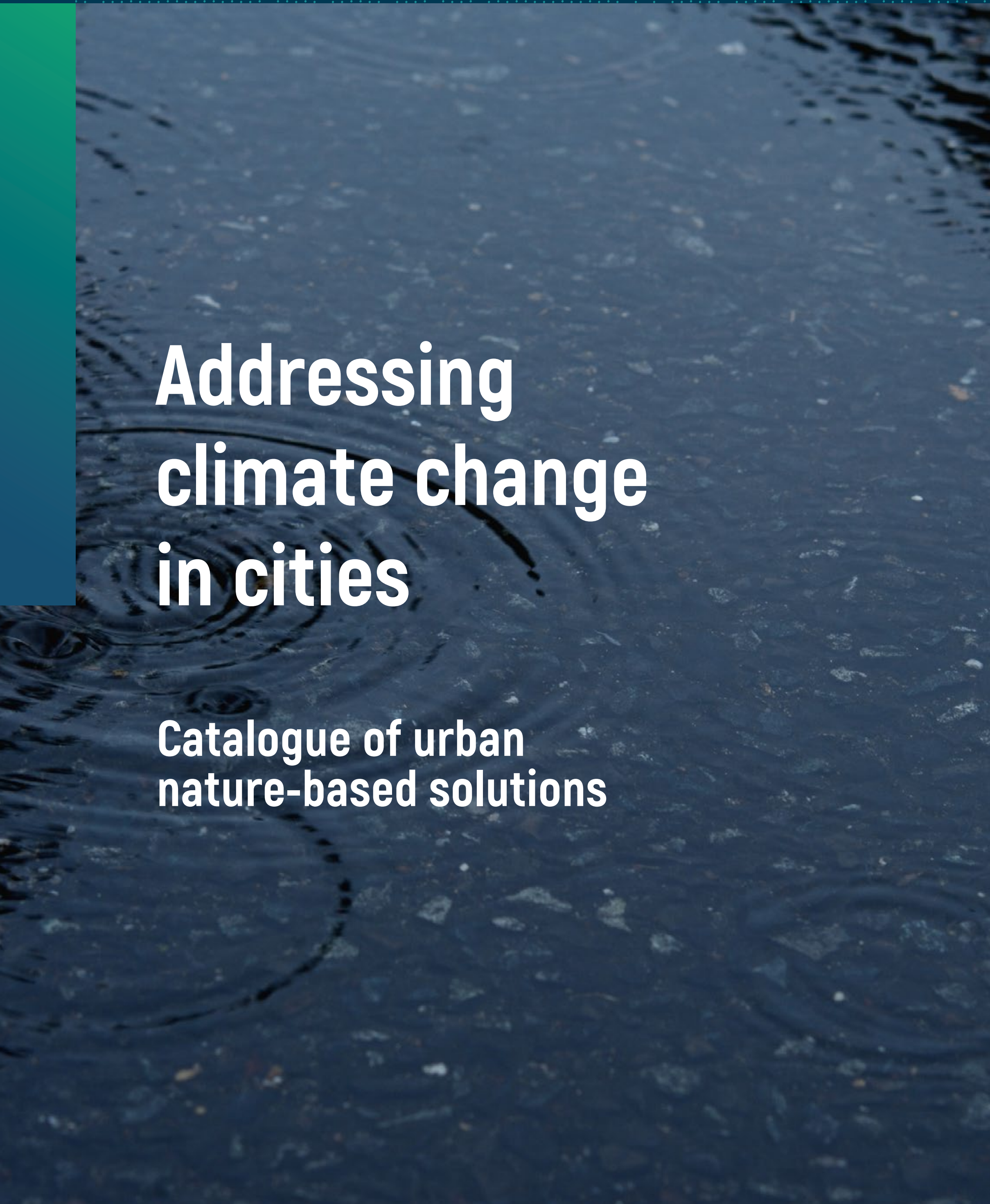

Addressing climate change in cities

Catalogue of urban nature-based solutions

Ecologic Institute and Sendzimir Foundation
2019

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Addressing Climate Change in Cities – Catalogue of Urban Nature-Based Solutions

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Berlin – Krakow 2019
ISBN 978-83-62168-10-1 (printed version in Polish)
ISBN 978-83-62168-11-8 (online version in Polish)
ISBN 978-83-62168-12-5 (online version in English)

Published by
The Sendzimir Foundation
www.sendzimir.org.pl

Printed on recycled paper

This project is part of the European Climate Initiative (EUKI). EUKI is a project financing instrument by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). The EUKI competition for project ideas is implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. It is the overarching goal of the EUKI to foster climate cooperation within the European Union (EU) in order to mitigate greenhouse gas emissions. The opinions put forward in this publication are the sole responsibility of the authors and do not necessarily reflect the views of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU).

Supported by:

Federal Ministry
for the Environment, Nature Conservation
and Nuclear Safety

European
Climate Initiative
EUKI

based on a decision of the German Bundestag

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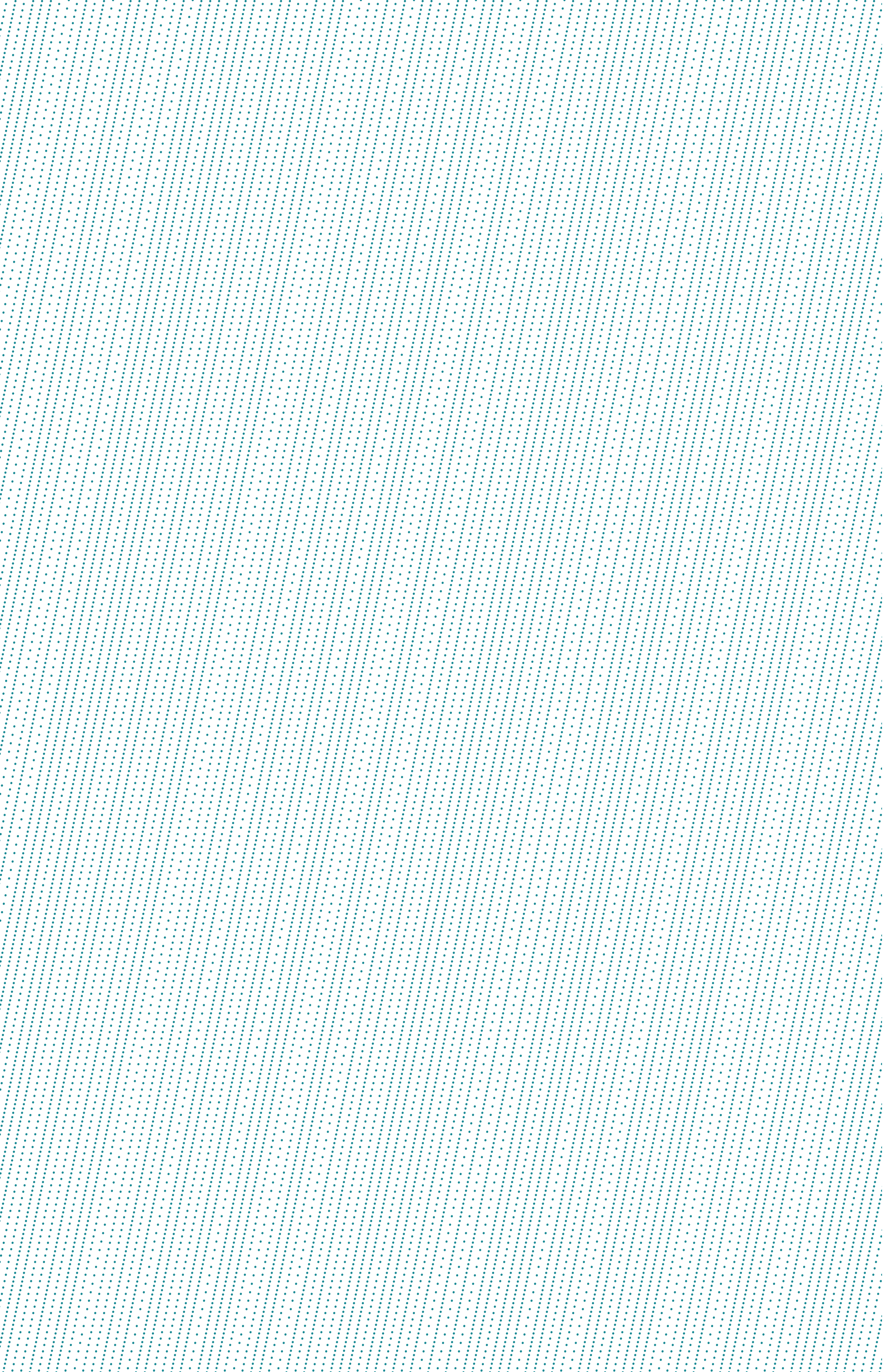

Introduction

Intense development in many urban areas places increased investment pressure on undeveloped land. At the same time, cities and their inhabitants face a number of challenges, such as air pollution, the heat island effect, water scarcity, local flooding, loss of nature and lack of social cohesion. The deployment of nature-based solutions (NBS) is recognised as an effective approach to address many of these challenges in parallel. By utilising NBS such as green roofs and facades, sustainable urban drainage systems or bioretention infrastructure, cities can support climate change mitigation and greenhouse gas emissions reductions, while producing further social, economic and environmental benefits.

Although significant potential exists, NBS remain underexplored and underutilised as a climate mitigation and adaptation solution for cities. Some barriers, which have prevented wider uptake across many cities in Europe, include a lack of relevant experience and technical knowledge on NBS planning and implementation as well as a shortage of context-specific policy instruments to support mainstreaming across sectoral policies.

This catalogue responds to these gaps and presents a wide selection of NBS. It has been produced within the "Climate NBS Poland" project and supported by the European Climate Initiative (EUKI) of the German Ministry of Environment. Case studies focus on NBS which have been deployed in Germany. However, these exemplify high climate mitigation potential and applicability across a range of urban contexts. Information on cost-effectiveness and NBS' potential to mitigate climate change are presented alongside implementation guidelines. The selected case studies show how NBS can be used in combination with one another in order to create systemic solutions that address multiple urban challenges in parallel – at sites as small as a playground or as large as an entire city.

This catalogue is designed to support planners, designers and landscape architects in various sized urban areas in Europe and beyond in applying NBS instead of or alongside traditional approaches. It is complemented by "Addressing climate change in cities: Policy instruments to promote nature-based solutions", a guide on policy instruments that can be used to foster NBS uptake in cities.

1. Individual NBS

Nature-based solutions are solutions that are inspired and supported by nature. They can be used in urban settings to complement or replace “traditional” or “grey” solutions to perform functions, such as thermal insulation and stormwater retention and filtration. NBS can be integrated into existing urban landscapes, for example as part of the roadside or transport infrastructure.

As opposed to their traditional counterparts, NBS often perform multiple functions at once. This is particularly significant in the context of urban climate change adaptation and mitigation. For example, individual NBS introduced primarily to provide on-site stormwater retention can also contribute to carbon sequestration, reduce air pollution or mitigate the urban heat island effect. This holds true especially when implemented on a larger scale.

The first section introduces ten multifunctional NBS that cities can implement. The solutions have been selected based on their potential to deliver climate mitigation and their ability to respond to a variety of common urban challenges. Each chapter contains a description of the technical characteristics of the selected nature-based solution, including a schematic diagram illustrating its construction and operation. The descriptions include requirements for the care and maintenance of each of the solutions, to ensure their durability and effective performance. Potential problems and limitations of each solution and suggestions on how to overcome them are also presented. The accompanying tables include information about the challenges that the solution helps to address, the suggestions for areas of application and the associated benefits.

The descriptions include approximate costs for the construction of each NBS, which will vary across different specific markets and sites of application. We provide information about the possibilities of combining a given solution with other NBS and, where applicable, reference to case studies from the second part of the guide where the NBS have been implemented.

Photo: Ewa Iwaszuk

Photo: Agnieszka Kowalewska

Figure 1. Urban water retention pond at Potsdamer Platz, Berlin, Germany (above), and Staw Służewiecki in Warsaw, Poland (below)

1.1. Water retention ponds

Retention ponds (Figure 1) are ponds or pools designed with additional storage capacity to store and treat water following rainfall events. They are comprised of a permanent body of water and landscaped banks and can be created in an existing depression, by excavating a new depression or by constructing embankments. Using existing water bodies is not recommended as it carries the risk of any resulting poor water quality damaging the natural ecology. When overflowing, the ponds empty into canals or other receiving water bodies. Retention ponds have the added benefits of storing water for reuse in drought conditions, providing a habitat for urban wildlife and creating a public green space. They can also remove urban pollutants (such as stormwater runoff) through sedimentation, absorption by vegetation and biological uptake. They differ from detention basins in that they are permanently filled with water. The use of native vegetation that grows well in high-moisture conditions is recommended. In Central Europe, this can include sedge, irises, loosestrife, lakeshore bulrush or common rush.

Overview

Space requirement

Minimum drainage area: 3–10 ha (or less if the retention pond has another source of water) (Aver, 2012); space requirement: 3–7% of drainage area, designed as a single pond or series of pools, average depth of 1 m (Woods-Ballard et al., 2015)

Potential costs (€)

Capital costs: 10–60 EUR/m^3 storage volume

Maintenance costs: 1–5 EUR/m^2/year surface area (NWRM, 2013)

Place of application

Open public spaces – parks, urbanised areas, e.g. city squares

Mitigation benefits

Cooling and insulation	✓
CO_2 sequestration	✓
Renewable energy production	
Use of low-carbon materials	✓
Promotion of sustainable behaviors	✓

Urban challenges addressed

Air pollution	✓
Heat island effect	✓
Water scarcity	✓
Rainwater drainage / runoff	✓
Flood resilience	✓
Ecological connectivity	✓
Urban upgrading	✓
High energy use	

Can be combined with

Green surfaces, bioretention structures and single trees

Found in case study

2.1. Constructed urban wetland: Landscape Park Duisburg Nord

2.6. Eco-city districts: “Jenfelder Au” in Hamburg

2.9. Sustainable urban drainage systems: Potsdamer Platz, Berlin

Technical details

In general, ponds should consist of the following features (Figure 2):

- an upstream pre-treatment system, such as a sediment forebay/inlet;
- a permanent pool that stores water throughout the year and serves as the main storage and treatment zone;
- a temporary storage volume for flood control along the landscaped banks;
- a passageway to empty into a receiving water body (outlet) for emergency water overflow;
- shoreline design that supports visible and submerged aquatic vegetation for further benefits (see Figure 2 below and NWRM (2013) for more information).

Design considerations may include hydraulic, treatment, amenity and biodiversity features, depending on the location and motivation (see Woods-Ballard et al., 2015). In the *hydraulic* design, the temporary storage volume of the pond should be sized to accommodate up to 10, 30 or 100/200 year flood events. Allowance should also be made for potential climate changes and increased urbanisation.

In terms of *treatment* potential, pond design should emphasise the effective pre-treatment of pollutants at the source via other NBS. The remaining pollution risks can be addressed at a forebay by encouraging pollutants to settle before entering the permanent pool. This also facilitates pollutant monitoring and removal measures. Treatment efficiency is determined by the volume of the permanent pool, where approximately double the amount of the mean annual stormwater volume is considered to provide the maximum treatment capability for this NBS (see Woods-Ballard et al., 2015).

To increase the *amenity* value, especially in urban areas, the retention ponds can be designed for recreational use by diverse social groups and even environmental education. The location can also be used to increase ecological connectivity and thus foster the wider *biodiversity* value of the NBS.

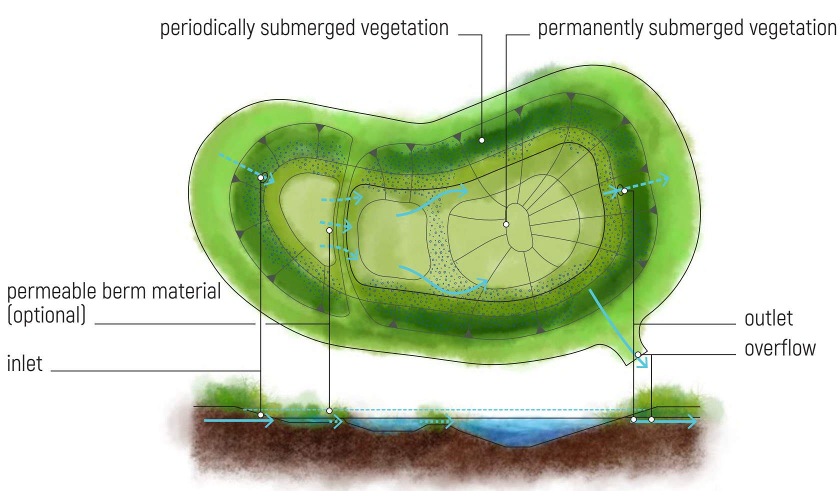

Figure 2. A typical pond design in plan view and profile (based on Woods-Ballard et al., 2015)

Maintenance

Monthly maintenance of a water retention pond includes removal of trash, floating debris, floating leaves, sediment accumulation and any unwanted growth. Removal of obstructions from water outlets is of particular importance. Mowing of banks may be required, depending on design. Annual maintenance includes inspection and repair of any occurring erosion or damaged structures e.g. outlet pipes.

Vegetation, such as native plants that grow well in high-moisture environment may reduce the maintenance requirements, by protecting against erosion and preventing pollutants from running into the water – while adding aesthetic value to the pond (GSWCD, 2019).

Potential challenges

Potential challenges	Solutions
Maintaining water quality (algae, falling leaves, invasive species, etc.)	Larger pond sizes have a more stable climate and can be accessorized with e.g. helophyte banks and measures that ensure regular inflow for aeration Design should allow for water level fluctuations; a deeper pond will also keep temperature relatively low in summer, diminishing the risk of algae blooms (>1 m is recommended)
Perceived safety risks	Installation of light fencing and other protective measures

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Photo: Mississippi Watershed Management Organization

Photo: the Sendzimir Foundation

Figure 3. A bioretention basin in Labelle Park, Columbia Heights, Minnesota, United States (left); biorention basin at the centre of a roundabout, Miarki k. Warszawy, Poland (right)

1.2. Bioretention basins

Bioretention basins are densely vegetated areas that collect and filter stormwater as it percolates through different layers (Aecon et al., 2011). Subsequently, the water infiltrates the ground or flows to nearby stormwater drains or receiving waters in case of excessive precipitation (LSS, 2019). Bioretention basins are often installed in public areas. They are suitable at locations that have little pervious surface, are exposed to contaminated runoff, are in need of stormwater management practices or near cold water streams. The design should incorporate conditions specific to the site (LSS, 2019). Depending on the amount of stormwater received, the bioretention basin is either wet or dry. Bioretention basins offer several benefits, including reduced runoff from drainage areas, the removal of pollutants from stormwater, as well as flexibility in design and relatively low maintenance requirements. Moreover, they can be aesthetically pleasing, which is closely related to the quality of the design and maintenance (LSS, 2019).

