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Nature-Based Solutions in Humanitarian Settlements

Guidelines for Integrating Nature-Based Solutions in Settlement Planning

Technical Support Section

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Mariam Hassan Muse engages in an agricultural program at Buramino settlement, Ethiopia. © *UNHCR/Petterik Wiggers*

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1 INTRODUCTION

Nature-Based Solutions (NBS) is a new term for an old idea – working with nature to address societal needs. Throughout history, societies at different stages of economic and technological development have harnessed natural processes and features to address needs and improve living conditions. In their current forms, NBS thus reformulate old ideas into new practices.

Recent expansion of NBS in research, public policy, and practice is driven by recognition of the harmful environmental consequences of industrialisation and urbanisation and the new societal challenges these consequences entail. Climate change and other forms of environmental degradation present myriad challenges such as increasing climate risks (e.g., extreme heat and floods), water scarcity, and loss of biodiversity. In this context, NBS are presented as localised ways to address these societal challenges while protecting, restoring or creating new ecosystems.

Urban environments, where large populations entail convergences of societal challenges and environmental risks, have received particular attention regarding the potential of NBS. In urban settings NBS are identified as ways of integrating natural features and processes within developed landscapes to simultaneously provide environmental, social and economic benefits. Different forms of urban NBS are presented as alternatives or extensions to conventional infrastructure or as new nature-oriented urban features.

Humanitarian settings are a particular type of urbanism where NBS could be beneficial. Settlements providing accommodation, assistance and protection for refugees and Internally Displaced People (IDPs) take a wide variety of forms. Underlying this variety is a humanitarian impetus and the intended temporary accommodation of displaced people. While settlements often operate for extended periods, the intended temporary character, water scarcity and other common environmental limitations of land where settlements are located can present obstacles for NBS. Notwithstanding such obstacles, integration of NBS into settlements could support protection and restoration of ecosystems while simultaneously addressing many of the myriad challenges of developing and operating of humanitarian settlements and meeting the needs of displaced people.

Integration of NBS into settlement planning and development aligns with UNHCR's strategic policy framework intended to address climate change and other environmental impacts. Specifically, the UNHCR Strategic Framework for Climate Action aims:

> *"...to preserve and rehabilitate the natural environment and mitigate environmental degradation in displacement settings",*
>
> and
>
> *"to enhance the resilience of displaced people and host communities to climate-related and other environmental risks [by] investing in anticipatory action to reduce and manage these risks."*

Similarly, UNHCR's Operational Strategy for Climate Resilience and Environmental Sustainability 2022-2025 states:

> *"UNHCR and partners will continue to learn from and adapt to local traditional and indigenous knowledge, including nature-based solutions."*

This document is intended to support efforts to integrate NBS into current settlement planning, development and management practices. It provides a general overview of NBS and technical guidance regarding integration of particular forms of NBS into settlements. This information can support initial considerations about potential integration of NBS into settlement planning prior to more detailed feasibility assessments and design.

Part I provides a brief overview of NBS and identifies issues affecting the integration of NBS into current settlement planning and development practices. Part II provides a catalogue of different forms of NBS that are relevant to settlements, including technical guidance on design and operation.

Afforestation activities by Afghan refugees in the Surkhandarya region of Uzbekistan. © *UNHCR/Elyor Nemat*

Tani Yadaka working in a tree nursery at Minawao refugee camp, in Cameroon's Far North Region. © *UNHCR/Caroline Irby*

2 WHAT ARE NATURE-BASED SOLUTIONS?

This chapter provides a brief introduction to nature-based solutions, including definitions of key concepts and identification of different types of interventions.

2.1 Definitions

Nature-Based Solutions (NBS) are strategies that are intended to harness the benefits of natural processes to address societal needs. Industrialisation and urbanisation have, to varying extents, widened distances between societies and natural ecologies. Yet, increasing recognition of the harmful effects that human activity has had on the natural environment, and the threat that this damage to natural ecologies ultimately poses for societies, underpins increasing attention given to NBS and increasing prevalence of the term in public policy discourse.

The International Union for the Conservation of Nature (IUCN) provides a definition of NBS that has been endorsed by UN Habitat, the World Bank, and other international institutions:

> *Nature-based Solutions are actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits. (IUCN, 2016)*

As per usual with emerging fields of inquiry and action, a range of definitions of NBS are available that vary in emphasise and priorities (see (Chausson et al., 2020)). Yet the range of definitions of NBS consistently involve convergence of two elements: natural ecosystems, and societal challenges.

Related terms

Other terms overlap with the concept of NBS, such as: community-based adaptation, ecosystem-based disaster risk reduction and climate adaptation services. Ecosystem-Based Adaptation (EBA), which closely relates to NBS, refers to harnessing ecosystem services specifically in building resilience and reducing vulnerability to effects of climate change, compared to the broader range of societal challenges encompassed by NBS.

Ecosystem types

Ecosystem types are distinguished by climatic conditions, biotic and abiotic elements, and the processes through which they interact. Different ecosystem types include:

- Tropical and subtropical forests
- Temperate forests
- Tropical and subtropical grasslands
- Temperate grasslands
- Deserts and xeric shrublands
- Mediterranean shrublands and forests
- Montane/alpine
- Wetlands
- Ponds and lakes
- Streams and rivers
- Peatland
- Coastal
- Saltmarsh
- Mangroves
- Deltas and estuaries

Ecosystems

Natural ecosystems involve complex interactions of biotic and abiotic elements. Organic ecosystem elements include all plant and animal life while inorganic elements include non-living materials such as soil, water and atmospheric gas. Various biotic and abiotic elements of an ecosystem interact through myriad processes, including biological processes such as fertilisation, hydrological processes such as evapotranspiration, and geological processes such as erosion. Different combinations of climate, ecosystem elements and processes distinguish different ecosystem types, that include: tropical forests, subtropical forests, temperate grasslands, deserts, shrublands, wetlands, and mangroves. The concept of NBS is underpinned by the objective of protecting or restoring such natural ecosystems, including the creation of new ecosystems. Ecosystem services are the benefits that these ecosystems provide to society, such as the provision of food, filtration of air and water, decomposition of waste, and accommodation of recreational activities.

Arid ecosystem

Temperate ecosystem

Subtropical ecosystem.

Tropical ecosystem.

Societal challenges

In the context of NBS, societal challenges encompass the wide range of requirements for societies to survive and prosper sustainably. For individuals, essential requirements relate to nutrition, physical and mental health, education, dignity, etc. Societal challenges aggregate and balance myriad individual and communal requirements and interests. Diverse societal challenges can involve provision of public infrastructure and services, cultural preservation, assurance of equality and respect for diversity.

Among the diverse range of societal challenges that may be addressed, emerging impacts of climate change provide the impetus for increasing prominence of NBS. Changing climatic conditions are associated with a range of critical interconnected societal challenges including increasing disaster risk, heat stress, food and water scarcity and changing patterns of human settlement. Disaster risk reduction is particularly important among the challenges that may be addressed through NBS, including addressing increased risks associated with flooding, drought, erosion, landslides, and extreme heat.

At the scale or urban settlements, societal challenges include the provision of basic urban amenities such as drainage and sanitation, space for recreation and social interaction, and adequate ventilation. Societal challenges in urban settings also include social requirements such as safety and security, opportunity for adequate livelihoods, community cohesion and cultural preservation.

NBS are intended to address these various societal challenges in accordance with the elements and processes that characterise local ecosystems.

The IUCN defines the overarching goal of NBS as:

> *"to support the achievement of society's development goals and safeguard human well-being in ways that reflect cultural and societal values and enhance the resilience of ecosystems, their capacity for renewal and the provision of services… [and] to address major societal challenges, such as food security, climate change, water security, human health, disaster risk, social and economic development."*

(IUCN, 2016b)

NBS Principles

The IUCN defines eight principles to guide design and implementation of NBS:

1. *NBS embrace nature conservation norms and principles;*
2. *NBS can be implemented alone or in an integrated manner with other solutions to societal challenges, including technological and engineering solutions;*
3. *NBS are determined by site-specific natural and cultural contexts that include traditional, local and scientific knowledge;*
4. *NBS produce societal benefits in a fair and equitable way in a manner that promotes transparency and broad participation;*
5. *NBS maintain biological and cultural diversity and the ability of ecosystems to evolve over time;*
6. *NBS are applied at a landscape scale [including urban landscapes];*
7. *NBS recognise and address the trade-offs between the production of a few immediate economic benefits for development, and future options for the production of the full range of ecosystems services;*
8. *NBS are an integral part of the overall design of policies, and measures or actions, to address a specific challenge.*

Abdi Hassan searches for water in the midst of a drought in southeast Ethiopia. © *UNHCR/Mary-Sanyu Osire*

2.2 Types and forms of NBS

NBS encompass a wide range of interventions and initiatives that may be described, characterised and categorised in different ways. One way of categorising NBS distinguishes between structural interventions that involve abiotic (hard) elements, and non-structural interventions primarily involving biotic (soft) elements and processes. Another manner of categorising NBS focusses on types of ecosystems and forms of intervention, defining six categories (Chausson et al., 2020):

1. *Natural ecosystem protection*
2. *Natural ecosystem restoration*
3. *Other management of natural/semi-natural ecosystems*
4. *Combination of natural ecosystem protection, restoration and/or management*
5. *Created ecosystems establishment or management*
6. *Combination of natural/semi-natural and created ecosystem*

The European Commission (EC, 2015) categorises NBS in a manner that takes into account both ecosystem contexts and intervention objectives, defining seven categories of NBS that support or provide:

1. *urban regeneration*
2. *well-being in urban areas*
3. *coastal resilience*
4. *watershed management and restoration*
5. *sustainable use of materials and energy*
6. *enhanced ecosystem insurance value*
7. *increased carbon sequestration*

Within these categories may be grouped a wide range of NBS responding to different objectives and harnessing different natural processes and operating at different scales. Among this range of NBS, those applicable to urban environments – to towns, cities and other settlements – pertain to created ecosystems and combinations of natural/semi-natural and created ecosystems.

2.3 NBS and grey infrastructure

NBS in urban settings generally involve an approach to urban amenities and services that differs from conventional infrastructure – so-called grey infrastructure that typically includes built structures such as reservoirs, canals, piped water drainage systems, and concrete or other impervious materials.

Despite the different approaches, these two forms of infrastructure can be integrated to effectively deliver urban amenities and address societal challenges. Integration of NBS and conventional grey infrastructure can optimise provision of urban amenities and resilience taking into account the range of performance requirements and associated costs and benefits of each approach.

