptation solutions.*

Benefits
Health, Flood and Heat Stress Risk Reduction.
Source
City of Copenhagen, HOFOR, GHB Landskabsarkitekter
https://urban-waters.org/sites/default/files/uploads/docs/tasinge_plads.pdf

Photo by Carlos Felipe Pardo on Flickr

Integrated in a comprehensive task of city recovery

Provision of institutional capacity and urban services

External funding

Project #2: *Dar es Salaam Metropolitan Development Project, 2015–22*
Location: *Dar es Salaam, Tanzania*
Description: *The City of Dar es Salaam has undergone a period of unprecedented urbanization, contributing to the degradation of the natural environment. With a growth rate near or above 5% for the past three decades, Dar es Salaam is the fastest growing city in East Africa. The development objective of the Dar es Salaam Metropolitan Development Project is to improve urban services and institutional capacity in the metropolitan area, and to facilitate potential emergency response. The project comprises infrastructure improvements and constructions of primary and secondary drainage systems—including bank stabilization detention ponds—and connection to a secondary network around five river basins.*

Benefits
Health, Economy, Flood and Heat Stress Risk Reduction.
Source
World Bank
https://projects.worldbank.org/en/projects-operations/project-detail/P123134

Photo by Chris Hamby On Flickr

Integrated in sewerage system expansion

Infrastructure renewal and traffic calming strategy

Participatory process with local communities

Project #3: *Street Edge Alternatives (SEA Streets) Completed Spring 2001*
Location: *Seattle, USA*
Description: *The Street Edge Alternatives (SEA Streets) project introduced bioretention, along a typical curbless neighborhood street with informal drainage infrastructure and traffic calming. The project created a sense of place and community in the neighborhood. The project helps local residents understand their own role and contribution to managing stormwater and environmental impacts. The addition of a sidewalk that separates pedestrians from traffic increased the feeling of safety. As a result of this project, many community members have become stewards in efforts to improve water quality and stream health in Pipers Creek. SEA Street has created environmental awareness and community action.*

Benefits
Health, Education, Flood and Heat Stress Risk Reduction.
Source
Seattle Public Utilities, Seattle Department of Transportation
https://nacto.org/case-study/street-edge-alternatives-sea-street-pilot-seattle/

Photo by Ricardo Cardim / CARDIM Arquitetura Paisagística

Showcase for climate adaptation

Community and local stakeholder involvement

Funded by local resident

Project #4: *Araucárias Square: Rain Garden and Pocket Forest, 2017–18*
Location: *Sao Paulo, Brasil*
Description: *This is the first rain garden implemented in a Brazilian city in 2017 with the active involvement of residents. The garden collects runoff across a surface of 900 m² that would otherwise go directly into the drainage system, and which used to flood lower areas of the city. After its implementation, the vegetation thrived and runoff has been reduced. Residents and leaders of the grassroots movements actively participated to transform this remnant derelict piece of land. Social media was also used to invite and motivate other volunteers in the collective efforts to plant pocket forests in small plots of land. This social experience, with people of all ages coming from various districts to actively contribute to nature's reconstruction in the park, has also led to private funding contributions to maintain and protect the new pocket park.*
Benefits
Community, Education, Identity, Flood and Heat Stress Risk Reduction.
Source
CARDIM Arquitetura Paisagística
https://oppla.eu/casestudy/20079
http://www.cardimpaisagismo.com.br/portfolio/largo-das-araucarias/

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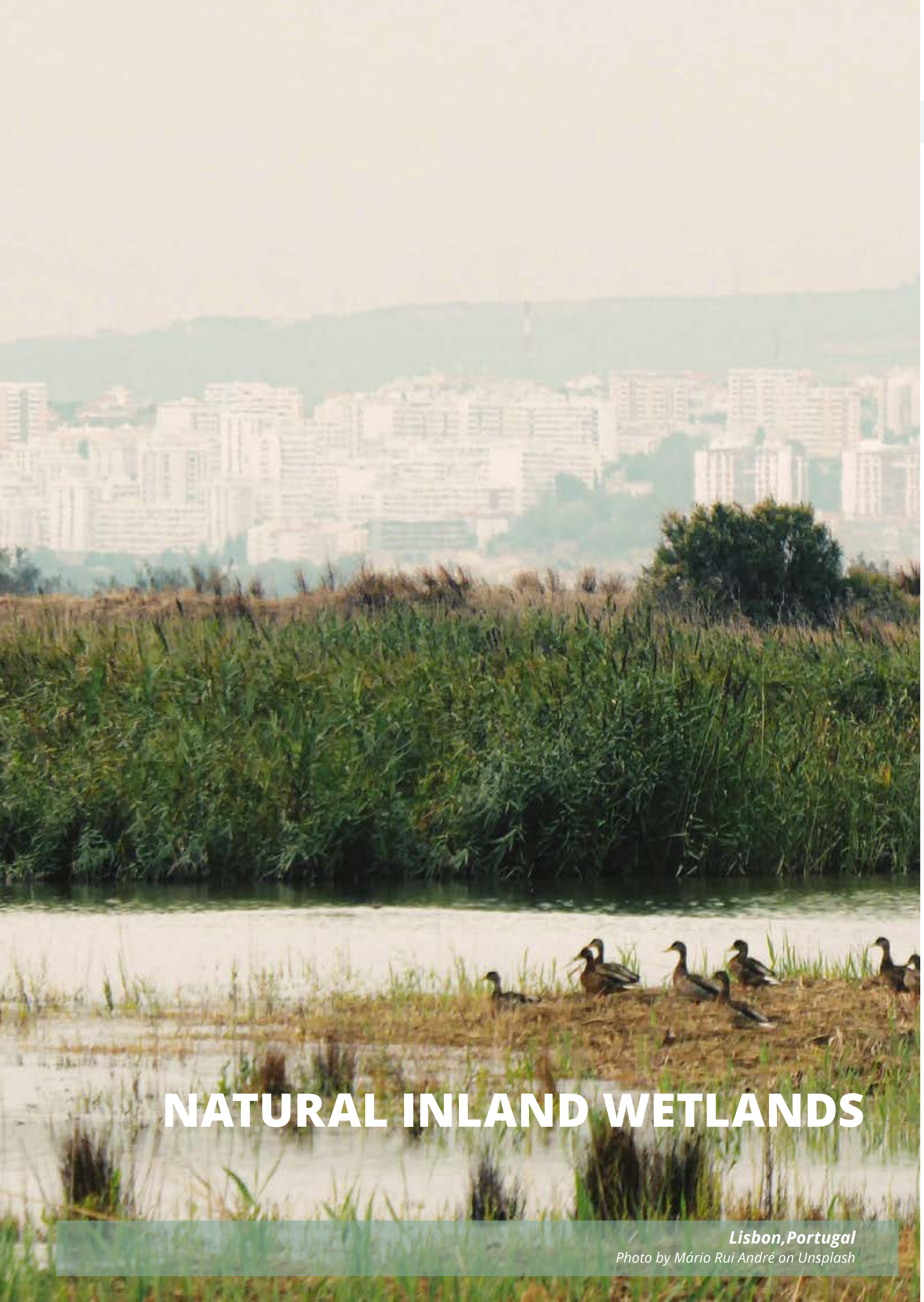
Minneapolis, MN, USA
Photo by Minneapolis Public Works TPP on Flickr



FACTS AND FIGURES

DESCRIPTION

Natural inland wetlands are highly biodiverse, productive ecosystems that form an interface of land and water, and deliver valuable ecosystem services. Historically, their value has been largely misunderstood leading to their destruction in many parts of the world. In recent decades however, cultural attitudes toward wetlands have changed as their ability to protect cities from floods gained recognition. For a long time perceived as wastelands and prime areas for urban infill projects, natural inlands wetlands are now increasingly recognized as critical environmental infrastructure that can contribute to address climate change effects in cities.

Wetlands sequester carbon, and in some cultures, their plants are harvested for building materials and food. They work as a natural sponge against flooding and drought and help offset climate change. Natural inland wetlands are frequently or continuously inundated by water. They are also home to a special type of wet feet-tolerant plants and the vegetation has adapted to saturated soil conditions that filter, remove sediment, nutrients, and pollutants from water. These wetlands also provide habitat for wildlife, fish, other aquatic, threatened, and endangered species. They are an extraordinary scenic and recreational asset, increase biodiversity, and provide opportunities for birdwatching and hiking in nature.

Successful natural inland wetland restoration projects are delivering tangible climate adaptation benefits, and many cities have granted them protection status, and initiated rehabilitation efforts. There is a great diversity of wetland types worldwide that range in character from wet meadows, marshes, and vegetated floodplains.

TYPE OF CITY

Coastal · Delta · River · Mountain

SCALE

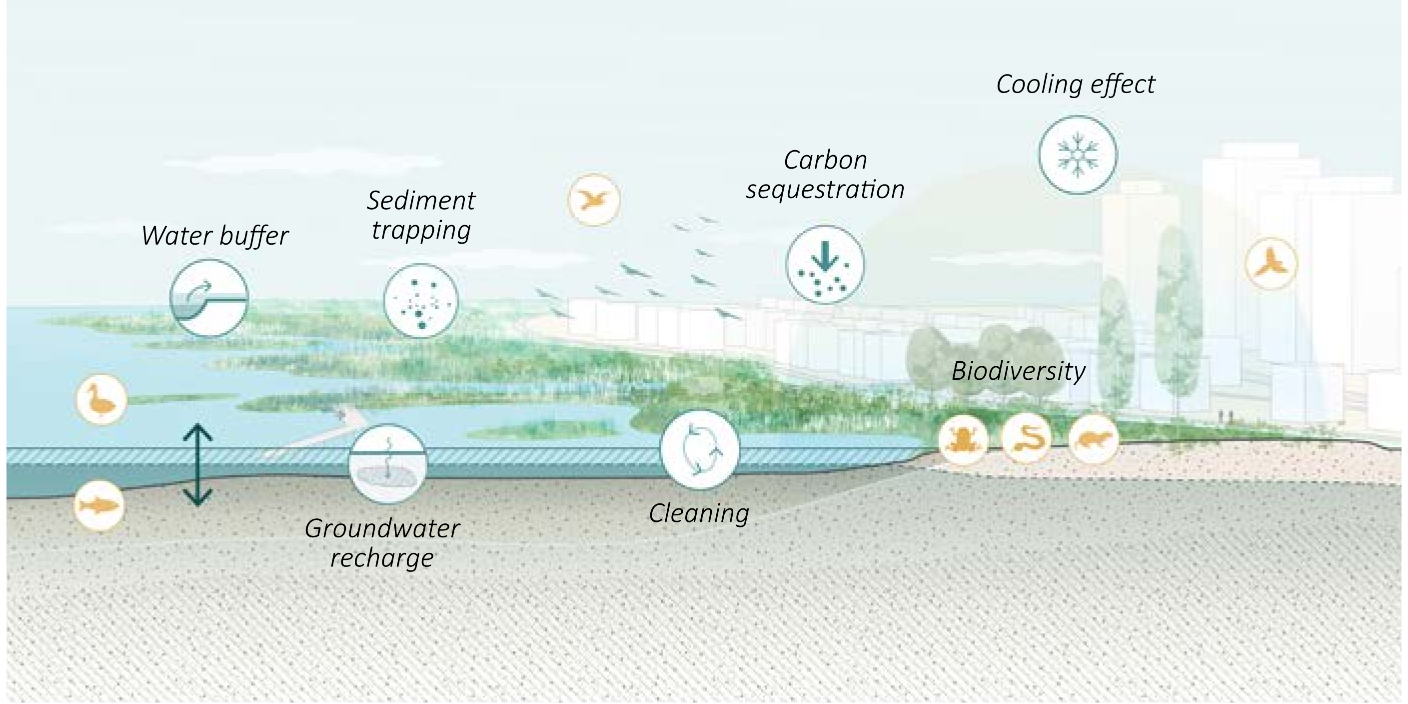
Neighborhood · City · River basin

APPROACH

Protect
Protect and preserve existing natural inland wetlands and their hydrological processes.

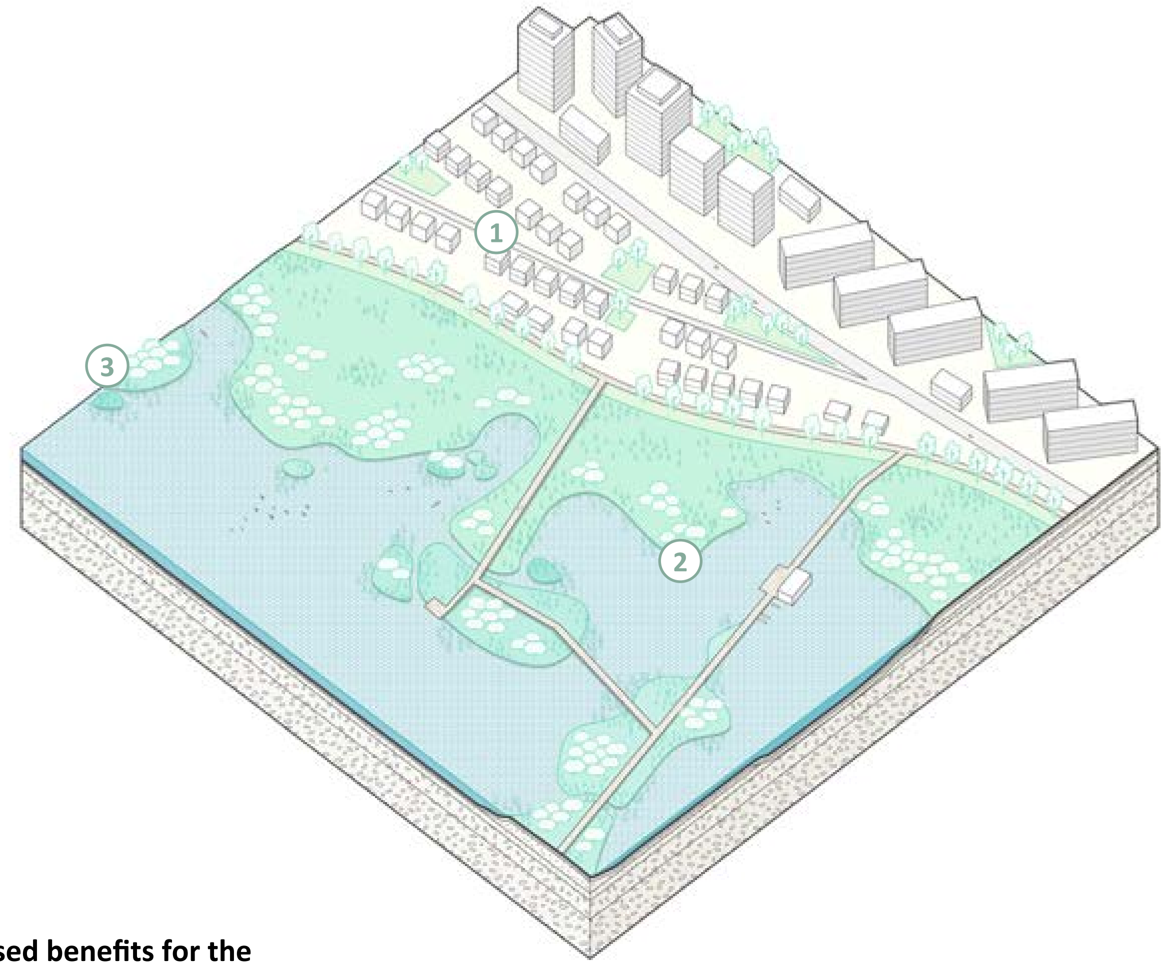
Rehabilitate, Restore, Enhance
Rehabilitate existing wetlands and restore or enhance their natural functions so they can deliver ecosystem services.

PROCESSES

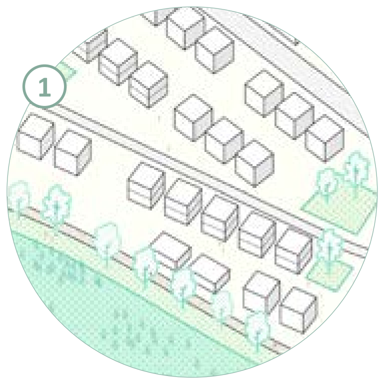


VISUALIZATIONS

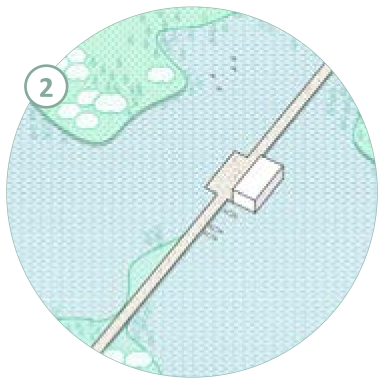
VISUALIZATION OF NATURAL INLAND WETLANDS IN THE URBAN CONTEXT



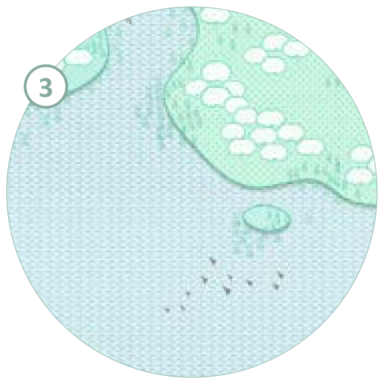
Details of increased benefits for the urban living environment



Wetlands form an interface between land and water. They are a part of both the aquatic and the terrestrial ecosystem and function as a two-way buffer, mitigating storms and assimilating pollutants.

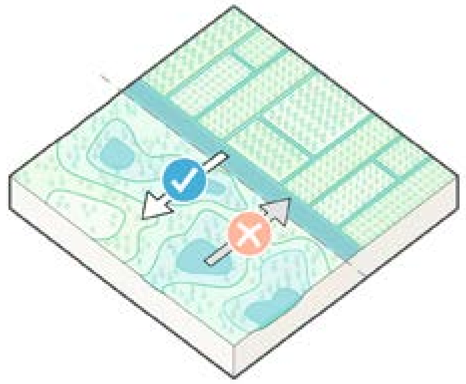


Natural wetlands provide excellent opportunities for communities to connect with nature and learn about the broad suite of values that nature-based solutions provide, especially when trails and educational facilities are integrated.



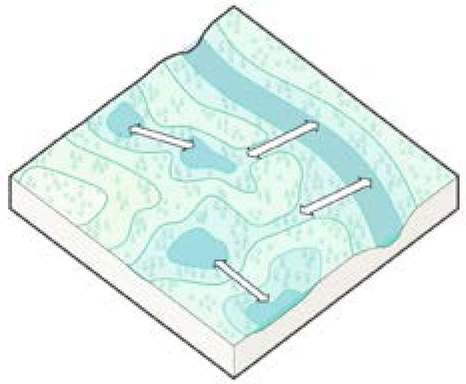
A combination of habitats contributes to aesthetic and biodiversity values. Open water areas offer recreational options such as kayaking and boating.

SPECIAL TECHNIQUES FOR NATURAL INLAND WETLANDS



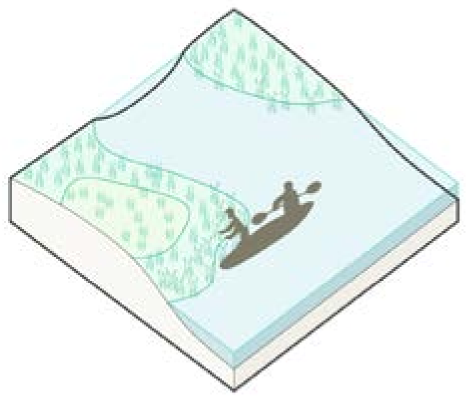
Drainage reduction

Natural inland wetland areas have been used for agriculture in many regions around the world. To make the land suitable for crops, drainage systems are installed to control the water table and provide irrigation. To reverse the destruction of the wetland, natural water fluctuation must be restored together with the composition of the anaerobic hydric soil formed over a long period. The first step is to remove a section of the underground agricultural tile that is draining the wetland basin or create a ditch plug by building an earthen wall to impound water.



Improving lateral connectivity

In many urban contexts, canals and artificial berms were built to disconnect the main water body from the floodplain and its wetland. This resulted in the disruption of wetland hydrology. Rehabilitation would require a reversal of this action and an improvement of lateral connections between the main body of water and the wetlands. Re-establishment of lateral connections will reactivate wetland areas and improve its environmental performance. It will also bring back the waterfowl and other wetland biota.

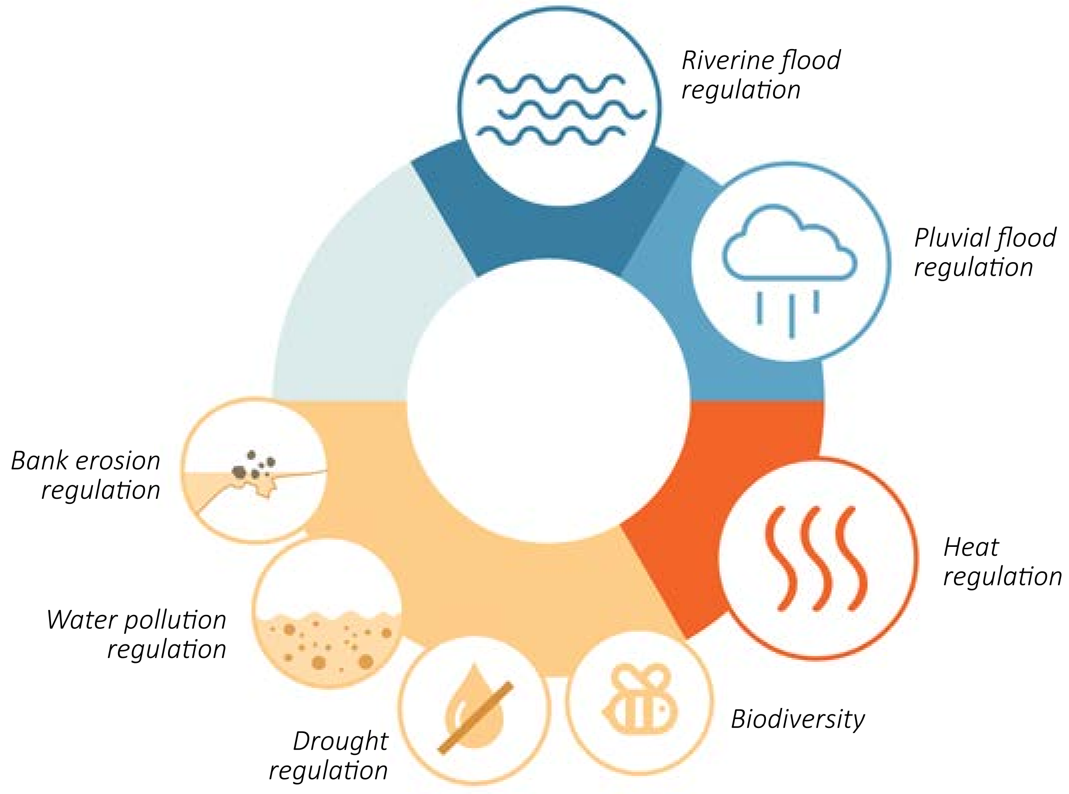


Maintenance and cleaning

The health of a natural inland wetland and its environmental performance depends on proper lateral connections, hydrological cycles, the right soils, and plants. Invasive plants can push out native species, wreak havoc in the natural wetland habitat, change flow patterns and degrade the water quality. In some instances, degradation can be offset by restoring natural hydrological conditions; however, undesired invasive plants may need to be controlled through appropriate mechanical, chemical, or biological control measures.

FUNCTIONS

The diagram in this section shows relevant functions of natural inland wetlands.



Pluvial and riverine flood regulation: Certain inland wetlands attenuate stormwater flow by spreading it evenly across their flat and wide terrain, instead of confining it to a narrow channel. This way they can hold back considerably more stormwater, while infiltrating and removing the sediment and pollution and stabilizing the water table (Ozment et al. 2019). The potential for flood attenuation varies across wetlands and is based on their size, vegetation and soil type, shape and capacity of the basin, and other factors.

Heat regulation: In highly humid conditions, the rate of wetland evapotranspiration significantly impacts local and regional climate (Roggeri 2013). Studies suggest that wetlands may have cooling effect. For example, a study conducted in Mexico City measured the effect of wetlands on temperature and recorded an incremental rise of about 2°C (35.6°F) every 35 meters as the distance from the body of water increased (Wetlands International 2020). Heat reduction can be further increased in areas with large, dense canopy trees or if the airflow can pass unobstructed across the open water areas.

Other functions: In urban environments wetlands extract pollutants from the surface water, lessen stream erosion, recharge groundwater, store stormwater, and release it during dry periods (Wood and van Halsema 2008). Natural inland wetlands mitigate the loss of biodiversity in urban environments and provide key habitats for local and migratory species.

BENEFITS

The diagram in this section shows a sampling of important benefits that natural inland wetlands can provide to people.

Pluvial and riverine flood risk reduction: Natural inland wetlands mitigate floods in urban environments and protect urban rivers by capturing, buffering, and storing stormwater (Wood and van Halsema 2008), reducing the velocity and the amount of peak stormwater flow, and preventing large quantities of untreated water from entering the water bodies (Maltby 1986).

Water quality and sediment management: The practice of using natural inland wetlands to treat wastewater and improving water quality in urban environments has been around for hundreds of years (McEldowney et al. 1993). Research on the ability of wetlands to purify water has shown that anaerobic conditions—typical of wetlands—enhance the retention of many compounds and facilitate processes such as denitrification, ammonification, and the formation of insoluble phosphorous metal complexes (Bastian and Benforado 1988). Inland wetlands also act as natural sediment traps with the slow flow of water through wetland vegetation promoting sediment deposition. Elevated rates of sediment accumulation may however lead to a tipping point where erosion leads to a loss of sediment from the system.

Biodiversity: Wetlands are one of the most productive habitats in the world, with greater species diversity, nutrient recycling, and niche specialization than most other ecosystems. Almost all the world's waterbirds and migratory birds use wetlands as feeding, migratory way-stations and breeding grounds (CBD 2015).

Resource production: In many cultures, wetlands are important sources of food and building materials. These uses need to be carefully managed so as not to undermine other ecological functions, which require balancing agricultural uses and needs of biodiversity (Wood and van Halsema 2008).

Tourism and recreation: Natural inland wetlands are some of the last remaining pieces of natural habitat in cities. As such, they offer a possibility to contemplate nature and engage in a whole range of activities such as fishing, hiking, nature observation and photography, bird watching, canoeing, and boating (Wood and van Halsema 2008). Large wetlands support important wildlife populations and offer significant tourism potential.

Carbon storage and sequestration: Wetlands are globally important carbon sinks, storing vast amounts of carbon and thereby helping to mitigate climate change. Peatlands, in particular, hold a disproportionate amount of the earth's soil carbon while inundated wetlands can potentially sequester substantial amounts of soil carbon over the long term because of slow decomposition and high primary productivity, particularly in climates with long growing seasons (Valach et al. 2021). Sequestration rates increase with vegetation cover (Valach et al. 2021) and are likely to be higher for woody than herbaceous systems. Drained or damaged wetlands on the other hand, are a major source of greenhouse gas emissions since human disturbance, particularly drainage, releases carbon in CO_2, leading in years to the loss of carbon that accumulated over centuries or millennia. The wise use and restoration of natural inland wetlands is therefore essential to protect stored carbon and reduce avoidable carbon emissions (The Ramsar Convention Secretariat, 2018).

Stimulate local economies and job creation: As wetlands have a significant tourism potential, they can stimulate the local economy, for example by creating park ranger and service jobs. Practices to harvest food and building materials have a direct economic impact on the livelihoods of local people (Chabwela and Haller 2010; Barbier et al. 1997; Van der Duim and Henkens 2007).

SUITABILITY CONSIDERATIONS

ENVIRONMENTAL

Location and climate: Natural inland wetlands have wide geographic distribution and can be found in every climate. Nearly half of the world's wetlands are found between 50°–70°N latitude in the peat-rich boreal and arctic regions where bogs and fens are abundant. More than one-third of the Earth's wetlands exist between 20°N and 30°S latitude, where forested wetlands and marshes prevail (including tropical rainforests and floodplain wetlands). The remaining 20% may be found in temperate zones (Tiner 2009).

Hydrology: Watershed dynamics and the character of the urban environment—in particular the extent of paved area—define the hydrology of natural inland wetlands in urban areas. These parameters are part of its composition (Faber-Langendoen et al. 2008):

Sources of water: Natural inland wetlands are supplied by runoff from the immediate catchment area, direct precipitation and any connected river or a lake. They may also be recharged by ground water. Water inputs in urban wetlands typically differ considerably from rural wetlands, with a reduction in low flows and an increase in the magnitude and intensity of storm events often radically altering natural water inputs.