Overview

Space requirement

Area: approximately 5% of the drainage area, maximum area should not exceed around 2 ha (1 ha is preferred) (Shafique, 2016; LSS, 2019)

Costs (€)

Capital costs: 25–135 EUR/m^2; becomes expensive when designed for large areas (LSS, 2019)

Place of application

Small sites and highly urbanised spaces (e.g. residential areas and parking lots), as well as areas that have little permeable surface (LSS, 2019)

Mitigation benefits

Cooling and insulation	
CO_2 sequestration	✓
Renewable energy production	
Use of low-carbon materials	✓
Promotion of sustainable behaviors	

Urban challenges addressed

Air pollution	✓
Heat island effect	✓
Water scarcity	✓
Rainwater drainage/runoff	✓
Flood resilience	✓
Ecological connectivity	✓
Urban upgrading	✓
High energy use	

Can be combined with

Sustainable urban drainage systems (SUDS), such as bioswales, rain gardens and green ditches

Technical details

A bioretention basin (Figure 4) should consist of the following features (LSS, 2019; NRM, 2012):

- grass buffer strip: decreases the runoff velocity of stormwater and takes out suspended solids;
- shallow ponding area with a depth of 20–40 cm: excess stormwater is stored here, which allows for its evaporation and the settling of particulate matter;
- mulch: an optional organic layer that fosters the micro-biological degradation of petroleum-based pollutants. The mulch should be composed of shredded hardwood or chips that are approximately 2.5 to 5 cm big, at a depth of 5 to 10 cm. This layer helps to filter pollutants and reduce soil erosion;
- the main filtration and retention layer, with a depth of at least 40 cm, planted with vegetation. The vegetation that is used should be able to thrive in sandy soils, as well as withstand both extended wet and dry seasons. This layer supports the vegetation, as well as the uptake of nutrients and water storage. Dense and high vegetation contributes to the quality of the water treatment. When choosing the materials for the filter media, there is a trade-off between allowing sufficient water to pass through and retaining water for the vegetation. Generally, a sandy-loam type of material is appropriate, but the soils can always be mixed based on the characteristics of the vegetation;
- a 100–150 mm deep transition layer, consisting of clean, well-graded sand (less than 2% fines). Provides drainage and aeration of planting soil, and helps to flush pollutants;
- underdrain system: ensures that excess runoff, which has been treated, flows to stormwater drains or receiving waters. The drainage layer – typically made up off 5–7 mm graded clean, fine gravel – covers the drainage pipe and is around 50–150 mm deep.

The design of a bioretention basin is flexible and can be adjusted to various scales, but needs to account for both dry and wet seasons. For this purpose, several elements can be integrated, such as a coarse sediment forebay to prevent sediment smoothing, a saturated zone beneath the filter

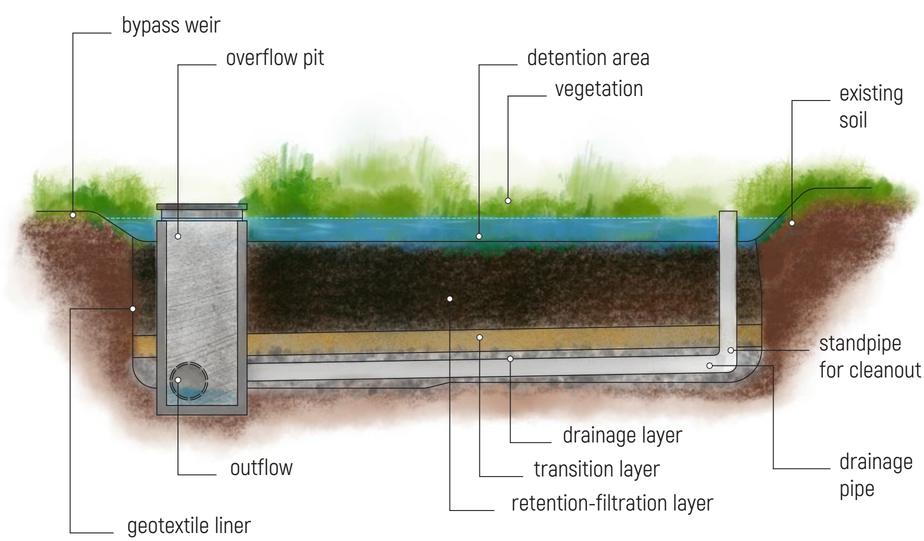

Figure 4. Cross-section of a typical bioretention basin (based on Leister et al., 2010)

media to ensure the soil is moist even during dry periods and supplemental irrigation for the vegetation (Aecon et al., 2011). The most important features to consider during the design process are pretreatment, treatment areas, water conveyance, maintenance and landscaping (LSS, 2019).

Maintenance

It is necessary to conduct regular maintenance and ensure that sufficient pretreatment takes place to avoid clogging. After the construction of the bioretention basin is complete, the vegetation should be watered daily for a minimum of two weeks. Other maintenance tasks, on an as-needed basis, include the re-mulching of void areas, mowing of turn areas, treating plant diseases, watering plants during consistent droughts and replacing the 2.5–5 cm layer of planting medium in case water stands in the basin for more than 48 hours (LSS, 2019). On a monthly basis, the bioretention basin should be inspected to identify maintenance requirements, litter and plant debris should be removed and eroded areas should be restored (LSS, 2019).

Potential challenges

Potential challenges	Solutions
Use limited to small drainage areas	Integration of bioretention basins into a broader drainage strategy
Space requirement	Small scale design of bioretention basins; provision of additional aesthetic benefit

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Photo: Aaron Volkening

Photo: Agnieszka Kowalewska

Figure 5. A bioswale in Greendale, Wisconsin, United States (left) and Wilanów, Warsaw (right)

1.3. Bioswales

Bioswales are multi-layered, vegetated ditches that collect, slow down and filter surface run-off water and reduce the pressure on traditional sewage systems. Generally, they are linear in nature and parabolic, trapezoidal or v-shaped (NRC, 2019). Bioswales replace typical drainage elementssuch as concrete sewage channels, e.g. in car parks, along pedestrian and bicycle routes – in areas with slopes not exceeding 5%. They offer a variety of benefits, such as improved urban water systems, reduced heat stress, a (small) positive impact on air quality, enhanced biodiversity and an increased aesthetic value of landscapes (Atelier Groenblauw, 2019). Additional economic, public health and social co-benefits are achieved by means of reduced water treatment costs and healthier natural areas for recreational purposes (NRC, 2019). It is recommended to use native grasses and plants, which are suited to fluctuating water levels as occur naturally on stream banks.

Overview

Space requirement

Minimum size: at least 1% of the drainage area (Morello et al., 2019)

The highest possible groundwater level at which a bioswale system can be introduced is between -1.5 and -2 m; a bioswale should be no steeper than 1:3 to allow mowing (Atelier Groenblauw, 2019)

Place of application

Car parks, roads, pedestrian and bicycle routes, public spaces

Costs (€)

Construction costs are closely related to the design/size of the bioswale, as well as the place of application (e.g. soil conditions) (Morton, 2017); they range between approximately 50–230 EUR/m² (for parking lot and roadside) (CNT, 2013)

Maintenance costs depend on the frequency of mowing, which is influenced by design of the bioswale; they range approximately between 0.58–2 EUR/m²/year (for parking lots and roadside) (CNT, 2013)

Mitigation benefits

Cooling and insulation	
CO_2 sequestration	✓
Renewable energy production	
Use of low-carbon materials	✓
Promotion of sustainable behaviors	✓

Urban challenges addressed

Air pollution	✓
Heat island effect	✓
Water scarcity	✓
Rainwater drainage/runoff	✓
Flood resilience	✓
Ecological connectivity	✓
Urban upgrading	✓
High energy use	

Can be combined with

Sustainable urban drainage systems (SUDS) – such as water retention ponds, green ditches, permeable paving, single trees

Found in case study

2.6. Eco-city districts: "Jenfelder Au" in Hamburg

Technical details

Bioswales should consist of the following features (Figure 6):

- a top layer consisting of structural soil with a maximum of 5% clay content, covered in diverse vegetation that filters out pollutants. Generally, a mix of sand and compost with 60:40 ratio is used to achieve a 5% organic matter by weight, which is needed for a healthy soil (SSSA, 2019);
- a drainage layer incorporating gravel, scoria or baked clay pellets wrapped in geotextile, with large empty spaces to drain off the rain water (Atelier Groenblauw, 2019);
- the top two layers have usually have a combined thickness of 30–70 cm;
- a perforated drainpipe underneath, with overflows attached, to prevent flooding in case of heavy precipitation (Atelier Groenblauw, 2019);
- the bioswale is normally 1.5–5 m wide.

Maintenance

Bioswales with grass mixtures require mowing at least every fortnight. Bioswales that are more natural need to be closely monitored for litter (Atelier Groenblauw, 2019). They should be managed like any other landscaping, which includes vegetation management, removal of sediment accumulation, damage reparation and replacement of gravel – as overgrowth reduces its ability to intercept

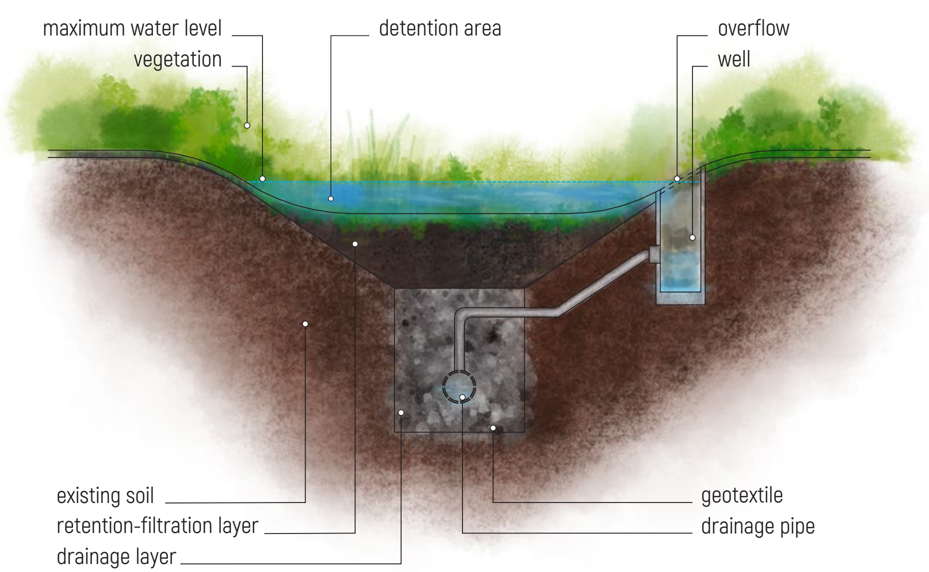

Figure 6. Section scheme of a bioswale when it is wet (based on Atelier Groenblauw, 2019)

stormwater. In case native vegetation does not survive, for example as a result of disease or interference of invasive species, replanting is needed. Monitoring for weeds and erosion is also required. Older bioswales (10 to 15 years) are more likely to require dredging with an excavator or replanting (Morton, 2017).

Potential challenges

Potential challenges	Solutions
Decreased effectiveness over time	Construction of bioswales on mild slopes (no greater than 5%) to reduce the risk for erosion; alternatively installation of erosion mats (Feit, 2018) Usage of native grasses and plants, which are adapted to the area avoidance of high maintenance plants that require fertilisation (Morton, 2017)

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Photo: Montgomery County Planning Commission

Photo: Agnieszka Kowalewska

Figure 7. An infiltration trench in East Norriton, United States (left) and Podkowa Leśna, Poland (right)

1.4. Infiltration trenches

Infiltration trenches (Figure 7) are shallow excavations covered with rubble or stone that enhance the natural ability of soil to drain water (NWRM, 2019). They remove pollutants and sediments from surface runoff water in several ways, such as physical filtration, adsorption onto the materials in the trench and biochemical reactions due to micro-organisms on the fill or in the soil (susdrain, 2019). Infiltration trenches can be easily integrated into existing sites and are most effective when combined with other drainage/ treatment solutions (NWRM, 2019). Infiltration trenches can increase soil water levels and groundwater flow rates, as well as reduce the velocity of surface runoff water and the risk of flooding.

Overview

Space requirement

The area of the infiltration trench should allow for infiltration through the trench bottom within 24 hours for medium sized rain; maximum drainage area: less than 5 ha (Dublin, 2019)

Place of application

Near playing fields, recreational areas or public open spaces

Costs (€)

Construction costs depend on the depth, geometry and soil/geology conditions of the infiltration trench; they amount to around 70–90 EUR/m^3 stored volume; maintenance costs range approximately between 0.25–4 EUR/m^2 (surface area)/year (NWRM, 2019)

Mitigation benefits

Cooling and insulation	
CO_2 sequestration	
Renewable energy production	
Use of low-carbon materials	✓
Promotion of sustainable behaviors	

Urban challenges addressed

Air pollution	✓
Heat island effect	
Water scarcity	✓
Rainwater drainage/runoff	✓
Flood resilience	✓
Ecological connectivity	
Urban upgrading	✓
High energy use	

Can be combined with

Green surfaces, Sustainable urban drainage systems (SUDS) – including bioswales, bioretention basins and permeable paving

Found in case study

2.6. Eco-city districts: "Jenfelder Au" in Hamburg

Technical details

In general, an infiltration trench should consist of the following features:

- a topsoil layer of minimum 15 cm with vegetation or gravel (Pennsylvania, 2006);
- a layer of coarse aggregate wrapped in unwoven geotextile (on the top, sides and bottom). The void ratio should be around 40 to 80 mm (NWRM, 2013);
- a continuously perforated pipe underneath, set at a minimum slope (Pennsylvania, 2006);
- a sand filter (or fabric equivalent) at the very bottom (Minnesota, 2015).

The soils underlying the site should be permeable and have a clay content of less than 20%, as well as a silt content of less than 40% (Dublin, 2019). Infiltration trenches can have vegetated, stone or gravel surfaces and require minimal land take, provided the design is carefully done. Generally, they should be 1–2 m deep and are restricted to relatively flat sites (NWRM, 2013). Infiltration trenches should be limited in width (around 1–2.5 m) and depth of stone (maximum of 1.8 m recommended) (Pennsylvania, 2006). To limit the velocity of surface runoff water and accommodate infiltration and pollutant removal, the longitudinal slope should not exceed 2% (NWRM, 2013). The infiltration structure should be at least 1 m above the seasonally high groundwater levels. Infiltration trenches are most effective for catching surface runoff water in locations with low sediment loading (e.g. car parks). If this is not the case, pre-treatment is needed to remove sediment and fine silt to prevent clogging (NWRM, 2013).

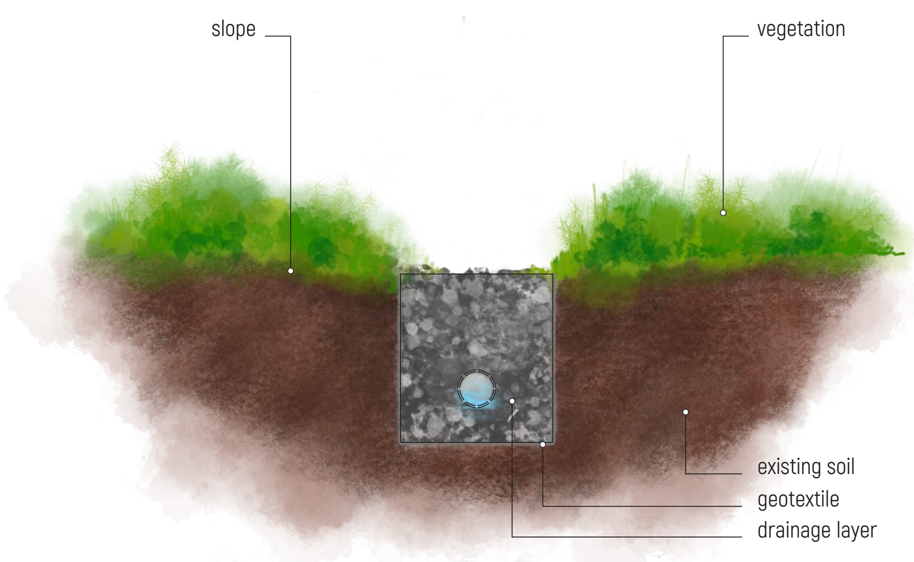

Figure 8. Intersection of a typical infiltration trench (based on Innovyze, 2016)

Maintenance

It is essential to conduct regular maintenance, including removing litter and debris, inspecting for clogging and trimming any roots that could cause blockages (NWRM, 2013). The catch basin and inlets require inspection and cleaning at least two times per year. In addition, the vegetation should be kept in good condition and bare spots should be repaired as quickly as possible (Pennsylvania, 2006). For the first few months after construction, the site should be inspected after every big storm to make sure the infiltration trench is stabilised and functioning (Minnesota, 2015).

Potential challenges

Potential challenges	Solutions
Construction limitations: cannot be used near buildings and when contaminated groundwater is present, are ineffective on steep slopes, loose or unstable areas (MW, 2017)	Preparation of geotechnical reports to inform the design and modelling process; during construction, ensure that heavy equipment (including vehicles) does not excessively compact the proposed infiltration area (Minnesota, 2015)
Limited to relatively small catchments	Integration of infiltration trenches into broader structures of drainage/treatment solutions

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Photo: DC Green Infrastructure

Photo: Centrum Informacji i Edukacji Ekologicznej w Gdańsku

Figure 9. Bioretention planter in Washington, DC, USA (left) and in Gdynia, Poland (right)

1.5. Biorentention planters

Bioretention planters are typically basins with concrete walls which are used to capture, treat and manage stormwater in a cost-effective manner. There are two main types of bioretention planters. The first are bioretention planter boxes (also called "flow-through" or "filtration based" planters), which have a closed, impermeable bottom and are combined with an underdrain pipe. The second type, an infiltration-based planter, has an open bottom through which the water flows to the underlying soil. In both types of planters, the stormwater is infiltrated for treatment, flowing through various layers of vegetation, soil and rock, before being released into the native soil or drained with a pipe.

The bioretention planters' key advantage is that they are adaptable to many contexts and can be located in parks, parking lots, courtyards and other urban areas. Their dimensions can be adapted to optimise infiltration rates in built-up constrained spaces. Bioretention planters need comparably less space to achieve the same stormwater management function as rain gardens. They also offer greater capacity for stormwater retention and infiltration than bioretention swales within the cross-section (NACTO, 2017). Bioretention planters provide aesthetic benefits and can be used to beautify streets and pavements in public areas.