Aims	Actions
Enhancing sustainable urbanisation	Multi-functional nature-based watershed management and ecosystem restoration
	Nature-based solutions for improving well-being in urban areas
Restoring degraded ecosystems	Establishing nature-based solutions for coastal resilience
	Multi-functional nature-based watershed management and ecoysystem restoration
Developing climate change adaptation and mitigation	Nature-based solutions for increasing the sustainable use of materials and energy
	Nature-based solutions for enhancing insurance value of ecosystems
Improving risk management and resilience	Increasing carbon sequestration through nature-based solutions

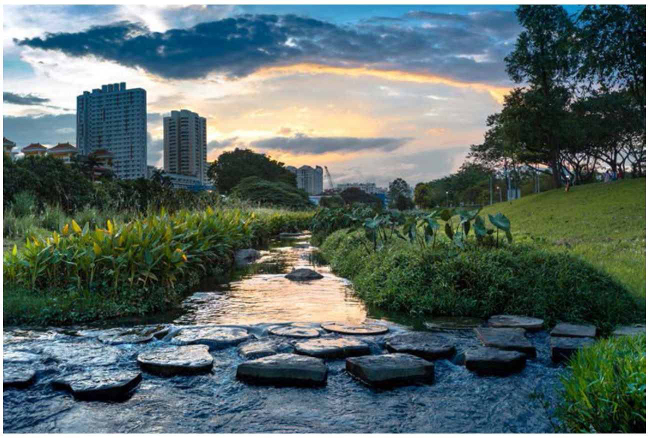
Adapted from *European Commission, 2015*


Green corridors at Medellin, Colombia. *Image WWF, 2021*


Green roofs at Malmo, Sweden. *Image WWF, 2021*


Restoration of urban industrial land, London. *Image EC, 2015*


Restored wetlands at Kabukuri-numa Japan. *Image IUCN, 2016*


River restoration at Singapore. *Image WWF, 2021*


Mangrove recovery at Guinea Basau. *Image WWF, 2021*


Forestation for hazard protection, Switzerland. *Image EC, 2015*


Rainforest recovery at Salvador, Brazil. *Image WWF, 2021*

3 INTEGRATING NATURE-BASED SOLUTIONS IN SETTLEMENTS

This chapter introduces a range of issues relating to integration of NBS in settlements accomodating refugees and IDPs.

Potential benefits of integrating NBS in any particular displacement response should consider both immediate requirements as well as extended benefits of different forms of NBS, such as environmental restoration, disaster risk reduction, social interaction and cultural preservation.

Feasibility assessments and planning of NBS should employ an integrated systems approach across several dimensions:

1. Integration of different types of NBS across different spatial scales of the settlement
2. Integration with conventional systems, including grey infrastructure and settlement management arrangements
3. Integration into the broader landscape, including the provision of benefits beyond settlement boundaries and beyond the settlement lifecycle

As with settlement development and infrastructure initiatives, design and implementation of NBS should be preceded by detailed assessment of the functions, benefits, suitability and costs in relation to local conditions and constraints.

3.1 Settlements for refugees and IDPs

Settlements providing accommodation, assistance and protection for refugees and IDPs take a variety of forms. They can be spontaneous or planned and dispersed or grouped, depending on the emergency, the response, and the context. Settlements also change over time. While settlements are temporary responses to displacement, they often operate and evolve over years or decades.

In most displacement situations, refugees and IDPs establish spontaneous settlements, with subsequent assistance focussed on improving living conditions in the context of established constraints.

For planned settlements, local conditions influence settlement planning and ongoing operation. Site selection should consider physical and environmental conditions such as topography, soil conditions and drainage; the quantity and quality of available water; and potential effects on local flora and fauna. Site selection should also consider social, economic and political factors such as accessibility, security and protection, potential livelihoods, public health issues, and the cooperation of host communities and authorities.

Self-settled new arrivals on the outskirts of the Dadaab refugee camps, Ethiopia. © *UNHCR/Mohamed Aden Maalim*

Dormiz 1 Settlement, Iraq. © *UNHCR*

Settlement size varies across displacement situations. To moderate pressure on local resources and environments, guidelines suggest a maximum settlement population of 20,000 people, with larger populations dispersed in multiple settlements separated by at least one-day walking distance (UNHCR, 2023a). Practical requirements and constraints often result in larger settlements or dispersed settlements that are separated by shorter distances.

Planned settlements involve substantial infrastructure investments. Construction of infrastructure supporting access, drainage, water supply and sanitation typically accompanies settlement establishment and development during operation. Beyond initial investment, settlement infrastructure entails significant management requirements and ongoing costs for operation and maintenance.

Ultimately, the location and form of settlements – including the size and extent of infrastructure – depends on the crisis and response context. Sites are sometimes allocated on vacant land that is unused due to low value, remoteness, and unsuitability for agriculture. Consequently, settlements may be established in less appropriate locations.

These general characteristics of humanitarian settlements have several implications for the potential integration of NBS.

NBS typically function at a landscape scale, which, for urban settings can be the scale of a neighbourhood. While smaller spontaneous or planned settlements may not be sufficiently large to accommodate many types of NBS, larger planned settlements that integrate multiple communities, blocks or sectors may be suitable for integration of different types of NBS.

NBS integrate natural processes and natural features such as vegetation that can require a longer period for establishment than conventional grey infrastructure. Extended development periods for NBS may be unsuitable for emergency situations, though can be accommodated within established settlements with longer operational horizons.

NBS rely on ecosystem services that may be limited in marginal land that is often allocated for settlements. Water availability is a critical consideration in settlement site selection and can be a critical restriction in the integration of NBS. While more arid, less fertile land may be less conducive to initial establishment of NBS, in the longer term, NBS can support improvements environmental conditions such as topsoil quality and water retention.

3.2 Settlement process considerations

Settlements are intended as temporary solutions, with the primary durable solution to displacement being the safe return home of refugees and IDPs. However, most displacement situations endure longer than expected. Settlements often remain in operation for decades, and early decisions about location, urban planning and infrastructure can affect living conditions of refugees and IDPs throughout this extended period.

Actual processes of settlement establishment, development, and occupation vary in each response situation. Nevertheless, settlement planning guidelines define three lifecycle stages: 1) settlement establishment and development, 2) settlement operation and maintenance, and 3) settlement closure.

While experiences in response operations differ widely from these conceptual stages, the three stages highlight settlement closure and decommissioning as an important consideration. Site restoration is a central objective of this final stage, addressing the range of damaging impacts that settlements have on local ecosystems.

The emergency and temporary character of humanitarian settlements have implications for the application of NBS. NBS integrate natural processes and features such as vegetation that can involve longer periods for establishment than conventional grey infrastructure. Extended development periods for NBS may be unsuitable for emergency situations, though longer durations for NBS development may be accommodated within established settlements and settlements with longer operating horizons. Development of NBS involving vegetation, modifications to topsoil and hydrological integration often require timing in relation to seasonal change.

NBS can be well suited across all stages of the settlement lifecycle. Ecosystem restoration is a central objective of the final settlement lifecycle stage and a fundamental principle and function of NBS. In addition to supporting settlement operation, NBS can improve outcomes of settlement closure and site restoration.

Ecosystem restoration and other functions of NBS can continue long after settlement closure.

Given typical NBS development timeframes and durability, inclusion of NBS should be considered early during site selection and settlement planning. Decisions about inclusion and design of NBS should consider the urgency of needs, expected duration of camp operation, and the potential benefits of NBS during settlement operation, closure and longer-term ecosystem restoration.

3.3 Environmental and ecological considerations

Settlement development involves rapid change in use of land and other natural resources that inevitably affects local environmental conditions.

Hydrological impacts can include effects on water tables and water availability. Influxs of displaced people at settlements place additional strain on local water resources, potentially lowering the water table and contaminating ground and surface water sources. Water availability is a critical determinate of site suitability. Guidelines for design and construction of settlement structures, including buildings and WASH infrastructure, are intended to reduce risks of groundwater contaminations.

Geological impacts depend upon topology and soil characteristics. Gently sloping sites with gradients of around 2-6% are generally preferred for settlements. Flat sites are more difficult to drain, while steeper sloping sites constrain land use and increase risks of erosion and landslides. Well-draining soils support site drainage and construction of latrines, which can otherwise be complicated in sandy or rocky conditions. Erosion is a common problem due to rapid site development in the absence of ground covering vegetation, leaving soil to degredation by wind and water. The preservation of topsoil is an important challenge for settlement development and subsequent site restoration.

Biological impacts include effects on flora and fauna. Settlement development places pressure on local vegetation, including through demand for materials for shelter construction and fuel. Loss of vegetation exacerbates erosion and alters soil moisture dynamics. Loss of vegetation is often the most visible ecological impact of settlement development and, along with increasing human activity on previously vacant land, entails loss of habitat for local fauna.

Considering these impacts, settlements should be located away from fragile ecosystems. Guidelines suggest settlements should not be closer than one-day walking distance from any natural resources that require protection.

Settlement development guidelines include requirements for environmental risk assessment and management that seek to minimise adverse environmental impacts. For emergency situations, guideline define requirements for rapid environmental risk assessments. For non-emergency situations after urgent humanitarian priorities have been addressed, guidelines define requirements of more detailed environmental impact and risk assessments (see IOM et al., 2015).

The UNHCR Environmental Guidelines, the Framework for Assessing, Monitoring and Evaluating the Environment in Refugee-related Operations (FRAME), and the UNHCR Emergency Handbook provide comprehensive environmental risk management protocols. These include requirements and procedures for identification of environmental impact risks during site identification and impact management during settlement development and management.

Environmental risk management guidelines also include requirements for restoration of sites following settlement closure. These include rehabilitation of hydrological, geological and biological conditions, such as restoration of the water table, topsoil, and vegetation. Rehabilitation is not restricted to a return to pre-settlement conditions at the site - it can also improve local ecosystem beyond pre-settlement conditions.

NBS can mitigate a range of settlement environmental risks in various ecosystem conditions. In parallel with addressing immediate settlement requirements such as drainage, public space, and disaster risk reduction, various NBS types can restore vegetation, soil and hydrological conditions. In short, beyond ameliorating environmental impacts, inclusion of NBS in settlement development could integrate site restoration into earlier stages of the settlement lifecycle.

Existing guidelines for environmental risk management such and UNHCR's FRAME guidelines provide a planning framework that can support inclusion of NBS in settlement planning. Early identification of risks and subsequent restoration requirements can support suitable NBS identification and provide performance benchmarks and design criteria.

Soil erosion has caused the formation of ravines at Kigeme refugee camp, Rwanda. © *UNHCR/Lilly Carlisle*

An aerial view from above of Kutupalong Refugee Camp and Camp Extension, Bangladesh. *Image @antonioguterres/X*

3.4 Settlement planning considerations

Guidelines for settlement planning and management provide extensive guidance regarding urban planning issues such as size and population densities, layout and circulation patterns, as well as land use and distribution of functions. Within the framework of these guidelines, actual planning of settlements varies with the unique conditions of each response situation. The framework of planning guidance and range of urban forms characterising settlements provides wide scope for the inclusion of NBS.

As mentioned earlier, guidelines suggest a maximum settlement population of 20,000 people, with larger populations to be distributed in multiple settlements separated by at least one-day walking distance. The UNHCR Emergency Handbook and Sphere Handbook suggests a minimum area of 45m2 per person, including areas of circulation, infrastructure, open space and other facilities. While this suggests a generic site area of approximately 90 hectares, actual site areas vary substantially.

Guidelines suggest that layouts of settlements be adapted to natural conditions, including topological and geological conditions and other natural features. Layout includes circulation patterns for roads, paths, and other infrastructure networks, which also determine arrangements of household plots. In hilly and sloping terrain, adaptation to natural conditions suggests organic layouts that support better drainage and better efficiency for land-use and infrastructure networks. On flat or gently sloping sites, natural conditions may support grid layouts that can be adapted to local site features.

For both organic and grid layouts, guidelines suggest a hierarchical approach to settlement planning. A planning hierarchy defines five units of settlement planning: family, community, block, sector, and settlement. For circulation layouts, hierarchies of primary, secondary and tertiary routes supports safe and efficient movement between planning units while minimising disturbance in family and community areas. This urban framework defined by the settlement layout and planning hierarchy influences design of networks for drainage, WASH infrastructure, firebreaks and other open spaces. For fire safety, guidelines require a minimum of 2m separation between shelters and firebreaks 30m separating each 300m of built-up area (UNHCR, 2023a).