Hydrologic connectivity: A wetland's connection to the adjacent body of water and its relationship to the rest of the green infrastructure in the city determines how the water moves in and out of the wetland. This connectivity affects the amount of sediment and pollutants to be processed by the wetland.

Upstream surface water retention: At the scale of a watershed, the amount of water that reaches a wetland depends on how much is intercepted and abstracted on the way by water storage facilities, such as reservoirs, sediment basins, retention ponds, paved and unpaved surfaces, and other factors that can reduce the volume.

Hydroperiod: The hydroperiod is the time of which a wetland is inundated by water per year. In some regions, natural inland wetlands have daily cycles governed by diurnal increases in evapotranspiration, and seasonal cycles governed by the wet season rainfall, stormwater runoff, and higher levels of water consumption during the dry season (Faber-Langendoen et al. 2008).

Soil: Natural inland wetlands are generally found in the lower areas of the watershed. Their location coincides with areas of hydric soil accumulation. Hydric soils are formed when soils are highly saturated or flooded for such a long time that the upper strata become anaerobic. These soils can then sustain water levels appropriate for wetland plants (Covington et al. 2003).

Landscape integration: While typically connected to the drainage network, the habitat value of a natural inland wetland is strongly influenced by its connection to other natural habitats. Buffer zones and green corridors that connect wetlands with the broader open space network of a city should therefore be enhanced wherever possible.

TECHNICAL

Planting and growing strategy: Wherever possible, only native plant species should be used in wetland rehabilitation projects. Plant selection should focus on the compatibility of plants and soils, the ability of plants to trap pollutants, and ability to withstand and influence the velocity of water moving through the wetland. Guidance for plant selection can be gained by visiting natural wetlands of a similar type and catchment context.

Hybrid infrastructure: When heavily degraded, gray infrastructure such as levees, low berms, diversions, grade stabilization and water control structures, can be used to restore and enhance key wetland functions. These artificial inclusions are typically necessary to prevent erosion and incision associated with increased catchment runoff. These structures, however, can be susceptible to damage during flood events, and the strengths and weaknesses of different options should be considered in the design.

URBAN

Land use: Suitable land uses for inland wetland restoration are water areas, green areas, and nature reserves.

Urban density: Suitable urban density for wetland restoration depends on the location of existing wetlands, but are generally low to medium.

Area: Medium to extra-large. Wetland protection and restoration is a nature-based solution typically implemented at city to river basin scale.

Integrated urban planning: Wetland restoration can be conducted as part of an environmental conservation program, development of green areas and public parks. Wetland restoration can also be integrated and funded as part of stormwater management upgrading.

MAINTENANCE

Natural inland wetlands are subject to encroachment, degradation, invasion by exotic species, accidental contamination, and other unforeseen circumstances. Regular monitoring and maintenance may be required to keep them healthy, maintain desirable plant communities, and remove exotic species and excessive sediment (NOAA et al. 2003). Wetlands may also require burning or mowing to maintain desirable plant communities.

COSTS

COST CONSIDERATIONS

Land

Access to or ownership of land is required for protection and restoration of natural inland wetlands.

Land on which natural inland wetlands may be located could be public or private.

The size of natural inland wetland areas will vary from smaller to larger areas, raising transaction costs if engagement and collaboration with multiple landowners and stakeholders is necessary for protection and restoration.

Example land-related costs:

- Acquisition costs
- Land use (e.g., payments to landowners) costs
- Land protection costs, including managing and controlling access

Construction and implementation

The costs of protecting and restoring or rehabilitating natural inland wetlands vary according to wetland size, hydrology, location, and condition; opportunity costs of protecting the wetland; and labor and material costs. Larger wetland areas are likely to have greater costs of protection and restoration, though economies of scale may result from larger projects.

Natural inland wetland restoration costs vary depending on the intensity of the restoration actions needed to restore hydrologic function. Actions may range from channel filling and tile drainage removal to erosion control, excavation of infill material or reshaping activities. In many instances, wetland restoration also involves the integration of gray infrastructure structures to manage flows and control water levels. Restoration also typically includes reintroducing plant and animal species through planting vegetation and transporting wetland species to the project site.

Maintenance

Long-term maintenance costs of natural inland wetlands will be site-specific and may include activities such as buffer mowing and invasive species removal. Costs associated with maintaining natural inland wetlands is generally lower than those of constructed wetlands where natural wetland ecosystem processes are well-established.

UNIT COST EXAMPLES THROUGHOUT THE GLOBE

- *Natural inland wetland protection (permanent wetland easement) and restoration costs in the US have been estimated to range from **US$170 –$6,100/acre (US$420–US$15,067/ha)** (Hansen et al. 2015).*
- *Natural inland wetland restoration costs were estimated at **US$9,900/ha** (restoration through hydrologic manipulation in Denmark); and **US$30,000/ha** (restoration through removal of phosphorus loads from open water bodies in Florida) (TEEB 2011).*
- *Buffer mowing is estimated to cost **US$3 acre/year (US$7.41/ha/year)** in the US (Iowa) (Plastina and Johanns 2016).*
- *Annualized costs of natural inland wetland restoration over a 40-year lifespan in Iowa: **US$785/acre/year (US$1,939/ha/year)** (EPA 1995).*

Tin Shui Wa, Hong Kong
Photo by Easton Mok on Unsplash

NBS IN PRACTICE

The four projects in this section highlight good practices and lessons learned about natural inland wetlands, drawn from the growing popularity of NBS throughout the globe.

Photo by Bing maps

Wetland protection approach. Conservation and Management Act

City largely depends on wetlands resources

Community sensitivity and local heroes for conservancy

Project #1: *East Kolkata Wetlands, 2006 to date*
Location: *Kolkata, India*
Description: *Spread over 12,500 hectares on the eastern side of the city of Kolkata, this natural wetland is a Ramsar site and one of the largest wastewater-fed aquaculture systems in the world. It provides fishing opportunities for locals and supports paddy and vegetable cultivation in small plots in and around the wetland system. The wetlands serve two functions that may seem contradictory at a first glance: they are the city's free sewerage works and they are also a fertile aquatic market garden. Wastewater is used in paddy fields and vegetables are grown on the verdant banks and on a long, low hill created by Kolkata's organic waste. Wetlands are also a habitat for fish. Not only do these wetlands provide affordable food and vegetables for the city, they also provide livelihood for about 1.1 million people.*

Benefits
Heritage, Economy, Water quality, Flood and Heat Stress Risk Reduction.

Source
East Kolkata Wetlands Management Authority (EKWMA)
http://ekwma.in/ek/
https://www.theguardian.com/cities/2016/mar/09/kolkata-wetlands-india-miracle-environmentalist-flood-defence

Photo by Dimitris Vetsikas on Pixabay

Partnership for protection and conservation approach

Co-funded by external sources

Rise of public awareness and environmental education

Project #2: *Oroklini Wetland Restoration, 2012–14*
Location: *Larnaca, Cyprus*
Description: *Oroklini lake is located close to the south coast of Cyprus next to the city of Larnaca within the boundaries of Oroklini village. The waterbody has undergone modifications and degradation since the 1940s, when the lake was dried out to alleviate the fear of diseases. The objective of the natural water retention measures (NWRM) restoration was to increase water retention and restore wetland habitats for the two important bird species and increase the overall biodiversity. The hydraulic works included creation of a retention area to secure water in the upper basin. Planting of wetland species aimed to have maximum effect on the biodiversity. The project was funded by the European Union, with support the Life+ project.*

Benefits
Biodiversity, Water Quality, Flood Reduction, Recreation.

Source
BirdLife Cyprus, Game Fund Department, Oroklini Community Board, Department of Environment.
http://nwrm.eu/sites/default/files/case_studies_ressources/cs-cy-01-final_version.pdf
http://www.orokliniproject.org/en/home

Photo by Kongjian Yu / Turenscape

Restoration approach for existing wetlands

Creation of a new urban park and recreation amenities

Showcase for water urbanism approach

Project #3: *Qunli National Urban Wetland, 2006–21*
Location: *Qunli New Town, China*
Description: *Qunli New Town is a new district on the outskirts of Haerbin City in North China. It was built to accommodate 350,000 new residents in over 32 million m² of buildings in 2010. 16.4% of the land to develop was zoned as permeable green space. The rest of the former flat plain was covered in impervious concrete. A 34.2-hectare park was designed on a former wetland area to mitigate flooding. Stormwater from the newly developed urban area is collected in a pipe around the circumference of the wetland. The water is filtrated in the ponds and then deposited into the wetland. Native wetland grasses and meadow grow in the ponds at various depths and following the natural evolution process. A recreational area was integrated into the park for sports and leisure activities.*

Benefits
Biodiversity, Health, Social, Flood and Heat Stress Risk Reduction.

Source
Haerbin City Municipality and Turenscape
http://landezine.com/index.php/2014/01/qunli-national-urban-wetland-by-turenscape/

Photo by Alphart Lungu on Flickr

Large-scale partnership for restoration efforts

Considered the lifeline of region economy

Community involvement in maintenance and job generation

Project #4: *Zambia Wetland Restoration Efforts, 2011–33*
Location: *Kafue Flats, Zambia*
Description: *WWF Zambia has worked to protect and restore wetlands and freshwater ecosystems for more than 50 years. It then engaged organizational and private sector stakeholders in a water stewardship approach in a 30-year project to restore the Kafue Flats floodplain grasslands while simultaneously enhancing their productivity divided in a short-term implementation (2003-2005), medium term (2006-2010) and long term (2011-2033). The project has undertaken a highly intensive eradication of the mimosa tree. The project has generated employment opportunities for at least 150 people from local communities.*

Benefits
Employment, Wildlife, Ecotourism, Food.

Source
WWF Zambia, Government of Zambia
https://www.wwfzm.panda.org/climate___energy_footer/?27825/Wetlands-for-Sustainable-Cities

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CONSTRUCTED INLAND WETLANDS

Urban Wetlands Park, Nugegoda, Sri Lanka
Photo by Shruthimathews on Flickr

FACTS AND FIGURES

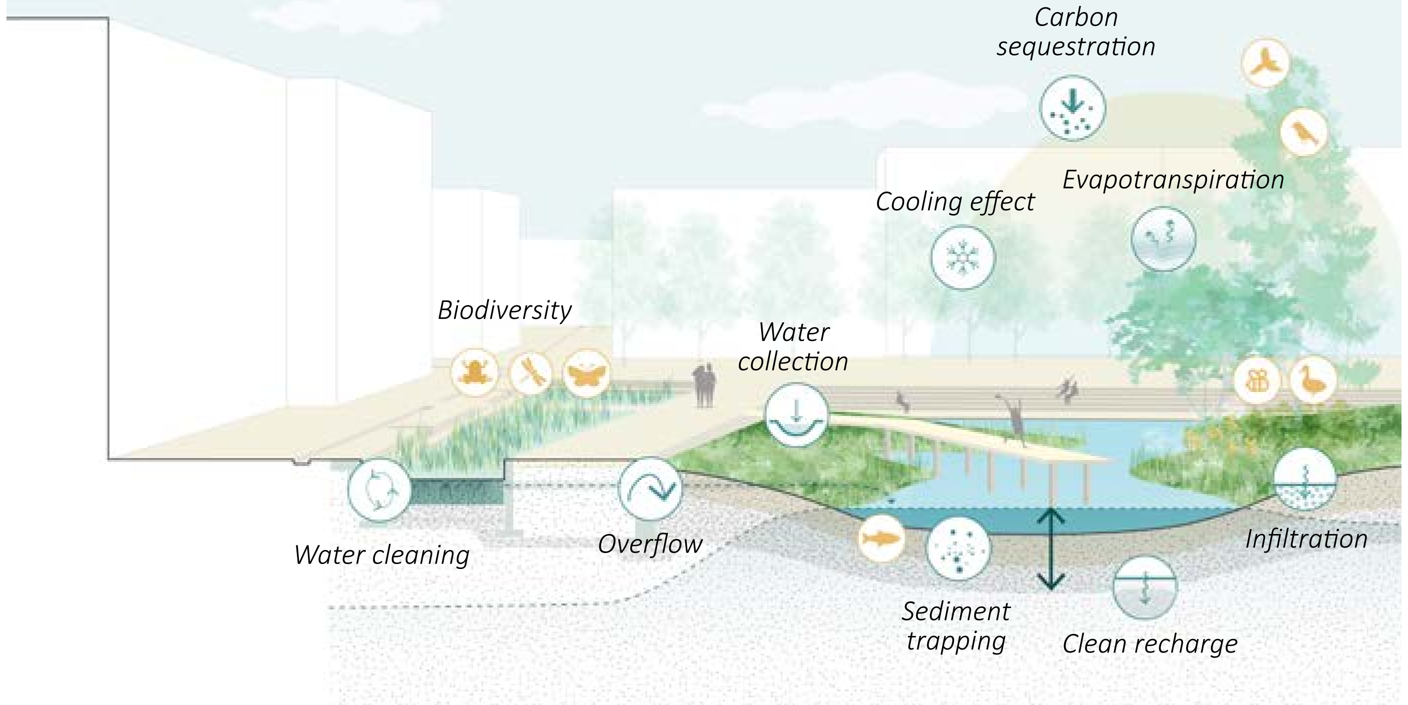
DESCRIPTION

Similar to natural inland wetlands in appearance, constructed inland wetlands are engineered systems that have been designed and constructed to utilize the natural processes involving wetland vegetation, soils and their associated microbial assemblages to assist in treating wastewater and to provide other supplementary functions. In urban regions, constructed inland wetlands can help offset the negative anthropogenic effects on the environment, sequester carbon, and help cities adapt to climate change. They can also help reduce organic, inorganic, and excess nutrient contaminants in surface and groundwater, municipal wastewater, industrial wastewater, domestic sewage, and other polluting sources. In arid climates and other areas with water shortages, constructed inland wetlands can also provide great value by cleaning and allowing the reuse of water, recharging the aquifers, and directly contributing to the conservation of natural resources. Constructed inland wetlands also offer scenic, recreational, educational, psychological, and economic value to the communities and a habitat for a great variety of species.

Constructed inland wetlands range in size and appearance with free surface water flow and subsurface flow wetlands being the most common types. As part of a green infrastructure network of a city, these wetlands contribute to the protection of urban areas from floods and help maintain water quality in ponds and rivers as well as engineered gray water recycling systems in buildings and neighborhoods.

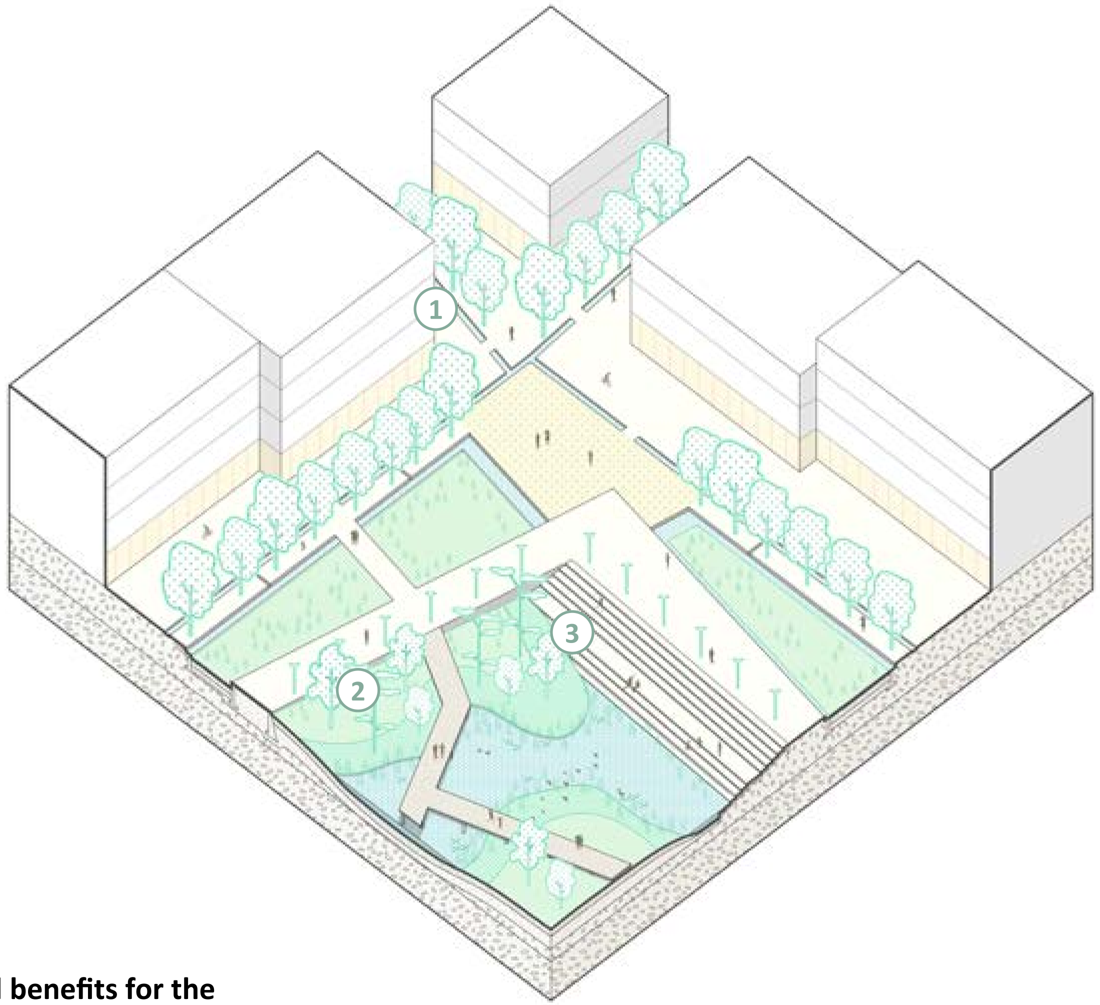
TYPE OF CITY	SCALE	APPROACH
Coastal, Delta, River, Mountain	Neighborhood, City, River basin	**Rehabilitate, Restore, Enhance** Convert existing green spaces into constructed wetlands. **Create** Construct new inland wetlands.

PROCESSES

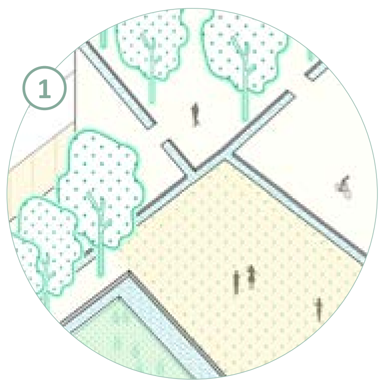


VISUALIZATIONS

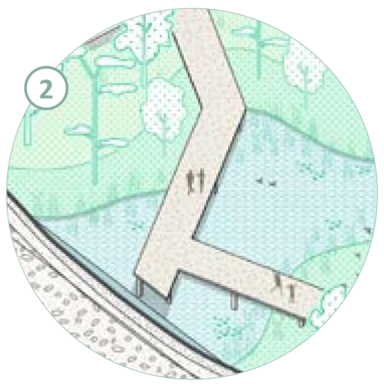
VISUALIZATION OF CONSTRUCTED INLAND WETLANDS IN THE URBAN CONTEXT



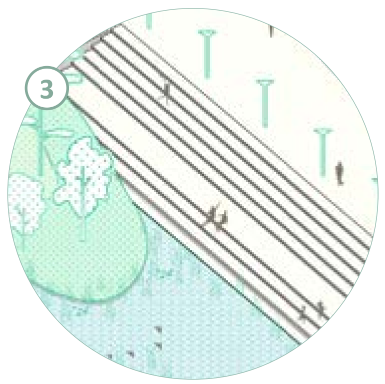
Details of increased benefits for the urban living environment



Constructed inland wetlands become recreational destinations in the city, transforming neighborhoods and adding diversity to green spaces.

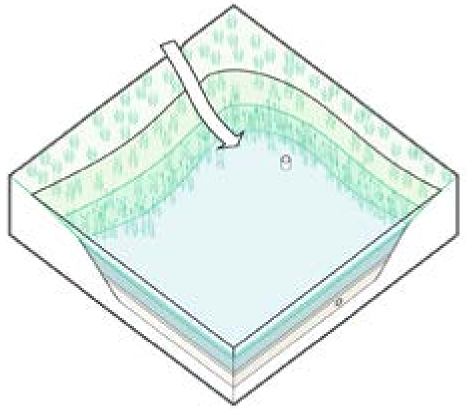


Constructed inland wetlands create an opportunity to raise community awareness and involvement in water and climate related challenges.



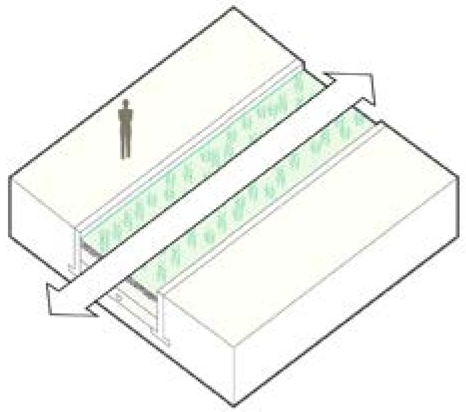
Constructed inland wetlands deliver aesthetic and sensory experiences for urban communities.

SPECIAL TECHNIQUES FOR CONSTRUCTED INLAND WETLANDS



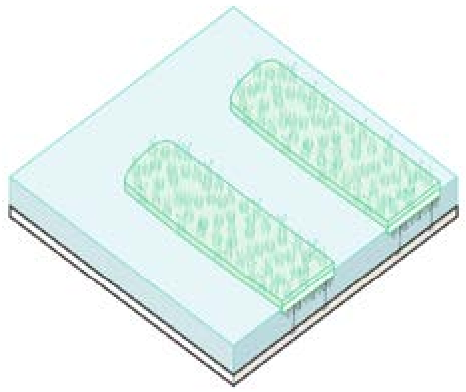
Surface constructed wetlands

Free water surface constructed wetlands clean water through a series of planted marshes and engineered soils that remove contaminants. They imitate a natural wetland ecosystem where plants filter water. Wetland plants are a great natural asset; in addition to purifying water, they often support high levels of biodiversity (Kennen and Kirkwood 2015).



Subsurface gravel wetlands

Horizontal subsurface-flow constructed wetlands treat contaminated water by pumping it slowly through the subsurface gravel beds where it gets filtered through the root zone and the soil in a vertical or horizontal flow pattern. Subsurface wetlands offer the advantage of space efficiency and the ability to prevent mosquito breeding (Kennen and Kirkwood 2015).

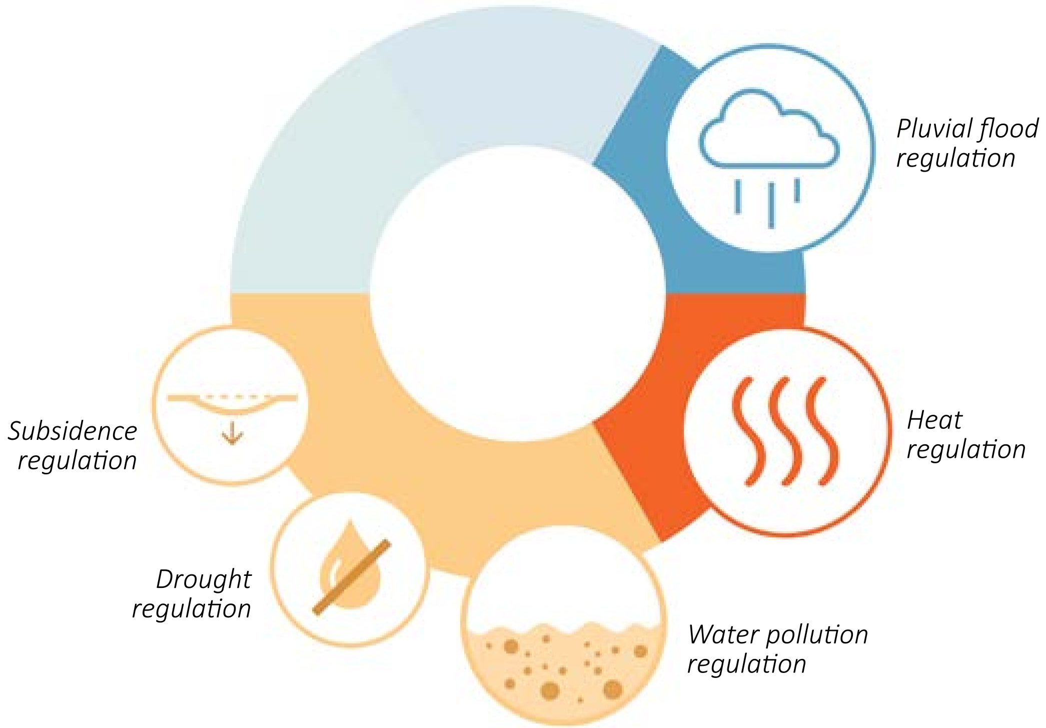


Floating wetlands

Constructed floating wetlands have plants installed on floating structures that are placed in existing water bodies to filter contaminants. Existing contaminated water bodies, urban rivers, canals, and ponds may be treated with floating wetlands. Secondary benefits include water cooling and habitat for wildlife (Kennen and Kirkwood 2015).

FUNCTIONS

The diagram in this section shows relevant functions of constructed inland wetlands.



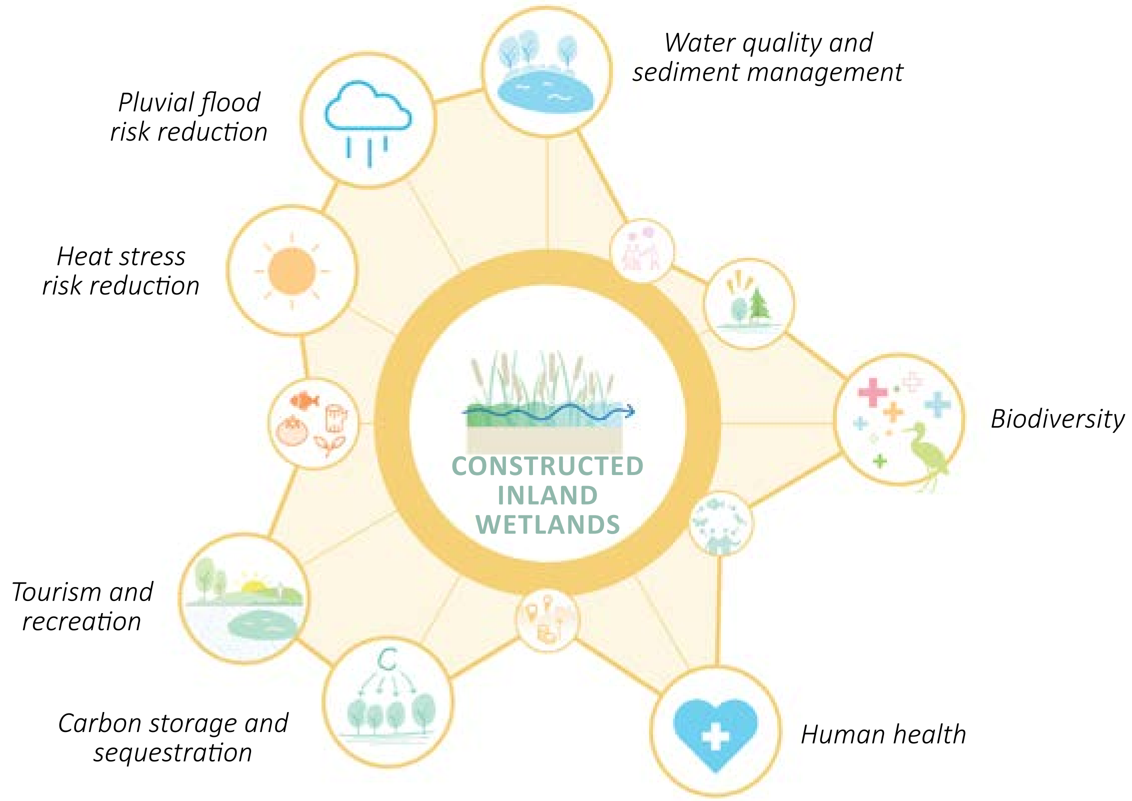
Pluvial flood regulation: Constructed inland wetlands reduce the amount of stormwater runoff by collecting and storing water during flood events. Attenuation capacity of constructed wetlands is determined almost entirely by the size and shape of the basin and the controls used to manage outflow during flood events (Ozment et al. 2019).