Overview

Space requirement

The size of a bioplanter depends on the available space and determines its retention capacity; where possible, the size of the planter should amount to 2–5% of the drainage area

The bottom of a bioplanter should be at least 120 cm wide to promote vegetation health; narrower units can be implemented in areas where space is limited, but must be designed with consideration for plant health; the maximum ponding depth is between 15–30 cm (NACTO, 2017); there are no limits to the length of a bioplanter (see NACTO, 2017)

Bioplanters should be placed at least 90 cm above the groundwater table, and on slopes smaller than 5%; the infiltration planters should not be located too close to property and both infiltration planters and flow-through planters should not be located too close to water wells (Cuaran and Lundberg, 2015)

Place of application

Parks, parking lots, courtyards, public and private gardens and other urban areas

Potential costs (€)

Example capital costs: from 230 EUR/m^2

Example maintenance costs: 0.3 EUR/m^2/year (Massachusets, 2019; Delta, 2015)

Mitigation benefits

Cooling and insulation	✓
CO_2 sequestration	✓
Renewable energy production	
Use of low-carbon materials	✓
Promotion of sustainable behaviors	

Urban challenges addressed

Air pollution	✓
Heat island effect	
Water scarcity	✓
Rainwater drainage/runoff	✓
Flood resilience	✓
Ecological connectivity	✓
Urban upgrading	✓
High energy use	

Can be combined with

Bioswales, engineered soils, rain gardens and other elements of sustainable urban drainage systems (SUDS)

Found in case study

2.7. Floodable squares and parks: Zollhallen Plaza in Freiburg

Technical details

In general, bioretention planters should consist of the following features (Figure 10):

- the walls of the planter should provide room to retain water above the top layer (ponding areas). This can range from 5 cm (for mitigation runoff from sidewalk only or for fast draining soils) up to 30 cm to mitigate runoff from the road, and in case of slow draining soils;
- a top layer of mulch and vegetation: vegetation fulfills evapotranspiration and biotransformation functions. The choice of plants should take into account their water sensitivity and the ponding characteristics of the planter. Choosing native species and species beneficial to pollinators and insects is recommended. The plants can include flowers, grasses, shrubs, perennial vegetation and small trees (e.g. willows, wheat, winter rye, alfalfa, yellow sweet clover);
- a layer of planting soil, with a composition that allows for filtering and retention of water (maximum 60% sand, less than 40% silt, 5–10% organic matter, less than 20% clay). The depth of the soil layer depends on the type of vegetation to be planted and should allow sufficient space for roots (Cuaran and Lundberg, 2015);
- a layer of gravel (10–15 mm crushed rock, 15–30 cm layer thickness).

In the flow-through planter, an underdrain pipe (10 cm dimension) is placed in the gravel layer. An overflow control is necessary, in case of storm events bigger than the planters were designed for. The infiltration rate constitutes a key design consideration for bioplanters. The bioplanters should be designed to drain within 24–72 hours after a storm event to avoid bacteria and algae formation or prevent insect breeding (NACTO, 2017). The infiltration rate should be between 25 and 50 mm/h. In the infiltration planters, the underlying soil should have an infiltration rate of 13 mm/h (Cuaran and Lundberg, 2015).

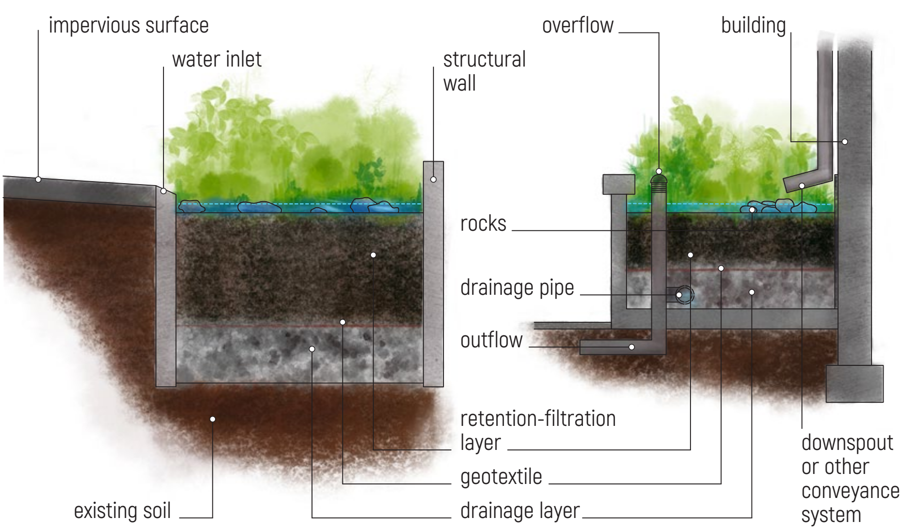

Figure 10. Section scheme of infiltration planter (left) and flow-through planter (right) (based on Cuaran and Lundberg, 2015)

Maintenance

Following the construction, vegetation needs to be watered regularly to ensure the establishment of roots. After the first storm event, the planter should be inspected for proper drainage, erosion as well as inlet and outlet functioning in case of flow-through planters.

Plants need to be trimmed monthly or as necessary to maintain the desired appearance. Dead leaves and trash may need to be removed to ensure the surface remains permeable.

It is recommended to monitor vegetation twice a year to ensure successful root establishment, inspect for erosion, clogging and vegetation damage, remove debris from inlets and outlets to avoid clogging and add mulch to bare areas. It is recommended to replace dead or diseased plants on a yearly basis and re-grade soil surface if erosion has occurred (Cuaran and Lundberg, 2015; Massachusetts, 2019).

Potential challenges

Potential challenges	Solutions
Newly built planter may require irrigation during the first 1–3 years after installation	Usage of reclaimed water to offset freshwater use, although this requires additional infrastructure
Water may flow through the sides of the planter as it infiltrates into the media and may be at risk of entering adjacent basements and structures	Increase of wall depth or use of liners to mitigate water migration

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Photo: FPP Enviro

Photo: FPP Enviro

Figure 11. A green bus stop in Białystok, Poland (left) and Radom, Poland (right)

1.6. Green bus stops

A green bus stop (Figure 11) is a piece of innovative urban street furniture that serves several functions. Apart from being a shelter for passengers waiting for the next connection, it retains stormwater and provides extra green space for people and nature. Stormwater is retained in several ways: each bus stop is covered with a plant-based green roof with a water retention layer. Such a roof retains up to 90% of the stormwater falling on its surface. During dry weather periods, the water is used by the plants and evaporates, making space for the next fallout. The water which is not used on the roof, combined with the excess stormwater from the surrounding sidewalk, is retained in a vegetated retention-infiltration box in the back of the shelter. The box supports climbing plants that grow on the green wall at the back of the construction. The excess water from the box is then directed to nearby green areas or trees. A green bus stop helps to minimise local flooding, stormwater sewage system overload and urban heat island effect. It also supports local biodiversity more than traditional bus stops by providing a "stepping stone" for insects and limiting bird collisions with the glass.

Overview

Space requirement

Size of the standard shelter: length approx. 5.4 m, width approx. 1.9 m (can differ in individual design)

Maximum size of the surrounding sidewalk area that can be drained with the standard design: up to 60 m^2

Place of application

City centres and urbanised areas reached by public transport

Potential costs (€)

Capital costs: 18,000 EUR/item (including shelter construction, green roof insulation, retention, substrate and vegetation layers, climbers for the green wall and additional accessories, e.g.: bench, advertisement display, litter bin, etc.)

Maintenance costs: 3,000 EUR/year

Mitigation benefits

Cooling and insulation	✓
CO_2 sequestration	✓
Renewable energy production	
Use of low-carbon materials	
Promotion of sustainable behaviors	✓

Urban challenges addressed

Air pollution	✓
Heat island effect	✓
Water scarcity	
Rainwater drainage/runoff	✓
Flood resilience	
Ecological connectivity	✓
Urban upgrading	✓
High energy use	

Can be combined with

Green areas, single trees

Technical details

A green bus stop consists of the following elements (Figure 12):

- construction of the shelter – innovative design made by laser cutting and firing of welded and galvanised steel profiles, galvanised and painted with powder coating. The walls are made of tempered glass. The construction is based on concrete pre-fabricated foundations;
- the green roofs – including drainage layers, substrate and vegetation mats – are adopted to the shelter construction requirements;
- the walls – covered with evergreen or blooming climbers growing in a retention-infiltration box, which ensures effective watering of the plants and protects them against frost;
- connection to additional water retention elements (infiltration trenches, swales, tree-trenches and others).

Green bus stops can be located in areas with higher proportion of greenery, as well as in highly sealed and densely developed areas, where all stormwater is directed to sewers. They allow existing infrastructure to deliver more functions (such as stormwater infiltration and retention, creating green spots for urban heat island effect mitigation and biodiversity), without taking up additional space. The green bus stop design described in this catalogue is protected by industrial property rights.

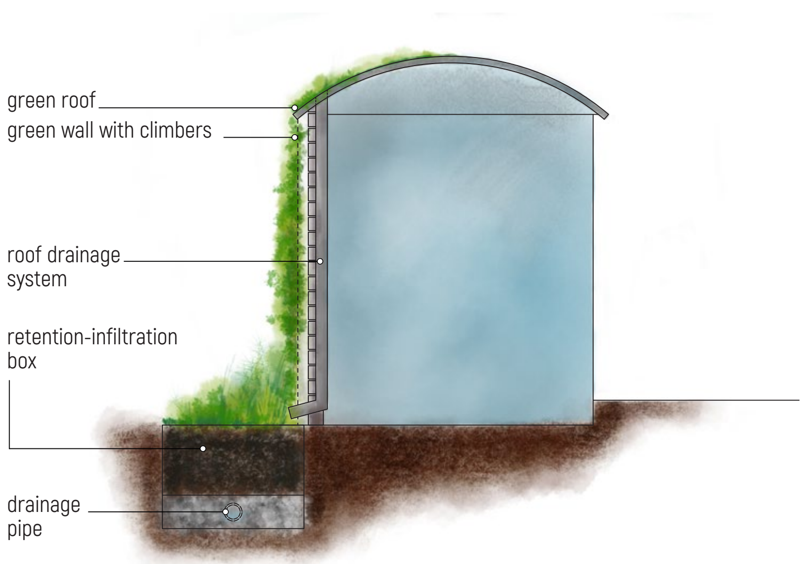

Figure 12. Section scheme of a green bus stop

Potential challenges

Potential challenges	Solutions
Maintenance of green roof and wall vegetation	Usage of native species of plants, resistant to heat and dry weather Intensive watering of the roof is needed for the first 2–3 months of operation (every day evening) and during persisting hot and dry weather (once a week) afterwards
Draining surrounding sidewalk area	Ensuring slopes of the surrounding pavements are adequate in order to drain additional area; alternatively, installation of green bus stops during urban retrofitting projects and/or during the reconstruction of pavement, so the slopes can be obtained in this process
Higher maintenance costs	Green bus stops may be categorised as a green facility; part of maintenance cost can be covered by the budget for the maintenance of green areas

Photo: ACME

Photo: Agnieszka Kowalewska

Figure 13. Green roof in Berlin, Germany (left) and at Copernicus Science Centre, Warsaw, Poland (right)

1.7. Green roofs

Green roofs are spaces on top of buildings covered in vegetation, planted in a growing substrate. They are an increasingly popular measure to introduce more greenery in densely built-up areas, without sacrificing additional space. Green roofs come with a multitude of private and public benefits, many of which contribute to urban climate mitigation and adaptation. Green roofs cool and humidify surrounding air, reducing the urban heat island effect and improving the urban microclimate. They improve air quality by binding dust and toxic particles. Vegetation on green roofs captures and stores carbon. Green roofs improve the energy performance of buildings by providing thermal insulation on both hot and cold days. Green roofs increase rainwater retention: they can reduce run-off from the roof by up to 90% and can reduce building construction costs (pipes and drains) and even sewer network maintenance costs when implemented at a wider scale. Additional benefits include: providing functional open space, noise insulation, increasing longevity of roof construction materials, providing space for food production and habitat for wildlife (Schwarz-v. Raumer, 2019).

Two main categories can be distinguished: intensive green roofs and extensive green roofs. Intensive green roofs have a thicker substrate layer, a higher variety of vegetation, and are more frequently established on roofs accessible to residents or public, to create space for activities such as gardening, relaxing or socializing. Intensive green roofs require more maintenance than extensive green roofs. Extensive green roofs consist of a thin layer of substrate covered in low-maintenance vegetation such as moss, sedum, wildflowers or grasses. Extensive green roofs are cheaper to install than intensive roofs and require minimum maintenance after installation (Schwarz-v. Raumer, 2019; Atelier Groenblauw, 2019).

There are many additional variations of green roofs, such as: "retention roofs" or "green-blue roofs" that come with system solutions to increase water storage and reduce discharge; "urban rooftop farms" focused on growing food; "solar green roofs", which combine extensive green roofs and solar panel systems; or "wetland roofs", which mimic wetland conditions in a roof setting.

Overview

Space requirement

Roof pitch: 0–5° (sloping green roofs with a slope of up to 45° or more can be installed with the use of anti-slip mats and other systems); depth: from 7 cm (extensive green roofs) to 125 cm (intensive green roofs); weight: 80 kg/m^2 (extensive green roofs) to 570 kg/m^2 (intensive green roofs); water storage: 25 l/m^2 (extensive green roofs) to 160 l/m^2 (intensive green roofs) (Schwarz-v. Raumer, 2019; Atelier Groenblauw, 2019)

Place of application

A green roof can be applied on any construction that can withstand its weight – public and private residential and commercial buildings, roofing over petrol stations etc.

Mitigation benefits

Cooling and insulation	✓
CO_2 sequestration	✓
Renewable energy production	✓
Use of low-carbon materials	✓
Promotion of sustainable behaviors	✓

Potential costs (€)

Intensive green roofs: Capital costs: from 150 EUR/m^2 upwards (Info-dachy, 2015)
Maintenance costs: varied estimates in literature, from 3.50–5 EUR/m^2/year to 10–15 EUR/m^2/year (Schwarz-v. Raumer, 2019)

Extensive green roofs: Capital costs: from 50–225 EUR/m^2 (Info-dachy, 2015)

Maintenance costs: low: 0.5–3 EUR/m^2/year (Schwarz-v. Raumer, H., 2019)

Urban challenges addressed

Air pollution	✓
Heat island effect	✓
Water scarcity	
Rainwater drainage/runoff	✓
Flood resilience	✓
Ecological connectivity	✓
Urban upgrading	✓
High energy use	✓

Can be combined with

Green walls and facades

Found in case study

2.5. Highway Green Roofing: Hamburg A7 Highway Cover

2.6. Eco-city districts: "Jenfelder Au" in Hamburg

2.9. Sustainable urban drainage systems: Potsdamer Platz, Berlin

Technical details

In general, an extensive green roof should consist of the following features (Figure 14):

- vegetation layer: low-maintenance vegetation such as moss, sedum, succulents, herbs, grasses;
- light substrate layer (8–15 cm) (Bauder, 2019);
- drainage layer;
- protection layer: usually a waterproof protecting mat, to protect the roof construction from the roots and water.

Intensive green roofs normally consist of the following features:

- vegetation layer: wide variety of vegetation is possible (small trees, shrubs, perennials, edibles);
- substrate layer (20–60 cm) (Atelier Groenblauw, 2019);
- filter layer which prevents fine substrate and sediment from being washed into the water storage or drainage component;
- water storage and drainage layer helps to maintain the balance between the amount of water that is held on the roof to support the vegetation, whilst allowing the surplus amount to drain away so that the substrate does not become waterlogged;
- root protection layer;
- protection and separation layer delivering protection against mechanical damage (Bauder, 2019).

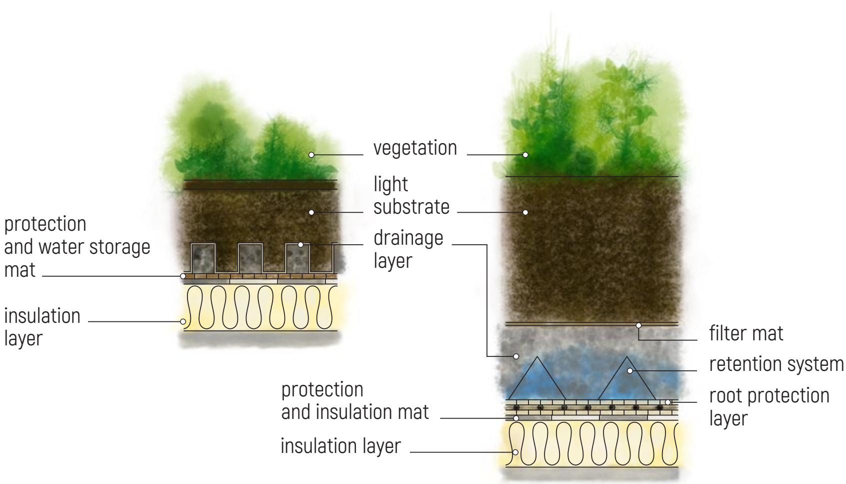

Figure 14. Section scheme of extensive green roof (left) and intensive green roof (right) (based on Atelier Groenblauw, 2019)

Maintenance

All green roofs require semi-annual inspections to ensure water outlets and shingles are clear of dead and live plants. Extensive green roofs require minimal maintenance (semi-annual or quarterly) to ensure unwanted species are not established and plant growth is healthy, but also to remove debris, fallen leaves and other unwanted items. An intensive green roof requires regular maintenance linked to the planting scheme and landscape design, similar to garden maintenance.

Potential challenges

Potential challenges	Solutions
Structural limitations: some roofs and load-bearing walls may not be strong enough to withstand the weight of a green roof	Extensive green roofs are lighter than intensive green roofs. The latter may require additional supporting construction Assessment of load capacity of a roof should be conducted prior to construction, taking into account possible natural events such as snowfall, heavy rainfall and seismic events
Root penetration: plants with aggressive roots may damage the water-proofing layer of green roofs	Waterproofing membranes used in conjunction with green roofs should be chosen based on their root-resistance

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Photo: Ewa Iwaszuk

Photo: Michał Markowski

Figure 15. Vertical garden in Kreuzberg, Berlin, Germany (left) and Kraków, Poland (right)

1.8. Green facades and walls

Green facades and walls are walls partially or completely covered by greenery, created by growing plants vertically across a wall or a facade of the building. Green walls offer many climate mitigation opportunities in urban environments, due to their temperature control benefits, reducing the need for heating and cooling. At the neighbourhood level, they mitigate the urban heat island effect through shading, as well as reducing reflected heat and evapotranspiration (Sheweka and Mohamed, 2012). At the building level, they attract and release less heat (Atelier Groenblauw, 2019), contributing to improved thermal insulation. Moreover, green walls improve indoor and exterior air quality by capturing and storing airborne pollutants. They also insulate sound, provide aesthetic benefits and can help protect building structure by reducing damage caused by temperature fluctuations and UV radiation (Sheweka and Mohamed, 2019). Green walls can be used to introduce more greenery into heavily built-up areas, as they take up minimal area on the ground. They promote biodiversity by providing a habitat for birds and insects.