Settlement planning units

Family		4-6 persons
Community	16 x families	80 persons
Block	16 x communities	1,250 persons
Sector	4 x blocks	5,000 persons
Settlement	4 x sectors	20,000 persons

The framework of settlement planning guidelines provides opportunities for integration of various NBS in different ways.

NBS generally function at the landscape or neighbourhood scale, which accommodates a range of settlement sizes. NBS such as green corridors, urban forestry (inc. consolidated and dispersed forestry), urban gardens and various nature-based drainage solutions can operate effectively at the scale of communities, blocks, or sectors. Given the scale and delineation of planned settlements from surrounding areas, NBS involving forestry, agriculture and drainage solutions could be integrated into settlement edges to define boundaries while maintaining connections with surrounding landscapes and host communities. With dispersal of larger populations in multiple settlements, development of NBS such as forestry and agriculture-related interventions could provide linkages between settlements and with host communities while supporting ecosystem restoration.

NBS can be integrated within particular levels of settlement planning and circulation hierarchies. For example, urban gardening or dispersed tree planting may operate at the scale of individual families, a community, or a block. Bio-retention ponds and other drainage solutions could operate effectively at the scale of the block or sector. NBS may be integrated across planning hierarchies. For example, green corridors may be integrated with secondary paths between sectors and can connect smaller parks that are dispersed at the community level. Hierarchies of settlement planning can provide a useful framework for integrating NBS in ways that serve specific functions at different planning units.

NBS can also be integrated with other elements of settlement planning and infrastructure. Nature-based drainage solutions including swales and retention ponds can be integrated with conventional drainage infrastructure. Green corridors, urban farming and forestry can be integrated with fire breaks and boundaries between planning sectors.

While current settlement planning guidelines do not explicitly address NBS, the technical requirements and potential benefits of NBS can be coordinated with current settlement planning standards and practices.

IDP camp at Bentiu, South Sudan. © *UNHCR/Andrew McConnell*

3.5 **Governance considerations**

Governance of settlement infrastructure - including management and maintenance – is typically the responsibility of a Camp Management Agency. Settlement management guidelines also recognise benefits of active participation of the settlement population in various aspects of local governance. Establishment of camp committees with a sector-specific or cross-cutting focus, such as a WASH Committee or an Environment Committee - are one channel participation in local governance.

This model of participative governance is appropriate for NBS. Various types of NBS have maintenance requirements and provide benefits that can be managed through existing channels of camp management and participatory governance. NBS such as urban farming, forestry, and nature-based drainage solutions require active engagement and maintenance suited to participatory management. Governance arrangements for these and other forms of NBS can be accommodated within existing camp management arrangements.

Beyond the settlement population, interaction of NBS with natural processes and resources and the potential ongoing operation of NBS after camp closure may warrant inclusion of host communities in governance arrangements. Local environmental knowledge of host communities may be critical for appropriate NBS design and maintenance. NBS may have enduring effects on local landscapes - such as terracing, forestry solutions and diversion of floodwaters in drainage solutions – warranting consideration of involvement of host communities in NBS design and management.

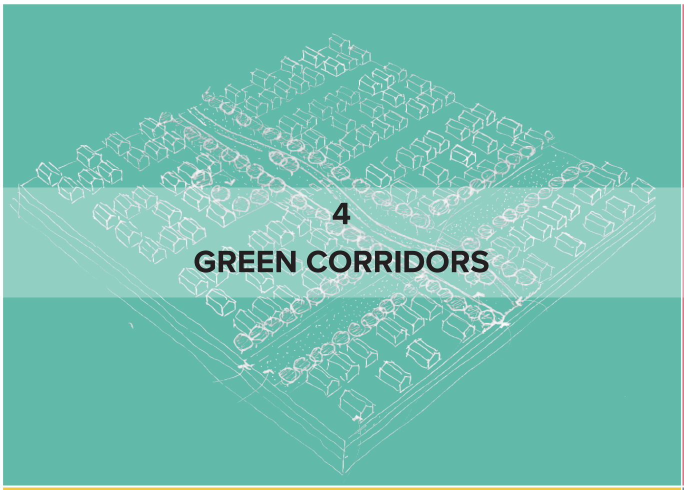
3.6 **Cost considerations**

Reliance on natural processes and ecosystem services ensures that design and implementation requirements varies with local conditions including climatic, geological and hydrological conditions. For example, the depth and absorption capacity of local topsoil has significant implications for the feasibility, design and operation of various types of NBS. These local peculiarities entail wide variations in cost. Generic comparisons of NBS costs, including comparisons with costs of grey infrastructure equivalents, are generally not available for humanitarian relief contexts. Reliance on local conditions entails greater variability in NBS costs compared with grey infrastructure. Nevertheless, as with usual processes for infrastructure development, initial assessments of local conditions can enable NBS cost estimates that may be refined during development of designs.

Costs can be considered in relation to upfront and ongoing maintenance costs. Upfront costs include land-related costs (which may not be relevant for humanitarian settlements) and costs of design and implementation, including labour and material costs that can vary with location and season. Maintenance costs include costs of ongoing interventions to ensure proper functioning of the NBS. Maintenance requirements may change seasonally and across the process of development (e.g., changing costs of protection and watering of new vegetation). Long-term maintenance costs should be planned with proper consideration of local conditions and life-cycle changes in maintenance requirements.

One of the refugee WASH committees at Gendrassa refugee camp in South Sudan.© UNHCR/Mary Sanyu Osire

PART II
CATALOGUE



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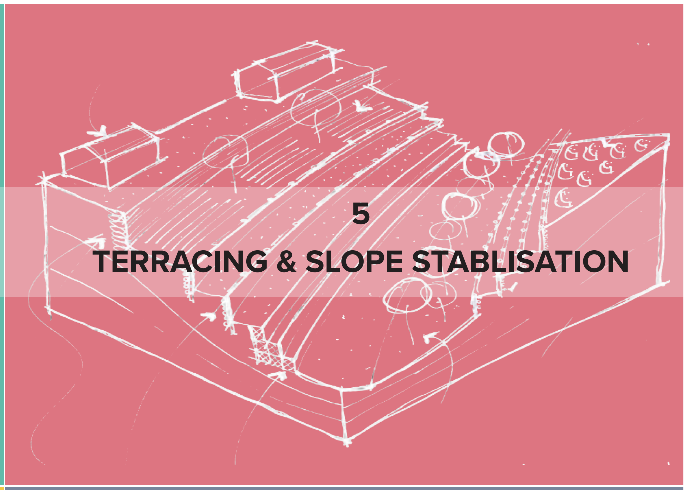
GREEN CORRIDORS



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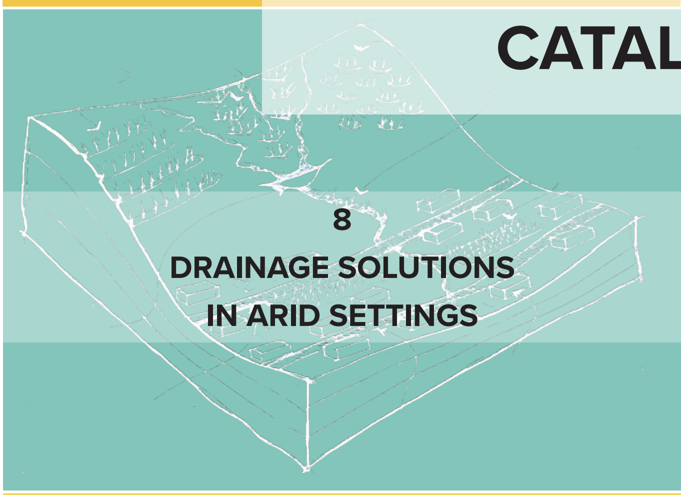

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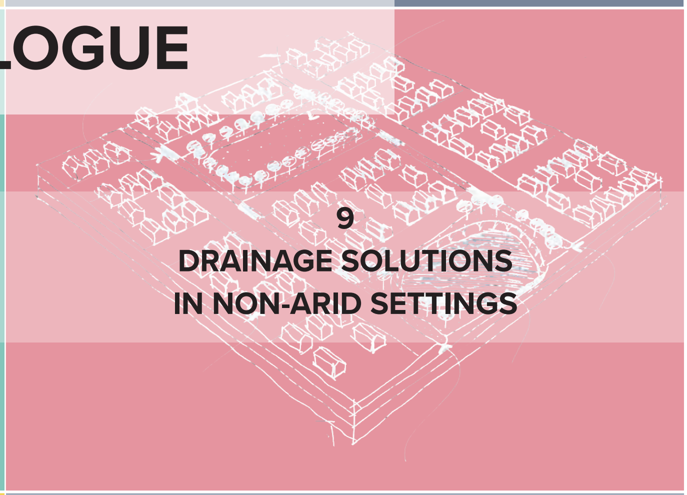

9
DRAINAGE SOLUTIONS IN NON-ARID SETTINGS

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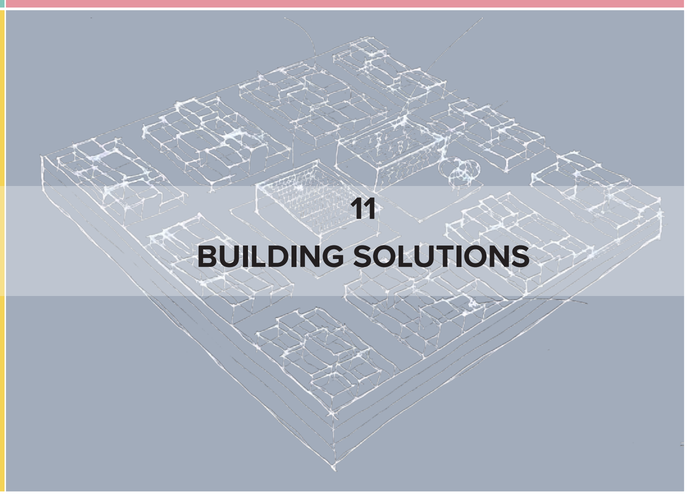
PONDS & WETLANDS



11
BUILDING SOLUTIONS

4 GREEN CORRIDORS

Description

Green corridors are strips of greenery – including trees, shrubs, grass and other vegetation – integrated into urban planning. They can operate at a range of scales and dimensions, with the essential characteristic of a linear geometry that can span and connect neighbourhoods. Typically, green corridors are integrated with other open spaces such as detached local parks, thereby creating green infrastructure networks through which natural features are connected and ecosystem services are made more accessible in urban environments (World Bank, 2021). In humanitarian settlement planning, green corridors can be integrated with clustered and hierarchical planning approaches, connecting spaces and services that operate at community, block, and sector planning units.

Tree canopies and ground vegetation are essential features of green corridors. Development of vegetation in humanitarian settlements must take into account issues such as water availability, and protection of vegetation, particularly during initial stages of growth.

The distributed network character of green corridors also enables integration with other infrastructure networks. Green corridors can be integrated with conventional drainage networks, combining nature-based and grey drainage infrastructure. Integration of nature-based drainage solutions (see Chapter 9) can yield multiple benefits from open space and vegetation (Woods Ballard et al., 2015). Green corridors may also be integrated with circulation networks, including roads and paths, utilising permeable paving to support water absorption and vegetation (World Bank, 2021). In humanitarian settlement planning, fire-breaks between blocks could support integration of green corridors into standard planning arrangements.