Heat regulation: Open water surfaces of constructed inland wetlands have the capacity to absorb heat and help regulate the rate of air temperature change. Open water and wetlands reflect solar radiation and influence humidity and microclimates through natural processes. Similar to natural wetlands, these conclusions can be drawn from a study conducted in Mexico City that measured the effect of wetlands on temperature and recorded an incremental rise of about 2°C (35.6°F) every 35 meters as the distance from the body of water increased (Wetlands International 2020). In addition, a study of a large industrial wetland in the Middle East demonstrated a reduction in temperature of 10°C (50°F) between the center and the perimeter of the wetland in a one-kilometer distance (Stefanakis 2019).

Other functions: Constructed inland wetlands are typically designed to address water quality risks by removing various pollutants (Kennen and Kirkwood 2015). They can clean stormwater, wastewater, and groundwater by removing and—partially or completely—degrading organic contaminants and nitrogen, while filtering out and storing other inorganic contaminants in the soil (Kennen and Kirkwood 2015).

BENEFITS

The diagram in this section shows a sampling of important benefits that constructed inland wetlands can provide to people.



Pluvial flood risk reduction: Constructed inland wetlands collect urban stormwater runoff during storm events. While their flood attenuation benefits may vary, they typically include a flood bypass channel to prevent damage to the wetland during major flood events. As such, their flood mitigation potential is typically most optimal for small flood events.

Heat stress risk reduction: Constructed inland wetlands can contribute to reduce the heat island effect in urban areas. This is because constructed wetlands are dominated by open waters that reflect sunlight at low angles and take much longer to absorb heat from solar radiation than paved or built areas. This ability to maintain lower temperatures allows wetlands to provide cooling for the surrounding areas, which is significantly relevant in urban environments where heat stress is more critical (Wetlands International 2020).

Tourism and recreation: Constructed wetlands are designed to imitate and perform the functions of natural wetlands. They act as aesthetically pleasant urban green spaces, which contribute to the wellbeing of the residents and provide opportunities for recreational activities. They also invite residents to get involved in outdoor activities, such as bird watching and sports (Stefanakis 2019).

Carbon storage and sequestration: As with natural inland wetlands, constructed wetlands can also play an important role in carbon sequestration. Performance does however depend on design, and if not managed and designed properly, constructed wetlands could become a source rather than a sink of greenhouse gases (Rosli et al. 2017).

Human health: Strong evidence supports that access to water bodies has positive mental health benefits (Volker and Kistemann 2015). Visiting rivers, lakes and streams increases happiness (Helliwell et al. 2020). Urban wildlife, particularly birds improve the overall effect of green space, provide calming effect, and help relief stress (Ulrich 2002). In the urban context, constructed inland wetlands support physical health and psychological wellbeing.

Biodiversity: The water-based natural habitat associated with constructed inland wetlands attracts wildlife species and can support the creation of healthy multifunctional landscapes, connected to the larger landscape mosaic. In larger wetlands, biodiversity values and habitat variability can be enhanced by introducing islands and creating areas of varying water depth. As a strong source of biodiversity, constructed inland wetlands can positively change the character and identity of the urban environment (Stefanakis 2019).

Water quality and sediment management: Constructed wetlands transform or remove various organic and trace element and nutrient pollutants through a series of physical, biological, and chemical processes, and improve the water quality. Although efficiency of removal can vary considerably, constructed wetlands may be highly effective in addressing water quality risks (Stefanakis 2019). While constructed wetlands can trap sediments, this may undermine other functions and sediment traps are often included in the designs, requiring regular maintenance.

SUITABILITY CONSIDERATIONS

ENVIRONMENTAL

Location and climate: Constructed inland wetlands are well-suited nature-based solutions for stormwater management and water reuse in tropical and temperate regions (Stefanakis 2020). In colder regions however, low temperatures reduce physical and biological activity and reduce purification capacity of wetland plants. As such, constructed wetlands, installed to clean wastewater in cold climates, require extra technical measures to maintain their performance, as seasonal variations in performance may occur (Maehlum et al. 1995).

Hydrology: Maintaining appropriate hydrological regimes—including appropriate levels of soil saturation and inundation—is critical for the proper functioning of a constructed inland wetland. This includes avoiding highly variable flows that can flush the system and undermine treatment functions. The distance to the groundwater table is not a major constraint because a high water table can help maintain wetland conditions (DDOE 2012). However, wetlands designed to treat domestic and agricultural wastewater require lining to avoid any contamination of the groundwater (EPA 1995).

Soil: Soils underlying the proposed inland wetland should have the right infiltration rates and other subsurface properties. Highly permeable soils will make it difficult to maintain appropriate patterns of saturation and inundation to maintain wetland habitat and associated treatment functions. If adequate soils are not available, artificial liners should be installed to facilitate better performance (DDOE 2012). Soil tests can be conducted to determine the soil characteristics.

Water quality: The effectiveness of constructed inland wetlands in assimilating pollutants primarily depends on the quality of inflowing water and wetland size in proportion to the catchment area. As such, the design of constructed wetlands should be informed by a sound understanding of expected inflow volumes and water quality characteristics.

Substrate: Constructed inland wetlands include soil or gravel-based horizontal flow systems. Depending on the type of soil, such systems may require a ground liner that helps maintain saturation levels and prevents contamination of the groundwater. They serve as a sink for pollutants and have a high water-holding capacity. They also facilitate plant growth and propagation and may hinder the growth of undesirable species (DEP 2006).

Mosquitoes: Mosquitoes are not uncommon in constructed inland wetlands, however it is possible to reduce mosquito infestation and larvae development by creating continuous water flow, shaded water surface, and abundance of local fauna that eat mosquitoes. Avoiding stagnant backwaters is particularly important to reduce mosquito levels (EPA 1995).

TECHNICAL

Slope: While constructed inland wetlands can be built almost anywhere; a site with gradual slopes that can be easily altered to collect and hold water will simplify the design and construction, and minimize the costs (EPA 1995). The wetland, including the longitudinal slope, must then be designed in such a manner that water retention time is optimized to allow for effective treatment.

Dimensions: Constructed wetlands are normally designed to occupy between 2% and 5% of the contributing drainage area depending on the nature of water to be treated. The design, dimensions and the layout of different wetland zones should be site and context specific but typically include: an inlet zone for removal of course sediments; a macrophyte zone for removal of fine particles and uptake of soluble nutrients; a macrophyte outlet zone that channels stormwater into adjoining downstream structures; and a high flow bypass channel to protect the wetland from potentially damaging abnormally high flow.

Planting and growing strategy: Vegetation is an integral part of the wetland system. It reduces stormwater flow velocities, promotes sediment settling, provides growth surfaces for beneficial microbes, and absorbs pollutants. Constructed wetlands should have several different zones of vegetation with robust, noninvasive, fast growing perennial plants (DEP 2006).

URBAN

Land use: Urban parks and green areas in residential, commercial, or industrial areas as well as major infrastructure networks are suitable land uses for constructed wetlands.

Urban density: Suitable urban density for constructed wetlands areas ranges from low to medium.

Area: Small to medium. Constructed wetlands are nature-based solutions typically designed for application at a neighborhood and city scale.

Integrated urban planning: Constructed wetlands can be integrated with green public areas, public parks, and stormwater drainage systems. They can be installed as part of the sewerage upgrade and system capacity expansion.

MAINTENANCE

For the first two years following the installation, constructed inland wetlands should be inspected at least four times a year, especially after major storms. Wetland and buffer vegetation may require support during the first three years and undesirable species should be removed. Once established, constructed wetlands should require relatively little maintenance (DEP 2006) although regular removal of litter and sediment may be necessary in some contexts.

COSTS

COST CONSIDERATIONS

Land

Access to or ownership of land is required for constructed inland wetlands.

Land on which constructed inland wetlands may be located could be public or private.

Land area required for constructed inland wetland areas will vary from smaller to larger areas, raising transaction costs if engagement and collaboration with multiple landowners and stakeholders is necessary.

Example land-related costs:

- Acquisition costs
- Land use (e.g., payments to landowners) costs
- Land protection costs, including managing and controlling access
- Community resettlement costs

Construction and implementation

Costs associated with wetland construction are site-specific and will vary according to site conditions, soil characteristics, hydrology, and design specifics.

Inland wetland construction cost components include planning and design, engineering, project preparation, soil excavation, and planting. Constructed wetlands are usually less expensive than gray infrastructure options for the same function (Ozment et al. 2019).

Maintenance

Long-term maintenance costs of constructed inland wetlands are site-specific and may include activities such as buffer mowing, replacing gates and other control structures, ensuring a continuous supply of water, and invasive species removal.

UNIT COST EXAMPLES THROUGHOUT THE GLOBE

- *First year costs in the US (Iowa) of a constructed wetland: **US$10,000/acre (US$24,700/ha)**.*
- *The cost of constructed wetlands in the Mid-Atlantic region of the US ranges from **US$34–US$40/m³** of detention volume (EPA 1995).*
- *Buffer mowing is estimated to cost **US$3/wetland acre (US$7.41/ha)** in the US (Iowa) (Plastina and Johanns 2016).*
- *Replacing control structure gates is estimated to cost **US$15/wetland acre (US$37/ha)** in the US (Iowa) and be required every eight years. (Christianson et al. 2013).*
- *Maintenance cost of constructed wetlands have been estimated at **US$0.1/m²/ year (US$1,000/ha/year)** of wetland surface area in the UK (Aerts 2018).*

Oslo, Norway
Photo by L. Ulrich, Licensed under Creative Commons

NBS IN PRACTICE

The four projects in this section highlight good practices and lessons learned about constructed inland wetlands, drawn from a range of case studies from across the globe.

Photo by Cord Rodefeld on Flickr

Climate awareness and identity

Public space renewal program

Participatory process with local communities

Project #1: *Tanner Springs Park, 2009–12*
Location: *Portland, USA*
Description: *Located in Portland, Oregon, the celebrated Tanner Springs Park is centered around a bioengineered wetland. The project captures and filters stormwater from every roof and paved surface in the surrounding area, reduces flooding during extreme precipitation events, improves water and air quality. This high performance constructed wetland of one acre boasts a great deal of biodiversity and offers a pleasant, accessible social hangout for the neighborhood and delivers significant social benefits for the community. The park also features a boardwalk, an art installation, and a recreational path running through its central area. Park programming emerged through a series of participatory charrettes with the community, which built a strong sense of pride and ownership among the participants.*

Benefits
Health, Education, Heat Stress Risk Reduction.
Source
Atelier Dreiseitl
https://sustainability.asu.edu/urbanresilience/2018/11/portland-oregon-tanner-springs-park/

Photo by Landprocess / Panoramic studio

Urban icon

Design oriented: Launched as an international idea competition

Integrated in educational and cultural institution

Project #2: *Chulalongkorn Centenary Park, 2012–17*
Location: *Bangkok, Thailand*
Description: *The Chulalongkorn University Centenary Park is the critical first part of Bangkok's green infrastructure designed to mitigate environmental degradation and add much-needed outdoor public space to the gray city. The park water treatment system is built around constructed wetlands with detention lawns and retention ponds. The constructed wetlands follow the slope of an inclined plane, and steps down through a series of weirs and ponds. Water passes through a weir, cascades down, flows through a plant- filled pond below, passes through another weir, and flows through another pond. Water is cleaned every time it passes through plants until reaching the retention pond, where children and adults can safely play and enjoy the water.*

Benefits
Pollutants Reduction, Biodiversity, Tourism, Social Interaction.
Source
LandProcess, Kotchakorn Voraakhom
www.nparks.gov.sg/-/media/cuge/ebook/citygreen/cg16/cg16_05.pdf

https://worldlandscapearchitect.com/chulalongkorn-centenary-park-green-infrastructure-for-the-city-of-bangkok/#.YWV7s_IBxPY

Photo by Michael Miller on Flickr

Brownfield restoration

Stimulate neighborhood reinvestment

Water cleaning process as design element of park design

Project #3: *Chattanooga Renaissance Park, 2005–13*
Location: *Tennessee, USA*
Description: *Completed in 2006, Renaissance Park has been a catalyst for reinvestment in Chattanooga's growing Northshore neighborhood ever since. The park is an environmentally focused brownfield redevelopment project that successfully demonstrates how a once-polluted area can be restored to a natural park setting within an urban-driven landscape. A created wetland system now collects and cleans runoff before release into the Tennessee River and is the centerpiece of the park that now serves as an amenity for adjacent new residential and mixed use developments.*

Benefits
Environmental, Biodiversity, Education, Heat Stress Risk Reduction.
Source
Hargreaves Associates
https://www.landscapeperformance.org/case-study-briefs/renaissance-park

https://www.landscapeperformance.org/sites/default/files/Renaissance%20Park%20Methodology_0.pdf

Photo by Daniel Segura / OBRAESTUDIO

Public space renewal program

Design oriented: Launched as an idea competition

Water cleaning and water reuse as social interaction catalyst

Project #4: *Usaquén Urban Wetland, Completed 2016*
Location: *Bogotá, Colombia*
Description: *The 8,500 m^2 landscape project, completed in 2016, aims to transform and revitalize an emblematic public space in northeastern Bogotá. Its design concept is based on the wetlands of the Bogota Savannah, a neighboring rocky area, and the typical plant species. The project recreates the geometry of the half aquatic, half terrestrial ecosystem, its colors, and textures. A rainwater garden in the main square uses recycled water and creates a native urban wetland that blends with its surroundings, the Andean hill backdrop, and preserves the native vegetation in its natural habitat. Despite the seemingly wild, natural, and free-form aspects of the urban design, a clear, rationalized structure and construction style underlies the spatial composition.*

Benefits
Education, Health, Economy, Heat Stress Risk Reduction.
Source
Obraestudio
https://architectures.jidipi.com/a139012/usaquen-urban-wetland/

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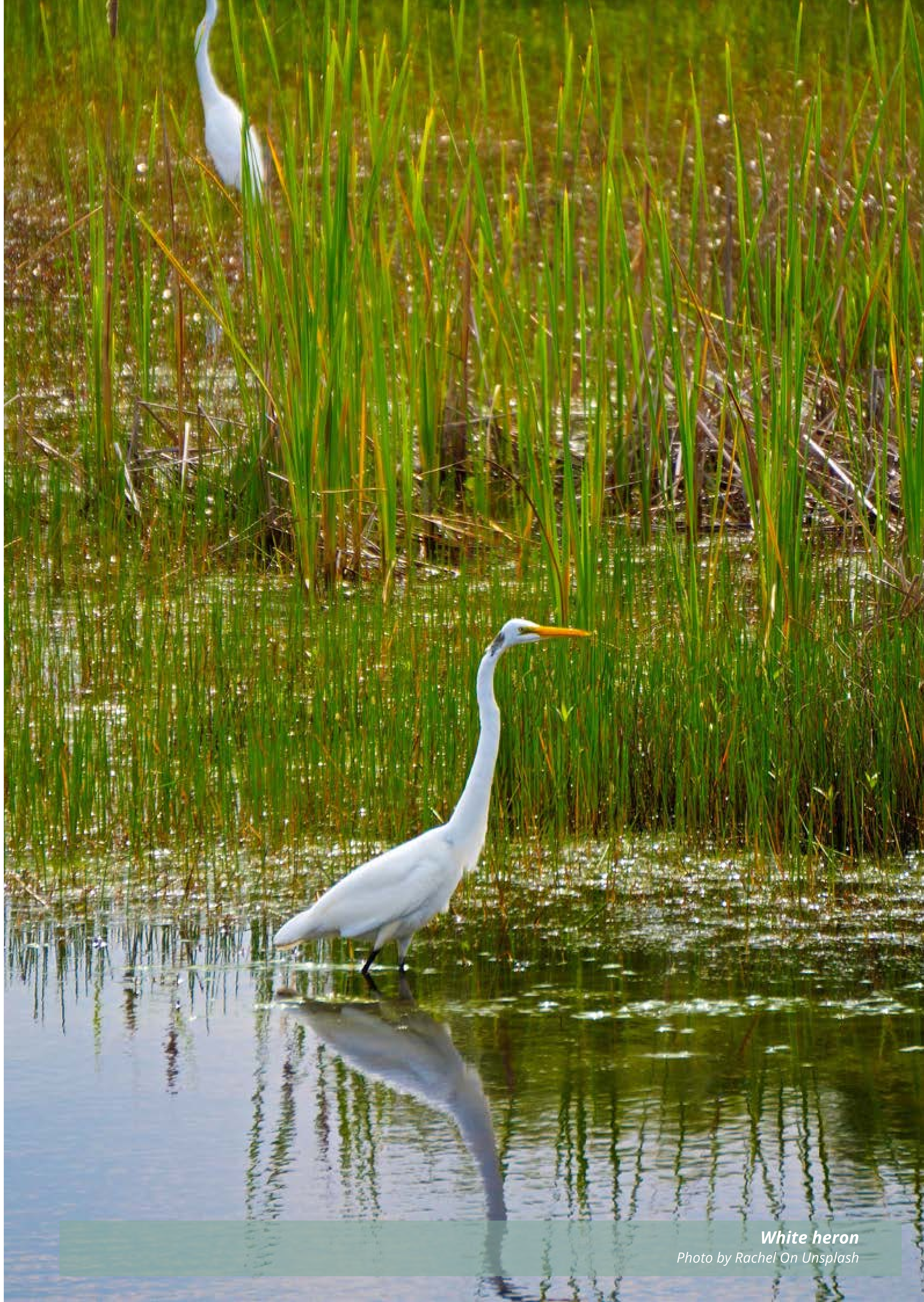


White heron
Photo by Rachel On Unsplash

RIVER FLOODPLAINS

Upper Serangoon Crescent, Singapore
Photo by Z on Unsplash

FACTS AND FIGURES

DESCRIPTION

For centuries people settled along rivers, and used floodplains for agricultural purposes. As development continued, the incidence of flooding increased in urban areas leading to growing concerns around flood risk management. The traditional response was interfering with natural floodplain dynamics by building levees to contain water and sediment flows, or by straightening and dredging rivers to move water more quickly beyond flood prone areas. While these techniques reduce local flood risks, they can also exacerbate downstream flooding effects, and sometimes, create an artificial sense of security that encourages more development in floodplains.

Climate change and a better understanding of these effects, has resulted in communities to demand sustainable, multifunctional and flexible solutions. In response, cities worldwide are investing in river and floodplain restoration projects that address flood risks while also improving waterfronts and creating multifunctional spaces that can be enjoyed by residents. This new paradigm, often known as "Room for the River," focuses on enhancing the space available for rivers to be able to safely process higher water levels. While these projects are typically directed at addressing flood risk, rehabilitation actions are also designed to deliver additional environmental and social benefits including providing, increased biodiversity, additional habitat for wildlife, space for play, recreation, and sports.

TYPE OF CITY

Coastal
Delta
River
Mountain

SCALE

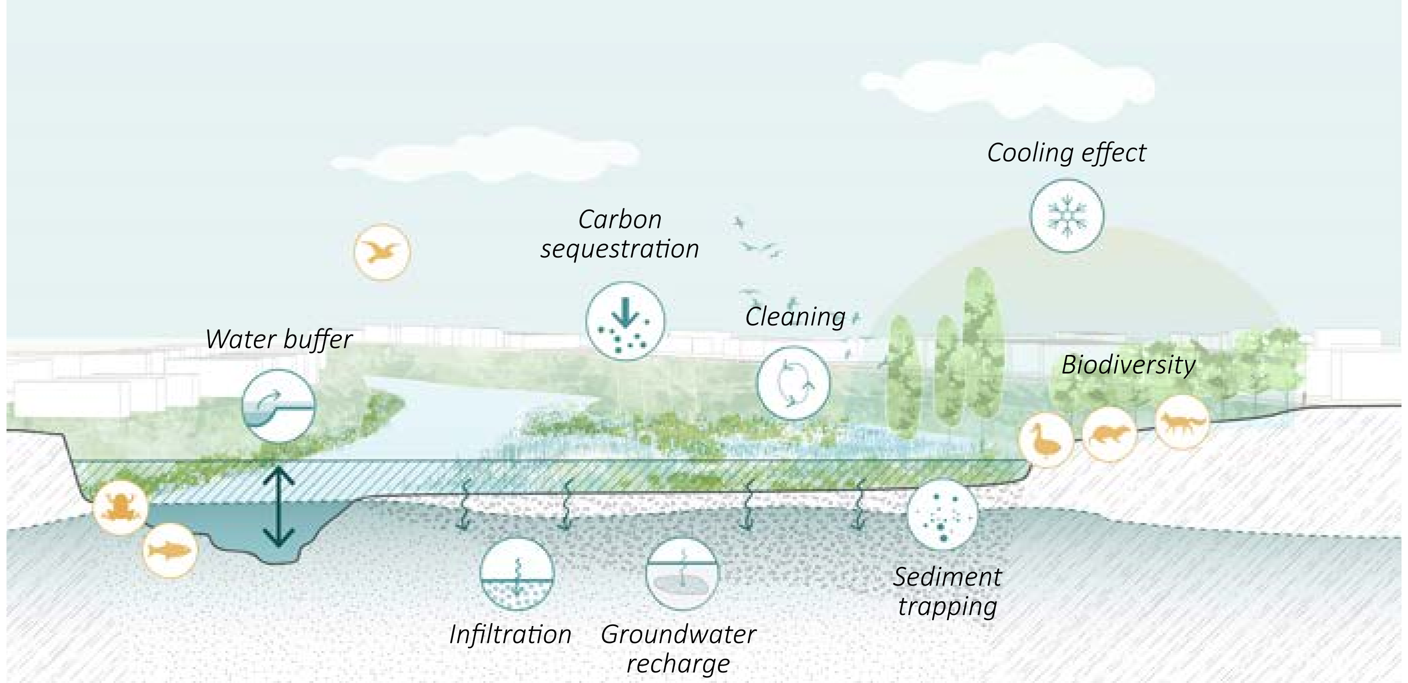
Neighborhood
City
River basin

APPROACH

Protect
Prevent encroachment and incompatible use of floodplains. Preserve existing tree structure.

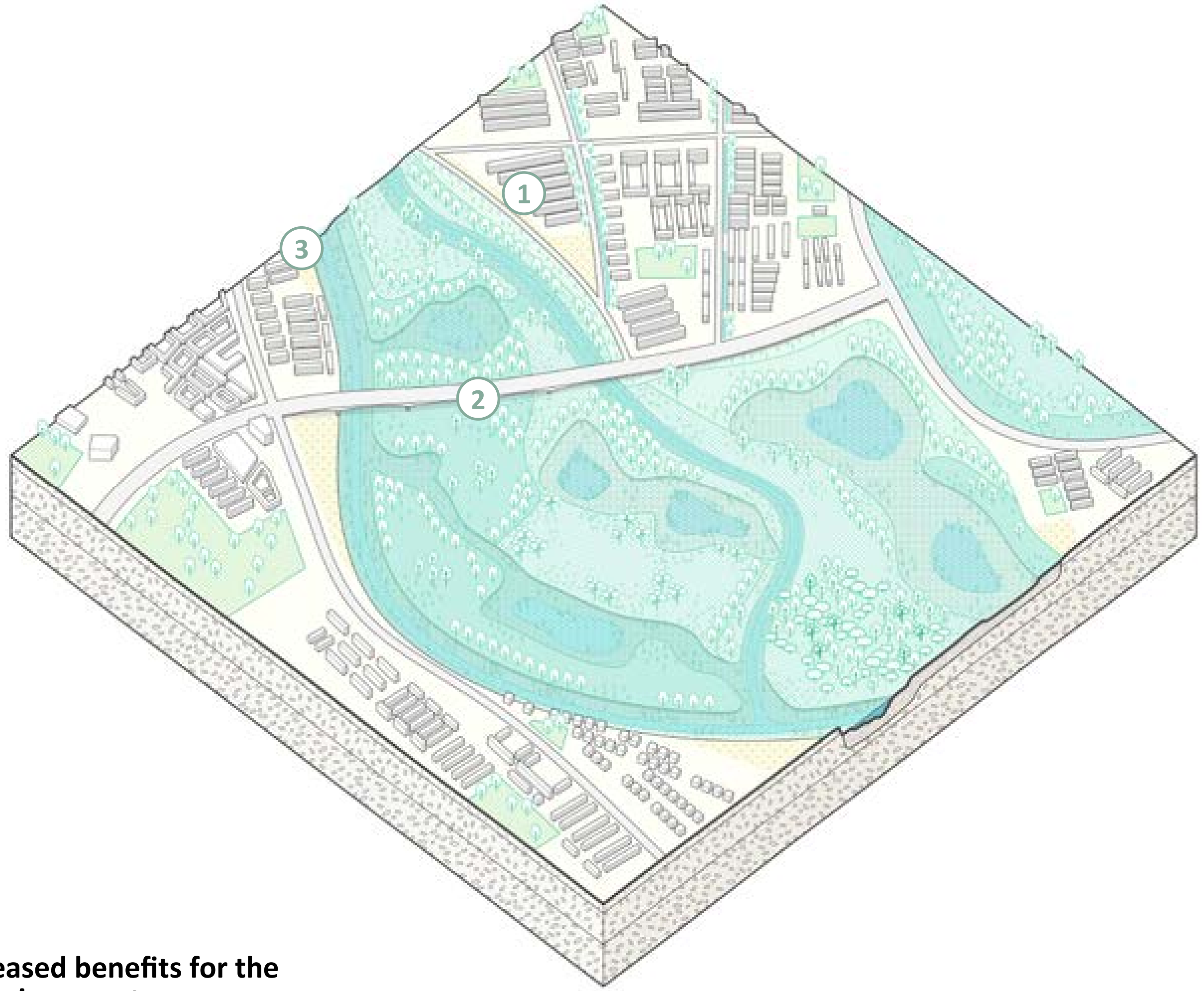
Rehabilitate, Restore, Enhance
Reinstate more natural floodplain dynamics.
Enhance flood attenuation capacity.
Invest in recreational and other social benefits.

PROCESSES

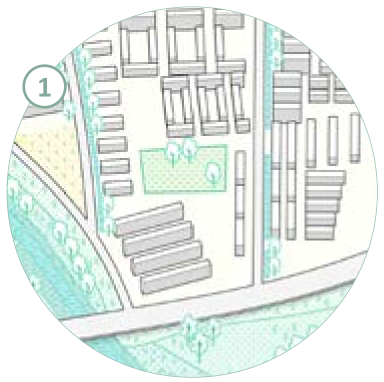


VISUALIZATIONS

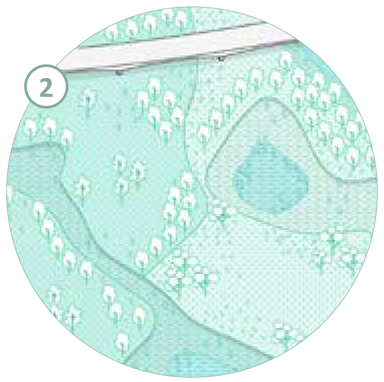
VISUALIZATION OF RIVER FLOODPLAINS IN THE URBAN CONTEXT



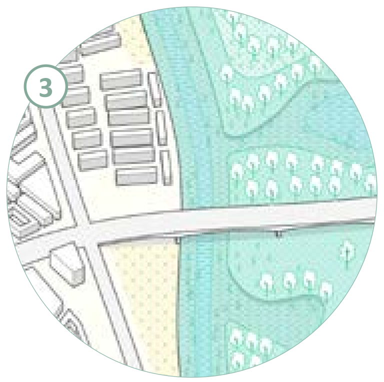
Details of increased benefits for the urban living environment



Floodplains can serve to intercept and treat polluted runoff, capturing sediment and reducing pollution risks for downstream communities.

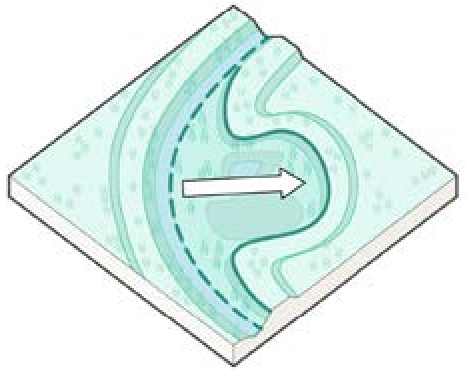


Rehabilitation efforts that reconnect the river to the floodplain can enhance attenuation and provide a diversity of habitats for wildlife.