Some cities are experimenting with so-called productive facade systems, which can be used for energy or food production. This includes bio-photovoltaic panels and moss voltaic panels that produce energy from natural microbial processes. A building in Hamburg has a facade that is constructed from panels where algae are grown in a saline solution. Algae consume CO_2 to grow and can be used as a sustainable biofuel as well as an organic fertiliser (Syn.De.Bio, 2014).

Overview

Space requirement

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; sufficient space should be available underground for roots to remain healthy

Place of application

Walls of public and private buildings; both indoor and outdoor application is possible

Potential costs (€)

The costs of a green wall will vary widely depending on type of green wall or facade used; for direct, ground-based green facades the cost includes purchasing self-climbing plants and the optional planters, initial planting and installation and annual maintenance and inspection

Indoor living wall systems with irrigation and lightning systems, requiring regular maintenance and care, may cost as much as 3,200 EUR/m^2 (total cost of installation and maintenance over 5 years) (StyleGreen, 2019)

Mitigation benefits

Cooling and insulation	✓
CO_2 sequestration	✓
Renewable energy production	✓
Use of low-carbon materials	✓
Promotion of sustainable behaviors	

Urban challenges addressed

Air pollution	✓
Heat island effect	✓
Water scarcity	
Rainwater drainage / runoff	
Flood resilience	
Ecological connectivity	✓
Urban upgrading	✓
High energy use	✓

Can be combined with

Green roofs

Technical details

When designing a green facade, the main elements to be decided upon are the type of vegetation to be used, the growing medium and the supporting construction. Direct, ground-based green facades (Figure 16.1) use self-climbing plants, which use suckers, twinning stems or tendrils to attach directly to the wall. In this case no supporting construction is required (Atelier Groenblauw, 2019). The plants are planted directly in the ground or in soil placed in planter boxes. It requires a strong facade with no cracks or gaps between the bricks (Schwarz-v. Raumer, 2019).

Indirect green facades (Figure 16.2–3) use vegetation that climbs on a supporting structure installed in front of the wall, such as grape vines, parthenocissus and clematis (Atelier Groenblauw, 2019). Possible supporting structures include cable systems for faster growing plants with dense foliage, wire-rope systems, which provide more versatility in use or three-dimensional, lightweight modular trellis panels (Rakhshandehroo, 2016). The vegetation can be planted directly in the ground or in planter boxes at the base of the wall. The volume, drainage and type of substrate of the planter box should be chosen to accommodate plant growth over the years. The ground-based direct and indirect green facades do not require additional irrigation but are dependent on natural water cycles and may be vulnerable to drought stress (Schwarz-v. Raumer, 2019). The choice of plants should take into account climatic conditions and the direction of the facade which will determine the amount of sunlight received. This sort of green wall usually uses one dominant species. Ground-based green facades need 5–20 years to cover a house facade.

Living walls or vertical gardens (Figure 16.4) use climbing or hanging plants growing from pots or felt pockets attached to the facade or substrate attached to the wall (Rakhshandehroo, M., 2016). Living walls are normally installed with an automated drip-irrigation system and nutrition delivery systems. Special substrates are used to reduce the weight of the facade. As a result, they are more expensive and require a higher use of resources in construction and maintenance. Living walls allow for a combination of 10–15 plant species, most often mosses and perennials. Living walls will green faster and in a more uniform way than ground-based facades. Because of the thinness of soil or substrate, living walls are less frost-resistant than ground-based green facades (Schwarz-v. Raumer, 2019). They are, however, appropriate for indoor installation.

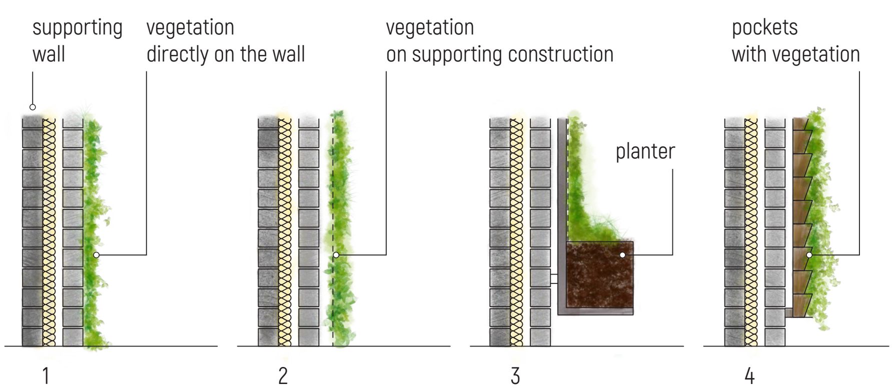

Figure 16. Different types of green walls. 1 – direct, ground-based green facades; 2 – Indirect, ground-based green facade; 3 – Indirect green façade combined with planter boxes; 4 – Living wall system / vertical garden. (based on Perini K, Rosasco, P., 2013)

Maintenance

Ground-based facades may require support and checking in the first months after installation to ensure they grow in correct direction. Afterwards they need little maintenance such as annual inspection of the supporting system and wall building material. Storm drains and gutters close to the facade need to be monitored and cleaned of debris and falling leaves. Irrigation may be necessary if droughts occur.

Complex living wall systems supported by irrigation systems require regular professional maintenance, usually offered by the company that installs the system. Living wall systems consume water and energy and their upkeep can become costly. Because of the limited space allowed for growth in living wall systems, the plants may need to be replaced every 5–10 years.

Potential challenges

Potential challenges	Solutions
Facades with cracks or loose mortar can be destroyed by self-climbing plants	Inspection for and reparation of any damage to building
Building residents may be concerned with increased number of insects and spiders	Installing facades on walls with no windows; keeping windows clear of vegetation
Increased risk of fire in case of drought	Ensuring appropriate irrigation in case of drought
Wind can create problems for plant attachment for multi-level facades	Indirect facades with supporting constructions may be better suited for wind-exposed tall facades

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Photo: DeepRoot

Photo: Agnieszka Kowalewska

Figure 17. An example of permeable paving on a square in front of Century College Stormwater Education Island, White Bear Lake, United States (left); permeable parking in front of Contemporary Art Museum, Warsaw, Poland (right)

1.9. Permeable paving

Permeable paving (Figure 17) allows surface runoff water to permeate into the ground, by having open parts or using porous materials in its design. The design can be accustomed to the proposed application, which can vary greatly. For example, materials used in footpaths, playgrounds and private gardens can include open cell concrete blocks, grass concrete pavers, woodchips, shells or gravel. For roads and parking areas that are used intensively, other materials such as porous clinkers, open-joint clinkers, open paving patterns, gravel, or shells can be used (Groenblauw, 2019). Permeable paving offers several benefits, such as the elimination of surface runoff water, recharging of groundwater, trapping of suspended solids and pollutants, reducing of surface temperatures, as well as reducing the need for retention basins and water collection areas.

Overview

Space requirement

Permeable paving can replace existing pavements or be used instead of sealed pavement in new constructions

Costs (€)

Capital costs: Approx. 43–86 EUR/m^2

Maintenance costs: Approx. 0.05–0.21 EUR/m^2/year. (Morello et al. 2019)

Place of application

Footpaths, playgrounds, private gardens, roads, parking areas

Mitigation benefits

Mitigation benefits	
Cooling and insulation	✓
CO_2 sequestration	
Renewable energy production	
Use of low-carbon materials	✓
Promotion of sustainable behaviors	

Urban challenges addressed

Urban challenges addressed	
Air pollution	
Heat island effect	✓
Water scarcity	✓
Rainwater drainage/runoff	✓
Flood resilience	✓
Ecological connectivity	
Urban upgrading	✓
High energy use	

Can be combined with

Sustainable urban drainage systems (SUDS) such as bioswales, infiltration ditches and water retention ponds; single trees

Found in case study

2.2. Blue-green living streets: Vauban district in Freiburg

2.3. Water plazas: Rain playground in Neugraben-Fischbek, Hamburg

2.6. Eco-city districts: "Jenfelder Au" in Hamburg

2.7. Floodable squares and parks: Zolhallen Plaza in Freiburg

Technical details

Permeable paving consists of the following features:

- the surface layer is what users are able to see. It differs with the type of permeable paving. There are many different types of permeable paving, such as permeable concrete, permeable asphalt, permeable interlocking concrete pavements, concrete pavers and plastic reinforcement grid pavers. Other examples include woodchips and pinebark, gravel, stone chippings and shells;
- gravel base underneath the surface layer (with the exception of permeable concrete) to support vehicles. The gravel also retains water during and after rain events. The thickness of this layer differs for each design;
- a sub-base, which is the native soil that can be found below the gravel base. Installing permeable paving in a sandy sub-base provides more structural support and infiltration capacity compared to a clay sub-base (Hunt and Collins, n.d.);
- underdrains (optional) – usually small plastic pipes of around 10 to 20 cm – to transport water to the stormwater network. Underdrains are most often incorporated when the permeable paving is installed in soils that contain clay.

The slope of the proposed installation site for permeable paving should not exceed 5% – the flatter, the better. It should not be installed within 1.2 m above bedrock or a ground water high point, within 30 m of a well, within 3 m of building foundation located above the proposed installation site or 30 m for building foundation situated below the proposed installation site. It should never be within the vicinity of possible contamination sources, such as gas stations (LSS, 2019).

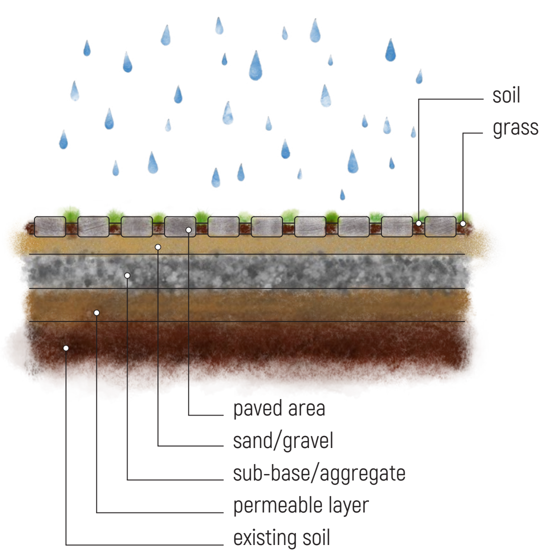

Figure 18. Schematic cross-section of an example of permeable paving (based on Atelier Groenblauw, 2019)

Maintenance

Proper maintenance is important for the durability of permeable paving. This ensures that it does not clog and eventually needs complete replacement. Debris, including grass clippings, sediment, trash and leaves should be removed on a monthly basis. The permeable pavement should be vacuum sweeped once or twice per year and snow should be removed during winter. Using sand to deal with ice formation should be avoided, since it will clog the permeable pavement. Other practices to avoid are regularly parking or driving of large vehicles. The structural integrity of the permeable pavement as well as drain outfall should be monitored. Repairs and replacements should be made where needed.

Potential challenges

Potential challenges	Solutions
Insufficient retention capacity	Integration of permeable paving into a larger drainage system
Reduced effectiveness over time	Construction of permeable pavements away from areas with soil disturbance; in cold climates, carefully consider the use of permeable pavement; in such climates, repaving is required around every 15 to 25 years (CTC, 2012)

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Photo: NCAT CAES

Figure 19. Biochar can used as a soil amendment to create structural soil

1.10. Structural soils

Structural soils are produced with soil and soil components, such as sand, silt, clay and organic matter/compost, with a mixing ratio aligned to serve a particular application (USCC, 2016). The soil can then be used for planting trees, bushes, perennials and grasses, but also in Sustainable urban drainage systems (SUDS). Potential other soil components include peat and biochar (Embrén, 2016). A key benefit related to mixing in biochar into soil composition is the controlled accumulation of carbon in soil (Renforth et al., 2011).

As opposed to other soil components, biochar is not affected by compression and compaction, which is a threat to trees and other perennials in urban areas due to the resulting lack of available water and oxygen to the tree roots (Embrén, 2016). Biochar has many benefits, such as increasing soil fertility, immobilising heavy metals, pesticides, herbicides and hormones, preventing nitrate leaching and faecal bacteria into waterways and reducing N_2O and CH_4 emissions from soils. Other benefits include improved water retention and cation exchange capacity. Moreover, biochar is believed to be very stable in soils and can potentially be a valuable carbon sink (Renforth et al., 2011).

Overview

Space requirement

Space requirement: Engineered soils can replace existing soil or be used instead of traditional soil in new installations

Place of application

Places of application that require use of soil

Costs (€)

Capital costs: The capital costs depend on the soil components used

Mitigation benefits

Cooling and insulation	
CO_2 sequestration	✓
Renewable energy production	
Use of low-carbon materials	✓
Promotion of sustainable behaviors	

Urban challenges addressed

Air pollution	
Heat island effect	
Water scarcity	✓
Rainwater drainage/runoff	✓
Flood resilience	
Ecological connectivity	
Urban upgrading	
High energy use	

Can be combined with

Sustainable urban drainage systems (SUDS) – such as bioswales, bioretention basins, bioretention planters, rain gardens and green roofs – individual trees, bushes, perennials and grasses

Technical details

One urban tree requires approximately 2.25 m³ of structural soil with porosity of around 40% (Embrén, 2016). The mix should be around 85% gravel (32–63 mm in size) and 15% biochar (particle size 1–10 mm). Even though the characteristics of the blend differ per situation, a common, successful one for perennials and bushes consists of three parts of gravel (2–6 mm in size) and one part of biochar (Embrén, 2016).

The quality of biochar and particularly the toxicants it contains can pose a problem. To this end, several certification schemes have been developed (e.g. the European Biochar Certificate). In addition, the term "biochar" can apply to a wide variety of materials, since their physical and chemical properties differ significantly from one another.

Potential challenges

Potential challenges	Solutions
Quality issues related to soil components	Usage of certified soil components

References

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Figure 20. Map of Germany with specific examples of NBS case studies presented in this catalogue

2. Nature-based solutions case studies: Ten German examples

The following section presents ten case studies of complex, combined nature-based solutions applications implemented or planned for specific sites in German cities. Whilst being applied in Germany, the examples have been chosen for their climate mitigation potential and high applicability across a range of urban contexts in Europe. The examples include greenfield developments, where new areas were designed from scratch (Chapter 2.6 Eco-city districts: "Jenfelder Au" in Hamburg), as well as examples of brownfield regeneration (e.g. Chapter 2.1 Constructed urban wetlands: Landscape Park Duisburg-Nord or Chapter 2.2 Blue-green living streets: Vauban district in Freiburg). The case studies show how nature-based solutions can be applied to address urban challenges at a city-wide scale (e.g. Chapter 2.8 Ventilation corridors network: Stuttgart), but also at the scale of an individual square or playground (e.g. Chapters 2.7 Floodable squares and parks: Zolhallen Plaza in Freiburg and 2.3. Water plazas: Rain playground Biberland in Hamburg).

The case studies focus on how NBS that have been integrated as part of a broader approach can be used to address multiple urban challenges. In addition to providing details about the introduced solutions, the case studies highlight the motivation behind utilizing an NBS, barriers overcome in developing the projects and key success factors. Respective project budgets are also presented.

All case studies were developed in consultation with individuals involved in commissioning, designing or implementing the specific solutions, such as project managers or municipal officers. Contact details are provided for each case study.

The authors of this catalogue are very grateful to all individuals and institutions who provided invaluable information about and feedback to the case studies that was essential to the creation of this catalogue.

Figure 21. Stormwater retention pool within Landscape Park Duisburg-Nord

2.1. Constructed urban wetlands: Landscape Park Duisburg-Nord

Constructed urban wetlands are artificial wetlands engineered to naturally treat wastewater and stormwater runoff in urban areas. They improve the quality of surface water and purify precipitation runoff from cities through their component vegetation, soil and microorganisms. They also create a green oasis in cities, offer opportunities for leisure, mitigate the urban heat island effect and provide a habitat for wildlife. Wetlands can furthermore buffer the run-off from precipitation to prevent urban flooding.

One such urban wetland was constructed as part of Landscape Park Duisburg-Nord in Duisburg (Figure 21). The entire landscape park was built on reclaimed land on a major former industrial site that closed its steel and coal works in 1985 (Stilgenbauer, 2005). The total area of the park amounts to 180 ha, with about 150 ha green areas, approx. 30 km of cycling and hiking trails and approx. 13 ha of agricultural land. The water park was developed by transforming the Emscher River (Figure 22), which cuts across the site and formerly served as an open sewer canal. The river was subdivided into five main sections: a clear water canal, a dyke, a channel, a gorge and a stream. The former open wastewater canal of the Emscher river was re-constructed into a clear water canal with bridges and footpaths that is fed only by clear rainwater. Wastewater is now carried by a 3.5 m diameter underground main that collects and treats run-off from the buildings, bunkers and former cooling ponds (L+P, 2019). A wind power installation was set up in the mill tower of the former sintering plant to support the cleaning and transportation of the water (L+P, 2019a).

The built-in barrages and water shoots make it possible to collect rainwater and release it with a time delay so that the Emscher river retains its oxygen levels even in dry spells (Landschaftpark, 2019). Platforms extend over the water to make the new environment accessible to the park's visitors.

Overview

The "International Building Exhibition Emscher Park" (*Internationale Bauausstellung Emscher Park*) managed and financed the construction of the landscape park and its constructed wetland. This financing was made possible by the City of Duisburg, the State of North Rhine-Westphalia, LEG Immobilien AG (a German property company) and the Federal Government (Landschaftpark, 2019).