Applicability

Local conditions for plant growth including trees and grass are fundamental considerations affecting the applicability of green corridors in humanitarian settlements. Sufficient water should be available to support vegetation, considering irrigation system requirements and potential water table effects. Soil and sunlight conditions also affect potential for plant growth and the applicability of green corridors in a specific context.

Protection for vegetation in the context of relatively high population densities and accessibility of public spaces, especially during early stages of growth, should also be considered in relation to the design of green corridors.

Availability of land also affects applicability of green corridors in settlement planning. By operating at a range of scales and dimensions, green corridors entail a range of land area requirements. For new planned settlements in open locations, land requirements can be accommodated within existing settlement planning standards. In existing settlements or locations in which land areas are constrained, application of green corridors may be supported by integration with other infrastructure networks, including circulation networks or fire-breaks.

Green corridor at Medellin, Colombia. *Image WWF, 2021*

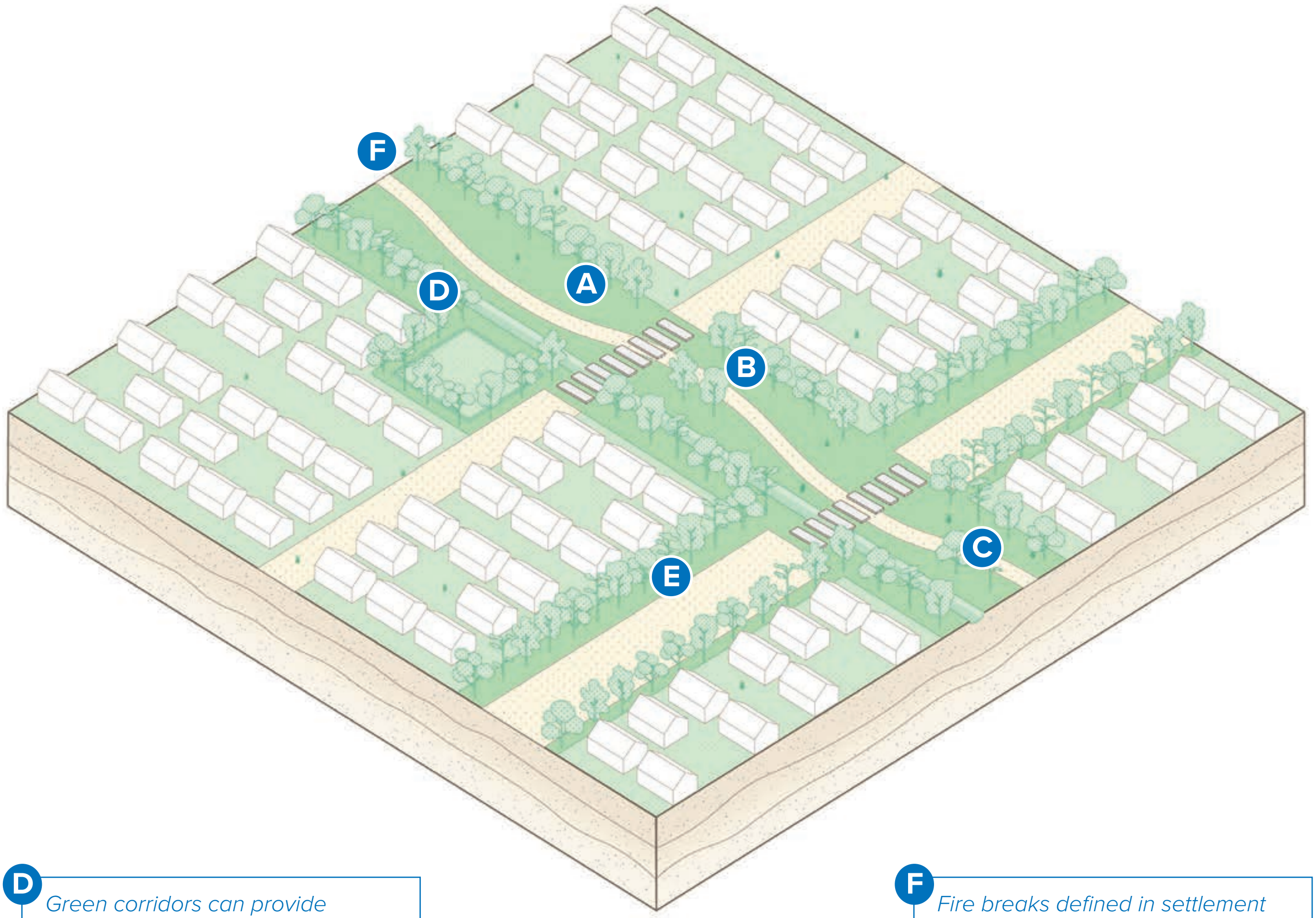
Green corridor at Medellin, Colombia. *Image WWF, 2021*

4 GREEN CORRIDORS

A *Tree canopies are an essential feature of green corridors. Shade is an important amenity in hot climates, particularly in situations where shelter designs magnify local temperatures and make internal conditions uncomfortable. Shade enables use of outdoor spaces in hot conditions, expanding the useful communal space of settlements and supporting social interaction.*

B *Green corridors are ideal for pedestrian circulation. Definition of pedestrian paths can help to control pedestrian traffic and protect vegetation. Permeable paving that allows infiltration of water – including pavers made from durable materials such as brick and concrete – can provide convenient pathways in wet and dry conditions.*

C *Green corridors can integrate nature-based drainage solutions including swales and retention ponds. Green corridors can provide a buffer alongside linear swales, which can follow straight or meandering routes. Permeable ground surfaces can support flood mitigation functions of both nature-based and conventional drainage.*



D *Green corridors can provide connections between local open spaces at the scale of communities or blocks in humanitarian settlements, creating green infrastructure networks that can optimise the functions and use of open spaces.*

E *Green corridors can be integrated with road networks, providing buffers between road traffic and residential plots. Use of permeable road surfaces, such as permeable pavers or engineered gravel surfaces, can maintain green corridor absorption, drainage and flood mitigation functions while maintaining vehicle access.*

F *Fire breaks defined in settlement planning guidelines can be utilised for green corridors, considering mandated fire break dimensions and other fire safety demands. Green corridors can address fire safety requirements for access and egress. This, however, requires careful consideration of local climate and fire risk as well as vegetation types and spacing.*

4 GREEN CORRIDORS

Benefits

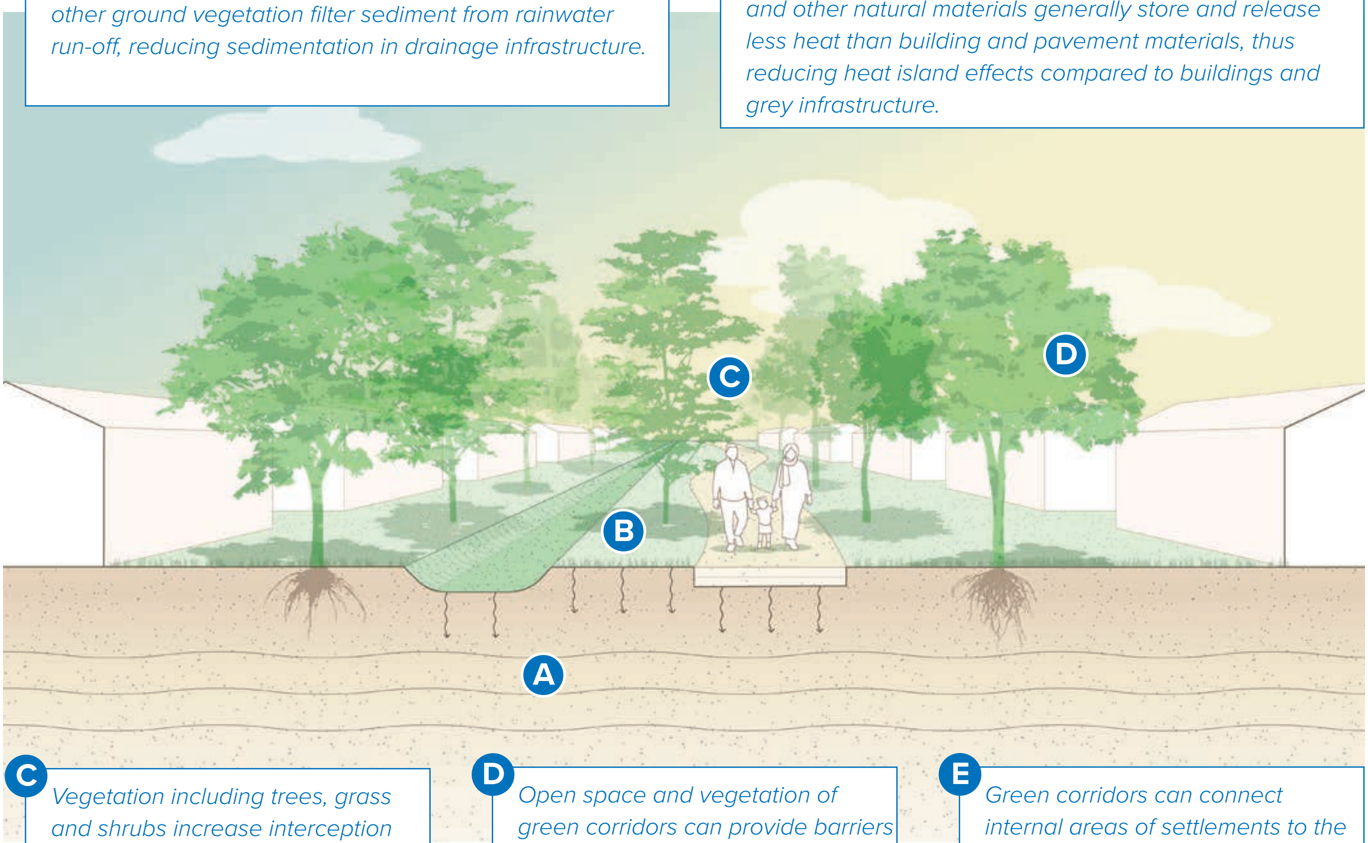
Green corridors can create networks of green infrastructure integrating vegetation and other natural features throughout the built environment of humanitarian settlements. This connected distribution of natural features can enable a range of functions that contribute to urban resilience. Green corridors and the vegetation distributed along them can increase interception and infiltration of rainwater thereby moderating peak runoff rates and the resulting loads on drainage systems (Eisenberg et al., 2022). Permeable and vegetated surfaces can also reduce sedimentation and pollution within drainage systems by enhancing sedimentation and filtration of soil water (Woods Ballard et al., 2015). Open spaces and vegetation of green corridors can moderate heat by providing shade and transpiration, thus offsetting heat absorption and the formation of heat island effects in densely built areas.

Vegetation and open space can also improve air quality by increasing trapping and deposition of dust and other particulate matter that may accompany rapid urban development in arid locations.

These natural functions supported by green corridors can provide a range of benefits for settlement inhabitants and host communities. Increased interception and infiltration of rainwater along green corridors can alleviate pressure on drainage systems and reduce flood risk. Trees and other vegetation in green corridors can reduce temperatures and reduce heat stress (World Bank, 2021). Green corridors provide distributed open space that promotes social interaction across community and block planning units. Following settlement closure, vegetation and other natural features distributed along green corridors can support revegetation and site restoration.