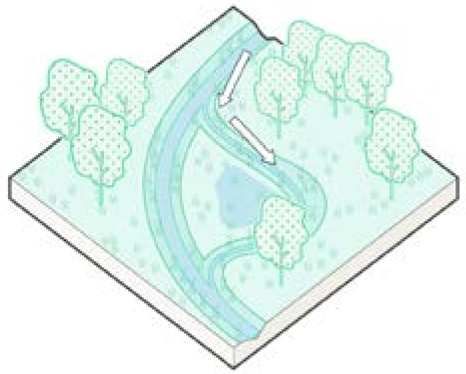
Rehabilitated floodplains can provide highly attractive landscapes and active riverfronts that attract investment and provide a range of opportunities for cultural and recreational activities.

SPECIAL TECHNIQUES FOR RIVER FLOODPLAINS



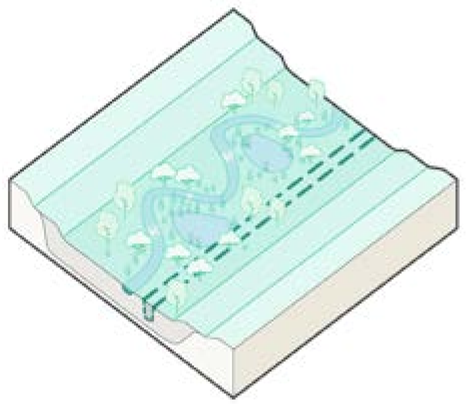
Setting levees back

Levee setback is the process of relocating a levee further back in the floodplain to provide extra space for the river to flood. Levee setback provides the river with more floodplain area to interact with and can result in lower flood elevation. The new space for the river allows new ecological and recreational activities (IDNR n.d.), and provides a greater diversity of floodplain habitats (Ayres et al. 2014).



River bypass or Oxbow

An oxbow is a historical river meander that is cut off from the main channel during the natural process of channel migration, or through man-made channelization. Water levels are maintained through larger flooding events overflowing into the oxbow and groundwater seepage. Based on the habitat proposed, inlet and outlet structures may need to be constructed to regulate the inflow and outflow of water for the oxbow (IDNR n.d.).

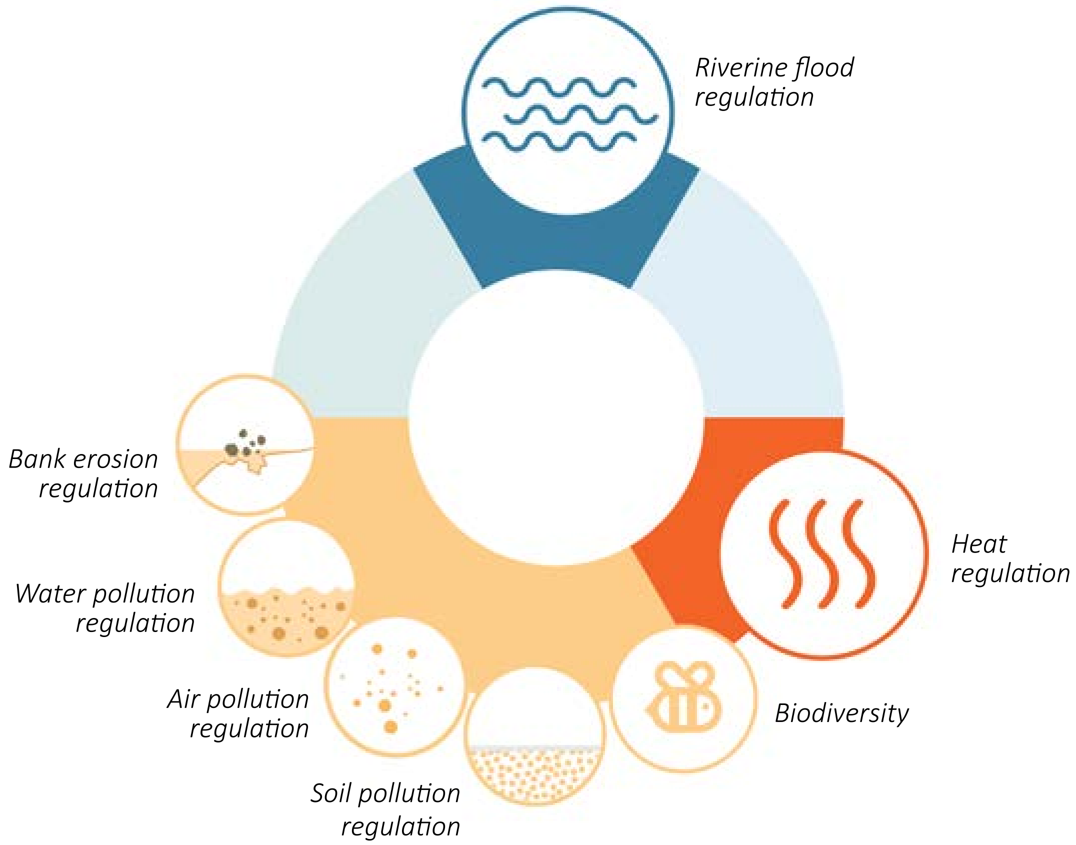


Re-activating the floodplain

In incised floodplains, a new meandering stream channel is excavated on the original floodplain by raising the stream bed elevation. The former incised channel is then filled, converting it to a floodplain feature. This approach is used in areas where there are few lateral constraints and where flooding on the adjacent land can be increased.

FUNCTIONS

The diagram in this section shows relevant functions of river floodplains.



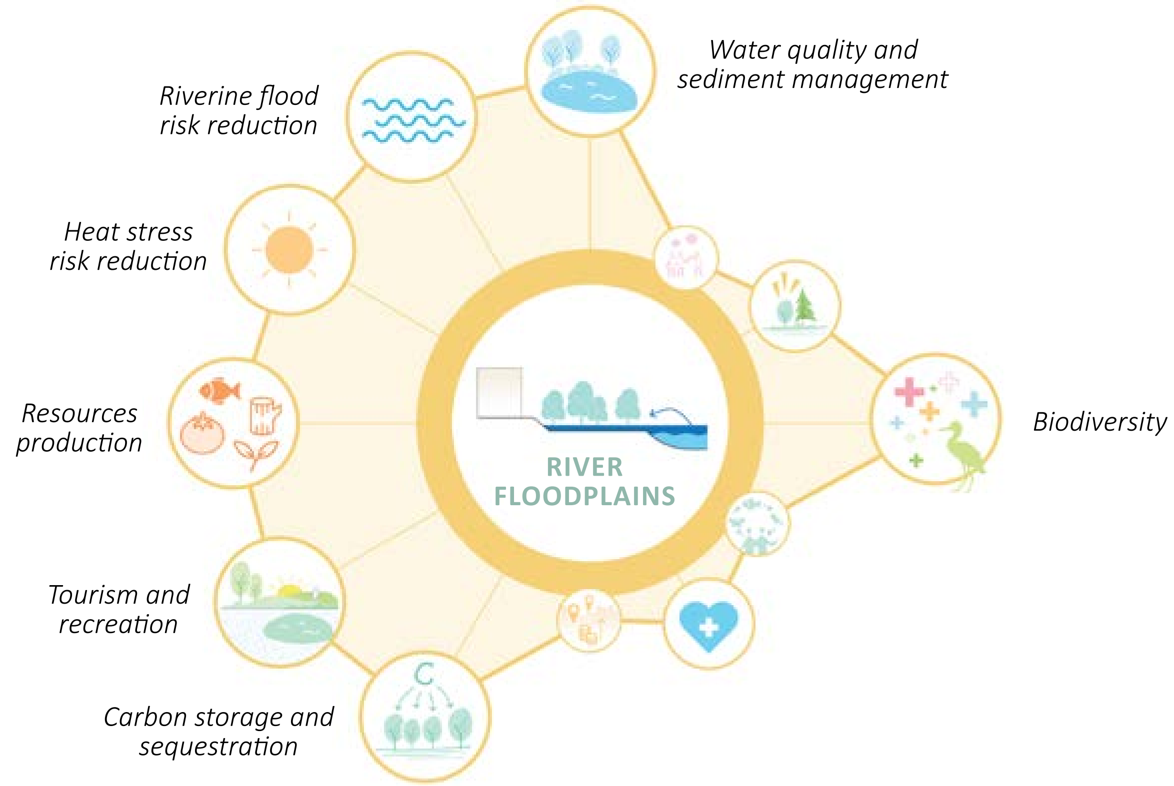
Riverine flood regulation: River floodplains reduce peak flows and downstream flooding by storing and slowly conveying water that overtop riverbanks during flood events (Ozment et al. 2019). In the event of a flood, a floodplain provides more space for the water. Floodplain vegetation reduces the speed of surface water flow, and floodplain topography controls the direction of surface water flow and manages the amount of sediment being transported by the water. Restoration actions on floodplains aim to provide enhanced flood capacity through the creation of flood bypasses, removal or rebuilding of the embankments at a different location, restoration of the riverine vegetation, and excavation of the floodplain (Dige et at. 2017).

Heat regulation: Rivers and floodplains mitigate urban heat. Riparian and floodplain forests control river temperature preserving aquatic flora and fauna. Ota River in Japan, for example, cools the temperature by up to 5°C (41°F) directly above the river with cooling effects extending 100 meters on both sides of the river (Hathway and Sharples 2012; Murakawa et al. 1991).

Other functions: Floodplain restoration improves water quality and reduces environmental pollution, facilitates sediment transport and storage, and mitigates soil erosion (Dige et at. 2017). Restored floodplains give room for seasonal water fluctuations, changes in meander patterns and other dynamic river processes and have a positive effect on aquatic biodiversity (Ahilan et al. 2018).

BENEFITS

The diagram in this section shows a sampling of important benefits that river floodplains can provide to people.



Riverine flood risk reduction: Floodplains are the first defense against flood damage when rivers overflow their banks, acting as a protective buffer for adjacent property and reducing the damage to vital infrastructure in urban environments. Floodplains store the water overflow from the river during a flood and slowly release the water back.

Heat stress risk reduction: Urban rivers and floodplains have a cooling effect on the surrounding areas. The degree of cooling is based on the ambient air temperature, seasonal water level variations and water temperature, solar radiation and the water albedo, wind speed, and relative humidity. Riparian and floodplain forests reduce and stabilize the temperature along the river, while the built environment reduces and dissipates the effect. Urban design for the waterfront areas should take advantage of the cooling effect, and specify surfaces that will not absorb too much heat. Opening of streets to the river for example, will reduce the air temperature, while a street shut off from the river will not gain any benefit for its microclimate (Hathway and Sharples 2012).

Resource production: In some cultures, floodplains are developed for extensive agriculture and provide a broad suite of natural resources for local communities. Care must however be taken to balance the benefits from cultivation with risks of flooding and loss of other important benefits such as water quality enhancement and biodiversity benefits.

Tourism and recreation: River floodplains are attractive habitats for wildlife, birds and other animals. Combined with their scenic value, opportunities for activities such as fishing, bird watching, biking, hiking, walking, swimming, and kayaking, they make for a uniquely rich recreational context (Tockner and Stanford 2002). These values can be enhanced through targeted investments in recreational, cultural, and educational infrastructure.

Carbon storage and sequestration: Floodplains can store large amounts of organic carbon in soils through overbank deposition of sediments originating from catchment erosion processes. For example, an empirical study from California (USA) found a soil carbon density of 2 tons CO_2 per ha in the upper 2 meters of soils (Steger et al. 2019). In terms of rates of sequestration, a study focusing on six rivers in southern England found sequestration rates of 69.2-114.3 g/m^2 (Walling et al. 2006), but these estimates can vary strongly by river basins and habitat types established in floodplain areas.

Biodiversity: Floodplains are among the most biologically productive and diverse ecosystems on earth, providing a range of microhabitats for different plant and animal species. Given the continual deposition and retention of nutrient-rich sediments, they tend to be more productive than adjacent uplands and are critical for maintaining aquatic and riparian biodiversity (Tockner and Stanford 2002). They also form an integral part of river ecosystems and act as important conduits for wildlife movement.

Water quality and sediment management: Reduction of the velocity of the river flow allows suspended sediments to settle in floodplain areas. This improves water quality, supports nutrient cycling, increases productivity, and improves fish habitat. Floodplains can also reduce downstream pollution by intercepting urban runoff and removing the sediment and pollution, before water is released into the river (Ozment et al. 2019).

SUITABILITY CONSIDERATIONS

ENVIRONMENTAL

Location and climate: Floodplains are defined topographically as relatively flat surfaces adjacent to river channels and occupy the area where water flows during floods. Floodplains are therefore found everywhere that rivers flow but are most prominent near a mouth of a large river and river middle courses, where the river also carries large amounts of sediment.

Hydrology: River floodplain characteristics are primarily determined by the water levels and the seasonal water discharge from upstream areas of a river. In the event of a flood, floodplains store water that overflows from the main river channel. Any interventions in a floodplain need to be carefully planned to ensure that measures are designed with a clear understanding of historic, present and future expected catchment hydrology and should include an evaluation of the impacts on local and broader flooding patterns. Flood modeling techniques help simulate these conditions and design interventions that meet multiple objectives.

TECHNICAL

Slope: The slope and the shape of a floodplain are key attributes affecting its retention capacity. Shallow slopes reduce flow velocity and prolong retention time whereas steeper slopes allow the water to run off quicker. The presence of oxbows and depressions can further enhance storage capacity.

Floodplain profile: In natural conditions, a floodplain profile is shaped by the actions of the river, frequency and strength of flood, and the volume and velocity of stormwater moving toward the river. While maintaining natural floodplain dynamics is desirable, this is often not achievable in an urban context—where emphasis of rehabilitation is often on reducing flood risks. Many floodplain rehabilitation efforts thus aim to strike a balance between enhancing natural processes, such as re-activating the floodplain, while also reducing flood risks. This may involve modifying the natural floodplain profile by artificially lowering it down or creating berms or levees to protect adjacent areas.

Dimensions: Where possible, the extent of the original floodplain should be protected and retained, together with a buffer to allow climate change related adjustments to be made in future.

Riverbanks: Floodplain restoration often includes reshaping river banks to prevent erosion and support natural vegetation. Such shaping should be accompanied by appropriate bank stabilization and revegetation measures, which typically include the use of an appropriate mix of seeds, and vegetation adapted to soil conditions and tolerant to periodic inundation.

Planting and growing strategy: Floodplain restoration should support native plants—trees, shrubs, and grasses that can survive frequent or prolonged floods. If trees are selected, these should be chosen for their ability to withstand high water table conditions and tolerate the wet soils of the floodplain (DEP 2006).

URBAN

Land use: Floodplains should be reserved as natural open space. Activities should be limited or restricted in floodplains that are occasionally flooded and used for only compatible activities.

Urban density: The suitable urban density for river floodplains is low to medium.

Area: Medium to Large: River floodplains range from those associated with smaller rivers and streams to large floodplains at a city scale.

Integrated urban planning: River floodplains are typically key structuring elements of cities and an integral component of open space networks and recreational areas.

MAINTENANCE

Riverbanks are subject to erosion during and immediately after construction. To maintain the health of the river, sediment that ended up in the watercourse during construction of the banks should be removed. Dredging of the riverbed or grading of its banks may be required to maintain design flow capacity (IDNR n.d.). Levees as well have to undergo maintenance and checks every year and reinforcement at the long term (Min. of IWM 2021).

COSTS

COST CONSIDERATIONS

Land

Access to or ownership of land is required for river floodplain protection and restoration.

Land on which river floodplains are protected and/or restored may be public or private.

Land area required for river floodplain protection and/or restoration will be relatively large, raising transaction costs associated with avoiding development and protecting river floodplains if engagement and collaboration with multiple landowners and stakeholders is necessary.

Example land-related costs:

- Acquisition costs
- Land use (e.g., payments to landowners) costs
- Land protection costs, including managing and controlling access
- Community resettlement costs

Construction and implementation

River floodplain protection and restoration costs will vary widely according to site conditions, location, hydrology, restoration actions required, planning, design and engineering requirements and labor and material costs.

Maintenance

River floodplain maintenance costs will vary according to location, hydrology, climatic conditions, and labor and material costs. Large floods may also result in significant damage that can result in unexpected maintenance costs.

UNIT COST EXAMPLES THROUGHOUT THE GLOBE

- *The cost of restoring and reconnecting floodplains in Europe is estimated to range from **US\$10,000–US\$800,000/ha** (EEA 2017).*
- *Floodplain restoration costs in Europe range from **US\$132–US\$363,800/ha**, with a median unit cost of **US\$27,566/ha** (Ayres et al. 2014).*
- *Removing levees along rivers in Europe: **US\$1–100/m³** (Ayres et al. 2014).*
- *Introducing meanders in Europe: **US\$15–US\$1,000/m** (Ayres et al. 2014).*
- *Dredging and river widening: **US\$2/m³** (Bangladesh)**–\$59/m³** (United Kingdom) (Aerts 2018).*
- *Reconnecting watercourses to their floodplains in Europe: **US\$2,400–US\$300,000/connection** (Ayres et al. 2014).*
- *Annual maintenance costs for floodplain projects are estimated at **0.5% to 1.5%** of total investment costs (Dige et al. 2017).*

Trukhaniv Island, Kyiv, Ukraine
Photo by Tanya Pro on Unsplash

NBS IN PRACTICE

The four projects in this section highlight selected good practices of river floodplain projects around the globe.

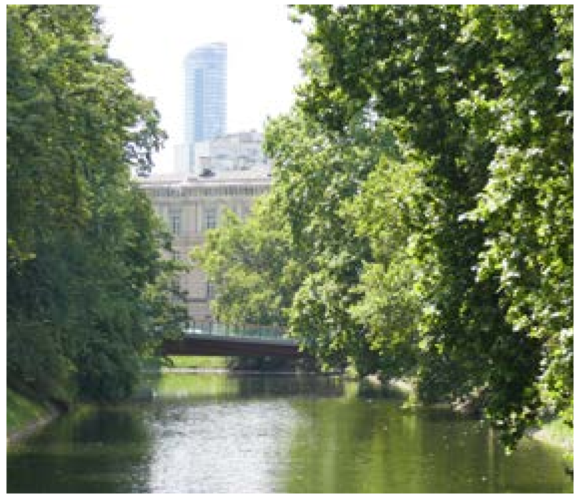


Photo by Maxence Peniguet on Flickr

Comprehensive flood protection strategy at city level | Strengthen the institutional capacity to mitigate floods | Hybrid strategy of NBS and gray infrastructure

Project #1: *Odra River Basin Flood Protection Project, 2007–20*
Location: *Wroclaw, Poland*
Description: *Wroclaw, the largest city in western Poland, is at risk from river flooding. The Odra River Basin Flood Protection Project is designed as passive flood prevention for the Odra River basin. The project is connected to a series of other projects that include components to combine existing gray infrastructure with natural features in the river basin. The project is a part of 1 billion euro program, co-financed by the World Bank and the EU Cohesion Fund. It has increased the floodwater flow capacity from 2,200 m^3/s up to 3,600 m^3/s and protects 2.5 million people against flooding in several towns along its banks.*

Benefits
Flood risk reduction, Economy, Health, Heat Stress Risk Reduction.
Source
Government of Poland, World Bank, Aecom.
https://documents.worldbank.org/en/publication/documents-reports/documentdetail/320251467986305800/poland-odra-vistula-flood-management-project

Photo by Kongjian Yu / Turenscape

Environmental stewardship for flood prevention through NBS | Creation of an iconic new urban park and recreation amenities | Equitable access and reduction of urban segregation

Project #2: *Yanweizhou Park in Jinhua City, Completed 2014*
Location: *Jinhua River, Jinhua, China*
Description: *The Yanweizhou project used a cut-and-fill strategy to balance earthwork by creating a water-resilient terraced river embankment covered with flood-adapted native vegetation. The terraced embankment remediates and filtrates the storm water from the pavement above. Although the design and strategies employed address only a small section compared to the hundreds of kilometers of river embankment, the Yanweizhou Park project showcases a replicable and resilient ecological solution to large-scale flood management. The park has meandering vegetated terraces, curvilinear paths, a serpentine bridge, circular bioswales and planting beds, and curved benches. The project has given the city a new identity and an acclaimed poetic landscape.*

Benefits
Flood risk reduction, Identity, Health and Wellbeing, Heat Stress Risk Reduction.
Source
Kongjian Yu, Peking University and Turenscape
http://landezine.com/index.php/2015/03/a-resilient-landscape-yanweizhou-park-in-jinhua-city-by-turenscape/

Photo by CAR (Corporación Autónoma Regional de Cundinamarca)

Water as leverage to establish partnership with local governments | Strengthening the capacity for the day-to-day implementation | Creation of new urban park and city ecological structure

Project #3: *Rio Bogota Environmental Flood Control Project, 2011–21*
Location: *Bogota, Colombia*
Description: *The objective of the Rio Bogota Environmental Recuperation and Flood Control Project was to transform the Bogota River into an environmental asset for the Bogota Capital metropolitan region by improving the water quality, reducing flood risks, and creating multifunctional areas along the river.*
The project rehabilitated eight areas—wetlands and meanders—with a total area of approximately 175 hectares, which function as flood detention areas, ecological habitats, and public spaces. The main strategies focused on reduction of flood risk and establishment of multifunctional zones along the river. Environmental improvement works included river dredging, embankment construction, meanders and wetlands, and the construction of a recreational landscape.
Benefits
Flood risk reduction, Recreation, Economy, Heat Stress Risk Reduction.
Source
World Bank
https://projects.worldbank.org/en/projects-operations/project-detail/P111479

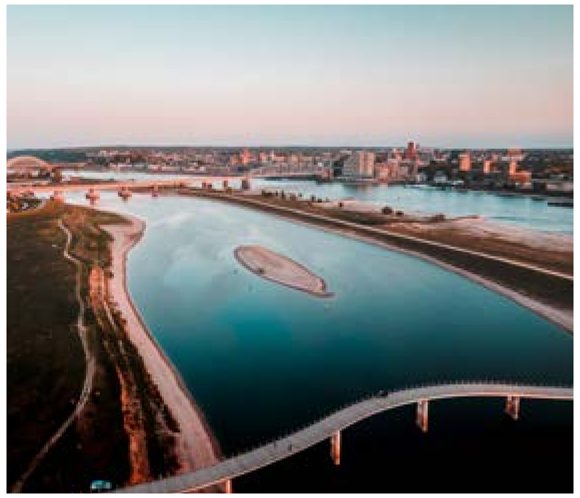


Photo by Richard Brunsveld on Unsplash

Government implementation leadership | Environmental stewardship in working with water rather than against it | Creation of new river waterfront and a new district development

Project #4: *Room for the River Programme, 2012–16*
Location: *Nijmegen, The Netherlands*
Description: *The Room for the River Programme in The Netherlands was developed to provide high water level protection for 4 million people along the Waal River catchment areas. To mitigate rising water, an existing levee was relocated 350 meters inland. A channel to cope with high water was excavated between the levee and the river, leaving an island between the channel and the river. Relocation of the levees provided the river more room that resulted in reduction to water level. In extreme floods, the water level reduces as much as 35 cm. The project increased spatial quality and environmental benefits tremendously. The entire area became a river park where nature and recreational activities now co-exist.*

Benefits
Flood risk reduction, Health and Wellbeing, Economy, Recreation, Biodiversity.
Source
Rijkswaterstaat (Dutch Ministry of Infrastructure and Water Management)
https://www.un-ihe.org/sites/default/files/13270-rvdr-brochure-governance-engels_def-pdf-a.pdf
https://www.dutchwatersector.com/news/room-for-the-river-programme

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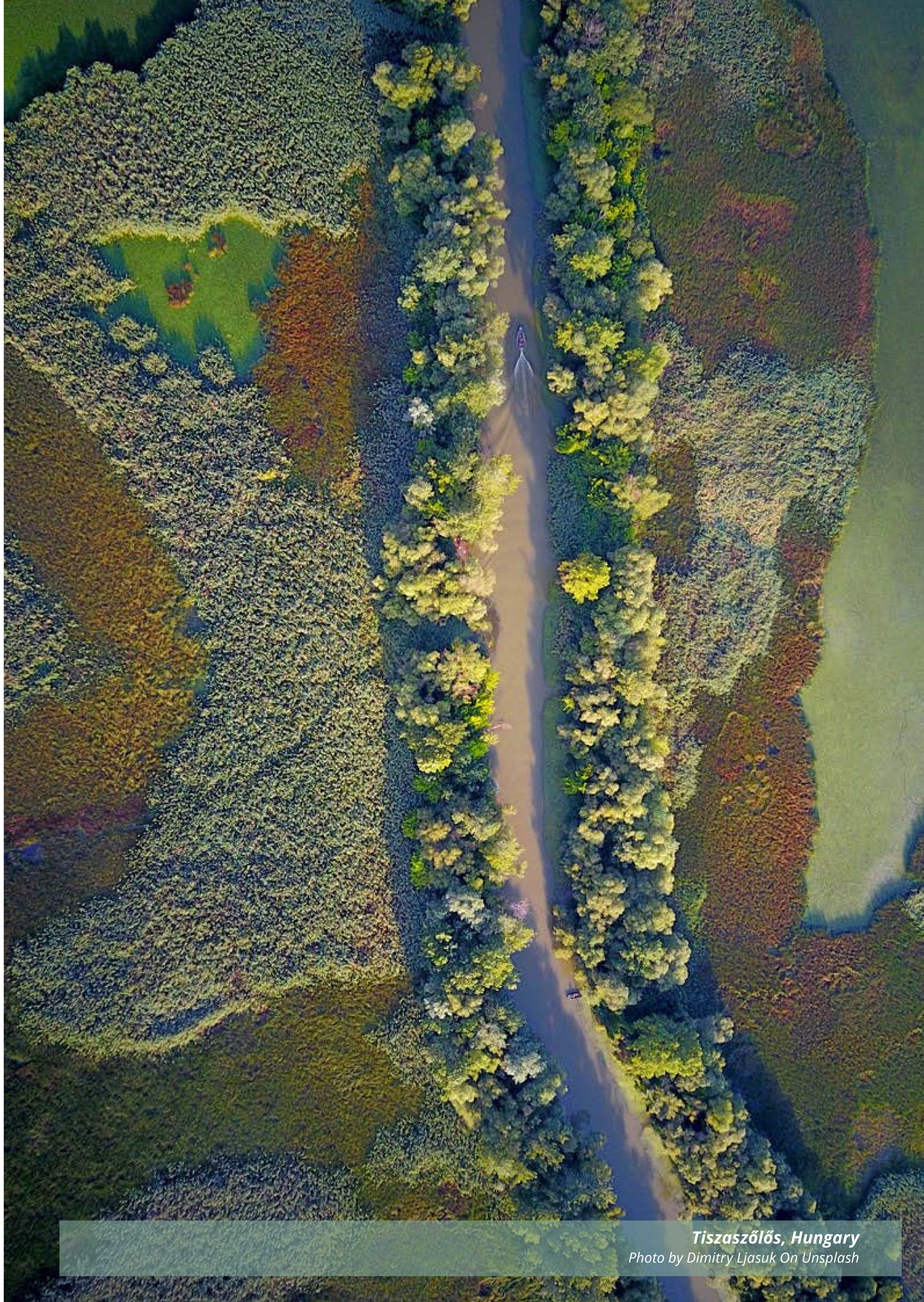
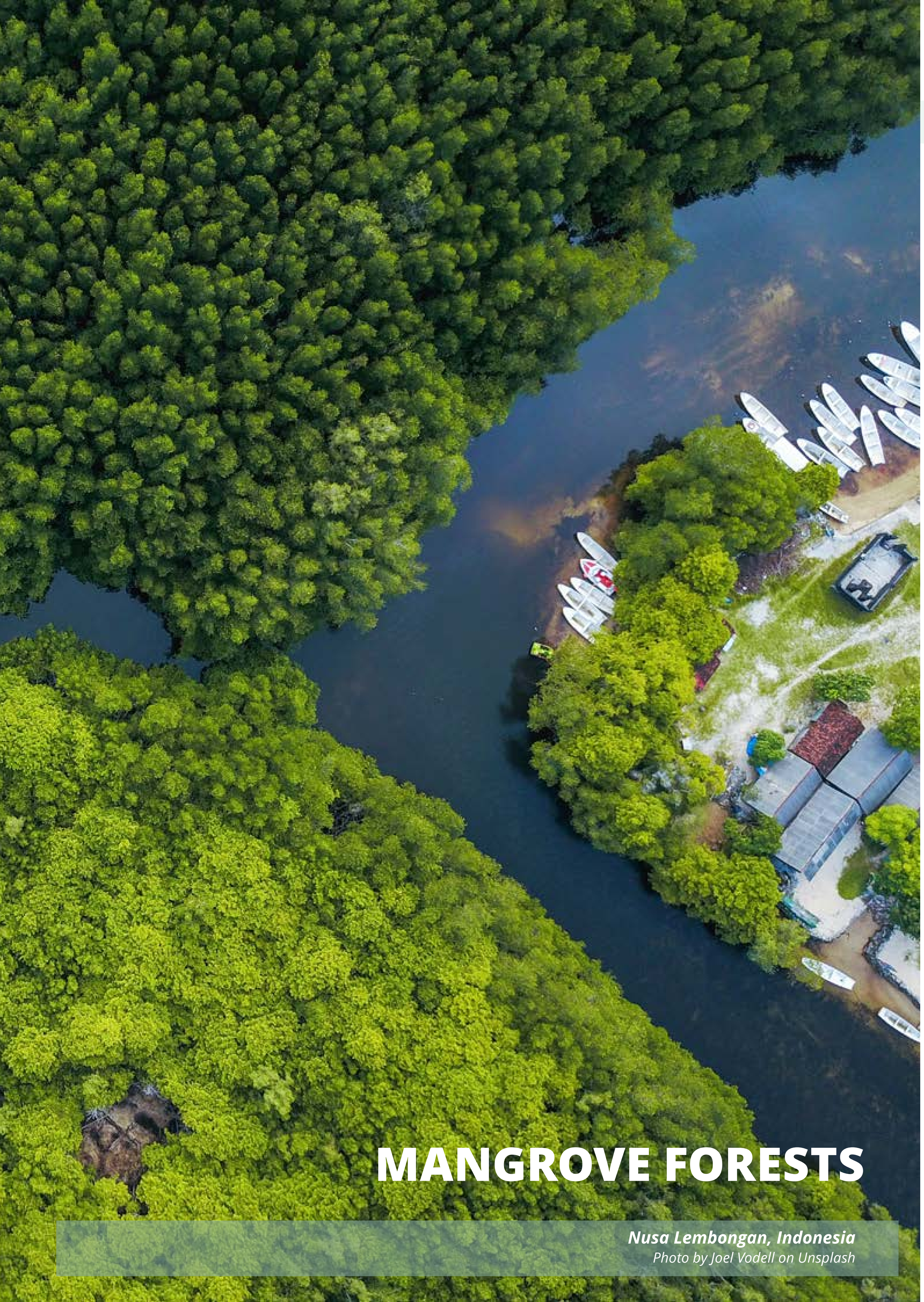