Mitigation benefits

Mitigation benefits	
Cooling and insulation	✓
CO_2 sequestration	✓
Renewable energy production	
Use of low-carbon materials	
Promotion of sustainable behaviors	✓

Urban challenges addressed

Urban challenges addressed	
Air pollution	✓
Heat island effect	✓
Water scarcity	✓
Rainwater drainage / runoff	✓
Flooding resilience	✓
Ecological and social connectivity	✓
Urban upgrading	✓
High energy use	

Duration

In 1988, the state of North Rhine-Westphalia acquired the site and made the ironworks a part of the International Building Exhibition Emscher Park (IBA); from 1990 to 12/2001 the planning and realisation of the project took place; construction work started in January 1992; in 1994 parts of the park were already opened to the public

Financing sources

State level: State of North Rhine-Westphalia – 30%; regional level: Regional Association Ruhr – 18%; local level: City of Duisburg – 11%; private finance: Duisburg-Nord Landscape Park Operating Company – 41%

Component NBS

Stormwater retention pools, clear water canal, dyke, channel, gorge and stream

Costs (€)

The budget for the construction of the entire landscape park, excluding land purchase and treatment of contaminated sites, was 15,500,000 EUR (L+P, 2011)

Project motivation and achievements

For most of the 20th century, Duisburg and the surrounding Ruhr area were heavily polluted as a major center of coal mining and steel manufacturing. The heavy industry left behind an ecological crisis and its decline contributed to a loss of cultural identity in the region. Inspired by a series of earlier "International Building Exhibitions" (IBA) in other parts of Germany, the state of North Rhine-Westphalia, local municipalities, and private companies formed a commission to oversee a regional ecological and economic regeneration. At Duisburg-Nord, the land development authority of North Rhine-Westphalia, with the support of a real estate fund, purchased the grounds of the former Thyssen Steelworks manufacturing plant. After the City of Duisburg changed its zoning to allow its conversion into a public park, an urban design competition was called and the Landscape Park Duisburg Nord, including the constructed urban wetland park, was conceived and built (Stilgenbauer, 2005).


Photo: Thomas Berns

Figure 22. Renaturalised above-ground part of the Emscher river in Landscape Park Duisburg-Nord

The transformation of the former blast furnace plant into an ecological landscape park, including the water park, has resulted in a number of awards,

Urban challenges	Solutions
Air pollution	Green spaces to reduce atmospheric pollutant concentrations Green spaces to encourage sustainable, non-polluting means of transport, e.g. biking over driving
Heat island effect	Green spaces to provide cooling via evaporation and shade from trees and plants Water features provide evaporative cooling and improve the micro-climate
Water scarcity	Building a system of barrages and water shoots, the Emscher River can be consistently replenished during dry periods
Rainwater drainage/ runoff	Extensive vegetation and permeable surfaces allow stormwater to be absorbed and released slowly
Ecological and social connectivity	The old industrial structures were not removed from site and memory but rather incorporated into the new design, whereby the former sewage canal was transformed into a method of cleansing the site; this helps build cultural memory and social connectivity in the region Public green and blue spaces to allow for the closer interaction of all social groups and to provide a venue for urban wildlife
Urban upgrading	A former site of ecological devastation and then economic decline has been transformed into an urban space that symbolises renewal and promotes sustainability

such as the Green Good Design Award 2009, EDRA Places Award 2005, Play & Leisure Award 2004, Grande Medaille d´Urbanisme 2001 and 1st European Prize for Landscape Architecture Rosa Barba 2000 (L+P, 2019b).

Barriers and success factors

Transforming the plots of varying sizes and dimensions in different areas of the park was a major challenge when establishing the park. In the early days of the park development, there was no comparable example that could be used as a model for the idea of transforming a disused steel mill into a multifunctional park (Figure 23). Consequently, the first park manager, Dirk Büsching, always jokingly called himself the "biggest scrap owner in Duisburg". Success factors for the implementation of the park project were the ever-increasing interest in industrial culture, the transformation of urban living space and the use of the park's potential for nature, culture and its varied landscape that allows for a great diversity of activities to be conducted in the park.

Photo: Thomas Berns

Figure 23. Details of the water park (left) and an ore bunker converted into a climbing wall (right)

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Photo: Poudou99

Figure 24. Green trough-trench system and green rails in Freiburg-Vauban

2.2. Blue-green living streets: Vauban district in Freiburg

Blue-green living streets, sometimes called green woonerfs, encourage the creation of shared community spaces and reduce the dominance of cars. This is made possible through the removal of road markings and traffic signs to encourage natural human interactions as well as the placement of trees, flower beds, play areas and front yards. The benefits of living streets with less traffic are less air and noise pollution, higher levels of accessibility for non-motorised modes of transport (e.g. bikes), improved safety, higher property values, increased social interaction and the more efficient use of urban living space.

Vauban district in Freiburg is an example of a car-reduced brownfield redevelopment with parking-free residential streets. Car ownership and use are half of what is seen in comparable districts. The district consists of nearly 2,000 low-energy homes (with different building standards including some net-positive energy houses) on 41 ha at a distance of approximately 3 km from the Freiburg city center. Of the 41 ha, about 19 ha form a residential area, approx. 9 ha are reserved for traffic/transport, approx. 3 ha are a mixed-use area, approx. 2 ha are public purpose land and another 2 ha are commercial area. The built area is accompanied by about 6 ha of public green spaces (Freiburg, 2019). The district has a relatively high density at 95 units/ha, high standards of thermal insulation (65 kWh/m² maximum, with 100 "passive houses" requiring only 15 kWh/m²), solar energy installations and renewable woodchip district heating. The abundant green space, community gardens and a stream at the edge of the site create possibilities for recreation activities without the need to travel out of the district (Field, 2011). While Vauban is accessible to private motor traffic from the east, cars must drive at walking speed, give priority to other road users and may only stop for dropping off or picking up. Since Freiburg's tram system was extended in 2006, all households are within 400 m of a tram stop (Figure 24).

Overview

Mitigation benefits	
Cooling and insulation	✓
CO_2 sequestration	✓
Renewable energy production	
Use of low-carbon materials	
Promotion of sustainable behaviors	✓

Urban challenges addressed	
Air pollution	✓
Heat island effect	✓
Water scarcity	
Rainwater drainage / runoff	✓
Flood resilience	
Ecological and social connectivity	✓
Urban upgrading	✓
High energy use	✓

Duration

Planning began in 1992; development from 1998 to 2004, with some phases of development continuing, such as the extension of the tram to the district (Field, 2011)

Component NBS

Green trough-trench systems with gravel-filled drain trenches, permeable paving, green roofs, garden plots, green areas/parks

Financing sources

Regional level: 2.5 million EUR (Grant from the state-level urban redevelopment program); city level: 2.5 million EUR (equivalent to regional funding) + 1 million EUR deficit at end of project; private: 85.6 million EUR from real estate sales; 10.8 million EUR additional income

Costs (€)

Approx. 102 million EUR (Freiburg, 2019)

Project motivation and achievements

After the French army vacated Vauban in 1992, local environmental campaigners formed the Forum Vauban association to introduce more radical design measures to the master plan for the area proposed by the City of Freiburg. This led to Vauban's distinct U-shaped streets with the explicit intention to deter car use and create safe streets for children's play. As a result, approximately 70% of households in Vauban do not own a car. In comparison to the city of Freiburg, in which cycling accounted for 34% of commuter trips in 2002, Vauban's car-owning and car-free households cycled for 61% and 91% of their trips (Field, 2011).

The tram line in Vauban is set in a grassy swale in order to muffle sound, decrease air pollution and contribute to the district's overall ecological stormwater management system. In Vauban, rainwater and wastewater are predominantly discharged separately (modified separation system). In spite of soils that were not suitable for infiltration, it was decided in 1996 to retain the rainwater in a system of trough drainages in order to infiltrate as much rainwater as possible and thus reduce the water inflow into the village stream. In order to keep surface runoff to a minimum, decentralised rainwater management measures such as green roofs, permeable pavements, green areas and trees were implemented. The combination of the trough-trench system and decentralised rainwater management measures has proven to be successful with a high annual territorial water retention (Jakisch et al., 2013).

The different blocks of houses are separated by five resident-designed parks that connect with the walking trail along Dorfbach creek, a natural area

Urban challenges	Solutions
Air pollution	Green spaces to reduce atmospheric pollutant concentrations Green spaces to encourage sustainable, non-polluting means of transport, e.g. biking over driving Traffic-calming measures and the ban of parking make cycling and tram usage more attractive alternatives to personal motorised vehicles
Heat island effect	Green spaces to provide cooling via evaporation and shade from trees and plants
Rainwater drainage/ runoff	Extensive vegetation and permeable surfaces allow stormwater to be absorbed and released slowly Trams run on unpaved surfaces to help mitigate stormwater runoff
Ecological and social connectivity	Public green spaces to allow for the closer interaction of all social groups as well as to provide a venue for urban wildlife
Urban upgrading	The former barrack buildings were partially refurbished and partially brought down to make room for new housing, of which 80% was self-developed by inhabitants in owner co-ops rather than by corporate homebuilders; this added to the individuality of the district and community feeling
High energy use	Green roofs and thermal insulation reduce energy consumption of buildings Short distances to shops and green recreation sites as well as the extensive use of non-motorised and public transport decrease energy consumption for transportation

Photo: Poudou99

Figure 25. Above-ground paving gutters in Freiburg-Vauban

bordering the south edge of Vauban. These parks serve as play and recreational areas that provide visual connection to the rural landscape beyond, but they also serve as ventilation corridors, bringing cooling breezes into the heart of the whole district (Coates, 2013).

Technical details

In addition to energy-efficient construction methods, solar technology and car-independent living, a very innovative drainage concept in a modified separation system with elements of near-natural rainwater management was realised for an area of approx. 16 ha.

The overall concept of the surface drainage consists of the following components:

- decentralised rainwater management measures on public and private areas (green roofs, permeable paving, green areas, trees and rainwater utilisation) to reduce the surface runoff generated on the areas;
- central trough-trench system with free overflow into the receiving stream for retention, infiltration and drainage of surface runoff.

The central trough-trench system consists of individual trough trenches, which are cascaded in series and form two parallel strands (Nordgraben, Boulevardgraben). Both trenches lead into a common trough, from which the water can flow via an overflow into the receiving stream (St. Georgener Dorfbach) – in the case of heavy rain events. The trench-like, greened troughs for infiltration are additionally equipped with overflow thresholds and piping and represent a certain above-ground retention volume. They absorb the surface water generated on the surfaces and store it temporarily so that it can gradually seep away. If the retention volume is exceeded, the overflow allows an unrestricted discharge into the receiving watercourse to take place. The supply from the residential areas to the troughs is mainly via above-ground paving gutters running on both sides of the road (Figure 25). At the road crossing, they are led in underground piping via a road inlet at the end of the gutter and cast iron pipes. Due to the increased traffic load, the main road is not drained in the separation system, but in the combined sewer (Jakisch, 2013). Figure 26 below shows the schematic representation of the surfaces drained in the separation system in the Vauban district with differentiation according to surface type and surface material.

Barriers and success factors

Vauban is an attractive and family-friendly district with a high quality of living, popular amongst its residents and beyond. The most important success factors for its recognition as a model for sustainable urban development were:

- the supervision of the development by the municipality through the sale of land owned by the municipality, after it was purchased from the federal level and a "project group Vauban" in the local administration;
- extensive citizen participation via Forum Vauban e.V. (including financial support) and the new Stadtteilverein Vauban e.V., after the first development plan gained legal force;
- the special location in the inner-city area and the close proximity to the surrounding green areas;
- the construction within existing green structures and their integration into the planning process;
- architectural diversity on the basis of a robust urban planning concept.

One barrier to the original masterplan of the Forum Vauban, which foresaw a complete restriction on parking, was the Baden Württemberg Land law, which requires all homes to have access to a parking space. A compromise was negotiated, whereby a parking ratio of less than 0.5 parkings spaces/

Figure 26. State of surface composition in May 2011 (based on Jackisch et al., 2013)

housing unit was reached and most parking was located in garages at the edge of the district. Residents of parking-free streets who chose to purchase a parking space pay an initial 16,000 EUR in addition to a monthly service charge (Field, 2011).

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Figure 27. Visualisation of the rain playground in Neugraben-Fischbek, Hamburg

2.3. Rain playground Biberland in Neugraben-Fischbek, Hamburg

Water plazas are multi-use public spaces that are designed to be used in dry and wet conditions. During rainfalls, these areas receive run-off water from surrounding streets. The collected water is then pooled to relieve pressure on sewage infrastructure and drained at a slow rate through a central point on-site. In order to be visually appealing and still functional for playing during wet conditions, these plazas include levels and channels for the water to be collected and featured, such as small ponds and rivers. Water plazas can take the form of squares, playgrounds, skate parks or basketball courts or even combine those functions.

The rain playground in Neugraben-Fischbek, Hamburg (Figure 27), is the first of its kind in Germany. In addition to serving the classic function of being a children's playground, it supports the rainwater drainage of the district. Features such as a drainage ditch and a rainwater trough run along the area, enabling the system to absorb excess rainwater and prevent it from going directly into the sewage system when needed. The water is then directed to an adjacent well protection area of the municipal water supply and disposal company, where it seeps away and contributes to groundwater recharge (RISA, 2013). The area of the rain playground is about 2000 m^2. The total catchment area is around 34 ha, from which 14 ha are sealed with roads and buildings that are connected to the sewer systems. The remaining 20 ha consist of green areas including bodies of water.

Overview

Mitigation benefits	
Cooling and insulation	✓
CO_2 sequestration	✓
Renewable energy production	
Use of low-carbon materials	✓
Promotion of sustainable behaviors	

Urban challenges addressed	
Air pollution	
Heat island effect	✓
Water scarcity	✓
Rainwater drainage/runoff	✓
Flood resilience	
Ecological and social connectivity	✓
Urban upgrading	✓
High energy use	

Duration

Construction: 2011–2013

Component NBS

Flood basin, seeping trough, infiltration ditch

Financing sources

Municipal funds: 100%

Costs

130,000 EUR

Project motivation and achievements

The "Haferacker" rainwater retention basin is located southwest of Hamburg in the urban district Hausbruch. During the 1970s, it was used as intermediate storage for rainwater coming from above building areas. In 1997 and 2002, an adjacent school was flooded due to heavy rain. After the 2002 flood, the situation led to a lawsuit. Despite a resizing of the basin in 2004 to prevent further flooding, the regional court of Hamburg decided in 2009 that the basin was still not sufficiently sized.

To further reduce the rainwater inflow into the "Haferacker" retention basin, a "rain playground" was built to store additional water (Figure 28). Another motivation to build the playground was a survey among citizens that revealed a need for an uplift of the old playground and a desire for a multi-generational recreation area.

The first heavy rain that tested the retention basin arrived on 9 July 2014. During this event, 51.4 mm

Photo: Katja Fröbe

Figure 28. Rain playground "Biberland"

of rain fell within 70 minutes on the catchment Neugraben-Fischbek. The heavy rain caused no damage to the adjacent school, even though the rain was much stronger than during the severely damaging flood of 2002. In addition, to help prevent damage to the surrounding area, the rain playground also closes the water cycle symbolically and demonstrates the function of the water cycle for residents. The water plaza in Hamburg is one of several multi-purpose projects being realised around the city within the overarching RISA project (*RegenInfraStrukturAnpassung*). This project aims to close the water cycle in the city and optimise flood protection for the district rainwater network.

Urban challenges	Solutions
Heat island effect	Green spaces provide cooling via evaporation and shade from trees and plants Water features provide evaporative cooling and improve the micro-climate
Water scarcity	Rainwater flows through natural landscape back to the local waters
Rainwater drainage/runoff	A paved trough allows the water to seep away and evaporate; this trough is connected to another infiltration basin and for very heavy rain events there is an overflow to another trough in a protected well area In addition, vegetation and permeable surfaces on the playground allow stormwater to be absorbed and released slowly
Ecological and social connectivity	Public green and blue spaces allow for social activities and provide a venue for urban wildlife
Urban upgrading	Redesign of existing green areas with a wide variety of playgrounds, recreation areas and respite areas

Technical details

Subsurface rainwater is discharged in a sub-area of the "Biberland" playground. This sub-area is designed as an infiltration basin (a trough/infiltration ditch). In heavy rainfall, which exceeds the capacity of the infiltration basin, the resulting rainwater is passed through a flood channel integrated into the playground design in the adjacent protected well area and infiltrated there.

The square has a central point that drains at a particularly slow rate. There are filters fitted on the drains feeding into the plaza, so that it does not fill up with contaminated water.

Barriers and success factors

The project faced certain practical challenges in the planning and implementation phase:

- water depth (to avoid any danger of drowning);
- water quality (as the water does not come from the tap, it is important to ensure that it is safe for children to play in the water – one important factor is the retention time of the water);
- water quantity (there should be enough water available, but the quantity should not allow for a dangerously high flow velocity).

Overall, the main barriers were traditional thinking regarding rainwater management and fears that the playground might not be safe for children.

Factors for the success of the overall project were:

- the existing necessity to change the rainwater management infrastructure;
- the desire to redesign, upgrade and revive the existing green area;
- a design of a playground where kids can play even on rainy days;
- a design which is safe for children playing on the playground;
- a design which helps residents experience the water cycle;
- clear division of responsibilities.

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Figure 29. Concept of the regenerated Bielefeld Luttergrünzug

2.4. Regeneration of urban green belts: Luttergrünzug, Bielefeld

An urban green belt is an undeveloped green area or agricultural land area that either surrounds or neighbours built-up urban areas. The regeneration of urban green belts is the process of redesigning and redeveloping aged, natural areas within and around cities that have become less effective in fulfilling their functions. This includes providing recreational opportunities, protecting the natural environment, improving air quality, ensuring ecological connectivity and securing habitats for plants and wildlife.

The Luttergrünzug – "Lutter" is the name of the urban stream, "grünzug" translates to "green corridor" in German – is an urban green belt that is located in Bielefeld. It connects the eastern city centre and the Heepen district (Bielefeld, 2019) and is of major ecological importance to the city's open space. The Luttergrünzug offers recreation opportunities for around 36,000 people and accommodates park areas, ponds, playgrounds, walking and jogging paths and the Lutter (DTP, 2017). In the Middle Ages, the Lutter was artificially created and altered on many occasions thereafter, contributing to the economic development of Bielefeld (Figure 29).

Due to the increasing rate of heavy-precipitation events in the future, the stormwater retention and flood-protection capacity of inner city areas will become increasingly important. The local government decided to regenerate the Luttergrünzug, so that it can continue to provide a valuable contribution in this regard (DTP, 2017).

Overview

Mitigation benefits

Cooling and insulation	✓
CO_2 sequestration	✓
Renewable energy production	✓
Use of low-carbon materials	✓
Promotion of sustainable behaviors	✓

Urban challenges addressed

Air pollution	✓
Heat island effect	✓
Water scarcity	✓
Rainwater drainage/runoff	✓
Flood resilience	✓
Ecological and social connectivity	✓
Urban upgrading	✓
High energy use	

Duration

Planning: September 2016-ongoing; The first four measures are to be completed in 2020/21, further measures from 2024 onwards (Uthmann, 2018)

Component NBS

Retention areas with specialised vegetation, dam ponds, individual trees

Financing sources

EU level: European Water Framework Directive (EU WRRL)

National level: public funding for urban development (Städtebauförderung) and Zukunft Stadtgrün KommInvest (Green Urban Futures Fund)

City level: INSEK urban development programme for the northern inner city, waste water fees from City of Bielefeld; private funds (Uthmann, 2018)

Costs (€)

Construction costs of the adopted variant are 5.8 million EUR; planning costs are 1.2 million EUR; total costs are approx. 7 million EUR.