A *Permeable ground surfaces increase infiltration of rainwater, reducing loads on drainage systems, increasing soil moisture and groundwater recharge. Grasses and other ground vegetation filter sediment from rainwater run-off, reducing sedimentation in drainage infrastructure.*

B *Shade and evapotranspiration from trees and other vegetated surfaces lower temperatures in outdoor spaces and can reduce heat gain by buildings. Also, vegetation and other natural materials generally store and release less heat than building and pavement materials, thus reducing heat island effects compared to buildings and grey infrastructure.*



C *Vegetation including trees, grass and shrubs increase interception of rainwater prior to entry into drainage systems. Increased interception along green corridors can moderate runoff rates and peak loads on drainage systems.*

D *Open space and vegetation of green corridors can provide barriers filtering airborne dust, which can be a significant issue in arid locations where settlement disturbs existing soil and vegetation thus potentially increasing dust sources.*

E *Green corridors can connect internal areas of settlements to the surrounding landscape, potentially reducing landscape fragmentation by providing connected habitats for local flora and fauna. This can be particularly relevant for site restoration.*

Flood Risk Reduction

Green corridors contribute to flood risk reduction by increasing infiltration and reducing surface runoff. Interception of rainwater by trees and other vegetation and infiltration into the soil during intense rainfall events delays the arrival of peak drainage loads and reduces their intensity. Filtration of sediment reduces sedimentation within drains, thus preserving the capacity of drainage systems and reducing maintenance requirements.

Heat Stress Reduction

Green corridors can reduce heat stress by reducing heat in outdoor spaces through shading and evapotranspiration, thus mitigating the heat island effects generated by buildings and paved surfaces. Reducing heat in outdoor spaces is particularly important in situations where shelter designs lead to excessively hot internal conditions.

Social Interaction

Green corridors and other open spaces provide opportunities for social interaction in comfortable outdoor spaces. Green corridors can connect different areas– including communities, blocks, and sectors – providing outdoor space and opportunities for social interaction across planning units.

Public Health

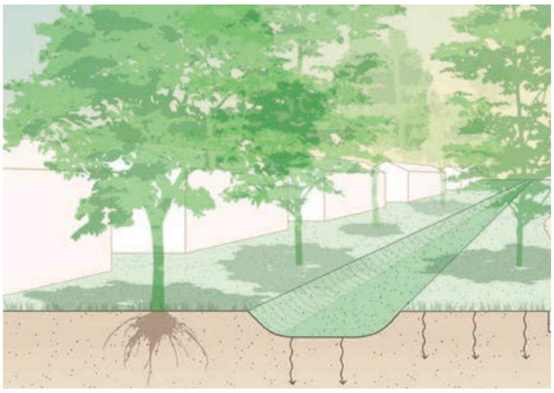
Green corridors can contribute to physical and mental health. Regulation of airborne dust can contribute to reducing respiratory problems and other dust-related health issues. Increased social interaction and engagement with natural environments can contribute to mental health, particularly in otherwise highly built up and densely populated settlements.

Site Restoration

Green corridors can entail an initial step in site restoration that develops during settlement operation. Green corridors enable establishment and development of vegetation and habitats for local flora and fauna. By connecting internal areas of settlements with surrounding landscapes, green corridors can provide established starting points from which broader revegetation and site restoration efforts proceed.

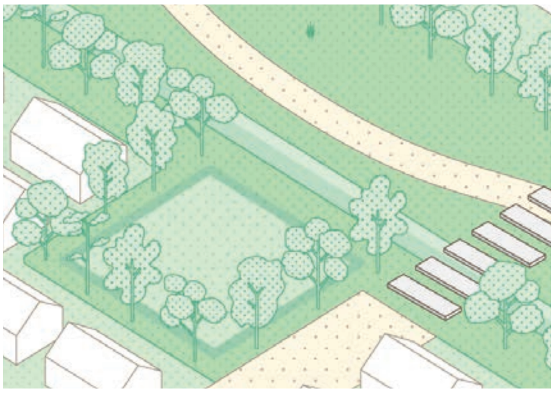
Technical Considerations

Important technical considerations for the integration of green corridors in settlements relate to ensuring appropriate conditions for plant growth and for ground water infiltration. Availability of water for establishment and maintenance of vegetation is a fundamental consideration. Selection of plant species should consider water availability, the local climate, and local soil conditions, as well as maintenance requirements and the likelihood of damage considering settlement population density. Absorption and retention of rainwater should be facilitated by ensuring appropriate ground cover, topsoil conditions, and use of permeable paving and road surfaces. Green corridors may be designed with a range of sizes; however, dimensions should be adequate to enable plant growth, considering that larger areas improve functions and benefits.



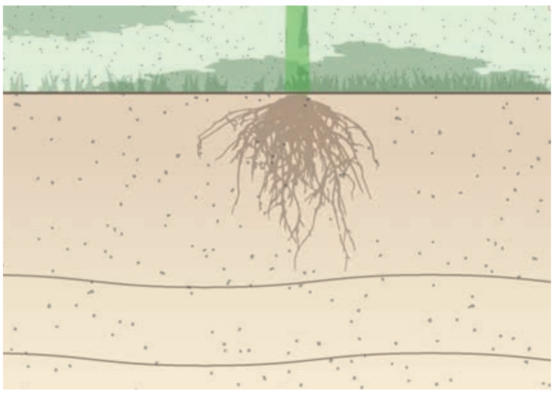
Hydrology

Availability of water is a fundamental consideration in determining the applicability of green corridors in a particular response situation. In general, water requirements for vegetation are greater during the early stages of plant growth; however water requirements vary with plant species, climatic conditions and soil conditions. Techniques to capture rainwater and encourage absorption (see Chapters 8 and 9) can support increased ground moisture and plant growth.



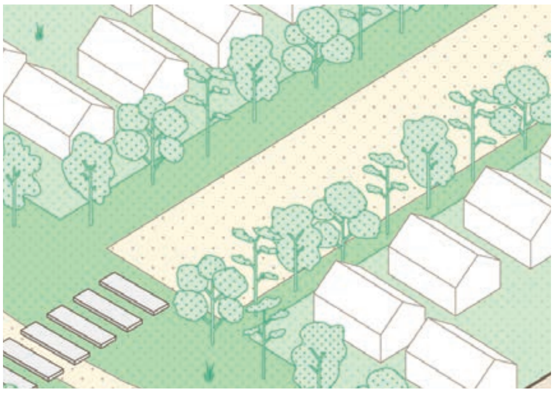
Planting

Plant species should be selected considering local conditions, growth and maintenance requirements, and plant characteristics to optimise green corridor functions. Species should be selected taking into account changing water requirements. In general, plant species should be selected that are robust to damage and minimise requirements for protection and maintenance. The extent of shade provided and provision of habitat for local wildlife should also inform plant selection.



Geology

Soil conditions including soil acidity and absorptivity affect plant growth and other functions of green corridors. A settlement site may be selected due to unsuitability for agricultural purposes, which may reflect poor soil conditions for plant growth. In general, the suitability of topsoil for plant growth relates to nutrient content, soil texture and structure (e.g., percentage of sand, silt and clay). Soil quality may be modified with the addition of nutrients and other suitable soils; however, the feasibility of such interventions should be considered in the context of costs and proximity resources.

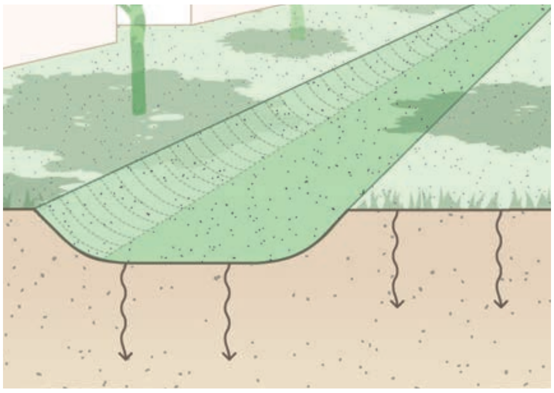


Geometry

The design of green corridors can feature a range of lengths, widths and shapes, including straight and meandering geometries. The width of a green corridor should take into account areas required for plant growth, including tree root systems. The size of root systems varies with tree species, however for many species the radius of above-ground branch growth provides an indication of the extent of the below-ground root system. As with settlement planning in general, gentle slopes are preferred to facilitate rainwater absorption and plant growth.

Pavement permeability

Permeable paving can provide pedestrian and vehicle access while allowing rainwater to infiltrate ground surfaces. This includes porous surfaces such as gravel, and permeable paving that includes gaps for water infiltration between durable impervious materials such as concrete and fired clay brick. The grade and density of gravel surface or base layers should be designed to allow for water infiltration.



Drainage

Green corridors can provide space for nature-based drainage solutions aimed at managing runoff, increasing interception and infiltration. Swales, for example, require more space than conventional grey infrastructure drainage solution.

Maintenance

Maintenance requirements for green corridors, as with other open spaces, depend upon the type of planting, paving and other features. Watering and protection requirements for vegetation will be greater during earlier stages of growth. Grasses may require cutting, although planting of native grasses can greatly reduce maintenance requirements.

Costs

Costs for establishing and maintaining green corridors will depend on factors such as size, extent of planting, type of planting, type of paving and any requirements for modifications to soil, slope, etc., during establishment. Protection and watering of plants during early stages of growth can entail significant costs that should be budgeted with initial construction costs.

4 GREEN CORRIDORS

Medellin Green Corridors Project

The Green Corridors project in Medellin, Colombia created 36 green corridors covering around 65 hectares between 2016 and 2019. The project was initiated by the municipal government and included planting of around 8,800 trees. Reported benefits include a 2ºC reduction in the local heat island effect around the green corridors and sequestration of around 160 tonnes of CO_2 per year.

Further information

Green corridor at Medellin, Colombia. *Image WWF, 2021*

Green corridor at Medellin. *Image C40 Knowledge Hub*

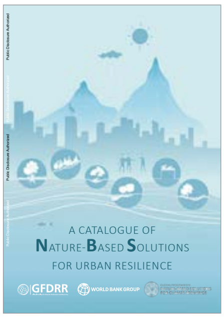
Key Take-aways

Green corridors can be integrated within existing settlement planning practices and can connect separate parks are open spaces to create green networks that optimise social and environmental benefits.

Green corridors can contribute to climate resilience through flood risk reduction and heat stress reduction while also providing public amenities that can enhance social interaction, health and well-being.

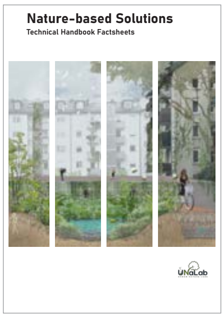
Green corridors include plants that require water, protection and maintenance, which can be optimised with selection of appropriate plant species and should be considered carefully during early planning and design.

Further Reading



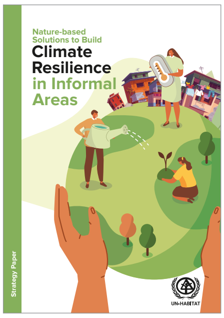
World Bank, 2021. A Catalogue of Nature-based Solutions for Urban Resilience. World Bank Group, Washington, D.C.

This report from the World Bank provides a general description of NBS, a comprehensive rationale for integration of NBS in urban environments, and a catalogue that describes the characteristics, benefits and technical guidelines for implementation of a range of NBS, including green corridors. It addresses NBS in urban formal urban settings – principally well-developed cities. Nevertheless, many of the characteristics, benefits and technical guidance is relevant to less developed urban settings including settlements for displaced people.



Eisenberg, B., Chiesa, C., Fischer, L., Jakstis, K., Polcher, H.G., 2022. Nature-based Solutions - Technical Handbook Factsheets. UNaLab Urban Nature Labs, Stuttgart.