Tiszaszőlős, Hungary
Photo by Dimitry Ljasuk On Unsplash



MANGROVE FORESTS

Nusa Lembongan, Indonesia
Photo by Joel Vodell on Unsplash

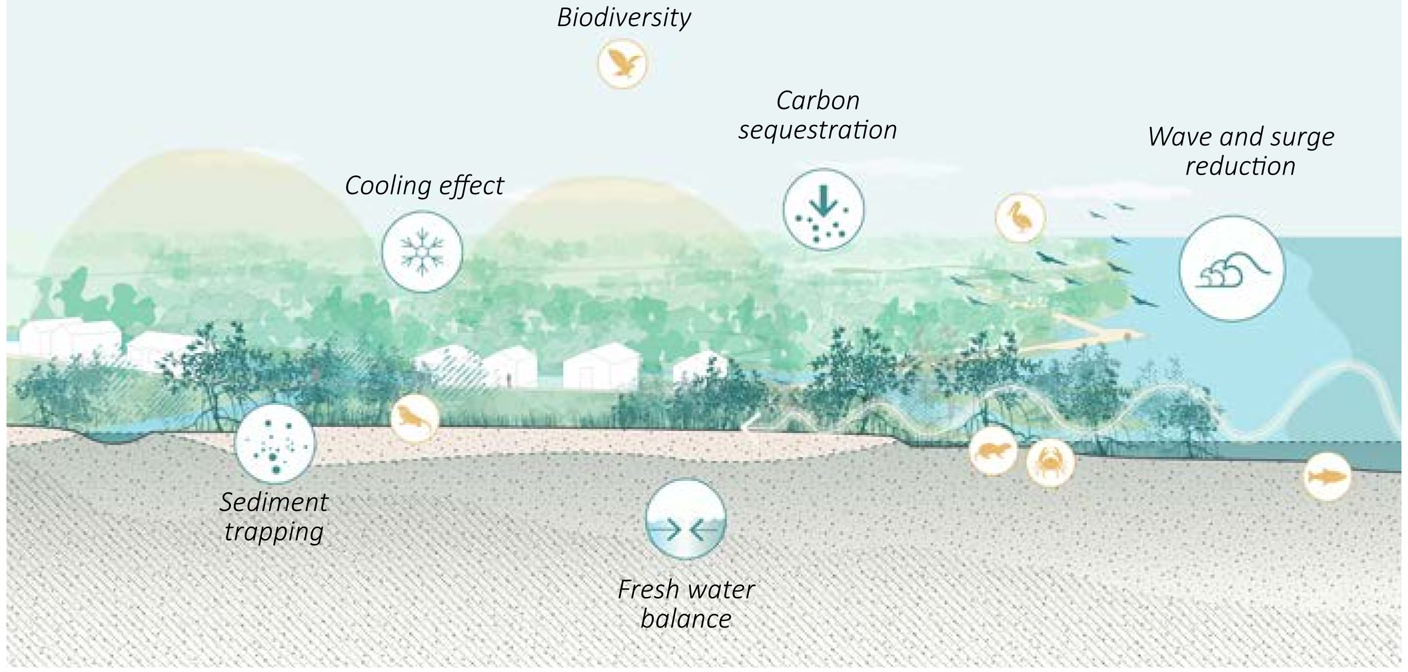
FACTS AND FIGURES

DESCRIPTION

Mangroves, also referred to as the blue forest, are a unique coastal ecosystem of halophytes — salt tolerant trees and shrubs that live in the coastal intertidal zone. About 80 different species of mangrove trees—red, white, and black mangroves—are found in many coastlines across tropical and subtropical latitudes near the Equator. They thrive in highly dynamics areas, such as deltas and coastal environments. In these coastlines, mangroves are often located close to urban environments and provide an important protective buffer from coastal hazards. Their flood protection benefits have been estimated more than $US65 billion per year globally (Menendez et al. 2020). Mangrove forests also help stabilize the coastline because they reduce erosion from storm surges, currents, waves, and tides. In addition to flood mitigation, mangrove forests also provide multiple economic and social benefits to coastal communities. Mangroves act as filters for nutrients and sediment, reduce erosion, maintain water quality, and offer feeding and breeding habitats for fish, birds, and crustaceans, critically contributing to the livelihoods of many fishing communities (Zu Ermgassen et al. 2020). Mangroves are also among the most carbon-rich forests in the tropics and one of the coastal ecosystems globally with the greatest potential to capture and store blue carbon (Taillardat et al. 2018).
Mangroves are unusually robust and demonstrate marvels of natural adaptation and resilience. Despite their important services to people and their environmental values, mangroves have been disappearing at an alarming rate (Barbier et al. 2011). In the 1970s, mangroves may have covered as much as 200,000 square kilometers, or 75 percent of the world's coastlines (Spalding et al. 2014). In the last 50 years, between 30 and 50% of mangroves have been lost globally and they continue to be lost at a rate of 2% each year (Valiela et al. 2001; Alongi 2002; FAO 2007). Major causes of destruction to mangrove ecosystems include deforestation, aquaculture expansion in coastal areas for shrimp farming, and aquaculture ponds (Barbier and Cox 2003), to freshwater diversion and land reclamation (Valiela et al. 2001) and other forms of unsustainable use of coastal resources and development. It has been estimated that 62% of global losses between 2000 and 2016 resulted from land use change, primarily through conversion to aquaculture and agriculture. Up to 80% of these human-driven losses occurred within six Southeast Asian nations (Goldberg et al. 2020). However, there is great potential to restore many mangrove areas by planting seedlings in combination with restoration of hydrological flows (Wetland International, n.d.).

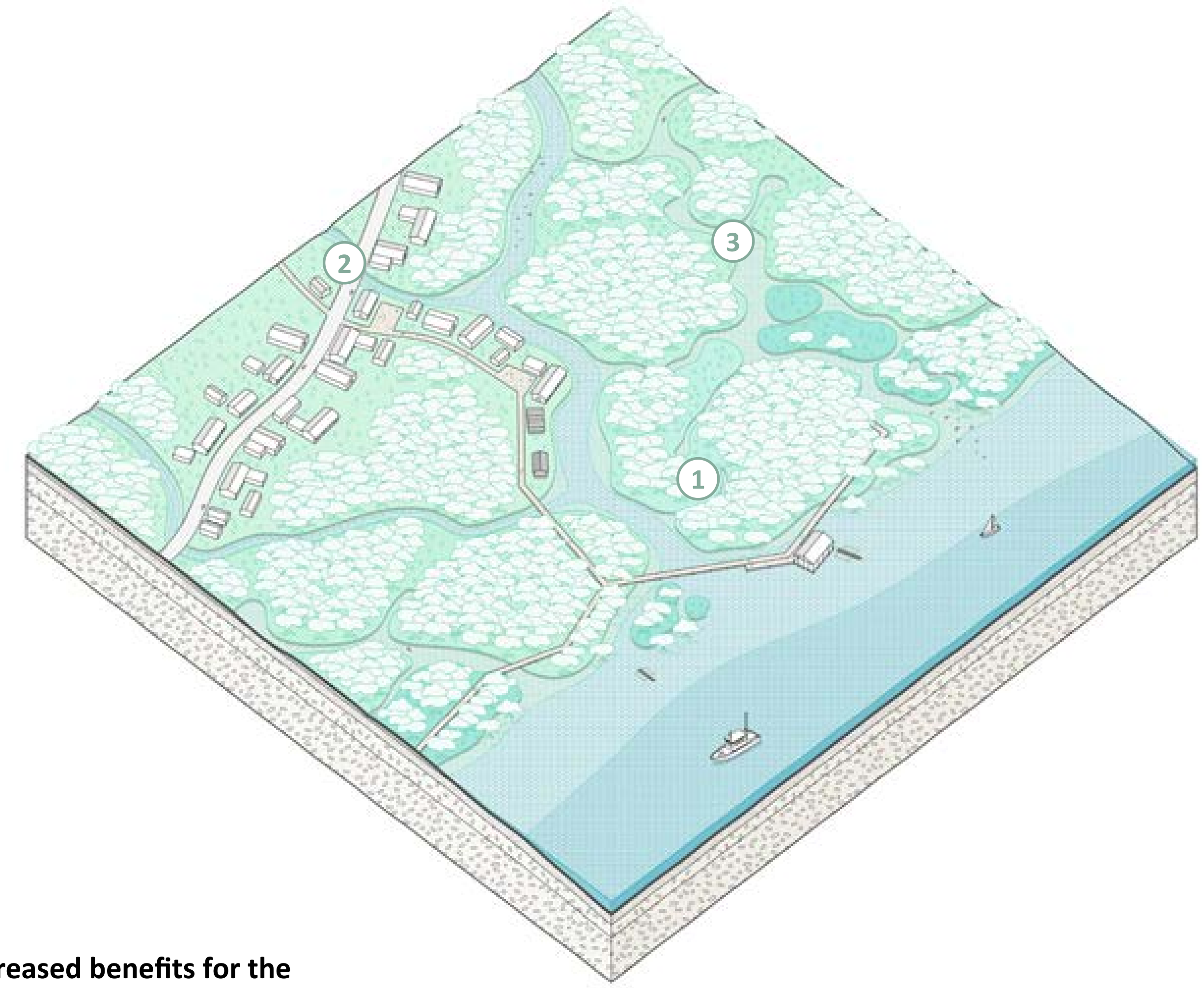
TYPE OF CITY	SCALE	APPROACH
Coastal, Delta, River, Mountain	Neighborhood, City, River basin	**Protect** – Conserve existing mangroves. **Rehabilitate, Restore, Enhance** – Restore existing mangroves and enabling conditions for natural regeneration.

PROCESSES

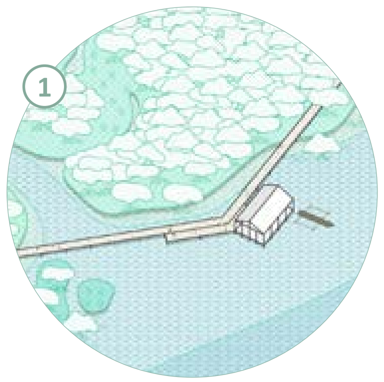


VISUALIZATIONS

VISUALIZATION OF MANGROVE FORESTS IN THE URBAN CONTEXT

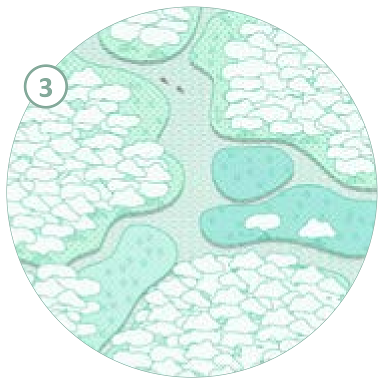


Details of increased benefits for the urban living environment



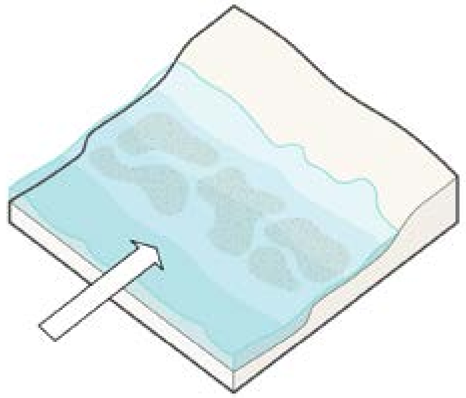
Shallow waters of mangrove forests provide a sustainable mobility network for water transportation for local communities.

Mangrove forests provide important benefits to communities that can leverage sustainable fishing and aquaculture for livelihoods or for nature-based tourism opportunities.



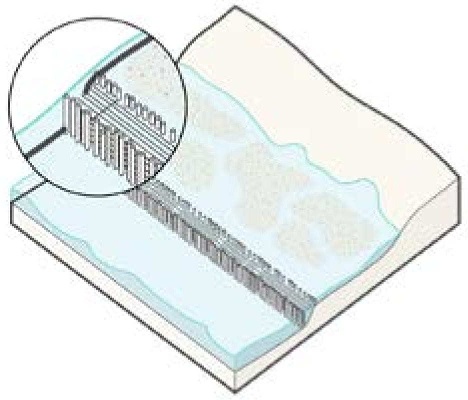
Mangrove forests improve water quality to sustain life cycles of commercial and recreational fisheries. A complex, healthy mangrove forest is also crucial for its flood mitigation performance.

SPECIAL TECHNIQUES FOR MANGROVE FORESTS



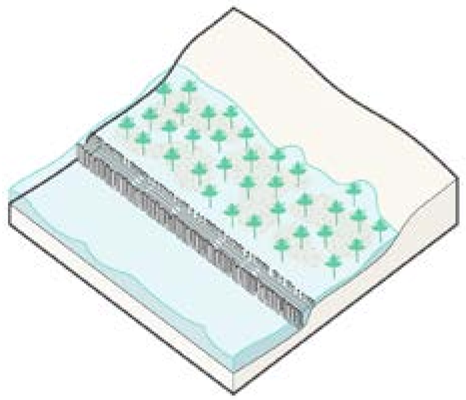
Restore hydrology

Mangrove forests rely on the tides for their growth and expansion. The strategic removal of certain water control devices will recover tidal influence and recreate the conditions for mangrove development, especially in areas were human activities previously restricted tidal environments.



Permeable structures

Permeable structures help mangrove forest restoration by capturing sediment and providing substrate for mangroves to grow naturally. The permeable structures are placed as a grid system facing the direction of the tidal current to maximize the sediment capture and dampen erosive waves. The construction can be done by local communities with structures made of local materials such as bamboo, twigs, and other brushwood (Deltares n.d.).

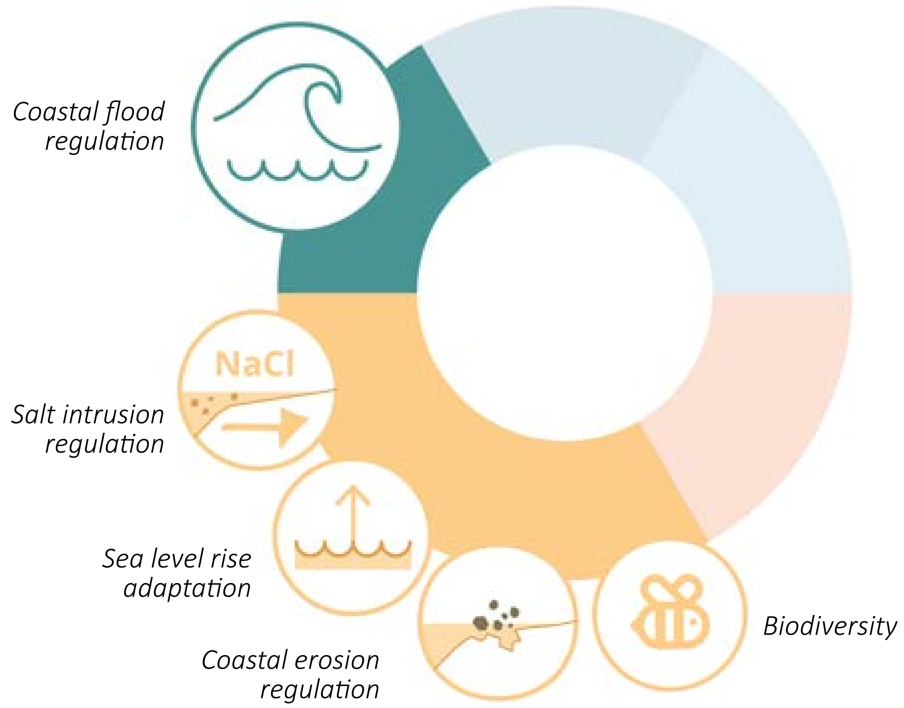


Planting or sowing

Planting or sowing mangroves requires previous study of the area to ensure that biophysical conditions are appropriate for mangrove recovery. The purpose of the planting is to assist or enrich the natural regeneration process when natural supplies of seeds and propagules are limited due to lack of nearby parent trees or lack of hydrological connection to these trees. This is often the case along coastlines that suffer widespread mangrove degradation (Deltares n.d.).

FUNCTIONS

The diagram in this section shows relevant functions of mangrove forests.



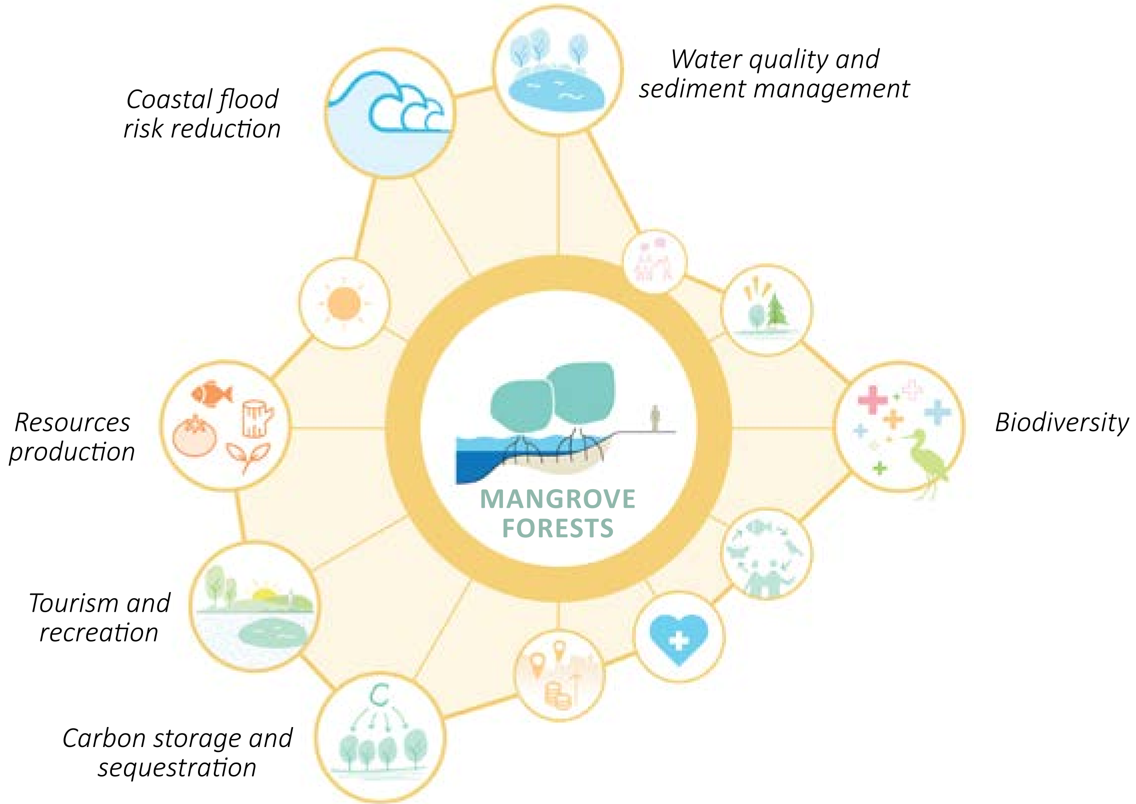
Coastal flood regulation: Mangrove forests act as natural barriers that mitigate wave action and lessen the effects of periodic storms and coastal flooding (Spalding et al. 2014; Alongi 2008). Their effectiveness and the magnitude of potential wave attenuation and surge mitigation depends on the complexity of the mangrove forest that is determined by species composition, width, structure and density, stem and root diameters of trees, age and height, shore slope, bathymetry, incident waves, and the tidal stage at the time it encounters the forest (Hashim and Catherine 2013). Research demonstrates the effects of mangrove forest on coastal flood mitigation:

- Mangroves reduce wave heights by an average of 31% (95% CI: 25–37%) (Narayan et al. 2016; Spalding et al. 2014);
- Modeling of natural mangroves suggest significant reduction in tsunami wave flow pressure in forests of at least 100 meters in width (Alongi 2008);
- Recorded water levels in southwestern Florida showed that mangroves lower flood water levels by around 93 mm/km from two hurricane events in 2004 and 2005 (Krauss et al. 2009);
- The capability of a mangrove forest to dissipate wave energy depends on its specie composition. The *Rhizophora spp*. and *Pandanus odoratissimus* are most effective in wave attenuation due to their complex aerial root structure that creates greater friction for the incoming waves (Hashim and Catherine 2013).

Other functions: Mangroves forests mitigate salt intrusion, coastal erosion, sea level rise depending on sedimentation or accretion rates of specific areas, and offset the loss of biodiversity in urban environments (Bann 1998).

BENEFITS

The diagram in this section shows a sampling of important benefits that mangrove forests can provide to people.



Coastal flood risk reduction: Mangrove forests act as natural barriers that protect coastal communities from periodic storm events and flooding. Mangrove forests reduce wave height and velocity with their dense vegetation and stabilize coastlines by trapping sediment with their root systems and during heavy rainfall or high flows in rivers (Bann 1998). Globally, they reduce flood damages by more than $US 5 billion per year (Menendez et al. 2020). Some of the cities where most people are protected by mangroves are in Vietnam, India, and Bangladesh. Many 20-kilometer coastal stretches, particularly those near cities, receive more than $US250million annually in flood protection benefits. Mangroves have been estimated to protect 15 million people per year from flooding, especially in Vietnam, India and Bangladesh (Menendez et al 2020).

Resource production: Mangrove forests are among the world's most productive fishing grounds, yielding vast numbers of fish, crabs, shrimps, and mollusks. Globally, more than 4 million artisanal fishers rely on mangroves (Zu Ermgassen et al. 2020). Mangroves also provide a sustainable supply of forest products, including wood products such as round wood, poles, fuel wood, and charcoal, and non-wood products such as nipa palm shingles, bark for tannin, traditional foods, dyes, and resins. Sustainable harvesting is required to ensure the continuity and the quality of the mangrove forest (Bann 1998).

Tourism and recreation: Mangrove forests are attractive destinations for ecotourism and offer important nature-based tourism opportunities (Spalding and Parrett 2019). They filter out sedimentation in offshore seagrasses and coral reefs and provide environments for snorkeling and scuba diving (Bann 1998).

Carbon storage and sequestration: Like inland wetlands, mangrove forests are a globally important carbon sink, with high soil and aboveground carbon densities that often exceed 1,000 tons CO_2 per ha. For example, for Indonesian mangroves, on average, carbon density is estimated at 1,083 tons CO_2 per ha (Mudiyarso et al. 2015). Mangrove restoration, particularly involving the establishment of mangrove trees, is highly productive and results in high removal rates estimated at 23.1 ton CO_2 per ha per year during the first 20 years of growth and remaining high at 10.5 tons CO_2 per ha per year, during the lifetime of mangrove stands (Bernal et al. 2018). These rates exceed those for most natural forests.

Biodiversity: Mangrove forests support the conservation of biological diversity by providing habitats, spawning grounds, nurseries, and nutrients for many animals. These include several endangered species: crocodiles, iguanas, the Royal Bengal tiger, otters, manatees, dolphins, and birds like herons, egrets, pelicans, and eagles. Mangroves also help protect offshore features such as coral reefs, seagrass beds, and shipping lanes by entrapping upland runoff sediments (FAO 2007).

Water quality and sediment management: Mangrove forests protect freshwater supplies, or inland aquifers, from salination by serving as a ground water pump and barrier between the aquifers and the sea. Mangroves also improve water quality by trapping sediments as their roots and forest complexity slow down water flow and promote the capture and stabilization of sediment. This facilitates sediment deposition and removes toxins and nutrients (Bann 1998).

SUITABILITY CONSIDERATIONS

ENVIRONMENTAL

Location and climate: Mangroves occur in tropical and subtropical coastlines between the 30° North and South of the Equator, approximately following the 20°C (68°F) isotherms of seawater temperature Rainfall and freshwater supply influence the distribution of mangroves through the reduction of salinity in an otherwise highly saline environment. In areas with low, irregular, or limited seasonal rainfall or lack of freshwater input, the number of mangrove species that can survive is limited (Spalding et al. 1997).

Hydrology: Development of mangroves is restricted to the intertidal zone.

Salinity: Best development of mangroves seedlings ranges from a salinity of 3–27 ppt. The resistance against salinity depends on species and life stage (Krauss et al, 2008). Seedlings are less resistant than adult trees, and the tolerance increases with the age (Kathires and Bingham 2001).

Inundation time: Mangroves require regular tidal flooding. Typical mangrove species such as *Avicennia spp*. and *Sonneratia* require between 7 and 13 hours a day (van Loon et al. 2007).

Wave exposure: Low. Protected coastlines are essential for mangrove communities. High wave exposure or currents can erode the sediment and lead to mangrove loss (Balke et al, 2011).

Sedimentation rate: Mangroves require sediments to sustain their elevation in the tidal range (Van Santen et al. 2007).

Soil: Mangroves grow on different substrates, but the most extensive mangroves are located in mud and muddy soils, usually found along delta coasts, in lagoons, and along estuarine shorelines (Hutchings and Saenger 1987).

Water quality: Mangroves are not suitable for areas with eutrophicated water or polluted water. High nutrient content harms mangrove development and reduces the resilience of mangroves to changes (Lovelock et al, 2009).

TECHNICAL

Natural regeneration: Mangrove forests require propagules (mangrove seedlings) for natural mangrove establishment. If these are not available, human intervention is required for sowing or planting; successful restoration also requires restoring the hydrological conditions and enough supply of sediment New seedlings may also require protection from waves and strong currents through the installation of temporary protection, such as permeable dams, until the mangroves reach enough complexity to retain the soil (EcoShape n.d).

Slope: Mangroves develop in relatively flat intertidal areas. The more extensive the shallows are, the greater the extent of mangrove development. On steep shores with shelves, where the shallow water zone is narrower, only fringe communities develop (Hutchings and Saenger 1987).

Hybrid infrastructure: In cases where protective infrastructure does not restrict mangrove development and does not impede landward migration in response to sea level rise, mangroves can be effectively combined with berm or levee infrastructure because they can reduce wave action and overflow. However, planting schemes on the levees should be avoided as they could produce potential damage of the roots to levees' slopes.

Dimensions: For effective wave action attenuation and protection against tsunamis, mangrove forests require complexity, width, and density of trees (Spalding et al. 2014). A width of at least 150 meters is required for sufficient wave dampening (Othman 1994). Additionally, the type of species and the density of the forest affects the effectiveness of mangroves (Hashim and Catherine 2013). Data analysis shows:

- 100 m of *Sonneratia* forest can reduce wave energy up to 50% (Alongi 2008).
- 50 m of *Avicennia* forest is sufficient to reduce waves from 0.3 to 1 m in Sungai Besar, Malaysia, corresponding to 70% wave height reduction (Othman 1994).