Project motivation and achievements

This project was initiated in order to regenerate the Luttergrünzug, which is ageing and has started to show structural and functional deficits. Ponds are silting up, conflicts between pedestrians and cyclists occur and the green corridor is increasingly overgrown. Citizens want to make the area more functional. The new requirements of the European Water Framework Directive on ecological connectivity and values, as well as flood protection against watercourses are other factors that have played a role in the process (DTP, 2017). The three dam ponds located in the Luttergrünzug were a central point of the discussion, because they currently restrict ecological connectivity (DTP, 2017). After it became clear that a solution without these dam ponds would be possible, the discussion focused on how to maximise the preservation of the water surface (DTP, 2017).

The planning office that is in charge of the project, DTP, designed a framework concept that contained ideas for the redesign and redevelopment of the area, based on the current situation and feedback from the citizens of Bielefeld that was collected during two workshops. The Bielefeld Committee on Environment and Climate Protection subsequently adopted the majority of these ideas, with the exception of the deepening of the area. For the new design, one of the dam ponds will be abandoned and another will be upgraded, extended and will function as the new Luttersee ("Lutter lake") (Uthmann, 2018). The framework concept proposes to better interweave the Luttergrunzüg with its surroundings within a 500 m radius, which contains urbanised and open spaces, and to upgrade road spaces and entrances (Bielefeld, 2019). For the core area, it provides suggestions to improve the experience of water, leisure, sport and other recreation opportunities, the quality of paths and open spaces, and to secure the further development of green areas (Bielefeld, 2019).

Urban challenges	Solutions
Air pollution	The Luttergrünzug has a climatic compensatory function that contributes to the filtration of air (DTP, 2017)
Heat island effect	The Luttergrünzug, due to its shape and geographical orientation, functions as an air duct and ventilation corridor for cold air; this reduces heat stress in summer periods (DTP, 2017)
Water scarcity	The newly created Luttersee will increase the water surface of the Luttergrünzug (Bielefeld, 2019)
Rainwater drainage/runoff	The former dam pond 2, as well as the areas along the Lutter will be turned into biotope and species protection areas, which will improve its retention capacity; vegetation will include reeds and typical water-accompanying woody plants (DTP, 2017)
Flood resilience	The biotope and species protection areas will strengthen the flooding resilience of the Luttergrünzug
Ecological and social connectivity	The Luttergrünzug will increasingly connect different green spaces to each other (e.g. the recreational focal points Sparrenberg in the west and Heeperholz in the east) (DTP, 2017)
Urban upgrading	Different parts of the city will be better connected through, e.g. the separation of pathways and bikeways; the Luttersee will have a concentrated arrangement of restaurants with public toilets, a playground, a sunbathing area and the Lutterterrace; the latter has already been built (DTP, 2017)

Technical details

The framework concept divides the Luttergrünzug into an eastern and western part and further subdivides it into sections A to D (Figures 30 and 31). In section C ("LutterPark"), the new Luttersee as well as the adjacent allotment gardens ("Kleingärten") can be found. Section D ("LutterLandschaft") includes a large green area. In both the western and eastern parts, several recreation opportunities will be located, including playgrounds and fitness areas. An area for ball games will also be built.

The cross-section of the deepening area of the Luttergrünzug (Figure 32) provides a more detailed insight into what the different renovated areas will look like in the future, such as the dimensions of the water surfaces and the type of vegetation used.

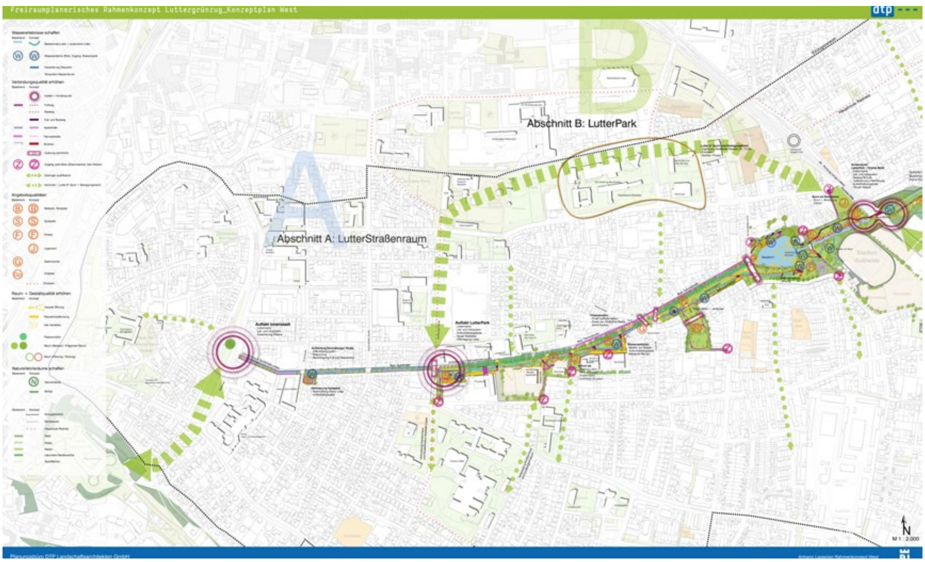

Figure 30. The western part of the Luttergrünzug as envisioned in the framework concept

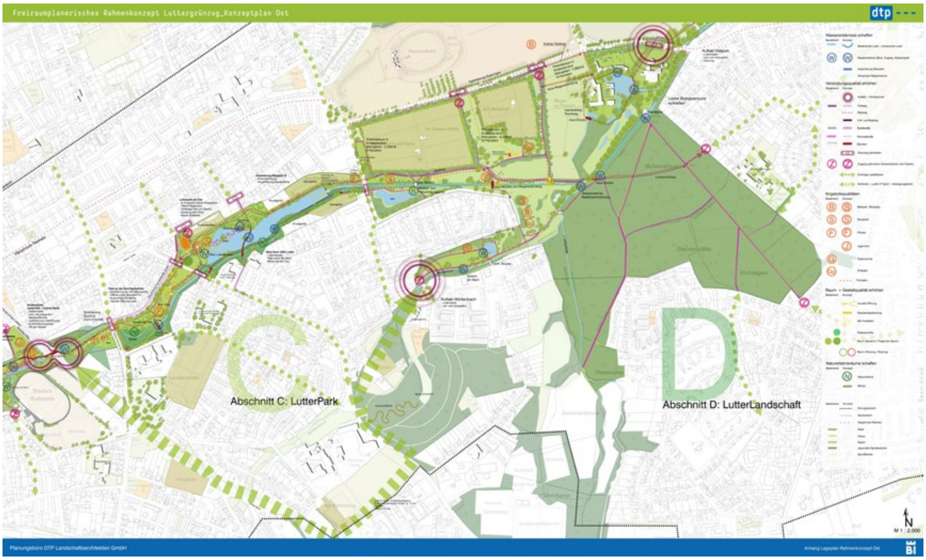

Figure 31. The eastern part of the Luttergrünzug as envisioned in the framework concept

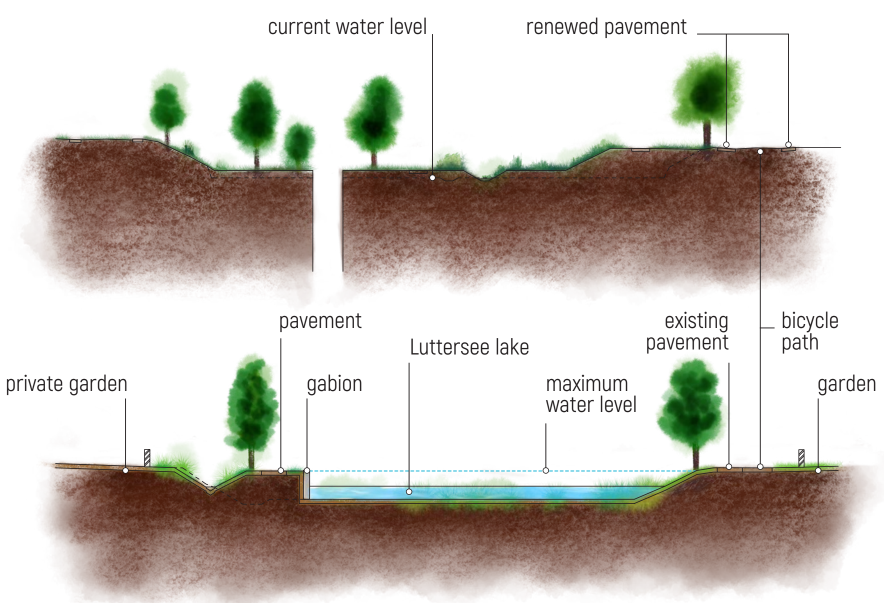

Figure 32. Cross-section of the deepening area of the regenerated Luttergrünzug (above). Part of the park between Lerchenstraße and the Nachtigallstraße (below) (based on Planungsbüro DTP Landschaftsarchitekten GmbH)

Barriers and success factors

The main points of discussion within the project were the preservation of the allotment gardens versus the enlargement of the green area with water surfaces. Eventually, it was decided that the allotment gardens should remain (Bielefeld, 2019).

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Figure 33. Visualisation of the A7 highway cover in Stellingen

2.5. Highway green roofing: Hamburg A7 Highway Cover

Creating green roofs or green covers over highways has emerged in recent years as a solution to counteract some of the disruptiveness and challenges that highways cause in urbanised areas. Specifically, these approaches help to reduce air and noise pollution and to address social and ecological fragmentation. Highway green cover also expands urban space, adds value to neighbouring properties, introduces a cooling effect and encourages sustainable behaviors such as urban gardening.

While several highway covers currently exist in Germany, the planned A7 highway cover in Hamburg will be the largest and most ambitious (Figure 33). The plan involves installing a 34 m wide and 2–3 m thick canopy over a total of 3.5 km of the motorway, which connects Germany to Scandinavia. The finished green cover will have 27 ha of newly acquired green space with a 1.2 m deep soil layer. It will feature wooded parkland, meadows, bike and walking pathways and garden plots. The garden plots will be awarded as compensation to owners that previously had allotments along the highway; the resulting 60 ha of newly noise-reduced areas along the highway will now be the site of 3,800 new apartments (Inhabitat, 2019).

Overview

Mitigation benefits

Cooling and insulation	✓
CO_2 sequestration	✓
Renewable energy production	
Use of low-carbon materials	
Promotion of sustainable behaviors	✓

Urban challenges addressed

Air pollution	✓
Heat island effect	✓
Water scarcity	
Rainwater drainage/runoff	✓
Flood resilience	
Ecological and social connectivity	✓
Urban upgrading	✓
High energy use	

Duration

Planning has been ongoing since 2007; the first section was completed between 2012–2019; the second section is under construction and is to be completed in 2020; the third section is in the planning phase and set to be built from between 2020–2028

Component NBS

Park areas, garden plots

Financing sources

National funds: 82%; municipal funds: 18%

Costs (€)

840 million EUR

Project motivation and achievements

The project is being carried out by the Hamburg Ministry of Urban Development and Environment along with the Hamburg Ministry of Economy, Transport and Innovation; the Federal Ministry of Transport, Building and Urban Affairs and the main contract holder Deutsche Einheit Fernstraßenplanungs- und -bau GmbH (DEGES) (NATURVATION, 2019).

The A7 motorway runs from Germany to Scandinavia and with six to eight lanes it is one of the busiest, most disruptive highways in Germany. It has long been a headache for Hamburg residents as it is loud, physically cuts through neighbourhoods and significantly reduces surrounding air quality. The canopy will create new livable urban space around the highway and urgently needed housing in the form of 3,800 apartments.

The large-scale project has become a defining feature of Hamburg's sustainability and urban development profile. In 2011, several years into the planning phase, Hamburg was chosen as the Green Capital of the EU, a programme that promotes and awards cities' commitment to tackling environmental challenges. In the 2016 report "Hamburg: European Green Capital: Five years on", the highway green cover is mentioned. The city's urban development strategy published in 2014, "Hamburg 2030", also takes note of the project (NATURVATION, 2019).

Urban challenges	Solutions
Air pollution	Green spaces to reduce atmospheric pollutant concentrations Green spaces to encourage sustainable, non-polluting means of transport, e.g. biking over driving
Heat island effect	Green spaces to provide cooling via the evapotranspiration and shadow of trees and plants
Rainwater drainage/runoff	Extensive vegetation and permeable surfaces allow stormwater to be absorbed and released slowly
Ecological and social connectivity	Public green spaces to allow for the closer interaction of all social groups as well as to provide a venue for urban wildlife
Urban upgrading	The new highway cover has allowed for the building of 3,800 new apartments in an area newly greened and with a high quality of living

Barriers and success factors

In the beginning, the lack of support of the allotment holders posed a challenge to the project. They did not want to leave their existing allotments, because they were sceptical about the soil layer on the cover. Yet, direct engagement of the allotment holders in the process of developing the soil layer and moving the allotments helped to overcome the scepticism (Figure 34). Other success factors for the implementation were the long planning history since 2007 and strong public support.

Figure 34. Visualisation of the A7 highway cover in Schnelsen with garden plots

In terms of financing, it has been an advantage that Hamburg only needs to pay the difference between the legally required noise protection and the additional costs for the cover sections and their design (Hamburg, 2019). The A7 cover is expected to cost 840 million EUR, around 82% of which will be financed by the Federal Government. The remaining sum will come from the sale to private developers of city-owned land adjacent to the highway and the city budget.

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Figure 35. Visualisation of Jenfelder Au district

2.6. Eco-city districts: "Jenfelder Au" in Hamburg

Eco-city districts are urban neighbourhoods that feature a variety of nature-based solutions with the objective of achieving high social, economic and environmental sustainability. They often include experimental designs and extensive consultation of local stakeholders and residents.

Jenfelder Au, one such eco-city district is being implemented in Hamburg (Figure 35). The district represents the first large-scale implementation of the HAMBURG WATER Cycle® (HWC), which is a holistic approach to achieve sustainable drainage and climate-neutral housing in urban and suburban neighborhoods. The area is located 9 km from the city centre of Hamburg, covers approximately 35 ha and encompasses 835 residential units that will be directly connected to the HWC (HW, 2019a). Around 20% of the area is comprised of green spaces and water elements (HW, 2019b). The district is also designed to separate various wastewater streams, allowing for the simultaneous protection of water resources and higher energy recovery from the wastewater. The system is expected to considerably reduce the amount of CO_2 emissions that would have been emitted in a conventionally-designed residential development.

Overview

Mitigation benefits

Mitigation benefits	
Cooling and insulation	✓
CO_2 sequestration	✓
Renewable energy production	✓
Use of low-carbon materials	✓
Promotion of sustainable behaviors	✓

Urban challenges addressed

Urban challenges addressed	
Air pollution	✓
Heat island effect	✓
Water scarcity	✓
Rainwater drainage/runoff	✓
Flood resilience	
Ecological and social connectivity	✓
Urban upgrading	✓
High energy use	✓

Duration

Planning: 2006–2013; construction: 2013-approx. 2022 (construction of last residential buildings)

Component NBS

Green squares, water retention ponds, ditches, permeable paving, bioswales

Costs (€)

13 million EUR (Gebauer, 2019)

Financing sources

EU level: EU LIFE+ Programme (approx.. 2.8 million EUR for the construction/ infrastructure)

National level: Research grants from German Federal Ministry of Education and Research (BMBF); Federal Ministry for Economic Affairs and Energy (BMWi)

Project motivation and achievements

This project was designed to respond to and address issues of high energy use and other urban challenges at a local scale. In Hamburg, an outstanding issue hampering the city's sustainability is that conventional wastewater is passed through a 5,000 km long sewerage system that mixes domestic sewage with rainwater during its transport. The diluting effect creates high energy costs for the plants to eliminate micro pollutants and recover nitrogen and phosphorus. The biogas recovered

Urban challenges	Solutions
Air pollution	Green spaces to reduce atmospheric pollutant concentrations Green spaces to encourage sustainable, non-polluting means of transport, e.g. biking over driving
Heat island effect	Green spaces to provide cooling via the evaporation and shadow of trees and plants Water retention ponds to provide evaporative cooling and improve the micro-climate
Water scarcity	Rainwater does not flow into the sewer network, allowing the water to flow over the natural landscape and recharge the groundwater All toilets are on a vacuum system, so that only about one litre of water is used per flush; this is expected to save about 11,000 litres/year/person of fresh water with about 2000 users (approx. 22,000 m^3/year)
Rainwater drainage/runoff	Open channels allow rain to flow to retention basins; flood protection is optimised as basins are designed to provide further storage potential in case of heavy downpours, up to 5000 m^3 of runoff Extensive vegetation and permeable surfaces allow stormwater to be absorbed and released slowly
Ecological and social connectivity	Public green and blue spaces allow for a closer interaction of all social groups as well as providing a venue for urban wildlife
Urban upgrading	Ensembles of urban townhouses are combined and arranged to create variety in the cityscape; some of the barracks buildings from 1934/35 and the former drill ground were placed under monumental protection as a historical site
High energy use	Energy for heat and electricity in the district is recovered by a biogas plant which collects blackwater; the biogas system with combined heat and power produces twice as much electricity as is needed for the waste water collection and treatment; the rest (equivalent to the average consumption of 100–180 people) is fed into the power grid; in terms of heating, the produced surplus equals the consumption of 50–100 households, depending on the energy standard of the building The rest of the heat used in the district will be provided in a climate-neutral way by the local heat supplier GETEC

from sludge in this conventional way is barely sufficient to power the plants, let alone move the districts toward carbon-neutrality.

In this particular eco-city model, the combination of sustainable urban drainage systems (SUDS) and nature-based solutions (NBS) allows the district to address a wide variety of urban challenges. The NBS measures include ponds, swales and the separation of water streams via grey infrastructure (vacuum-based toilet flushing system for black water, an alternative to the usual mix of grey and black water).

Technical details

The defining component of the HWC is the separate treatment of the different wastewater streams. Stormwater, wastewater from the toilet and wastewater from the kitchen and bathroom are collected and treated separately (see Figures 36 and 37). This facilitates the recovery of energy to be used for heat and electricity in the new district.