This report from an EU-funded research program provides descriptions and technical parameters for a range of NBS in urban settings, including green corridors. Consistent formatting of technical datasheets supports simple comparisons of benefits and performance across different NBS.



Greenwalt, J., Bütow, C., Carrillo Silva, D., Francisco, A., Klooste, J., Dudley, R., 2022. Climate Resilience Nature-based Solutions to Build in Informal Areas. UN Habitat, Nairobi.

This strategy paper published by UN Habitat provides a comprehensive description of principles underpinning NBS, a rationale for integration of NBS in informal urban settlements, and comprehensive descriptions of processes for defining and planning NBS in informal urban settlements. The document does not specifically address green corridors nor settlements for displaced people; nevertheless, the issues raised in relation to informal settlements are relevant.

5 TERRACING & SLOPE STABILISATION

Description

Terracing and other forms of slope stabilisation encompass a range of techniques employed on sloping sites to reduce erosion and to increase the utility of sloping terrain.

Different forms of slope stabilisation are distinguishable by the different extents to which they modify natural gradients of sloping sites. Terracing involves extensive intervention; re-forming slopes into series of horizontal steps and vertical retaining walls that stabilise the slope. The stepping of terrain controls rainwater and traps sediment. The size of terraced steps can vary with the gradient of slope, stability of the soil, and potential use of the levelled land, with terracing being used traditionally in hilly landscapes to create flat land for crops and other agricultural uses. In contrast with terracing, wattle fences and live smiles involve moderate interventions in the natural slope of land, creating mini terraces that stabilise soil and control the flow of rainwater and sedimentation. At the other end of the spectrum, new planting on sloping sites involves no significant land modification but utilises plant root systems to stabilise the soil.

Different forms of slope stabilisation are also distinguishable by the materials that they employ. Traditional forms of slope stabilisation including terracing of different dimensions utilise natural materials such as stone, branches and bamboo to create retaining structures. Gabion terracing utilises natural stones contained within steel mesh cages, providing structural retaining walls that are permeable to water and can support plant growth. Terracing and other forms of slope stabilisation can also utilise contemporary geotextiles of different types that can be used to contain soil (as in geo-tube terraces) or can be laid on the ground surface or between soil layers to increase soil stability and prevent erosion.

Applicability

Terracing and other forms of stabilisation are useful in sloping terrain where poor soil stability can lead to erosion and landslides. Factors affecting suitable forms of slope stabilisation and the geometry of terracing include the gradient of the slope, the type of soil, the degree of instability of the soil, and the amount of rainfall (Inter Sector Coordination Group, 2022). Generally, planting is suitable for stabilisation of a range of slope gradients; however, establishment and early stages of growth are more difficult on steeper slopes given the impact of fast-flowing runoff on new vegetation (Polster, 2003). Soil testing and engineering input is required to determine the suitability of stabilisation techniques for steeper slopes.

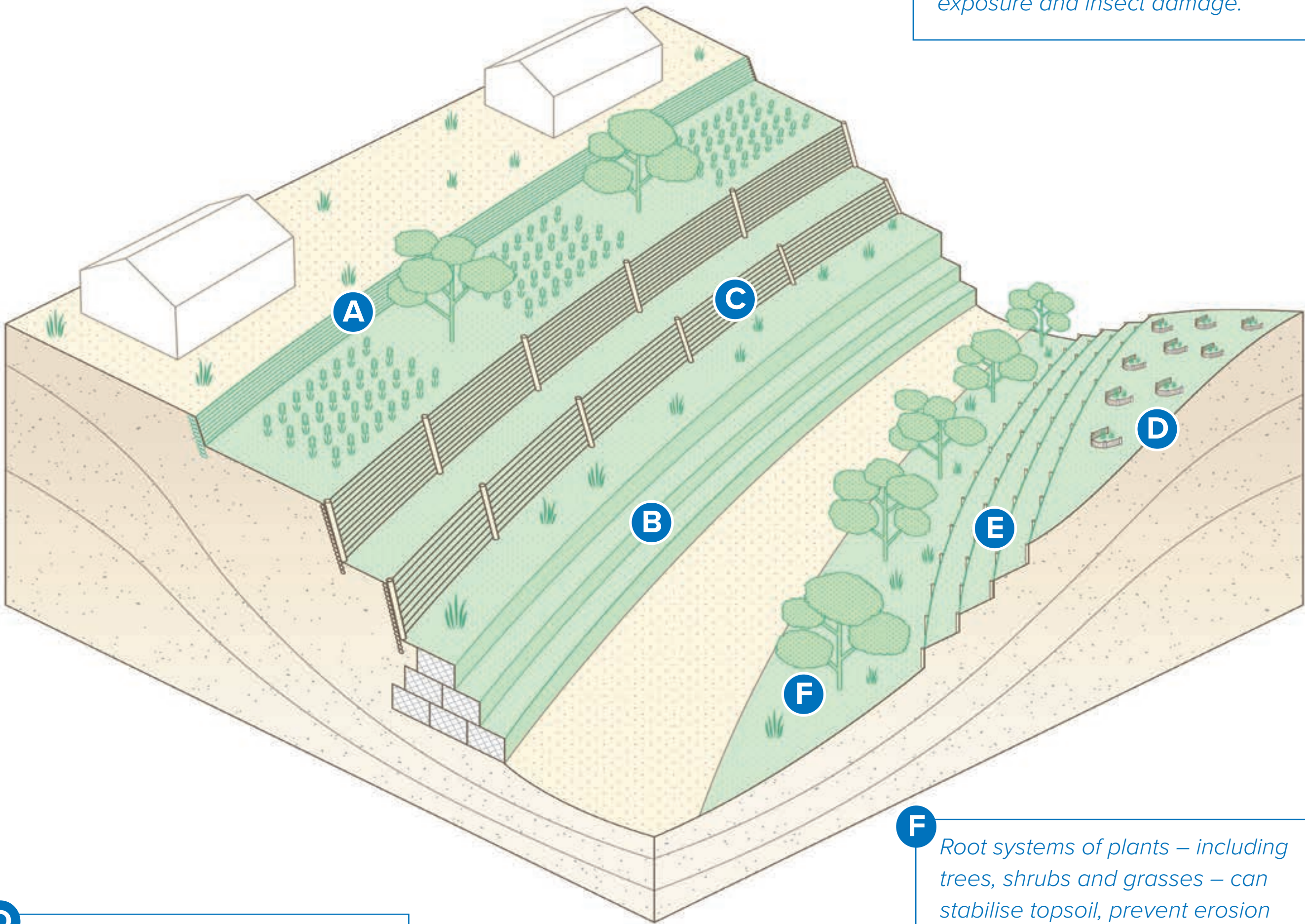
Terracing at Kutupalong refugee settlement, Bangladesh. *Image © UNDRR/Nusrat Khan*

5 TERRACING & SLOPE STABILISATION

A *Geo-tube terraces are a form of terracing in which retaining walls/ embankments are formed from specifically designed geotextile sacks filled with soil and/or sand. For stability, filled tubes are laid at a 45-60º slope to a maximum height of 1.5m. Geo-tube terraces are permeable and permit growth of vegetation. The durability of terracing is limited by the durability of the geotextile, which can degrade more rapidly when exposed to UV light (as in direct sunlight).*

B *Vegetated gabions are a form of terracing in which retaining walls are formed from cages formed from corrosion-resistant steel that are filled with stones. Gabions thus are a rudimentary form of stone masonry that does not require the skills, regular shaped stone and mortar required by other stone masonry. Stone gabion walls are permeable and permit the plant growth which can be supported by the deposit of soil and sediment between gabion stones.*

C *Bamboo crib walls are a form of terracing in which the terrace structure is formed from bamboo framing connected vertically across steps/levels. The bamboo frame supports bamboo matting or geotextile which provides a permeable barrier against soil erosion. Bamboo crib walls can be used to stabilise steep slopes and have been used extensively in operations at Cox's Bazaar. The durability of bamboo crib walls is limited by the durability of structural bamboo poles, which can be affected by consistent moisture exposure and insect damage.*



D *Living smiles involve small, curved retaining fences formed from branches and flexible plant cuttings supported by posted embedding into the slope. Living smiles are staggered across and down slopes in order to trap sediment, creating an array of mini terraces. By controlling runoff and trapping sediment, living smiles can support plant growth that provides further slope stabilisation.*

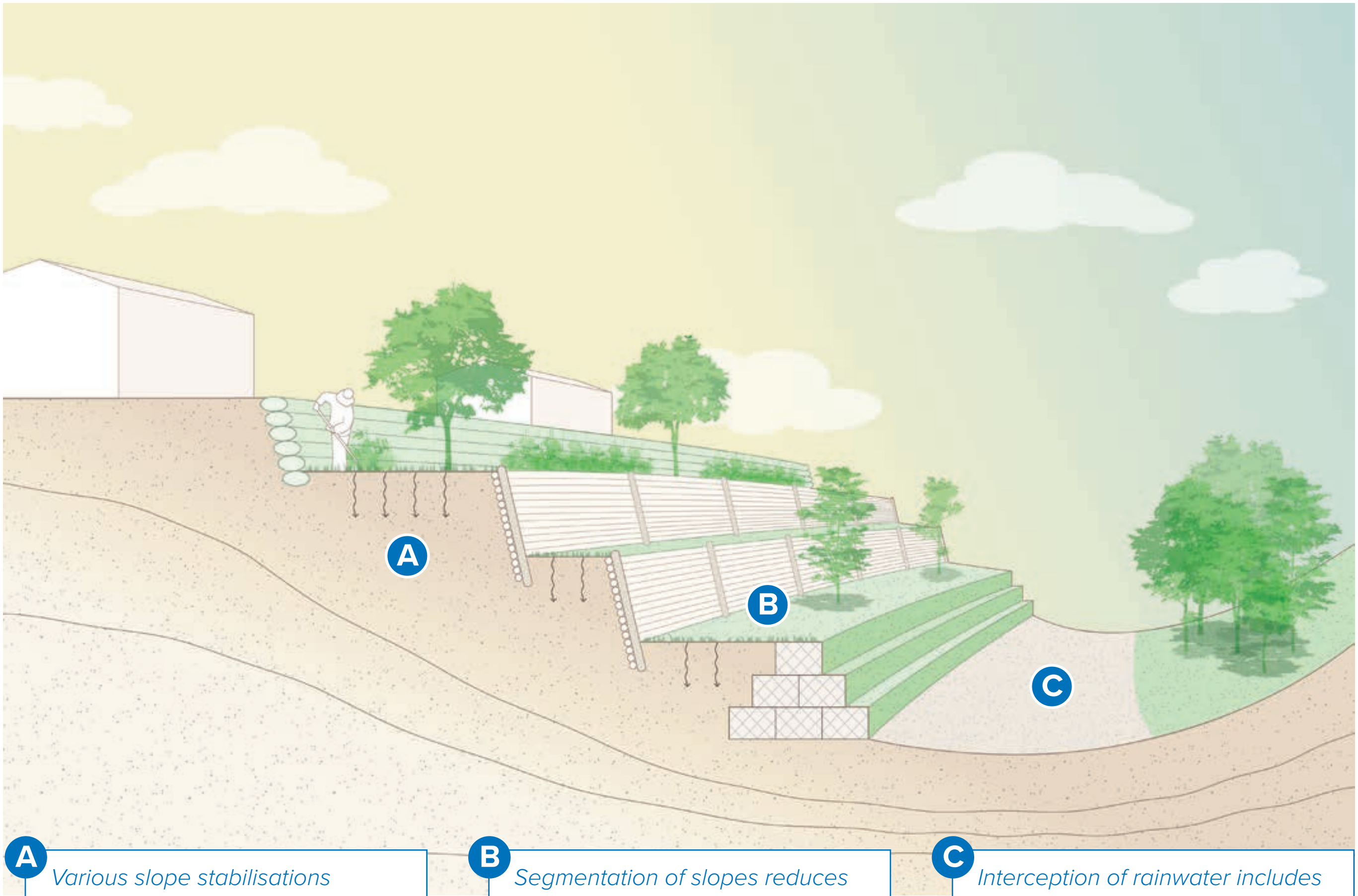
E *Wattle fences are made from posts embedded firmly in the soil and branches and flexible plant cuttings woven between posts. Wattles fences retain soil, breaking the sloping ground into small terraces that control runoff and trap sediment. By controlling runoff and trapping sediment, wattle fences can support plant growth that provides further slope stabilisation.*