URBAN

Land use: Coasts, park areas in coastal and river mouth areas, and natural reserve areas are well suited for mangrove forests.

Urban density: Suitable urban density for mangrove forests ranges from low to medium.

Area: Large to extra-large. Mangrove forests are NBS typically designed for application at a city and river basin scale as they require sufficient width and extent to represent an effective buffer against storms and deliver other services, for example, nurseries for fisheries.

Integrated urban planning: Mangrove forests can be an integral component of ecoconservation programs, tourism programs, food provision program, and new urban parks.

MAINTENANCE

Mangroves require monitoring strategies to control the correct establishment and evolution of the system, and intertidal dynamics that should keep a balance between marine seawater and freshwater input. Policies and management plans must ensure that the restored areas are able to maintain the hydrological processes for a functional mangrove forest.

COSTS

COST CONSIDERATIONS

Land

Access to or ownership of land in deltas and coastal intertidal areas is required for mangrove forest protection and restoration.

Land may be public or private. Surface of land required for protection and/or restoration of mangroves may range from small to large extents, with different costs associated to the type of development and land uses.

Engagement and collaboration with landowners and stakeholders are necessary.

Example land-related costs:

- Land acquisition
- Land use (e.g., payments to landowners)
- Land protection costs, including managing and controlling access
- Community resettlement

Construction and implementation

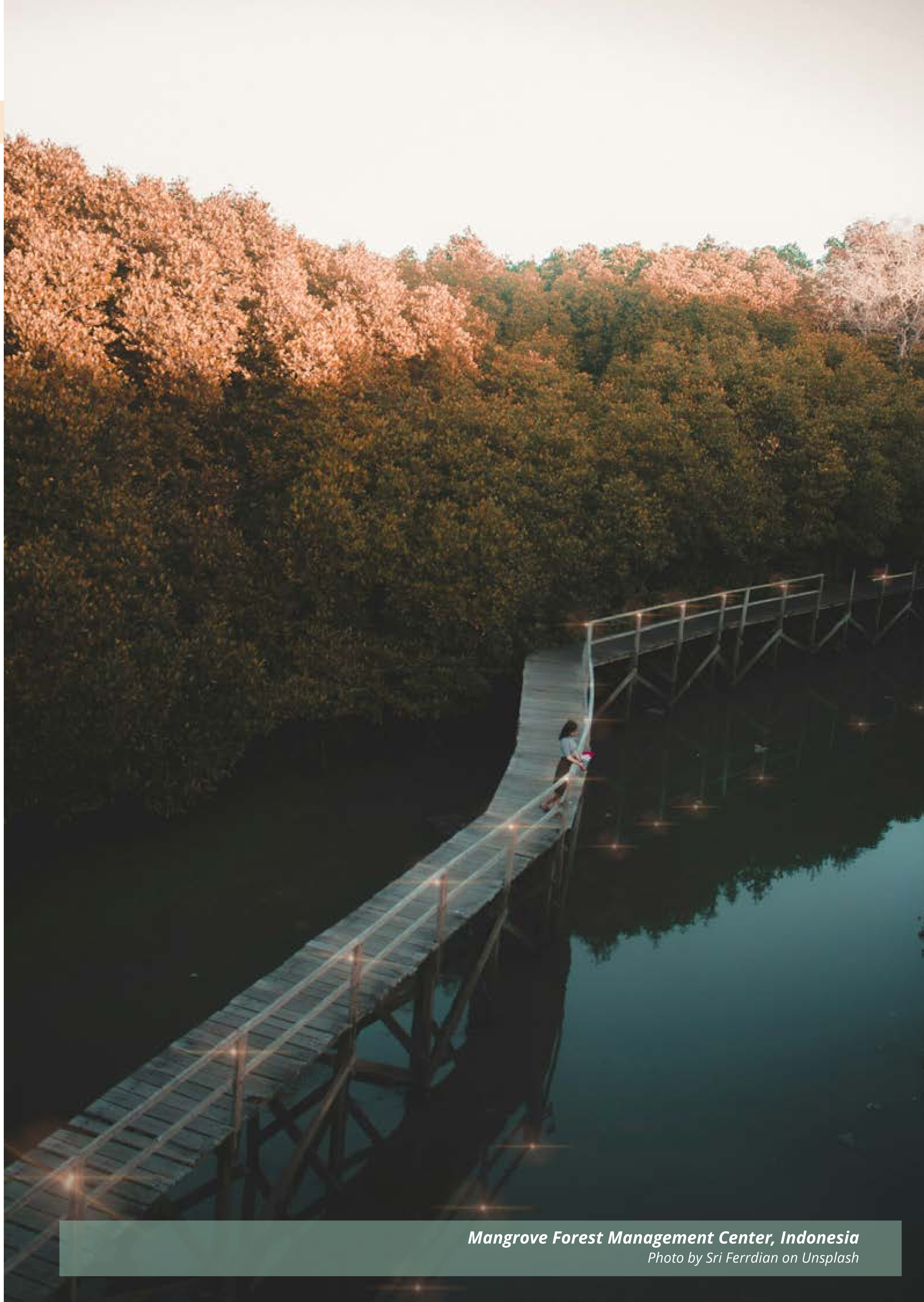
The costs of mangrove restoration can vary considerably depending on location, project area, site conditions, specific restoration activities to be implemented, and local labor and material costs.

Maintenance

Maintenance of mangrove forests is necessary due to the complex interplay of upstream (land) and downstream (ocean) processes on mangrove health. Maintenance will involve addressing upstream and downstream threats to mangrove health, as well as replanting mangroves in project sites depending on mangrove survival rates.

UNIT COST EXAMPLES THROUGHOUT THE GLOBE

- *A review of projects found that mangrove restoration costs could range from **US$225–US$216,000/ha** in developed countries, excluding the costs of the land (Lewis 2005).*
- *Globally, a meta-analysis provided a global cost range from **US$500–US$54,300/ha**. (Narayan et al. 2016), whereas other global analysis determined that mangrove restoration costs range from **US$1,506–US$49,324/ha** (Bayraktarov et al. 2016).*
- *In the Caribbean, restoration-site costs are **US$5,077/ha** (Adame et al. 2015).*
- *In Thailand, mangrove rehabilitation costs range from **US$8,812–US$9,318/ha** (Barbier 2007).*
- *Restoration costs for mangrove restoration in Indonesia included semipermeable dam construction (**US$260,000** in first-year costs that included site preparation, material, and construction), and mangrove planting and replanting (**US$85,000** in first-year costs), including seed, bamboo, rope, labor, boats and fuel) (Hakim 2016).*
- *For Vietnam, mangrove maintenance has been estimated at **US$7.1/ha**, at least four years after planting seedlings (Marchand 2008).*
- *In Kenya, a restoration project of mangrove ecosystem cost around **US$1,548.6**, with preparation and planting costs, and **US$143** for annual thinning and maintenance costs (Kairo et al. 2009).*
- *Maintenance costs for mangrove restoration in Indonesia were estimated as roughly 10% of total planting costs (Hakim 2016), at **US$258,000** per year for a semipermeable dam, including dam construction and materials, and **US$8,600** per year for mangrove replanting.*



Mangrove Forest Management Center, Indonesia
Photo by Sri Ferrdian on Unsplash

NBS IN PRACTICE

The four projects in this section highlight good practices and lessons learned about mangrove forests, drawn from the growing popularity of NBS throughout the globe.

Photo by Kongjian Yu / Turenscape

Mangrove restoration approach

Showcase of ecological restoration in a city environment

Environmental stewardship

Project #1: *Sanya Mangrove Ecological Park, 2015–19*
Location: *Hainan Island, China*
Description: *The 30-year urban development has brought tremendous ecological damage to Sanya. Detritus from garbage covered waterways and the concrete flood wall had erased the mangrove and floodplain ecosystem, and had blocked the connection between sea water and rainwater in upstream cities. The goal of the design was to restore the mangrove ecosystem and to demonstrate other urban restoration and ecological restoration projects. The design solved four major site problems for mangrove restoration: strong tropical monsoon floods gathered in the upper reaches; polluted urban runoff; travel ability, and combining public recreation with natural restoration. The Park is a great success in restoration and not only demonstrates its benefits to nature, but also brings tremendous improvement to public services.*
Benefits
Flood Protection, Recreation, Biodiversity, and Education.
Source
Turenscape Landscape Architecture
https://www.turenscape.com/en/project/detail/4654.html

Photo by Piqsels

Mangrove restoration approach

Equitable distribution of flood protection

Boost economic growth

Project #2: *Mangrove plantation in Vietnam, 1994–2005*
Location: *Thai Bin, Vietnam*
Description: *Restoration and rehabilitation of mangrove forests have been a central focus of both governmental and nongovernmental actors in Vietnam, as a means to combat the loss of natural coastal protection by safeguarding sea levees, reducing the risk of flooding and protecting livelihoods. The investment has translated into the creation of 9,462 hectares of forest (8,961 of them mangroves) in 166 communes and the protection of approximately 100 km of levee lines. It is estimated that approximately 350,000 beneficiaries were reached directly by the project's intervention, while another 2 million were indirectly protected through the afforestation efforts. Mangroves have also had a positive impact on the provision of additional income for coastal communities through an increase yield of aquaculture products such as shells and oysters.*
Benefits
Flood Protection, Community, Health and Wellbeing, Economy.
Source
International Federation of Red Cross and Red Crescent Societies (IFRC)
http://ifrc-media.org/interactive/wp-content/uploads/2016/06/2.-Mangrove-plantation-in-Viet-Nam.pdf

Photo by Rob Barnes / GRID-Arendal

Mangrove restoration approach

Community involvement

Gender empowerment

Project #3: *Mangrove Restoration at Gazi Bay, 2004–09*
Location: *Gazi Bay, Kenya*
Description: *Gazi Bay mangrove forests have been used by local people as a source of building and fuel wood as well as for fishing. Consequently, significant mangrove deforestation occurred, with much of the forests cut down or otherwise degraded. Without the trees, the shores of the bay became muddy and vulnerable to erosion. Recent mangrove rehabilitation projects used a community participatory approach to restore degraded areas of Gazi Bay and successfully restored the functions of mangroves so they could continue providing goods and services to the local community, while maintaining the integrity of its own ecosystem. The project included the planting of 6,077 mangrove trees in 46 experimental plots. Following the restoration, the women of Gazi, with support from the Kenya Marine and Fisheries Research Institute, established an ecotourism venture that benefits from the value of the mangrove's scenic beauty and biodiversity.*
Benefits
Flood Protection, Social, Economy, Education.
Source
Society of Ecological Restoration (SER)
https://www.ser-rrc.org/project/kenya-mangrove-restoration-at-gazi-bay/

Photo by David Stanley on Flickr

Mangrove protection approach

Community based land use mapping

Awareness of key government agencies and local communities

Project #4: *Liberia's Mangrove Forests and Coastal Mangrove, 2011–14*
Location: *Liberia*
Description: *Since the 1980s, almost 65% of Liberian mangrove forests have disappeared, owing to urbanization, construction of infrastructure, mining, and oil extraction. Recent conservation and restoration efforts called for an extensive community engagement process with various stakeholders working together to establish new and more sustainable land use rules. As a result, marine and coastal protection areas were established, to significantly impact agriculture, fisheries, and forestry. In addition to ecosystem restoration objectives, mangrove protection and restoration measures were viewed within the framework of economic development and poverty alleviation. The project anticipates increased employment, new enterprise, and property ownership as beneficial outcomes*
Benefits
Flood Protection, Social, Economy, Education, Gender Empowerment.
Source
Global Environment Facility (GEF), World Bank
https://www.conservation.org/docs/default-source/gef-documents/liberia-mangroves/5712-liberia-mangroves-stakeholder-engagement-plan.pdf?sfvrsn=8e6d8c96_2

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SALT MARSHES

Folly Beach, SC, USA
Photo by Bre Smith on Unsplash

FACTS AND FIGURES

DESCRIPTION

Salt marshes are transitional coastal wetland ecosystems with high levels of biodiversity. Tidal marshes occur along low wave energy coastlines as a result of fine sediment accumulation and colonization by halophytic or salt tolerant plants. They are a common habitat in estuaries worldwide, particularly in the middle to high latitudes, and are among the most productive ecosystems on Earth. Based on their position with respect to the mean water level, the extent of salt tolerance, and the composition of species, three main types of salt marshes exist: pioneer zone, the low marsh, and the middle or high marsh.

Salt marshes serve as a buffer from storms and floods and help prevent erosion by reducing waves and surges and stabilizing sediment. They may also reduce flooding by slowing and absorbing rainwater. Salt marshes also provide other essential ecosystem services: they filter pollutants from land runoff and hence help maintain water quality; provide critical habitat for marine species at different stages; and represent carbon sinks as they accumulate carbon in the soil. Salt marsh ecology is a complex food web and biomass that comprises primary producers, and primary and secondary consumers. Among primary producers are vascular plants, macroalgae, diatoms, epiphytes, and phytoplankton, while primary consumers are composed of zooplankton, macrozoa, mollusks, and insects. The low physical energy and high grasses provide a refuge for animals and safe and abundant habitat and breeding grounds for the birds. Tides supply nutrients for plants and carry out organic material that feeds fish and other coastal organisms. Over time, salt marshes build layers of deep mud and peat, which are waterlogged, root filled, spongy, and have extremely low levels of oxygen. This capacity to grow as a physical barrier and keep pace with the rising sea level may render salt marshes instrumental in protecting human habitat from flooding.

TYPE OF CITY

Coastal
Delta
River
Mountain

SCALE

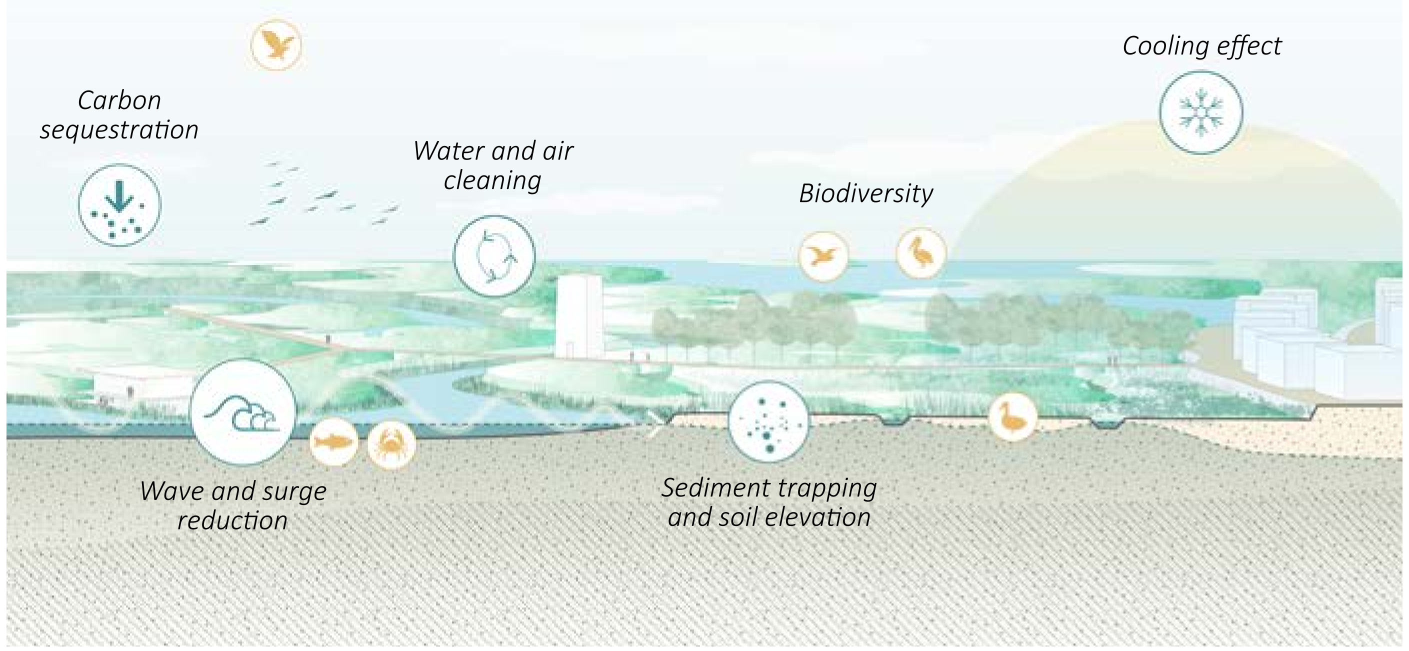
Neighborhood
City
River basin

APPROACH

Protect
Conserve existing marshes.

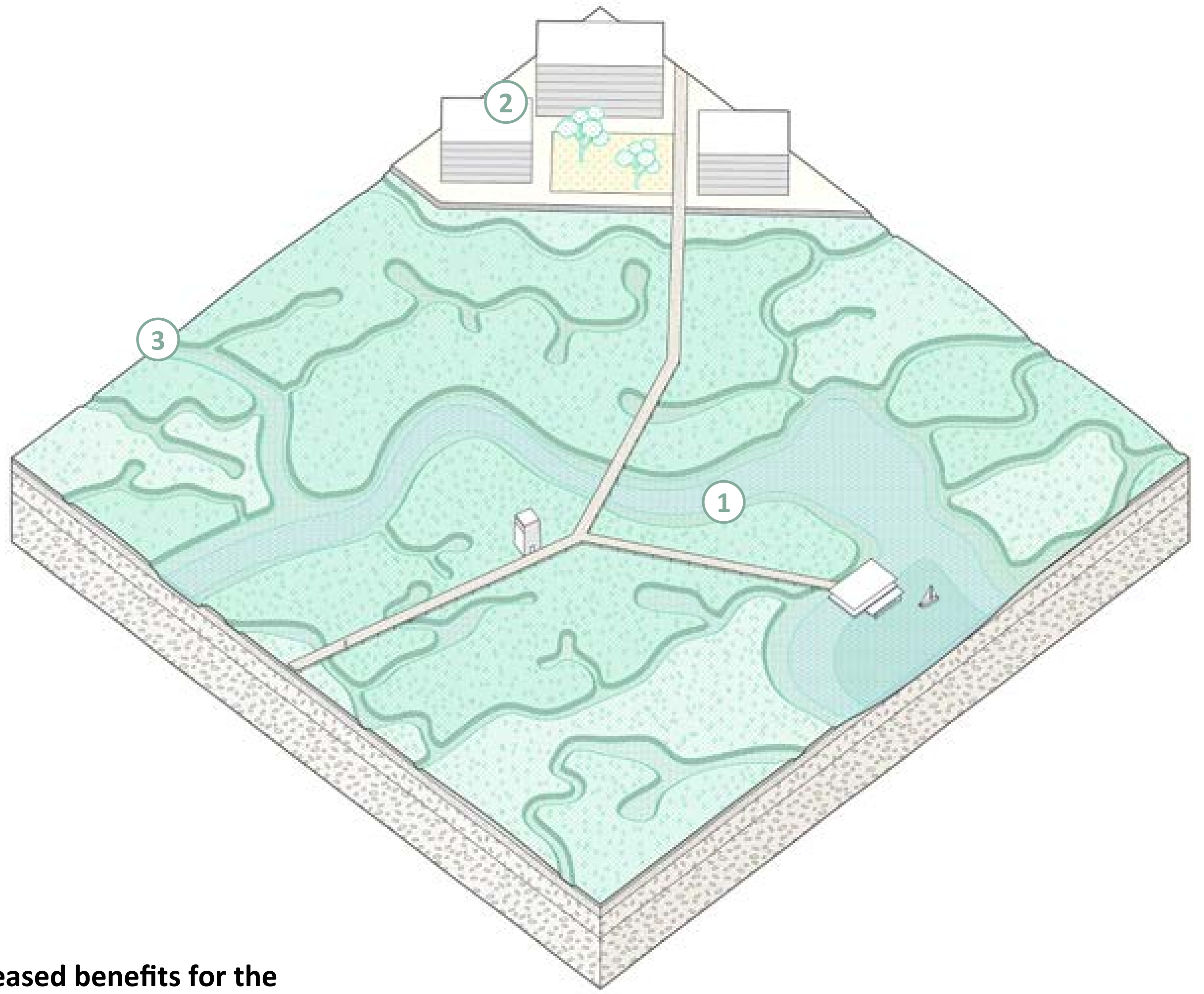
Rehabilitate, Restore, Enhance
Rehabilitate and re-establish a destroyed or degraded marsh.

PROCESSES

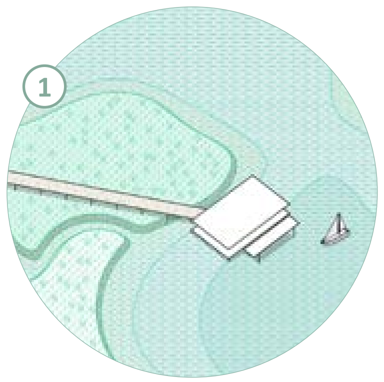


VISUALIZATIONS

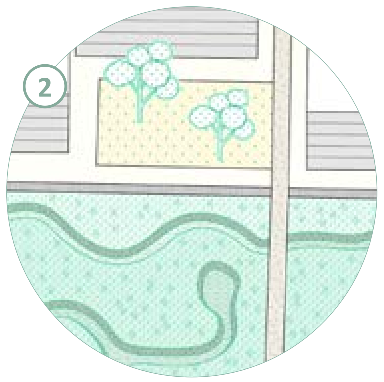
VISUALIZATION OF SALT MARSHES IN THE URBAN CONTEXT



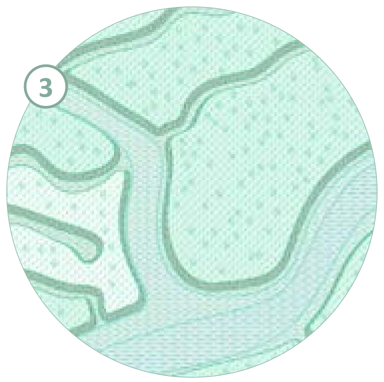
Details of increased benefits for the urban living environment



Salt marshes facilitate the safe interface of the land and sea by adapting to tidal dynamics and wave action.

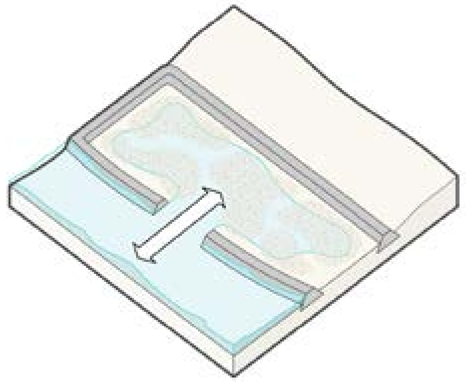


Land use zoning should facilitate the natural growth, expansion, and migration of salt marshes while protecting people, property, and gray infrastructure.



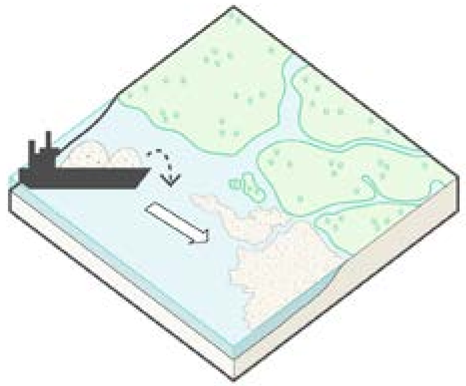
Salt marshes provide multiple ecosystem services. They also serve to connect the urban seafront with the natural system.

SPECIAL TECHNIQUES FOR SALT MARSHES



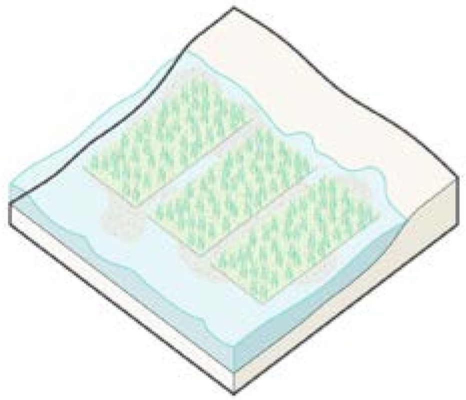
Restore hydrology

Salt marshes exist in synergy with the sea. They rely on tidal dynamics and local floods for their growth and expansion. Waves bring nutrient-rich sediment, which they capture, store, and use as additional growth medium. Areas where human actions disrupted this natural connection in the past may be strategically recovered by removing obstacles, restoring the tidal influence, and sediment flows to enable the conditions for salt marsh development.



Mud Motor

The Mud Motor technique is designed to gradually deliver additional growth to salt marshes. Dredged mud is placed out in the open, and close to the marsh, spread out so the tidal flow can slowly wash it off and deposit it in the salt marsh. This method imitates the natural sediment movement and allows the marsh to adjust gradually. The mud can be obtained from local sources, including harbor maintenance works (Baptist et al. 2021).

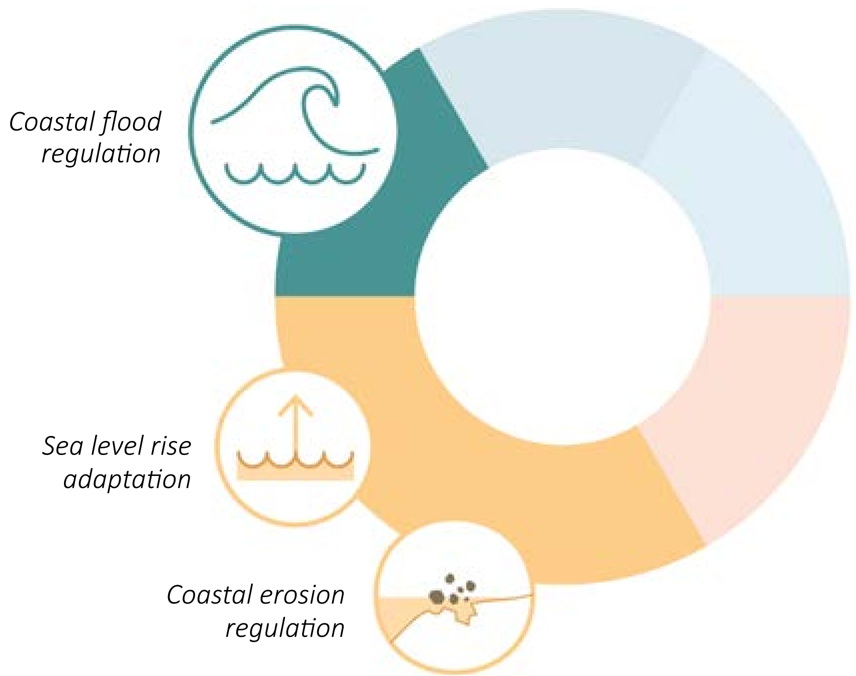


Planting mats

A planting mat is a bioengineered technique for salt marsh restoration. It facilitates the re-establishment of salt marsh species. Plants are grown on relatively dense coconut mats, where the roots can grow. The mats are then placed in the marsh protecting younger species during their initial growth phases. The coconut fibers degrade over time but the plants remain (EcoShape n.d.).

FUNCTIONS

The diagram in this section shows relevant functions of salt marshes.



Coastal flood regulation: Salt marshes provide coastal protection from waves and storm surges. Salt marsh ecosystems reduce the height of wind waves (Möller et al. 2014) and storm surges (Krauss et al. 2009; McGee et al. 2006; Wamsley 2010) through additional flow resistance by wetland vegetation and wetland geomorphology. Moreover, coastal wetlands reduce storm surges by increasing the storage area along estuaries or tidal rivers (Smolders et al. 2015).

Research demonstrates various effects of salt marshes on coastal flood mitigation:

- Salt marshes are estimated to reduce non-storm wave heights by an average of 72% (95% hCI: 62–79%) and wave energy by 60% (Narayan et al. 2016).
- The existence of stiff rigid shrubs may be up to three times more effective in wave damping than flexible grasses (Van Veelen et al. 2020).
- Studies in US mid-Atlantic coastal wetlands, estimate a reduction on flood water levels by 0–700 mm/km (Paquier et al. 2017).

Other functions: Salt marshes also prevent coastal erosion (Shepard et al. 2011), protect, and stabilize coastlines by capturing and storing sediments and stabilizing the soil with its roots (McKinley et al. 2018). They can also keep up with sea level rise as they can grow at a rate of 10 millimeters per year (Kirwan et al. 2010). Salt marsh vegetation has a significant positive effect on shoreline stabilization as measured by accretion, lateral erosion reduction, and marsh surface elevation change (Shepard et al. 2011).