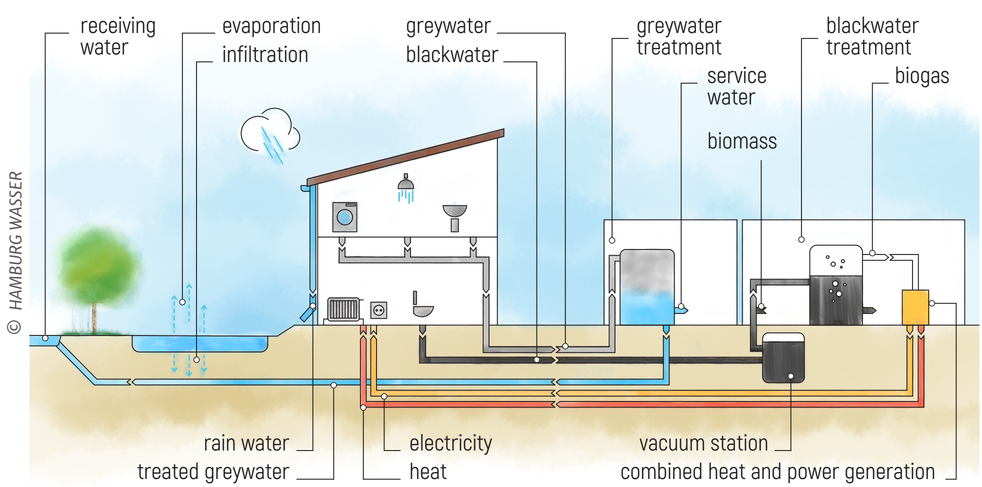

Figure 36. Diagram of the HAMBURG WATER Cycle® in the Jenfelder Au; the rainwater, greywater and blackwater are treated separately, and the blackwater is used to produce energy

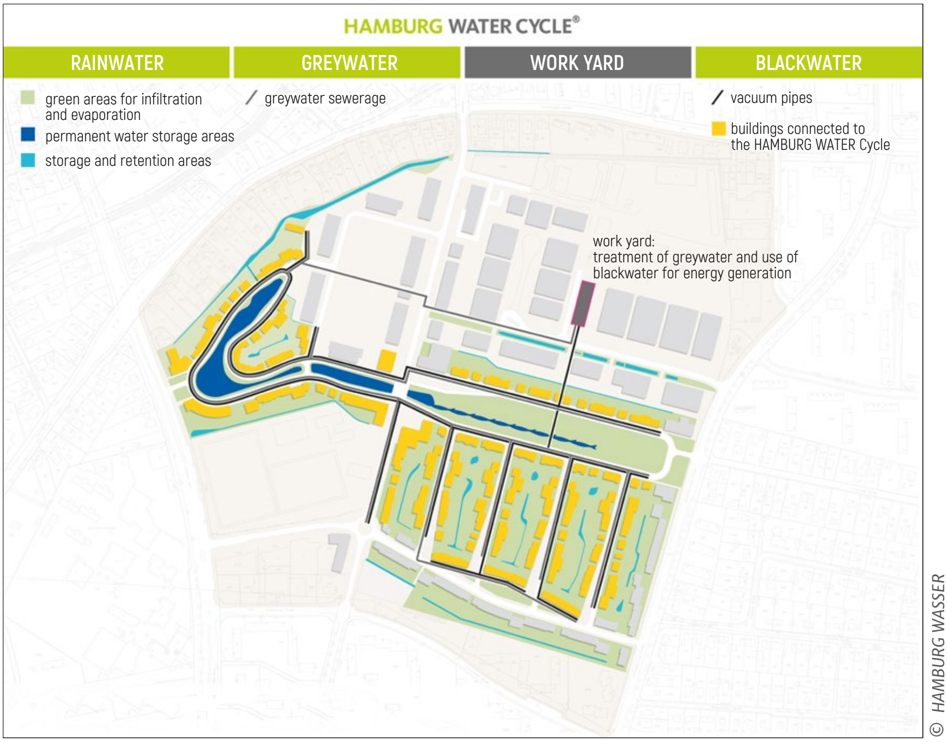

Figure 37. Functional plan of the separate sewer systems for grey- and blackwater as well as detention areas for rainwater forming part of the HAMBURG WATER Cycle® in the Jenfelder Au

Barriers and success factors

The planning process was a discursive procedure that encouraged high stakeholder participation. Urban planners and interested citizens were able to submit proposals during an urban development competition phase (IBA Hamburg, 2019). While the project encountered challenges such as long implementation period (with regard to property marketing), legal uncertainties (regarding the vacuum drainage) and higher costs compared to the design and construction of other neighbourhoods, various motivations paved the way for the ambitious project:

- local environmental goals;
- individual supporters (HAMBURG WASSER, District Office (*Bezirksamt*));
- innovation leadership adding to the prestige of the project;
- financial support from federal ministries (BMBF, BMWi), EU Life+.

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Figure 38. View of Zollhallen Plaza

2.7. Floodable squares and parks: Zollhallen Plaza in Freiburg

A floodable park or square is an area that can accommodate a wide range of rainfall events while being disconnected from the sewage system. Permeable surfaces and drainage gradients help prevent runoff flooding to neighbouring areas and encourage groundwater to be replenished. Floodable parks can also be designed to control water flow rates and decrease flow peaks by storing excess water until the risk of flooding has passed. They are effective for managing excess water from regular rain as well as flash floods. By integrating such features in their design, floodable parks reduce the need for maintaining and expanding sewage systems and deliver a range of social and ecological benefits.

Zollhallen Plaza in Freiburg (Figure 38) is an example of a 5,600 m^2 floodable park (FULL, 2019). It has been designed to handle dry conditions, regular rain, 10 year rain events and 100 year floods. This is possible due to a range of nature-based solutions such as permeable paving, a bench-planter area that floods when the soil infiltration potential is exceeded, low-maintenance infiltration planters that cleanse water for a large subsurface gravel trench and indented areas of the plaza to allow for a large surface flood zone when necessary (FULL, 2019). All of the hardscape materials have been recycled from high-quality demolition materials from the railyard that the site was previously used as (FULL, 2019).

Overview

Mitigation benefits

Cooling and insulation	✓
CO_2 sequestration	✓
Renewable energy production	
Use of low-carbon materials	✓
Promotion of sustainable behaviors	✓

Urban challenges addressed

Air pollution	✓
Heat island effect	✓
Water scarcity	
Rainwater drainage/runoff	✓
Flood resilience	
Ecological and social connectivity	✓
Urban upgrading	✓
High energy use	

Duration

Designed from 2009–2010; implemented in 2011

Financing sources

Municipal and private funds

Component NBS

Permeable planting areas, load-bearing substrate, stormwater retention boxes, filtration manhole, underground infiltration, on-ground retention in extreme weather events (10 cm)

Costs (€)

750,000 EUR

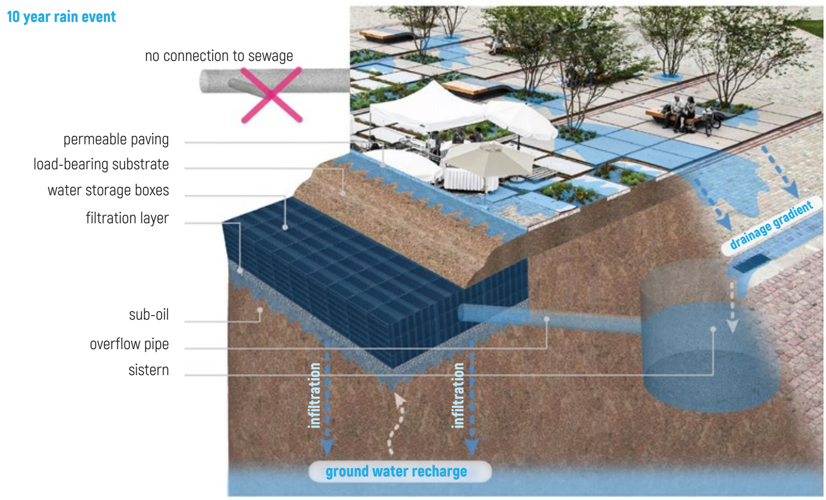
Project motivation and achievements

The capacity of the local sewage system in Freiburg was exceeded during storm events, which motivated the city government to seek solutions to relieve the stormwater burden (FULL, 2019).

Urban challenges	Solutions
Air pollution	Green spaces reduce atmospheric pollutant concentrations Green spaces encourage sustainable, non-polluting means of transport, e.g. biking over driving
Heat island effect	Green spaces provide cooling via evaporation and shade from trees and plants Permeable surfaces and paving with creeping thyme and planting pockets used in the plaza allow it to "breathe" by increasing evaporation and cooling (FULL, 2019)
Rainwater drainage/runoff	Extensive vegetation and permeable surfaces allow stormwater to be absorbed and released slowly
Ecological and social connectivity	Public green spaces allow for the closer interaction of all social groups and provide a venue for urban wildlife
Urban upgrading	The design with railroad components speaks to the history of the site, which was previously a railyard; cherry trees, perennials and ornamental grass provide shade and an attractive background for sitting and social interaction (FULL, 2019) The addition of the plaza to the historical architecture of the nearby customs hall makes it a multi-functional cultural asset

Technical details

Figure 39 provides an overview of the different nature-based solutions that are incorporated into Zolhallen Plaza – e.g. permeable paving – as well as its designated flooding zone. These elements allow the floodable park to deal with 10 year rain events, as well as 100 year flood events. In case of a 10 year rain event (above), the incorporated NBS are able to absorb the rainwater and slowly filter it through a technical filtration system into the sub-soil, to eventually recharge the groundwater. In case of a 100 years flood event, the floodable park will be submerged by water, protecting other areas of the city from being flooded.



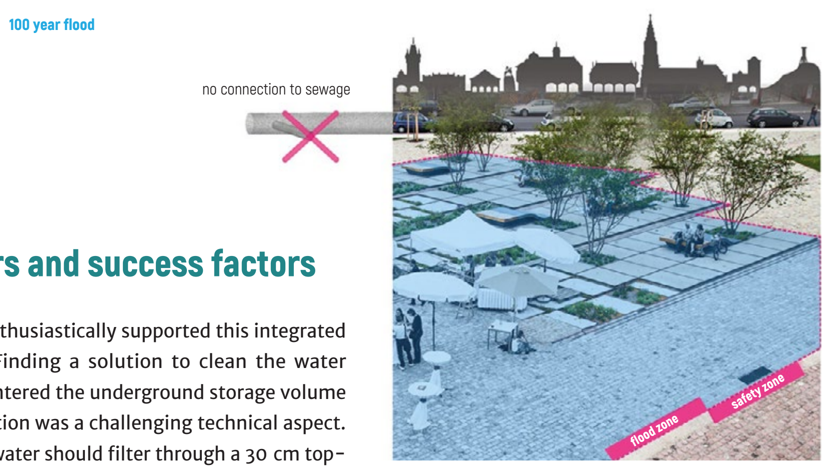


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Figure 39.Visualisations of the plaza under 10 year rain event and 100 year flood conditions

Barriers and success factors

The city enthusiastically supported this integrated strategy. Finding a solution to clean the water before it entered the underground storage volume for infiltration was a challenging technical aspect. Typically, water should filter through a 30 cm top-soil layer before dripping into the ground. In this case, a technical filtration system was necessary because it is cost effective and easy to maintain.

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Figure 40. The ventilation corridors network in Stuttgart in bird's eye view

2.8. Green corridors: Ventilation corridors network, Stuttgart

Green corridors are linear parks that help to re-nature cities by connecting green areas to one another to form urban green infrastructure networks. They are often retrofitted along areas of abandoned traffic infrastructure, e.g. railway lines or waterways, to create interconnecting parks. Green corridors are particularly beneficial for urban biodiversity as well as cooling cities and improving air quality by providing cool air pathways.

The city of Stuttgart took this concept and implemented it on a large, city-wide scale (Figure 40). Located in a valley with low wind speeds, the city is prone to the urban heat island effect and poor air quality. To overcome these challenges, Stuttgart implemented a natural green corridor strategy to create pathways for winds to sweep down from the hills to ventilate the city. This entailed zoning and regulations limiting real estate and other development along green corridors and divides. Additional benefits of this strategy include increasing connectivity between rural areas and the city center, enhancing biodiversity and supporting the well-being of citizens by ensuring more open space in an otherwise highly built-up urban environment.

Overview

Mitigation benefits	
Cooling and insulation	✓
CO_2 sequestration	✓
Renewable energy production	
Use of low-carbon materials	
Promotion of sustainable behaviors	✓

Urban challenges addressed	
Air pollution	✓
Heat island effect	✓
Water scarcity	
Rainwater drainage/runoff	✓
Flood resilience	
Ecological and social connectivity	✓
Urban upgrading	
High energy use	

Duration

1998–2014

Costs (€)

250,000 EUR

Component NBS

Ventilation lanes, extensive parks and green corridors, street greenery/trees, building greenery

Financing sources

EU funds: 30%; national funds: 10%; municipal funds: 60%

Project motivation and achievements

The motivation to create the ventilation corridors network in Stuttgart came from a combination of the city's topography in a mild-climate valley basin, low wind speeds, its major automobile manufacturing industry and the high volume of traffic. Moreover, in certain areas the city is very densely populated. Correspondingly, the sealing degree is high. This motivated the development of a *Climate Atlas for the Stuttgart region* (Adaptcity, 2015) where attention was paid to the distribution of temperature and cold air flows (Stuttgart, 2010).

Urban challenges	Solutions
Air pollution	Green corridors create air pathways to exploit natural wind patterns and reduce pollution in stagnant air Green spaces reduce atmospheric pollutant concentrations Green spaces encourage sustainable, non-polluting means of transport, e.g. biking over driving
Heat island effect	Green corridors create pathways for cool air to sweep down from the hillsides and reduce the higher urban temperatures Green spaces provide cooling via the evaporation and shadow of trees and plants
Rainwater drainage/runoff	Extensive vegetation and permeable surfaces allow stormwater to be absorbed and released slowly
Ecological and social connectivity	Public green spaces allow for the closer interaction of all social groups and provide a venue for urban wildlife

Technical details

In the case of Stuttgart, the city's topographic features, such as stream and meadow valleys, guided the designation of green belts and preferred ventilation pathways. Based on urban climatic mapping in the 1998 *Regional Plan of Stuttgart*, four cool air corridors – the Nesenbachtal valley, Feuerbachtal valley, the Lindenbachtal valley and the Rohrakker valley systems – were marked for special zoning and a ban on encroachment by buildings (Stuttgart, 2010). These were chosen on the basis of channeling cooler air through preserved, undeveloped park areas on hillsides as well as low-density developed areas. The result was also intended to connect rural areas to the city center. Within the city itself, the air flow corridors were connected to existing parks where possible, to reach local neighbourhoods (Figure 41). The

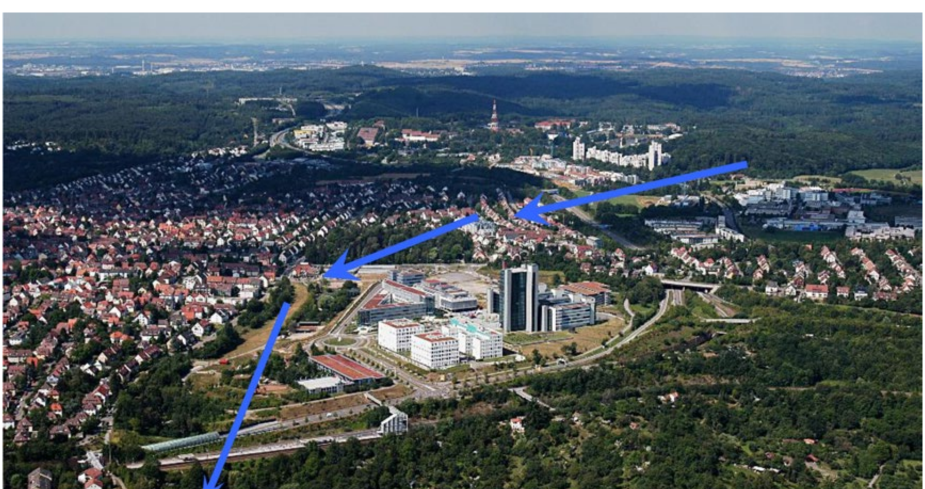

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Figure 41. Ventilation zone "Stuttgarter Engineering Park" (STEP), area "Unterer Grund"

preferred width of the green corridors is a minimum of 100 m (NATURVATION, 2017).

Today, the *Climate Atlas* provides basic information about wind, solar radiation, temperature and precipitation in the Stuttgart region (VRS, 2019). Based on this information, statements are made as to where cold air is produced and how it is exchanged. The so-called climate analysis maps provide information on air pollution in various areas of the Stuttgart Region. The *Climate Atlas* also provides information on how developed and undeveloped areas impair or promote air exchange.

Barriers and success factors

Stuttgart is an industrial, prosperous city with high real estate prices. The construction ban and other zoning policies to support the green ventilation network required decision makers to negotiate the city's priorities between competing interests. The supply of fresh air and heat island management had to be weighed against the loss of potential tax revenues from construction as well as the social dimensions of high housing costs. Hence, the main challenges for the project were considerations of giving greater weight to other concerns (e.g. economic interests, housing needs, etc.)

One main success factor for the project was that the city institutionalised the integration of urban climatic concerns into the planning. In the current process, the city examines each individual plan and adapts it with the principles and concepts of the cold air regime of the ventilation corridors. Furthermore, the impact mechanisms of the cold air regime are well-described in the *Climate Atlas*, so there is transparency for the measures that are undertaken.

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Figure 42. Potsdamer Platz, Berlin, Germany

2.9. Sustainable urban drainage systems: Potsdamer Platz, Berlin

Sustainable urban drainage systems (SUDS) are a mix of green and grey infrastructure, which together support urban areas in coping with severe rainfall. Specifically, they manage surface water and encourage maintenance of water quality, soil infiltration and groundwater recharge. Alongside grey infrastructure elements, SUDS consist of nature-based solutions like swales, water retention and detention basins, permeable pavements, filter strips and drains. Location-specific combinations of these elements help to reduce run-off volumes and rates, pollutant concentrations and the reliance on mixed sewage systems. In parallel, SUDS increase the amenity and aesthetic value of urban areas through their green and blue features.

SUDS are suitable for a variety of settings, including highly urbanised settings like Potsdamer Platz in Berlin. Here, a series of constructed wetlands and pools operate in tandem with other nature-based and grey measures to cover approximately 1.2 ha, including 12,000 m^2 of blue area containing 1,800 m^2 of biotopes (Atelier Groenblauw, 2019). These water features are fed solely by rainwater and serve to reduce the ambient temperature in summer, bind dust particles and humidify the air. Rainwater is collected from roofs, purified by a cleansing biotope and filtering substrate, and stored in underground cisterns to be used for flushing toilets, fire systems and irrigation (Ramboll, 2019). Approximately 12,000 m^2 of green roofs are part of this system, which are monitored to help control water quality (Dreiseitl, 2017). In addition to addressing hydraulic and water treatment aims, the space also encourages social interactions and provides opportunities for mingling and enjoying nature within an otherwise heavily urbanised environment.