F *Root systems of plants – including trees, shrubs and grasses – can stabilise topsoil, prevent erosion and reduce landslide risks. Generally, planting is suitable for stabilisation of a range of slope gradients; however, establishment and early stages of growth are more difficult on steeper slopes given the impact of fast-flowing runoff on new vegetation. Soil testing and engineering input is required to determine the suitability of stabilisation techniques for steeper slopes.*

5 TERRACING & SLOPE STABILISATION

Benefits

The principal benefits of slope stabilisation are landslide risk reduction, flood risk reduction, erosion reduction, and, for terracing, increased utility of sloping terrain. Terracing and other forms of slope stabilisation reduce landslide risks by stabilising topsoil layers, by segmenting slopes into smaller areas that have lesser risk of dislodgement, with breaks in slopes that can intercept smaller landslides (Polster, 2003). Flood risk reduction is supported by interception and increased absorption of rainwater runoff. Terracing breaks sloping terrain into horizontal strips, increasing accessibility and utility of the land for purposes such as agriculture, which is also supported by interception of runoff and sediment (World Bank, 2021). Terracing and other forms of slope stabilisation also support site restoration by reducing erosion and by supporting plant growth through interception of rainwater and sediment, noting that erosion and loss of vegetation are two of the more visible environmental impacts of settlement development.



A *Various slope stabilisations techniques intercept rainwater runoff and increase absorption, thereby increasing ground moisture and improving groundwater recharge.*

B *Segmentation of slopes reduces the mass of topsoil segments and reduces susceptibility to land sliding. Structural interventions such as retaining walls and embedded posts provide support and structural integrity for topsoil on sloping sites.*

C *Interception of rainwater includes interception of sediments carried by runoff, thereby reducing erosion and improving potential for plant growth at sites of stabilisation.*

5 TERRACING & SLOPE STABILISATION

Flood Risk Reduction

Terraces and other forms of slope stabilisation reduce flood risk by increasing interception and absorption of rainwater runoff, thereby reducing peak loads on drainage systems. Reduced erosion and sedimentation reduce maintenance requirements and improves the capacity of drainage systems.

Landslide Risk Reduction

Landslide risks are reduced by stabilising topsoil layers such that water absorption from rainfall is less likely to cause topsoil dislodgement. By segmenting sloping terrain, the mass of individual soil segments is reduced while breaks in slopes can intercept smaller segments of sliding soil.

Erosion reduction

Interception of rainwater runoff and sedimentation reduces erosion, which is usually the most visible environmental impact of settlement development. Interception of fertile sediments at terraces, living smiles and wattle fences supports plant growth which in turn improves slope stabilisation.

Improved land accessibility and utility

Terracing of slopes into stepping horizontal strips of land potentially increases accessibility and utility of agriculture and other purposes. Interception of rainwater runoff and sedimentation can support the growth of crops and other agricultural planting, which can in turn enhance slope stabilisation by protecting topsoil and developing root systems that bind topsoil.

Site Restoration

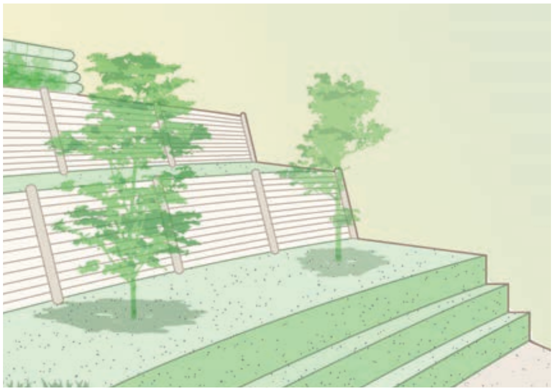
Terracing and other forms of slope stabilisation also support site restoration by reducing erosion and by supporting plant growth through interception of rainwater and sediment, noting that erosion and loss of vegetation are two of the more visible environmental impacts of settlement development.

Technical Considerations

Selection and design of any form of slope stabilisation should consider the gradient and area of the slope, the type and stability of the soil, and the local rainfall intensity. Safety and structural integrity of the intervention is critical, particularly in situations where retaining walls support heavy soil loads such that structural failure can result in landslides and cause harm to those using land on or below the slope. Above- and below-ground drainage, including weepholes in retaining walls, should be designed considering the pressure and increased load on retaining walls due to subsurface water. Selection of a form of slope stabilisation should consider the availability of requisite materials and skills for construction, as well as the durability of the resultant structure, noting that prolonged exposure to moisture and UV light (as in sunlight) impact the structural integrity of materials such as geotextiles, timber and bamboo.

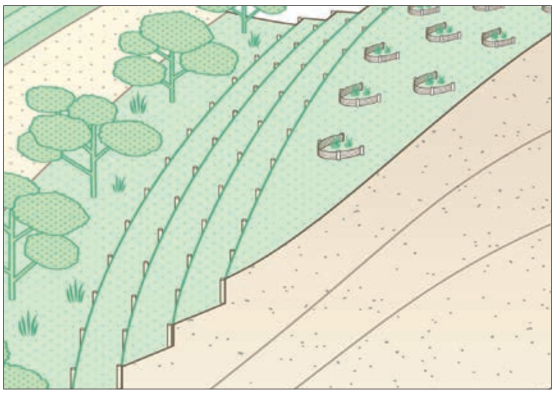
Structural integrity

Structural integrity is a critical consideration in selection and design of slope stabilisation techniques. Engineering design input is required for terracing and any other stabilisation interventions where structural failure affects the safety of those in the area, particularly in the context of increased loads associated with rainwater and heavier wet soil.



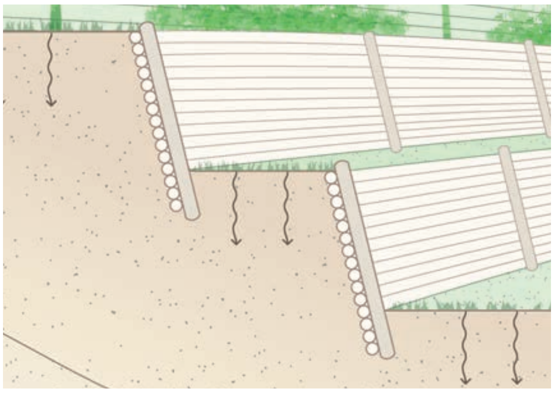
Geometry

Slope stabilisation techniques should be selected and designed considering the gradient and area of sloping land. For terracing, the width of terraces may be influenced by potential use of levelled land for agricultural and other purposes. The height of terraces depends upon design of retaining walls, considering soil stability, drainage requirements and other structural design parameters. Planting may be less appropriate for steep slopes considering difficulties establishing and maintaining new planting.



Geology

Slope stabilisation techniques should be selected and designed considering soil characteristics including stability and drainage. Shallow stabilisation techniques such as planting, living smiles, and wattle fences are less appropriate in less stable soil conditions. For terracing, retaining wall structural designs should consider soil absorption capacity and expansion (related to clay content), which affects structural loads.



Durability

Degradation of slope stabilisation materials affects structural performance and safety over time of areas above, below and on sloping terrain. Materials such as bamboo and other branches and geotextile used in slope stabilisation techniques degrade over time under exposure to moisture and sunlight. Regular inspection and maintenance are required to ensure structural integrity and safety.

Planting

Planting is an important component of several stabilisation techniques. Plant root systems penetrate and bind soil, creating a durable slope stabilisation that increases in stability over time with increasing spread of root systems. Plant species should be selected considering local conditions, stabilisation potential (i.e., root characteristics), and maintenance requirements. Planting may have limited stabilising effect during earlier stages of growth when greater maintenance and watering are required.

Maintenance

Regular inspection and maintenance are important requirements for slope stabilisation. The extent and regularity of inspections should reflect safety risks associated with any structural failure, including impacts on people using land above, below and on the sloping terrain. Maintenance requirements vary with the durability of materials used, with organic materials such as bamboo and branches subject to degradation and requiring replacement over time. Planting may require watering and other maintenance operations, depending on the species, typically with greater maintenance requirements during earlier stages of growth. Inspection and maintenance access to sloping sites should be considered during the selection and design of stabilisation techniques.

Costs

Establishment or construction costs for slope stabilisation vary across stabilisation techniques. For terracing involving extensive excavation, machinery may be suitable. However, in general, labour is a significant component of costs for slope stabilisation, including labour for excavation, planting, and construction of retaining walls, wattle fences and other structural elements. Engagement of labour in slope stabilisation may contribute to complimentary livelihood support.

Maintenance costs also vary across slope stabilisation techniques and local conditions. Maintenance of planting during early stage of growth, potentially including watering in hard-to-access locations, may be a significant component of early maintenance costs. Costs of inspection and maintenance of structural elements should be considered during planning and design, considering safety risks associated with any structural failure.

5 TERRACING & SLOPE STABILISATION

Kutapalong, Bangladesh

Terracing has been used extensive in displacement operations at Kutupalong settlement, Bangladesh since 2018. Various techniques have been developed to suit local conditions, engaging local communities and developing skills and expertise. Terracing has addressed significant landslide risks, flood risks, and erosion. In doing so, terracing and other forms of slope stabilisation have expanded the amount of safely accessible land across the settlements.

Further information:

Inter Sector Coordination Group, 2022. Cox's Bazaar Site Improvement Catalogue 2.0. IOM, Bangladesh.

Geo-tube terracing. *Inter-Sector Coordination Group, 2022*

Geo-tube terracing. *Inter-Sector Coordination Group, 2022*

Bamboo crib walls. *Inter-Sector Coordination Group, 2022*

Bamboo crib walls. *Inter-Sector Coordination Group, 2022*

5 TERRACING & SLOPE STABILISATION

Key Take-aways

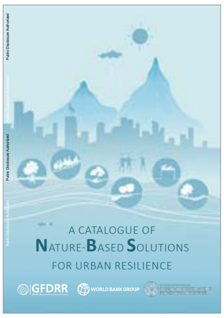
Terracing and other forms of slope stabilisation are important interventions to reduce landslide risks, flood risks, and erosion and to extend useful land in sloping sites.

Terracing and slope stabilisation can contribute to site preservation and restoration through erosion control, interception of sedimentation, and increased groundwater infiltration.

A wide range of slope stabilisation techniques are available, which should be selected to suit local conditions including slope gradients, soil characteristics, and rainfall.

Selection, design and construction of terracing and other slope stabilisation techniques should engage expert structural engineering advice to ensure safety of those using land on, above and below sloping terrain.