BENEFITS

The diagram in this section shows a sampling of important benefits that salt marshes can provide to people.

Coastal flood risk reduction: Salt marshes protect coastal communities from waves and storm surges. They also reduce erosion by stabilizing the sediments (Davy et al. 2009). Morgan et al. 2009). They are more efficient in offsetting the effect of storms than unvegetated mudflats (Barbier et al. 2011). Key salt marsh characteristics that are positively correlated to both wave attenuation and shoreline stabilization are vegetation density, biomass production, and marsh size (Shepard et al. 2011).

Resources production: Thanks to their complex structure, salt marshes provide safe and attractive habitat for young fish, shrimp, and shellfish that are inaccessible to larger predator fish (Boesch and Turner 1984). Therefore, salt marshes are also a resource to host important aquaculture and fishing; and can help maintain sustainable fisheries (Boesch and Turner 1984; MacKenzie and Dionne 2008). For example, salt marshes account for 66% of the shrimp and 25% of the blue crab production in the Gulf of Mexico (Zimmerman et al. 2002).

Tourism and recreation: Salt marshes also provide recreational and tourism opportunities because they are an important habitat for many species of birds and other wildlife. In urban areas, they offer recreation, education, and research opportunities, as well as leisure pursuits (Barbier et al. 2011).

Carbon storage and sequestration: Like mangroves and other wetlands, salt marshes are productive ecosystems that store and sequester significant amounts of carbon. On average, salt marshes store 334 tons CO_2 per ha (Alongi 2020), mostly through accumulation in the soil. As an indication of sequestration rates: in Australian salt marshes, the annual mean sequestration rate was estimated at 0.55 tons CO_2 per ha per year (Macready et al. 2017).

Biodiversity: Salt marshes provide important habitat with high diversity of plants, animals, birds, and insects. Salt marshes are also crucial spaces for breeding, wintering, and feeding grounds for local and migratory species of birds (McKinley et al. 2018). Many salt marsh areas, close to urban areas, are also designated Ramsar sites of international importance (UNESCO 1971).

Water quality and sediment management: Salt marshes act as natural filters that purify water entering the estuary (Mitsch and Gosselink 2008). Tall grasses create friction that reduces the velocity of river or stormwater that passes through the marsh (Morgan et al. 2009). They also capture and store suspended, nutrient-rich sediments that nourish the marsh. The ability of salt marshes to filter water and remove pollutants benefits both adjacent ecosystems and people (Barbier et al. 2011).

SUITABILITY CONSIDERATIONS

ENVIRONMENTAL

Location and climate: Salt marshes occur in many coastlines in middle to high latitudes. They form the upper part of the intertidal zone—the interface between land and sea—and are strongly controlled by geomorphological, physical, and biological processes shaped by local climate factors. Salt marshes rely on the tidal regime and wind–wave conditions. They develop best in bays and estuaries with low wave exposure and a surplus of fine, nutrient-rich sediment (Whitfield and Elliott 2011).

Hydrology: Salt marshes form the upper portion of the intertidal mudflats, between the mean high-water neap tides and the mean high water spring tides (Mccowen et al. 2017).

Salinity: Salt marshes have an average salinity between 18.0 and 35.0 ppt (Odum 1988).

Current velocity: A current velocity of 1.2 m/sec is considered as an upper threshold for salt marsh edge stability (Van Loon-Steensma et al. 2012).

Wave exposure: Salt marshes require low to medium wave exposure. An ideal setting would balance enough sediment suspended in the marsh with transport potential through regular flooding to the upper parts of the marsh (EcoShape).

Sedimentation rate: More than 20 mg/L concentration is necessary for marshes to keep up with conservative projections of sea level rise (Kirwan et al. 2010).

Soil: Salt marshes grow on various substrates from pure sand to clay and peat (Olff et al. 1997). The availability of silt and clay in the substrate increases the stability and ability to develop (Ford et al. 2016).

TECHNICAL

Natural regeneration: Salt marsh formation normally occurs naturally, from the seeds and propagules of established marshes. Seeds and propagules are transported by water. They can travel large distances and establish in new places quickly. Where natural colonization does not occur, restoration techniques can be used to start the process by restoring its hydrology and addressing the causes of limited sediment supply. Artificial sowing or planting, for example using planting mats or seedlings, can be used to restore and build a marsh (EcoShape n.d.).

Slope: Salt marshes develop on slopes ranging from 1:50 to 1:500. A new marsh would typically require to be set on a slope of 1:100 (Van Duin and Dijkema 2012). Slopes and tidal ranges determine three zones in a salt marsh:

- Pioneer zone: 40 cm below mean high tide (MHT);
- Low marsh: inundated during mean spring tides (100–400 floods per year);
- Middle or high marsh: with fewer than 100 floods per year.

Hybrid infrastructure: Salt marshes can be effectively combined with berm or levee infrastructure in situations where the infrastructure does not alter the hydrological and sediment conditions that are needed for the establishment and future inland migration of salt marshes in response to sea level rise.

Dimensions: Salt marshes require a minimum width to mitigate wave action effectively. Dependent on the marsh morphology and vegetation characteristics, a required width of at least 200 meters is required to achieve up to 40% wave mitigation (Van Loon-Steensma et al. 2015). Salt marshes of up to 6–10 km wide are required to reduce storm surges (Davy et al. 2009).

URBAN

Land use: Natural estuaries, coastal areas, parks, and nature preserves in intertidal environments are adequate areas for salt marshes.

Urban density: Low to medium density urban areas are suitable for salt marshes.

Area: Large to extra-large. Salt marshes are NBS typically designed for application at a city and river basin scale as they require sufficient width and extent to represent an effective buffer against storms and deliver other services.

Integrated urban planning: Salt marshes can become an integral component of ecoconservation and tourism programs, representing a key attraction as part of urban parks and landscape plans.

MAINTENANCE

Salt marshes require monitoring to control their establishment and evolution. Policies and management plans should prevent encroachment on the restored areas and maintain the appropriate hydrological conditions. The required maintenance should be included in the restoration strategy. Some techniques, such as salt marsh restoration by dredging and added nourishment, may require significant maintenance, while other restoration approaches that employ brushwood dams or similar permeable structures, have additional costs. However, these maintenance approaches can increase growth and success rates (Vuik et al. 2019).

COSTS

COST CONSIDERATIONS

Land

Access to or ownership of land in coastal intertidal areas is required for salt marsh protection and restoration.

Land ownership may be public or private.

Land area required for salt marsh protection and/or restoration is large, which increases costs associated and makes engagement and collaboration with multiple landowners and stakeholders necessary.

Example land-related costs:

- Land acquisition
- Land use (e.g., payments to landowners)
- Land protection costs, including managing and controlling access
- Community resettlement

Construction and implementation

Restoration costs associated with salt marshes includes removal of obstacles to hydrological flow, dredging, and adding nourishing materials (Vuik et al. 2019).

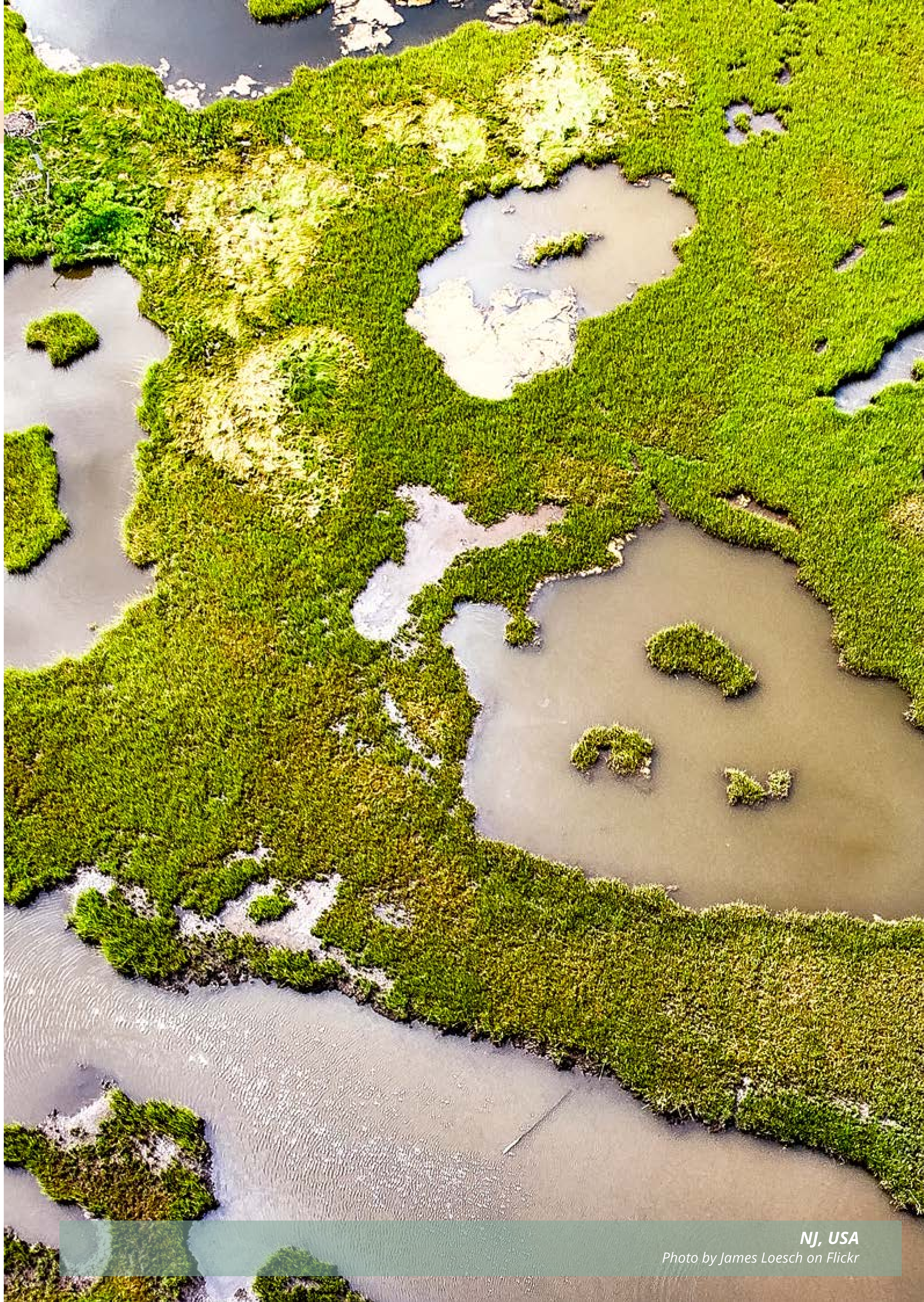
Maintenance

Maintenance needs for salt marshes will depend on how well the marshes are functioning; but in general terms, maintenance costs for functional salt marshes are low.

However, climate change, storm surges, and upstream process on land may impact salt marsh functioning and health. To support effective performance, maintenance will include monitoring to identify plant health and may include dredging and nourishment. The use of permeable structures constructed for salt marsh restoration may also be required.

UNIT COST EXAMPLES THROUGHOUT THE GLOBE

- *Median restoration costs for salt marshes from a global study are estimated at* ***US$11,100/ha*** *but can range from* ***US$100—US$33,000/ha*** *(Narayan et al. 2016).*
- *A study from New England, in the U.S., estimated that salt marsh restoration cost* ***US$39,500/ha (US$16,000/acre)*** *on average across eleven projects, with planning construction, and monitoring accounting for about 10%, 75%, and 15% of total restoration costs, respectively (Louis Berger and Associates 1997).*
- *Capital costs for salt marsh restoration in the UK is estimated to range from* ***US$14,800—US$81,000/ha*** *of restored habitat, including land acquisition costs (Cambridge Econometrics 2021).*
- *In New York City, costs for marsh-edge restoration have been estimated at* ***US$1.54 million/ha*** *(Propato et al. 2018).*
- *Monitoring costs of salt marshes can be significant, on average accounting for* ***15% of total project*** *costs across eleven salt marsh restoration projects in New England (Louis Berger and Associates 1997).*



NJ, USA
Photo by James Loesch on Flickr

NBS IN PRACTICE

The four projects in this section highlight good practices and lessons learned about mangrove forests, drawn from the growing popularity of NBS throughout the globe.

Photo by Martin Baptist

Salt marsh restoration approach | Regional development effort | Knowledge development for applicability

Project #1: *Salt Marsh Development in Delfzijl; Marconi project, 2018–21*
Location: *Delfzijl, The Netherlands*
Description: *Delfzijl project is restoring salt marshes by reusing sediment from the port of Delfzijl and the Eems-Dollard Estuary. The project was launched by the municipality of Delfzijl and is a part of the Marconi Buitendijks regional development effort. In addition to testing the technical aspects of salt marsh restoration, the project addresses several major issues faced by the municipality: a shrinking population, sea level rise combined with subsidence, and the poor ecological condition of the Ems-Dollard. The new marsh will improve water quality, provide new habitat for many species, enhance coastal defenses, and increase the attractiveness of the coast for tourism and recreation. The know-how generated by the project will be available to other locations through technical manuals.*

Benefits
Flood protection, Biodiversity, Ecotourism, Education.

Source
Ecoshape, Rijkswaterstaat, Municipalities of Delfzijl and Eemsmond.
https://www.ecoshape.org/en/pilots/saltmarsh-development-marconi-delfzijl-9/
https://www.sciencedirect.com/science/article/pii/S2772411521000057?via%3Dihub

Photo by NIOZ

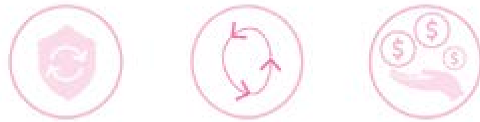
Salt marsh restoration approach | Boost sustainable activities for citizens | Knowledge development for future application

Project #4: *Pioneer Salt Marsh Restoration For Coastal Protection, 2012 to date*
Location: *Eastern Scheldt, the Netherlands*
Description: *The Eastern Scheldt witnesses continuous erosion of the intertidal flats and the decline of salt marshes. The Pioneer Salt Marsh is on the brink of disappearance. The Eastern Scheldt restoration project is testing a new method of re-establishing Spartina anglica or cord grass. The new marsh protects higher intertidal areas against erosion and will continue to expand. With sufficient tidal action and the sediment input, the grasses sustain a healthy population of species and support the biodiversity and ecological functioning of the larger area. Re-established salt marshes have added social value in the form of educational, recreational, and scenic opportunities. The natural technology used for this project can be used in other regions worldwide.*

Benefits
Flood protection, Biodiversity, Ecotourism, Education.

Source
IMARES, NIOZ, Ecoshape.
https://www.ecoshape.org/en/cases/pioneer-salt-marsh-%20restoration-for-coastal-protection-eastern-scheldt-nl/

Photo by U.S. Army Corps of Engineers on Flickr



Salt marsh restoration approach | Sediment reuse from adjacent sources. | Funded by environmental agencies

Project #3: *Shorter's Wharf Restoration, 2002 to date*
Location: *Chesapeake Bay, USA*
Description: *A group of conservation partners—U.S. Fish and Wildlife Service, the Audubon Society, the Conservation Fund, Maryland Department of Natural Resources, and the U.S. Geological Survey—are leading a series of experiments, which focus on the preservation and restoration of the Chesapeake Bay marsh. 26,000 cubic yards of sediment dredged from the Blackwater River were mixed with water and sprayed across 40 acres of inundated marsh in the beginning of the project. This allowed between 4 and 6 inches of sediment to accumulate and raise the surrounding area to the elevation of high marsh. Subsequently, 213,000 clumps of grass were planted, followed by the removal of earth and additional planting of hundreds of thousands of marsh plants. Lessons learned from this project are shared with specialists working to restore other endangered marshes and attempting to replicate this success.*

Benefits
Flood protection, Health, Education, Biodiversity.

Source
U.S. Fish and Wildlife Service, Audubon Society, The Conservation Fund, Maryland DNR, and the U.S. Geological Survey
https://www.audubon.org/news/the-ambitious-plan-save-chesapeake-bays-shrinking-saltmarshes

Photo by ACG Travel Videos

Salt marsh restoration approach | Creation of a new urban park and recreation amenities | Money saving by reusing dredged sediments from adjacent sources

Project #4: *Lincoln Park Wetlands Restoration, 2009–15*
Location: *New Jersey, USA*
Description: *A large tidal marsh adjacent to Lincoln Park in Jersey City, N.J. became a landfill without a permit. The wetlands, streams, and salt marshes were blighted and full of illegally dumped debris. The area was not a healthy habitat for birds and fish nor an effective coastline support against future effects of climate change. With help from WSP, the New Jersey Department of Environmental Protection received US$10.6 million to restore 42 acres of wetlands at Lincoln Park. A tidal marsh was designed to fit into the natural landscape while also meeting the recreational and public space needs of Hudson County. In addition, the design incorporated beneficial reuse of dredged material coming from the Hudson River.*

Benefits
Flood protection, Recreation, Wildlife.

Source
NJ Department of Environmental Protection, WSP
https://www.state.nj.us/dep/nrr/restoration/lincolnpkwest.html

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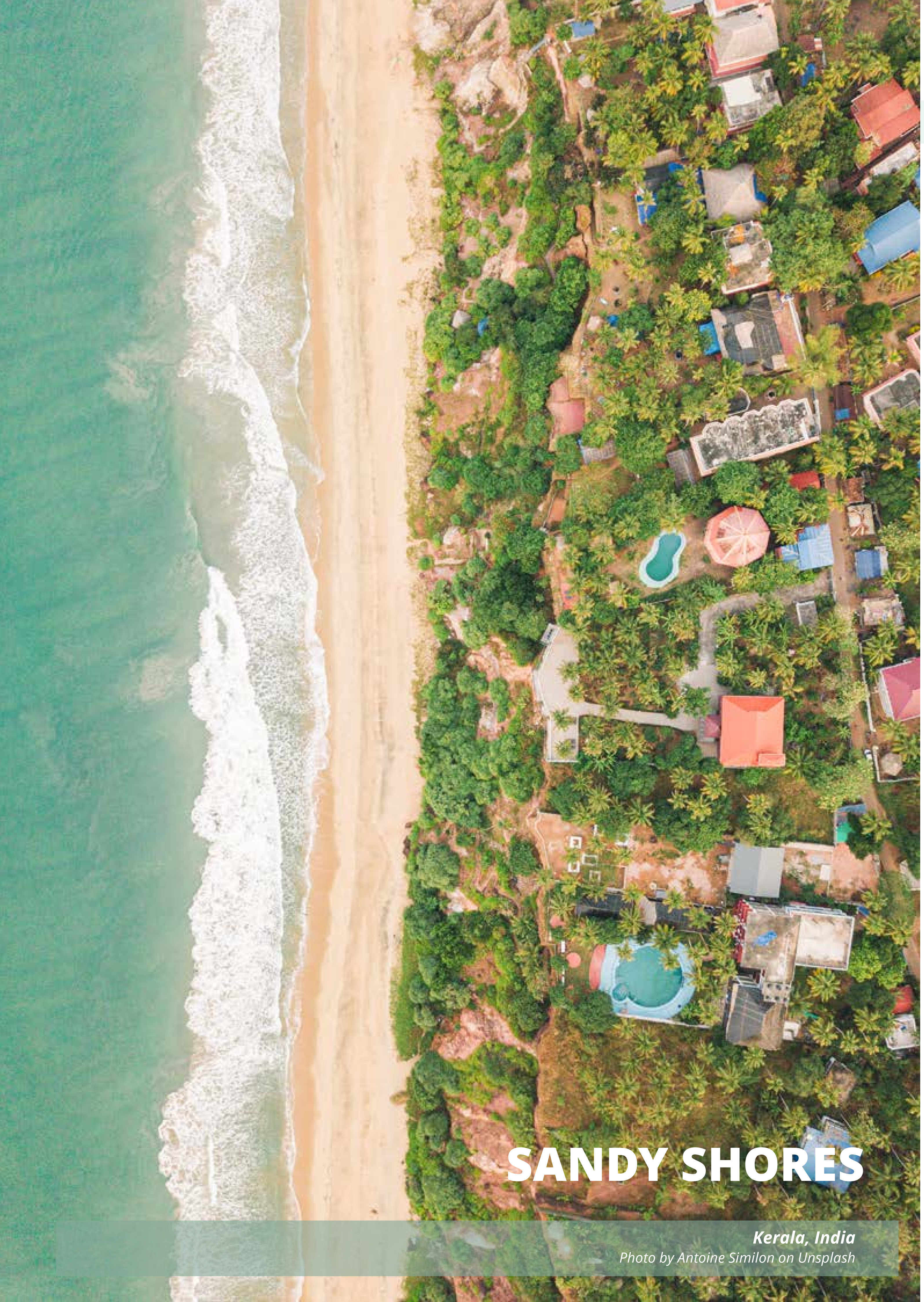


SANDY SHORES

Kerala, India
Photo by Antoine Similon on Unsplash

FACTS AND FIGURES

DESCRIPTION

Sandy shores represent the interphase between ocean and land and form a first line of defense for many coastal cities globally from wave action, storm surges, and wind impact. Sandy shorelines often include beach systems of different typologies, dunes and other features such as submerged biogenic reefs or seagrass meadows. Beaches are accumulations of unconsolidated and non-cohesive sediment and are largely controlled by the slope of the inner shelf and coastal area, abundance and type of sediments, tidal range, and wave energy (Wright and Short 1984). Dunes are accumulations of sand transported by wind to the backshore and stabilized by vegetation or other structures. Dunes protect against flood and erosion during storm conditions and represent sand reservoirs that naturally nourish the shoreline after storms. Vegetation in dunes accumulates sediment, allows dunes to grow and is a critical element for reducing erosion, overtopping, and flooding. Coral and shellfish reefs also protect coastlines by breaking wave energy offshore. Such reefs critically influence currents and transport of sediment that shape and configure the shoreline. Seagrasses also contribute to retain sediment in the submerged part of sedimentary shorelines and play a crucial role in contributing to erosion control and carbon retention in the soil.

These natural elements function in an interconnected manner and create rich ecosystems that provide many services in addition to coastal protection such as fisheries resources, carbon sequestration, cultural values, recreation, and tourism. Sandy shores are also economically valuable to cities because they accommodate coastal development and infrastructure such as boardwalks, marinas, beach accesses, and businesses associated to resources in coastal areas. However, urban development often directly conflicts with the preservation of these environments in many regions. The adverse effects of degradation, structures, and construction on the natural processes influence the coastal protection they provide. Furthermore, sand mining has led to severe erosion and flooding impacts in many regions because sand is a scarce but valuable resource in construction and industrial applications.

TYPE OF CITY

Coastal
Delta
River
Mountain

SCALE

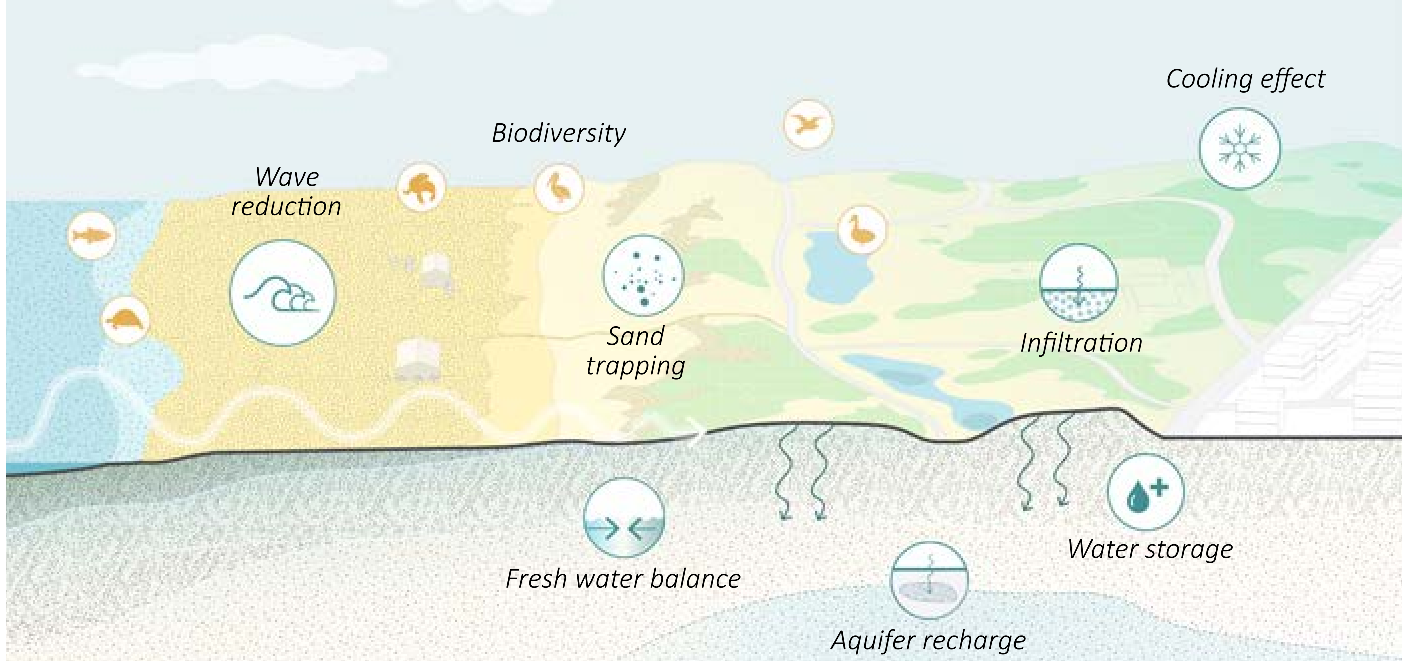
Neighborhood
City
River basin

APPROACH

Protect
Protect the integrity of reefs, beaches, and dunes.

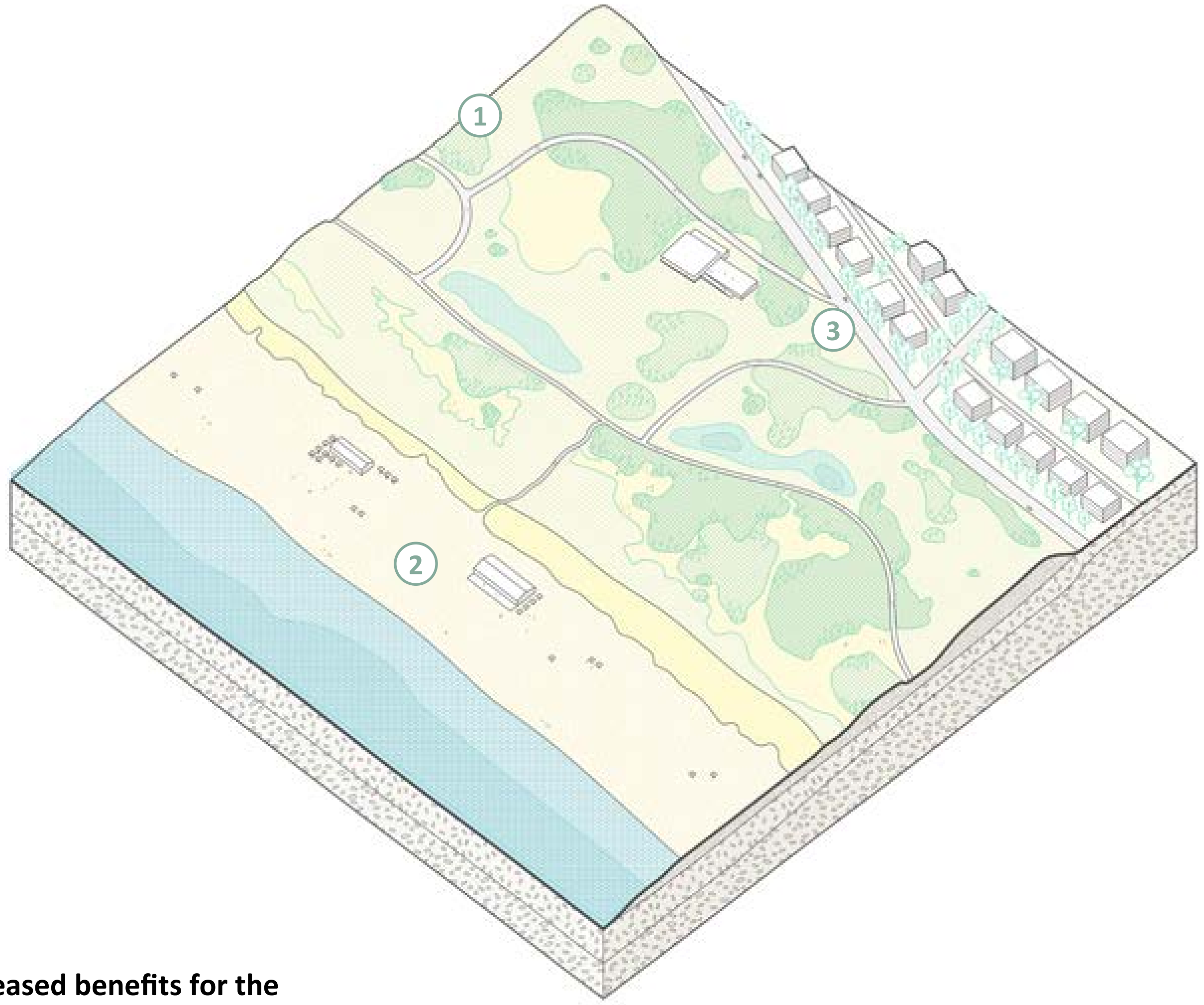
Rehabilitate, Restore, Enhance
Beach nourishment and replenishment.
Create conditions for natural dune regeneration or revegetation of dunes.
Reef restoration and management.