Overview

Mitigation benefits	
Cooling and insulation	✓
CO_2 sequestration	✓
Renewable energy production	
Use of low-carbon materials	✓
Promotion of sustainable behaviors	✓

Urban challenges addressed	
Air pollution	✓
Heat island effect	✓
Water scarcity	✓
Rainwater drainage/runoff	✓
Flood resilience	
Ecological and social connectivity	✓
Urban upgrading	
High energy use	

Duration

Planning: 1994–1998; construction: 1997–1998 (Atelier Groenblauw, 2019)

Financing sources

100% privately funded

Component NBS

Constructed urban wetlands/ponds, horizontal helophyte filters, urban water channels, underground cisterns, green roofs (Atelier Groenblauw, 2019)

Costs (€)

Approx. 8.5 million EUR

Project motivation and achievements

Urban challenges	Solutions
Air pollution	Green roofs and green spaces to reduce atmospheric pollutant concentrations Green spaces encourage sustainable, non-polluting means of transport, e.g. biking over driving
Heat island effect	Green roofs and spaces provide cooling via the evaporation and shade from trees and plants Water retention ponds provide evaporative cooling and improve the micro-climate
Water scarcity	Rainwater from the surrounding roofs of buildings is captured in large underground cisterns for use in the constructed pools, flushing toilets in offices and irrigating green areas (Groenblauw, 2019); as a result, freshwater usage in these buildings has been reduced (Ramboll, 2019)
Rainwater drainage/runoff	The underground water storage system as well as buffering capacity of water retention pools reduce rainwater runoff
Ecological and social connectivity	Public green and blue spaces allow for the closer interaction of all social groups and provide a venue for urban wildlife

Technical details

The green, blue and grey features of Potsdamer Platz are illustrated in Figure 43. The main water body covers 1.2 ha and can accommodate an additional 15 cm of water above its normal water level (a buffer of 1,950 m^3). The 1.7 km long channel has both hard and soft green banks and is designed to discharge large volumes of rainwater into the next major canal an average of three times every ten years, a rate similar to an unpaved surface (Ramboll Group, 2019). This is possible due to the five underground cisterns, which have a total holding capacity of 2,600 m^3; 900 m^3 of these are reserved for extreme rainfall (Atelier Groenblauw, 2019). Water quality is maintained through a process of sedimentation in the cisterns, seepage facilities in the southern pool and finally a biotope with vegetation (Atelier Groenblauw, 2019). Multi-layered structures help aerate the water and additional technical filters can be added in summer to avoid algae growth.

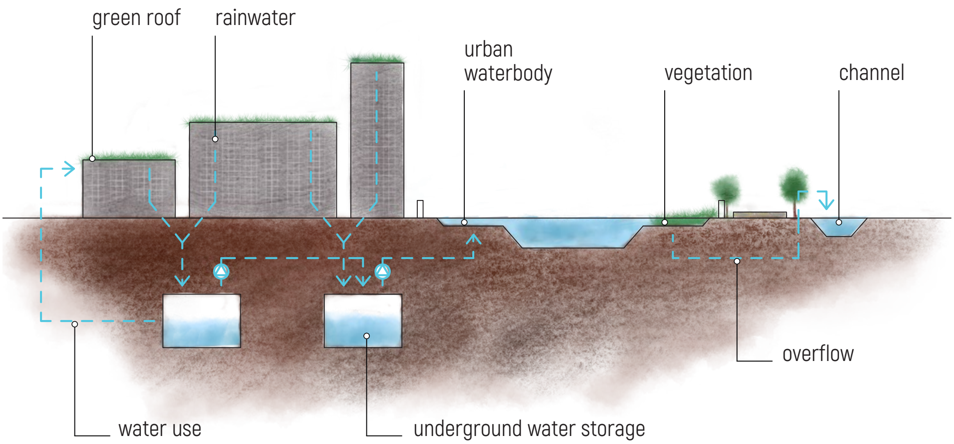

Figure 43. Design of the sustainable urban drainage system at Potsdamer Platz, Berlin, the central element of which is the retention pond (based on Dreiseitl and Grau, 2012)

Barriers and success factors

Convincing the client to accept the water cleansing system based on natural processes was a big challenge. Such a system had not been built before on this scale within a dense urban setting and it required many discussions, convincing arguments and expert opinions to finally persuade the client.

Although built on public land, the project could only be implemented due to a pre-financing model through private financing. After 15 years the city took over responsibility for the urban bodies of water.

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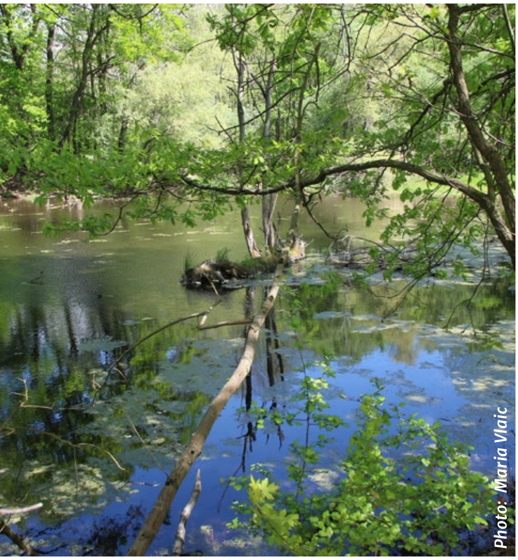

Photo:Maria Vitzthum

Figure 44. Example areas of Lebendige Luppe: Papitzer Lehmlachen – the artificial ponds are relicts of the former exploitation of alluvial clay and today valuable habitats foramphibians (left); former river course of the river Luppe – currently the old river courses are only filled during extreme flood events by seepage water (right)

2.10. Riverbank restoration: Living Luppe in Leipzig

Floodplain and river restoration involves re-establishing the natural dynamics and processes of a riverine landscape that has been modified in the last centuries. River and floodplain restoration is especially focused on restoring the ecosystem functioning to provide a large range of related ecosystem services, such as climate regulation, air purification, sequestration of carbon dioxide, mitigation of floods, nutrient retention, supporting biodiversity or cultural ecosystem services like nature based recreation. Physical actions to achieve this aim generally include, e.g.: reconnecting side channels and oxbow lakes, realigning river stretches, re-establishing natural floodplain dynamic, increasing stream flow and implementing land use change.

In Leipzig and the neighboring city of Schkeuditz, a major restoration project was launched in 2012 to improve the ecological situation of the Elster-Luppe floodplain. The aim of the project "Lebendige Luppe" (Living Luppe) (Figure 44) is to restore the floodplain forest's typical hydrology, to improve the water balance of the floodplain system, to promote biodiversity and to improve the quality of life for the neighborhood by providing a place for nature based recreation (Scholz et al., 2016). This will be reached by different measures in the floodplain of the Elster-Luppe-system. In the northern area, a number of maintenance measures such as replacing an inlet structure are being undertaken to support valuable amphibian habitats; in the southern section, a 1,216 km long river section, a former river course, will be revitalised by reconnecting former river arms. Inundation during natural flood events will improve typical hydrology in the currently disconnected floodplain.

These measures will improve functioning of the natural floodplain to support nutrient retention, deliver oxygen and fix carbon. In addition, the measures are accompanied by a large variety of project-related public relations work and environmental education, to inform people about the importance of floodplains with guided tours and varied pedagogical material (Scholz et al., 2018). A special feature of the project Lebendige Luppe is the high importance of natural and social science research, which accompanies the river and floodplain revitalisation with long-term scientific monitoring.

Overview

Mitigation benefits	
Cooling and insulation	✓
CO_2 sequestration	✓
Renewable energy production	
Use of low-carbon materials	
Promotion of sustainable behaviors	✓

Urban challenges addressed	
Air pollution	✓
Heat island effect	✓
Water scarcity	✓
Rainwater drainage/runoff	✓
Flood resilience	✓
Ecological and social connectivity	✓
Urban upgrading	
High energy use	

Duration

Feasibility study: 2006–2009; planning: 2012-ongoing; construction: 2015/2016 (NABU) until 2023 (Leipzig & Schkeuditz)

Component NBS

Natural riverbank revitalisation measures

Costs (€)

Currently no indication possible as still in planning stage

Financing sources

National level: Federal Agency for Nature Conservation (BfN) with funding from the Federal Ministry for Environment, Nature Conservation and Nuclear Safety (BMU); regional level: Saxony State Foundation Nature and Environment, Nature Conservation Fund; municipal funds: City of Leipzig & City of Schkeuditz; private funds: NABU Sachsen (Nature and Biodiversity Conservation Union in Saxony)

Project motivation and achievements

Human activities have significantly affected the floodplain of the Elster-Luppe-system for more than a century, with projects including the construction of the highly ecologically disruptive Neue Luppe canal, the construction of embankments for stream and flood control, the exploitation of alluvial clay and the drainage of wetlands (Scholz et al., 2018). The construction of a major outlet structure on a branch river Nahle between the 1930s and the 1950s has prevented any natural flooding from reaching the floodplain ever since, with the exception of the extreme floods of 2011 and 2013 and seepage water. This long-term loss of direct inundation and the decreasing groundwater table of the Elster-Luppe floodplain have had negative consequences on the ecosystem services and biodiversity in the area. But even today, the floodplain of the Elster-Luppe system still has high ecological value that is protected through the European Union's Habitats Directive as a Special Area of Conservation, the so called "FFH-site Leipziger Auensystem", which still contains one of largest floodplain forests in Germany and a high variety of endangered species. Measures of revitalisation are necessary to retain this unique landscape (Scholz et al. 2016).

Urban challenges	Solutions
Air pollution	Protection and improvement of the health of the floodplain forest, to continue mitigating air pollution
Heat island effect	Green spaces provide cooling via the evaporation and shadow of trees and plants Water features provide evaporative cooling and improve the micro-climate
Water scarcity	By connecting the water bodies in combination with inundation, the ground water levels of the river Luppe leading through the floodplains should be raised successfully
Rainwater drainage/runoff	Extensive vegetation and permeable surfaces allow rain water to be absorbed and released slowly
Flood resilience	The capacity of the floodplain for water retention will be improved, thanks to natural water retention measures
Ecological and social connectivity	Public green and blue spaces allow for the closer interaction of all social groups and to provide a venue for urban wildlife Green infrastructure improves biotope network and supports biodiversity (removing fragmentation)

Technical details

The project has two construction lines running side by side, one managed by the city of Leipzig (in close collaboration with the city of Schkeuditz) and the other by the Saxony branch of the NGO NABU (Nature and Biodiversity Conservation Union) (Scholz et al., 2019).

The first line focuses on the revitalisation of more than 12–16 km of a former river course in Leipzig's floodplain ecosystems by reconnecting still existing riverbed fragments (Figure 45). Connecting those riverbed fragments to the sections of Luppe with a still existing wild river bed in Saxony-Anhalt

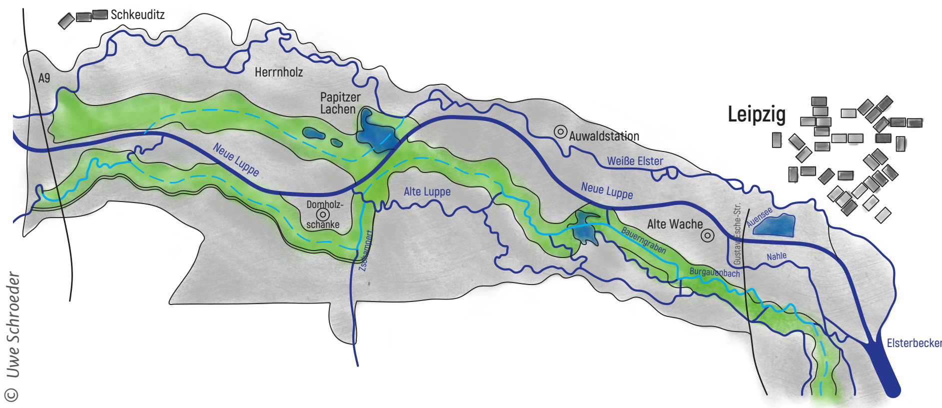

Figure 45. Scheme of the project area, with green shading indicating the area of search for newly connected and revitalised streams and the dotted line showing potential new river courses (based on LL, 2015)

will increase the ecological continuity up to the River Saale further upstream. Additionally the project aims to improve inundation by allowing significant floods to reach large areas of the floodplain via the new river course. With both measures the groundwater table should be stabilised and dynamised in most parts of the project area. The revitalisation of stretches of the Luppe should help to counteract the present situation of water shortage in the floodplain and again enhance the diversity of floodplain characteristic species and habitats and related ecosystem services. These measures are to be considered as a part of a mosaic of different actions to be taken to achieve a more extended revitalisation of the Leipzig floodplain in the future and is planned as a no-regret measure (Scholz et al., 2016; 2018). The revitaliaation of the former river course and

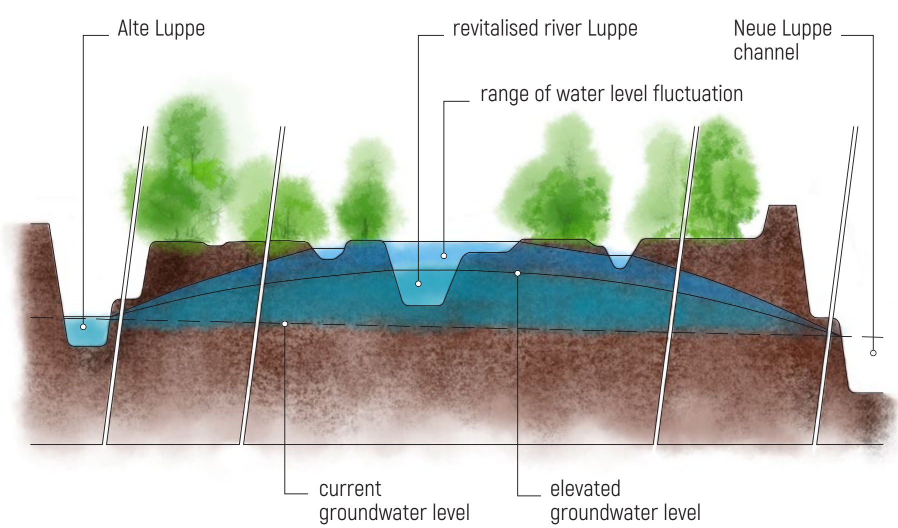

Figure 46. Lebendige Luppe - Revitalisation scheme to increase the groundwater level (based on Becker et al., 2009)

improvement of inundation during flood events is in a planning stage, with first construction works for a smaller river section to be started in 2021.

In parallel, a second line of construction measures in the northwestern floodplain was guided by the NABU Saxony and was already finished in 2016. This construction work was focused on repairing an existing watercourse through various maintenance measures. The water supplies several ponds, relics of former extraction of alluvial clay. Today, these man-made ponds serve as one of the most important habitats for endangered amphibians. Due to a lack of water because of a lowering groundwater table and missing inundation, an artificial water supply is vital to guarantee the hydrology of the ponds during the amphibian breeding season (Vlaic, 2017). This involved replacing a run-down inlet structure to allow the water to flow to surrounding ponds and former river courses during the reproduction season from March to July. These measures ensured the seasonal water supply of the ponds, which already had a positive impact on ecosystem resilience by both raising the groundwater level and counteracting drainage through the Neue Luppe canal (Figure 2) and stabilising the breeding population of the amphibians (Vlaic, 2017).

Barriers and success factors

The objectives of the project could be extended thanks to a constructive support for improving floodplain restoration offered by local NGOs for nature conservation and scientific experts. Moreover a communication process about the prospective development of this special landscape in the context of its urban neighborhood contributed to the success of the project.

There are still considerable planning challenges that need to be overcome to achieve a comprehensive revitalisation of the Leipzig floodplain because a variety of interests of other water users and owners must be taken into account. The river and floodplain network especially inside the city of Leipzig has been strongly modified in the past for technical flood protection. In addition, the water

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Figure 47. Strongly modified river networks inside floodplain forest of Leipzig – aerial image of the Burgaue, the floodplain forest and the New Luppe with the confluence with the Nahle (city of Leipzig in the background)

supply of the existing or new river arms especially during low or medium water discharge has to cope with small hydropower stations along the Weiße Elster, the dilution of the sewage treatment plant water, the minimum environmental instream flow of all water courses and the requirements of urban sanitary environmental engineering.

It should be noted that a full dynamic floodplain and river restoration cannot be achieved only via the measures of the project Lebendige Luppe (Figure 47). Wider processes are dependent on frequent large-scale inundations by natural flooding and the unregulated flow of sufficient water quantities from the floodplain rivers. The overarching framework conditions set for flood protection and sanitary environmental engineering are decisive for the regulation of flow in and close to the urban area and cannot be influenced by the actors of the Lebendige Luppe project yet (Scholz et al., 2016; 2019). These aspects need to be taken into account when revitalising a wetland in urban areas; they also offer opportunities for a climate-friendly urban development.

Acknowledgements

The authors of this NBS catalogue would like to thank Dr. Maria Vlaic, NABU (Naturschutzbund Deutschland), Mr. Mathias Scholz, Helmholtz-Zentrum für Umweltforschung – UFZ, Prof. Dr. Sylke Nissen, Universität Leipzig as well as Torsten Wilke, Angela Zabojinik, Stadt Leipzig, Amt für Stadtgrün und Gewässer for their extensive contribution and information provided to develop this case study.

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About "Climate NBS Poland"

Climate Mitigation through Nature-Based-Solutions in Urban Poland - Fostering Awareness and Capacity (Climate NBS Polska)

The "Climate NBS Poland" project aims to increase the understanding, acceptance and uptake of multifunctional NBS as a cost-effective urban climate mitigation and climate protection measure. By initiating and fostering co-operation and exchange between Polish and German planning, engineering and policy experts, the project seeks to build capacity, knowledge and skills among city officials, municipal staff and landscape planners to enable the conceptual and technical design and implementation of NBS.

To this end, the project includes the following activities and outputs:

- producing two publications: *Addressing climate change in cities: Catalogue of urban nature-based solutions* and *Addressing climate change in cities: Policy instruments to promote urban nature-based solutions;*
- developing tailored guidance and policy recommendations to promote urban NBS adapted to the reality of Polish cities and local governance;
- setting up a targeted capacity-building programme for the project's end-users including an online course, training events across Poland and a study visit to Germany;
- fostering the development of a Polish network of NBS experts and working closely with a number of Polish cities, such as Poznań, Kraków, Wrocław and Warsaw.

The project is carried out by the Ecologic Institute and the Sendzimir Foundation.

This project is part of the European Climate Initiative (EUKI). EUKI is a project financing instrument by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). The EUKI competition for project ideas is implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. It is the overarching goal of the EUKI to foster climate cooperation within the European Union (EU) in order to mitigate greenhouse gas emissions.' This publication is complemented by a guide on policy instruments that can be used to foster NBS uptake NBS in Polish cities.

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