PROCESSES

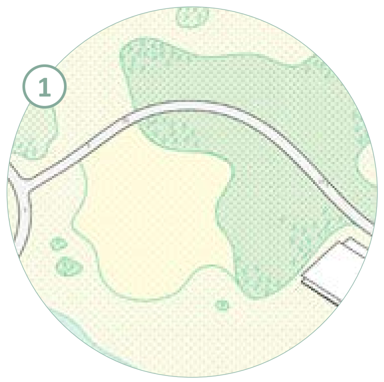


VISUALIZATIONS

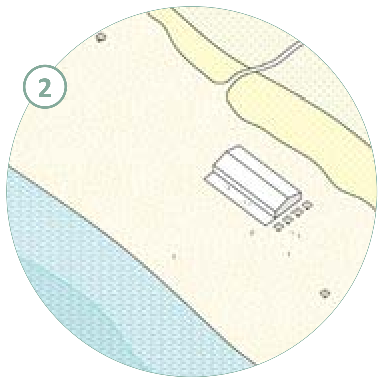
VISUALIZATION OF SANDY SHORES IN THE URBAN CONTEXT



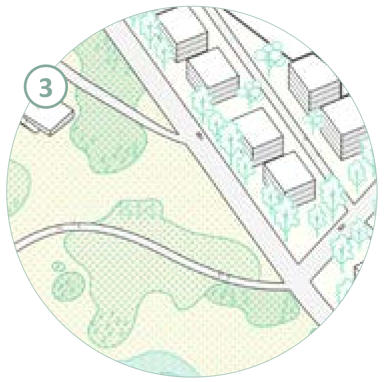
Details of increased benefits for the urban living environment



In addition to coastal protection, beach and dunes offer recreational uses and represent a connection of the city with the sea front. Reefs and seagrass meadows also provide benefits for artisanal fishing and tourism.

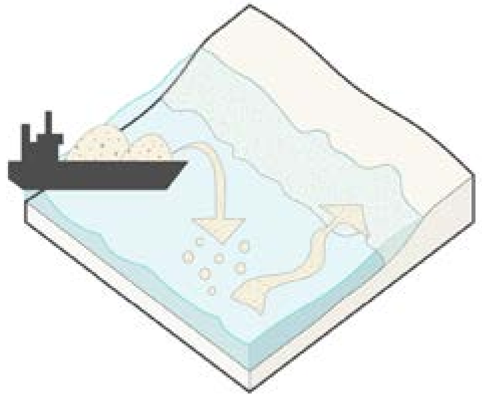


Sandy shorelines provide important nature-based recreation opportunities. Sidewalks, structures, and other development on dunes and beach, unless carefully planned, impact the natural processes and the protection they offer during storms.



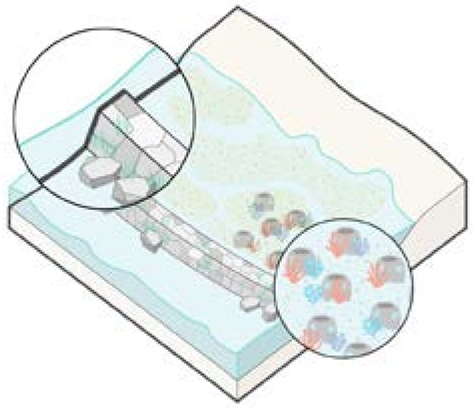
Dune environments represent a flood control boundary that urbanization plans should take as an important reference to protect both the natural systems and the urban infrastructure.

SPECIAL TECHNIQUES FOR SANDY SHORES



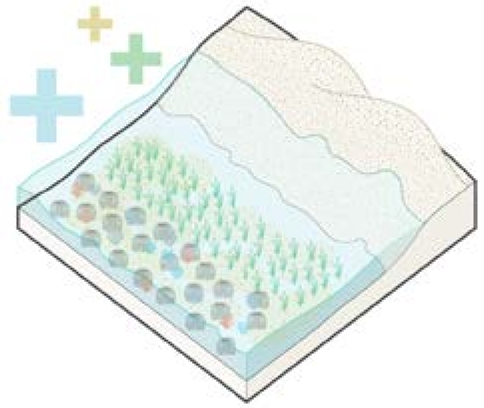
Beach nourishment and dune restoration

One common approach used in sandy shores for temporarily forestalling shoreline retreat or beach erosion is to artificially widen a beach with sand from some outside source, usually from an offshore continental shelf. Beach nourishment relies on feeding sand along or in front of a beach and allowing wave and tidal action to distribute it along the shore. Approaches to restore and manage beach systems include shoreface or beach nourishment (nearshore placement) and dune restoration and nourishment (USACE 2021; SNH 2000). Beach nourishment requires adequate planning because adding sand without addressing causes of erosion will lead to limited success and costly periodic nourishment cycles (Griggs and Reguero 2021).



Artificial reefs and submerged structures

Artificial reefs can work to maintain beach stability and prevent erosion by breaking waves and influencing currents that transport sediment. Artificial reefs also offer hard substrate for coral or oysters and create conditions to establish other ecosystems such as seagrass meadows, mangroves, and beach and dunes. Submerged structures can also serve to create perched beaches, where the beach profile is raised or protected. Long, low embankments parallel to the shore can provide support structures for new topography and create additional opportunities for biodiversity (Jacobsen 1982).

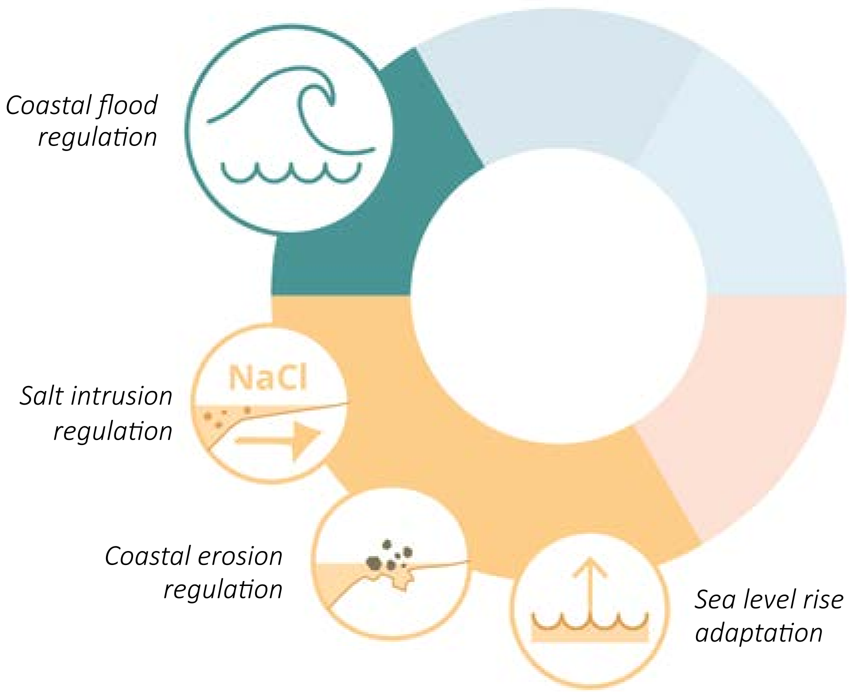


Connectivity and multiple lines of defense

Mangroves, seagrass meadows, reefs, and beaches and dunes are interconnected and support each other. Their flood protection also depends on maintaining healthy ecosystems. Reefs serve as submerged structures that allow lower energy environments for other ecosystems can establish and accumulate sediment in mangroves, for example. The presence of submerged and emerged vegetation can stabilize the seabed and enhance sediment deposition (Ondiviela et al. 2014; USACE 2021). A multiple line of defense with seagrasses, reefs, and beach and dune nourishment, approached with an integral view, can be used to provide effective protection and multiple benefits. Maintaining healthy ecosystems as a natural protection is often a no-regret, low-cost strategy, in the face of increasing threats of climate change along urbanized coastlines.

FUNCTIONS

The diagram in this section shows relevant functions of sandy shores.



Coastal flood regulation: Coastal beaches and dunes can prevent flooding because they dissipate wave energy (USACE 2021; Silva et al. 2016; Hanley et al. 2014). Their ability to attenuate waves depends on their geomorphology and factors including the slope, height, width, the presence of vegetation, and the volume of sand (Carter 1991; Short 1999; Hesp 1989; Hacker et al. 2012). Reefs also dissipate wave energy, and their effectiveness depends on their structural complexity, roughness, and depth. Vegetation reduces flooding through frictional effects depending on their relative submergence—height and water depth—density and size (USACE 2021).

Other functions: Beaches, dunes, and reefs prevent coastal erosion by retaining and stabilizing sand. They can also grow with rising sea levels and contributing to restore the coastline after the impact of storms (Hanley et al. 2014; Silva et al. 2016). Wider beach fronts and dunes can also protect inland resources from saltwater intrusion (Nehren et al. 2016). Reefs induce wave breaking and influence currents that transport sediment. Coral reefs are also sources of sediment to reef-lined coasts.

BENEFITS

The diagram in this section shows a sampling of important benefits that sandy shores can provide.

Coastal flood risk reduction: Sandy coastlines and dunes protect coastal areas from storm and flood damage. They can also mitigate the effects of climate change by trapping sediment and growing to keep pace with sea level rise and other changes in environmental conditions (Cunniff and Schwartz 2015; Silva et al. 2016).
Erosion and sediment management: Dunes buffer storm erosion and help the shoreline recover by naturally nourishing the shoreline during extreme events, serving as reserves of sand. Vegetation in dunes help prevent erosion and recover from the impact of storms (Silva et al. 2016). At the same time, vegetation is important to trap and store sand that allows dunes to grow and create additional storm protection (Cunniff and Schwartz 2015).
Biodiversity: Beach and dune systems provide habitats for marine, amphibian and terrestrial animals, dune vegetation, and indigenous plant species (Nehren et al. 2016).
Tourism and recreation: Sandy shores offer large economic value in coastal regions because they provide tourism and recreation opportunities such as surfing, scuba diving, boating, fishing, swimming, walking, and sunbathing (Barbier et al. 2011). Beach uses and activities, when sustainably managed, can provide many opportunities that contribute to benefit local communities and the environment.
Social interaction: Coastal environments positively influence social aspects of human wellbeing (Cox et al. 2004). Scenic coastal zones create a strong sense of place, forging a meaningful relationship between people and their surroundings (Jorgensen and Stedman 2001). A strong bond between the community and its environment helps build social cohesion and deliver multiple public health benefits (Shamai 1991).
Culture: Beaches and dunes are a proven source of aesthetic appreciation and inspiration for scientific research, cultural production, and art. Sites of international and national importance, they serve as settings for cultural, social, and educational events (Nehren et al. 2016), and are an important part of the local cultural and environmental heritage (Pérez-Maqueo et al. 2013).

SUITABILITY CONSIDERATIONS

ENVIRONMENTAL

Location and climate: Sandy coastlines occur worldwide but they present very different characteristics depending on climatic, environmental and geomorphological conditions (Luijendijk et al. 2018). Often, sandy coastlines have been highly developed and densely populated because of their real estate, tourism and recreational use. However, beaches are one of the most dynamic coastal geomorphic landforms, their spatial limits are not always fixed. The development and width of beaches are largely controlled by the slope of the inner shelf and coastal area, abundance and composition of sediments, tidal range, and wave energy (Wright and Short 1984). Dunes are part of the beach system, usually in the form of small hills or ridges. Coral reefs mostly occur in tropical coastlines associated to warm, low nutrients and clear waters that are optimal for coral growth. Shellfish reefs are formed by bivalve mollusks, mostly oysters and mussels, and can be found in sheltered temperate and tropical areas in bays, estuaries, and nearshore environments.

Soil and geomorphology: Sandy beaches depend on the continuous transport of natural sediment by the wind, sea, and rivers. Dunes rely on the vegetation to capture and stabilize the sand (EcoSpace n.d.). Beach nourishment strategies require low-lying oceanfront areas with nearby sources of sand that should be carefully assessed for grain size and volume of nourishment. The environmental effects of borrowing sources and placement also require careful study for long-term consequences. As with beach and dunes, reef-based solutions should attend to the drivers of historic degradation of natural reefs, and consider where natural biogenic reefs occur.

TECHNICAL

Dimensions: The spatial extent of the beach varies from depths where waves can mobilize sediment to the uppermost limit of wave action to the foreshore of the coastal profile. The foreshore usually has a steeper slope and is an active part of the beach system. Dune size and shape depend on wave action, tidal range, type of sediments and vegetation and geomorphology (Davidson-Arnott 2010).

Hybrid infrastructure: Projects in sandy shores often include structures such as breakwaters and groins to stabilize coastlines by blocking and influencing sediment transport. These solutions can be designed for effective coastal protection but require careful design and planning for local conditions. However, coastal structures can also have detrimental effects and erosion and flooding (Mangor 2020). These effects have been amply demonstrated in many urban coastlines as in India (Muthusankar et al. 2016). In these cases, de-engineering some of these barriers and favoring natural processes—sometimes with nourishment cycles and dune restoration—can effectively address flooding and chronic erosion problems, as demonstrated by experiences in Colombia (Rangel-Buitrago et al. 2020).

Slope and cross shore elements: Typical elements in a sandy beach and dune system may include long-shore bars or a reef system, beach cusps, and dunes. The geomorphology of beaches is very variable, but they can be broadly classified into dissipative and reflective beaches, each with different characteristics. Dissipative beaches occur in high energy environments, present surf zones 300–500 meters wide, shore normal bars and troughs, low-slopes, wide beach faces, and fine sand. Reflective beaches are characterized by steeper narrow beach face and slopes, coarser sediment of even pebbles, a narrow surf zone, and often present cusps on the upper part. Dunes have a better chance of developing over an extensive area with gentle slopes and where wind processes can accumulate sediment (Barman et al. 2015).

Site evaluation and preparation: Understanding the past, present, and possible future dynamics—more specifically, sediment budgets, hydrodynamics, sediment transport, and interactions with other ecosystems—is critical for determining the scale and feasibility of a project in sandy shorelines. Where natural beaches and dunes are present, restoring, maintaining, or enhancing processes, features, and dynamics should be the first goal of managers seeking to reduce flood and erosion risk (USACE 2021). Information on coastal processes and dynamics can help to understand the causes of flooding and erosion. Remote sensing can also provide valuable information on coastal changes that inform effective solutions.

A beach can also be enhanced with other elements to reduce flooding. Different techniques restore dunes that may include adding sand, revegetation, and sand trapping. However, if an existing system does not have dunes historically, it often indicates that the climatic and geomorphological conditions are not suitable. Similarly, restoration of reefs and construction of artificial reefs can be planned where reefs have been degraded or historically present.

Sandy shores need designed solutions that align with the original beach and dune as much as possible. Mimicking natural conditions and letting nature do most of the work—for example, by placing sediments where winds, waves, and tides can transport them for beach and dune growth—can reduce maintenance requirements substantially. The design of beaches should also consider changes in beach slope, volume, and width as primary design parameters, rather than attempting to create a static system.
Beach replenishment may fail when it lacks: (i) a realistic assessment of potential borrow areas of sand and volume; (ii) compatibility of added sand to the beach being nourished; (iii) construction costs and plans; (iv) attention to vulnerable geomorphic elements of the coastal zone; and (v) environmental impacts (Griggs and Reguero, 2021).

URBAN

Urban density: Low to medium density urban areas are suitable for sandy shores. Urbanization should occur behind stable and vegetated shorelines and should ensure setback zones. When buildings are developed on dunes or active parts of the beach system, flooding and erosion problems are the most frequent consequences.

Area: Large to extra-large. Local, small-scale interventions are often not effective because sediment transport processes often involve larger spatial scales and design assessments.

Integrated urban planning: Sandy shores and dune restoration can be aligned with conservation programs, but their long-term evolution requires careful consideration of the main drivers of historic degradation. With sea-level rise and increased wave action, beach nourishment will also need to be combined with other options, including adequate setback zones that can naturally nourish the system. Beach accesses or parking on dune system should also be restricted to specific areas to ensure the stability and integrity of dunes and vegetation and avoid degradation.

MAINTENANCE

Sandy shores are dynamic systems that pose serious management challenges, and may require regular nourishment cycles, and careful management (Cunniff and Schwartz 2015). Beach nourishment and dune restoration can have important environmental returns, but poor designs can also lead to adverse impacts and high long-term maintenance costs. Planning these projects requires considering the adequate spatial and temporal scales affecting coastal change locally. Reef-based solutions may combine structural and ecological features and maintenance may be required to maintain the environmental benefits such as coral restoration.

COSTS

COST CONSIDERATIONS

Land

Access to or ownership of land in coastal areas may be required.

Land ownership may be public or private.

Land area required will be large, which increases costs and makes engagement and collaboration with multiple landowners and stakeholders necessary.

Example land-related costs:

- Land acquisition
- Land use (e.g., payments to landowners)
- Land protection costs, including managing and controlling access
- Community resettlement

Construction and implementation

Protecting fragile beaches and dunes can maintain their ability to protect coastal areas from flooding and erosion. Protection may be sufficient in areas with low erosion rates and sufficient beach or dune presence.

In areas of high erosion, or where construction or augmentation of beaches and dunes are necessary, beach nourishment or dune restoration can be implemented.

Beach nourishment involves dredging sand from offshore and harbor areas and depositing the sand on beaches and dunes. Dune restoration includes replanting vegetation and installing sand fences. Costs associated with beach nourishment and dune restoration will depend on local labor, machinery, transportation, and material (e.g., sand) costs.

Maintenance

Maintenance costs of beach nourishment and dune restoration are driven by activities such as recurring dredging and sand deposition on these coastal areas and replanting of dune vegetation. The frequency and amount of sand required will depend on coastal erosion rates at the project site.

UNIT COST EXAMPLES THROUGHOUT THE GLOBE

*Global estimates show that beach nourishment costs may vary from **US\$4-US\$21/m³** as follows:*

- ***US\$5–US\$18/m³*** *in the USA (Aerts et al. 2018).*
- ***US\$4–US\$8/m³*** *in the Netherlands (Jonkman et al. 2013).*
- ***US\$5–US\$11/m³*** *in the EU (Linhman et al. 2010).*
- ***US\$7.7/m³*** *in Australia (Linhman et al. 2010).*
- ***US\$20.8/m³*** *in South Africa (Linhman et al. 2010).*
- ***US\$5–US\$8/m³*** *in Vietnam (Böös and Dahlström 2015).*

Example dune restoration costs:

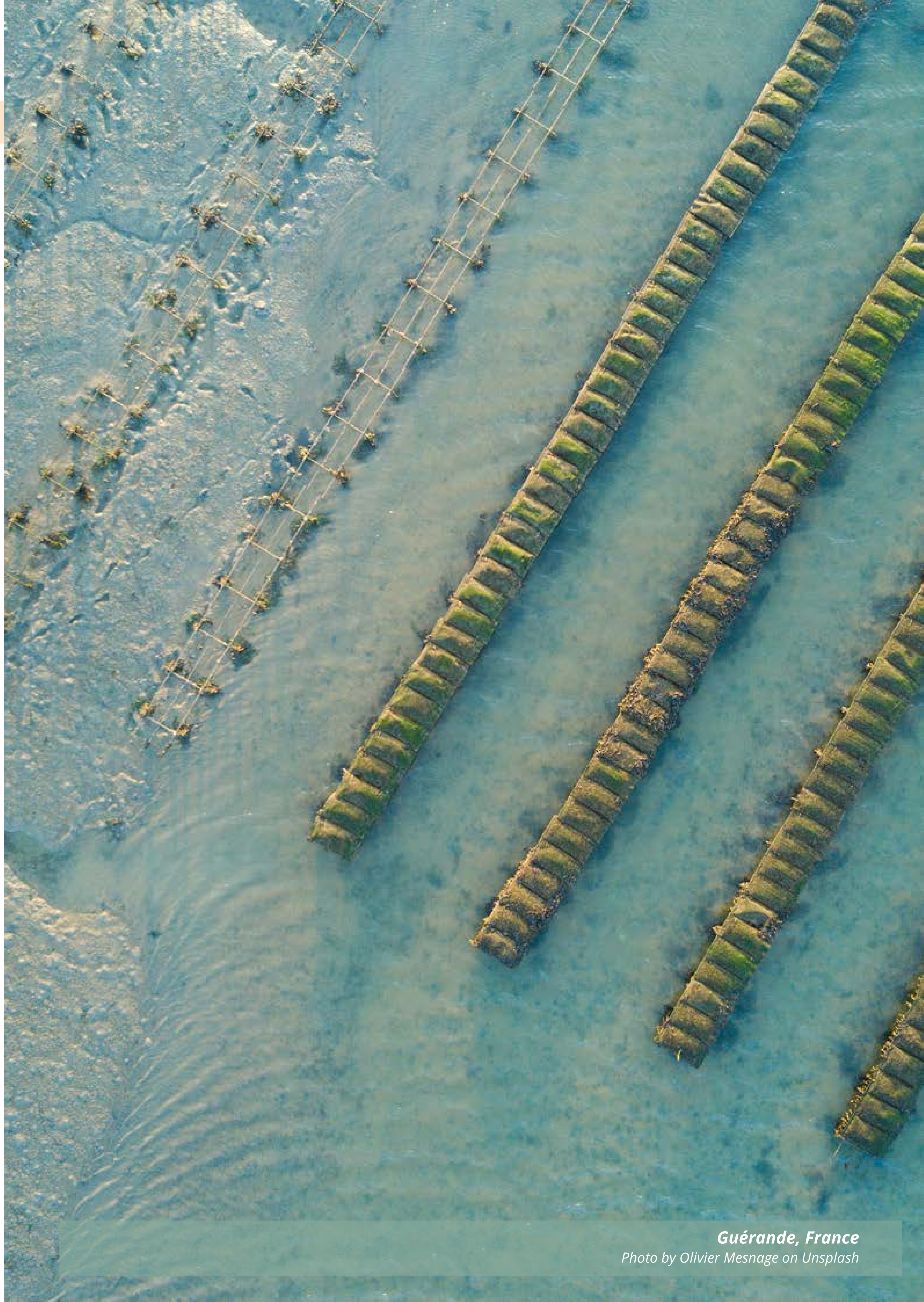
- *Dune revegetation projects in Australia and the US cost in the range of **US\$7,636–US\$13,888/ha**, including labor, vegetation, and sand (Aerts 2018).*
- *In Europe, planting vegetation on dunes is estimated to cost **US\$14,484/ha** (Verburg et al. 2017).*

Example of artificial reef restoration costs:

- *Ferrario et al. (2014) identified that the costs of building tropical breakwaters ranged between **US\$456–US\$188,817 m/year** with a median project cost of **US\$19,791 m/year.** The construction costs of structural coral reef restoration projects ranged between **US\$20–US\$155,000 m/year** with a median project cost of **US\$1,290 m/year**.*
- *Bayraktarov et al. (2016) determined that the average cost of coral reef restoration in developing countries is **US\$377,000/ha** (median value is **US\$89,000**).*
- *Oyster reef restoration cost on average is **US\$387,000/ha**.*
- *The average cost of seagrass restoration is **US\$106,000/ha***

Example beach and dune maintenance costs:

- *Maintenance costs of sand dunes from cases in Europe are estimated at**US\$336/ha/year** (Verburg et al. 2017).*
- *In Denmark, total maintenance costs associated with an artificially created dune were estimated at **US\$2,229/ha** (Vestergaard 2012).*



Guérande, France
Photo by Olivier Mesnage on Unsplash

NBS IN PRACTICE

The four projects in this section highlight good practices and lessons learned about sandy shores, drawn from the growing popularity of NBS throughout the globe.

Photo by INI Design Studio

Project #1: *Andhra Pradesh Disaster Recovery Project, 2015–21*
Location: *Andhra Pradesh, India*
Description: *Andhra Pradesh is one of the most natural hazard-prone states in India. 440 kilometers of its 974-kilometer coast are vulnerable to coastal erosion from tropical storms and related hazards. The development objectives of APDRP were to restore, improve, and enhance resilience of public services, environmental facilities, and livelihoods in targeted communities, and to enhance the capacity of state entities to respond promptly and effectively to crises and emergencies. Resilient electric network, restoration of connectivity and shelter infrastructure, protection of beach front were a few components of the project. The project restored mangroves for improving coastal resilience, acting as a shelter belt. Its beachfront restoration used some eco-friendly approaches.*

Benefits
Community, Health and Wellbeing.
Source
World Bank
https://projects.worldbank.org/en/projects-operations/project-detail/P154847

Photo by by Nicolas Desramaut / World Bank

Project #3: *Dune restoration in Mauritania, West Africa Coastal Areas Management Program, 2018–22*
Location: *Nouakchott, Mauritania*
Description: *Nouakchott, the capital of Mauritania and its biggest city, is located at or below the sea level. Its coast is protected by a series of dunes exposed to erosion, sand mining, livestock grazing, and detrimental leisure activities such as dune racing.*
The Mauritania Work project developed as part of the West Africa Coastal Areas Management Program prioritized the protection of Nouakchott and the reinforcement of the coastal dunes. This was accomplished by sand replenishment and the use of plants to stabilize soil. Restrictions on dune access and use prevented further physical destruction. A subsequent phase of the project will plant mangroves along the border with Senegal. These will act as a buffer zone and further help in erosion control along the Senegal River shoreline. Additional risk reduction measures focused on the local community are currently under preparation as part of the long-term resilience and adaptation plans.
Benefits
Health, Social Development.
Source
World Bank
https://www.wacaprogram.org/country/mauritania

Photo by Imad Cherkaoui

Project #4: *Integrated Coastal Zone Management (ICZM), 2012–21*
Location: *Moulouya, Morocco*
Description: *More than half of Morocco's urban population lives along the coast. The coast is negatively affected by various forms of pollution and unsustainable practices including the discharge of industrial effluents, municipal sewage, and solid waste disposal. The Moulouya Coastal Management project cleaned and restored degraded wetlands and dune ecosystems. In addition to the clear environmental improvements, the project has had a positive social impact. Direct employment of the local residents raised the average household income in the area by between 10 percent and 25 percent in the short term, and created a potential for further income growth between 20 percent and 500 percent in the medium to long term (EU 2008).*

Benefits
Biodiversity, Ecotourism, Education, Economy.
Source
World Bank
https://documents1.worldbank.org/curated/en/821161538145781490/pdf/Morocco-MA-GEF-Integrated-Coastal-Zone-Mgt.pdf

Photo by Rijkswaterstaat / Jurriaan Brobbel

Project #4: *The Sand Motor, 2009-2011*
Location: *The Netherlands*
Description: *The Sand Motor is a mega-nourishment project implemented in the Delfland Coast—North Sea coast of South Holland, The Netherlands. This innovative pilot project tested the upscaling of regular sand nourishment along the Dutch coast. Carried out by Rijkswaterstaat—part of the Dutch Ministry of Infrastructure and Water Management—the Sand Motor or sand engine was a peninsula covering 128 ha in 2011. The program aims at preservation of the coastline and protection against flooding. The Sand Motor also has the purpose to create temporary space for leisure activities and nature development. Without the Sand Motor, the coastline would require regular maintenance through frequent nourishment operations. By making use of natural processes to redistribute the sand over time, the Sand Motor is a buffer against sea level rise, and mitigates the impacts of storm surges and coastal flooding.*
Benefits
Education, Ecotourism, Economy.
Source
Deltares
https://climate-adapt.eea.europa.eu/metadata/case-studies/sand-motor-2013-building-with-nature-solution-to-improve-coastal-protection-along-delfland-coast-the-netherlands/delfland-coast_document-1.pdf

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A natural riverbank in Rome, Italy
Photo by Mark Harpu on Unsplash