Further Reading



World Bank, 2021. A Catalogue of Nature-based Solutions for Urban Resilience. World Bank Group, Washington, D.C.

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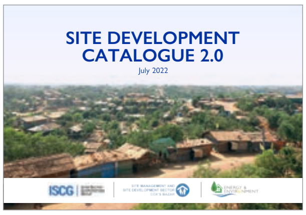


Inter Sector Coordination Group, 2022. Cox's Bazaar Site Improvement Catalogue 2.0. IOM, Bangladesh.

This catalogue published by IOM presents a range of site development interventions implemented in settlements at Cox's Bazaar, Bangladesh. Each site development intervention is presented with detailed technical information including drawings and photos. A range of different terracing and slope stabilisation techniques are included.

Polster, D.F. 2008. Soil bioengineering for land restoration and slope stabilization. Course material for training professional and technical staff. Polster Environmental Services. Duncan. British Columbia

These training materials provide detailed technical guidance on various forms of slope stabilisation, including detailed drawings and design parameters regarding slope characteristics and different stabilisation techniques.

6 TREES & FORESTATION

Description

Trees are important components of urban settings. In this context, urban forests can be defined as dispersed networks of groups of trees and individual trees spread throughout an urban area (Salbitano et al., 2016). Forestation in settlements thus encompasses consolidated tree planting of large numbers of trees in defined areas as well as dispersed planting of individual trees or small groups of trees. It also includes forestation at settlement boundaries and in surrounding areas.

Prevailing conditions in settlements are often challenging for forestation. In situations where water scarcity is a challenge for settlement operation, additional water requirements for forestation may not be appropriate. Protection and maintenance requirements for trees during early stages of growth may be challenging in settlements, considering potential damage to young trees from both people and animals. Also, given the relatively long timeframe needed for tree growth compared to settlement lifecycle, in many cases the provision of benefits to refugees and IDPs can be limited.

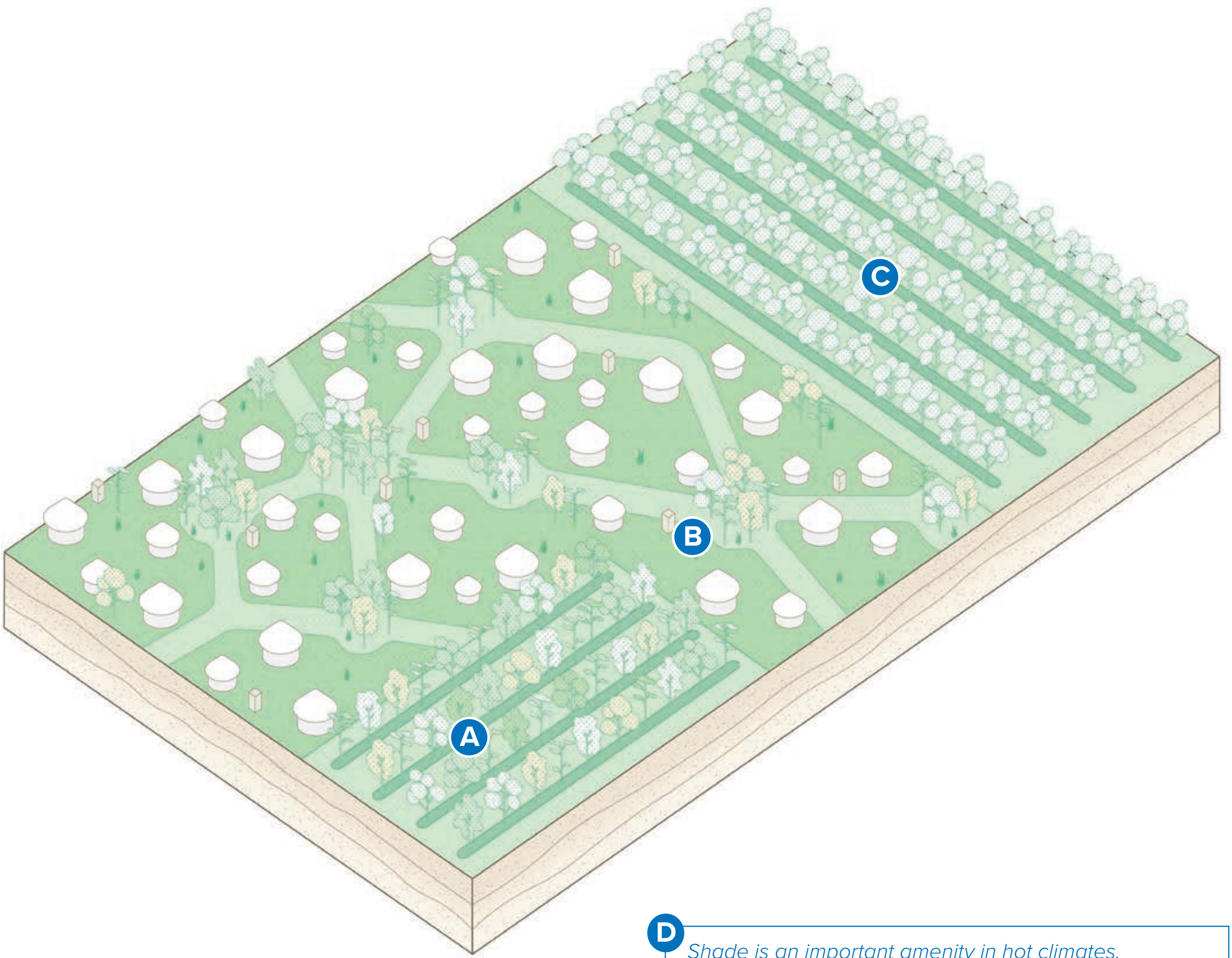
Applicability

With appropriate species selection and adequate protection, watering, and maintenance, trees can be established in most environments. Adequate water availability may be the most significant limiting factor for establishment of trees and urban forestation in displacement operations. Appropriate tree species selection can optimise water consumption. Nevertheless, watering is critical, particular during early stages of growth.

A tree nursery at Kutupalong refugee settlement, Bangladesh. © *UNHCR/Susan Hopper*

A *Consolidated planting of trees can optimise watering, protection, and maintenance efforts. Open space allocated for sport and recreation within settlement plans may be unsuitable for dense tree planting. However, empty land for forestation may be incorporated into settlement planning. Use of land allocated for firebreaks may be utilised for dispersed tree planting considering effects on fire safety.*

B *Dispersed planting may be accommodated throughout settlements in both public and private spaces with consideration of water and protection requirements. Regular dispersed planting may be included within hierarchical planning arrangements, for example by allocating limited planting areas within community or block units.*



C *Areas around settlements may be suitable for forestation, harnessing resources and governance arrangements of settlements to improve ecosystems beyond settlement boundaries. Protected tree planting may provide a permeable boundary, defining settlement limits while maintaining connections with surrounding areas.*

D *Shade is an important amenity in hot climates, particularly in situations where shelter designs magnify outdoor temperatures and make indoor conditions uncomfortable. Shade enables use of outdoor spaces in hot conditions, expanding the useful communal space of settlements and supporting social interaction. Shade contributes to climate resilience in the context of increasing temperatures and heat stress.*

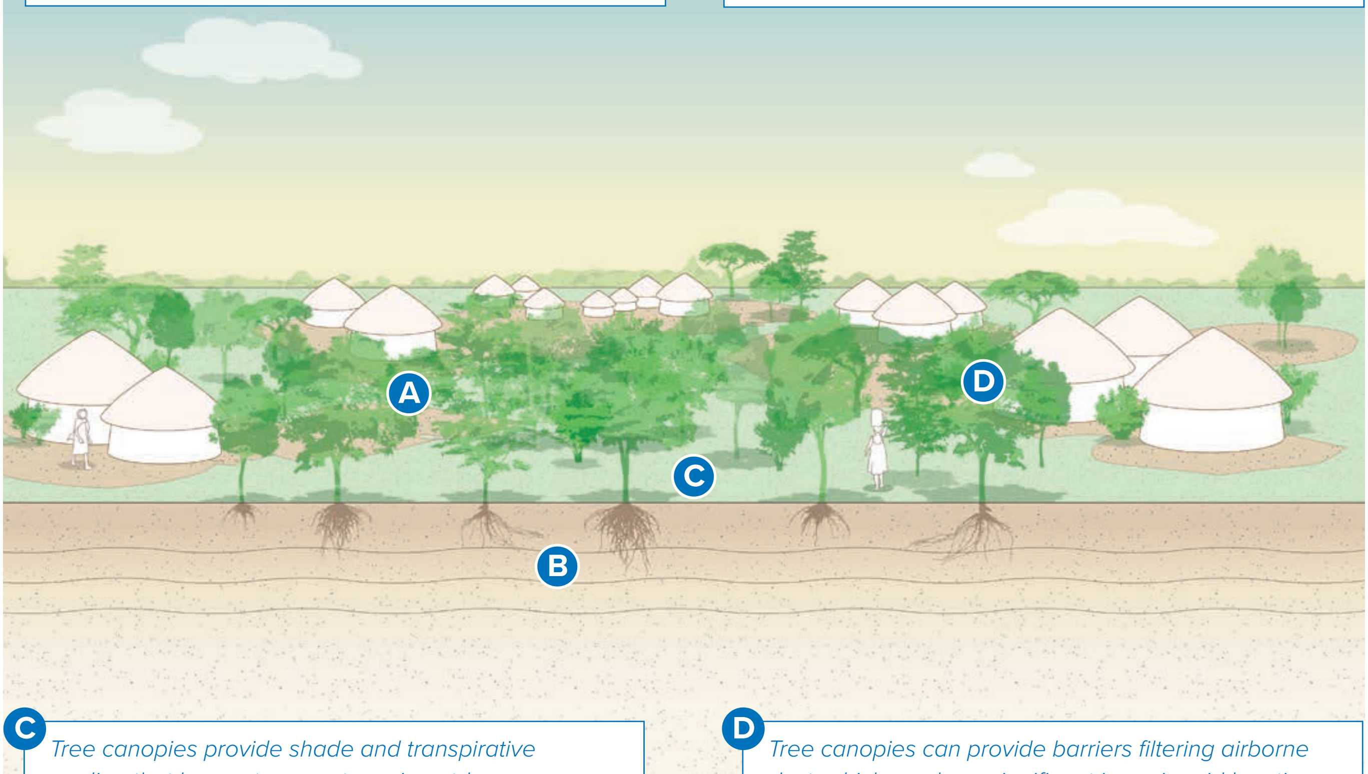
6 TREES & FORESTATION

Benefits

Urban forests, including individual and clusters of trees, provide a range of environmental and social benefits. Trees contribute to a more pleasant, aesthetic urban environmental that can offset the monotonous urban form that may characterise planned settlements featuring grid layouts and standard shelter designs. Tree canopies provide interception of rainwater and shade that contributes to flood and heat stress risks (World Bank, 2021). Shading from trees also supports provision of comfortable outdoor space that has social and human health benefits. Tree root systems enhance soil stability and access to groundwater. Beyond immediate benefits, urban forestation during settlement development can contribute to longer term ecosystem restoration providing benefits beyond the boundaries of settlement operation.

A *Tree canopies increase interception of rainwater while groups of trees moderate canopy densities and provide space for direct infiltration, contributing to moderation of peak loads on drainage systems.*

B *Tree root systems bind and stabilise soil and contribute to control of soil erosion. Strategic planting of trees and other vegetation can bind soil and provide soft barriers to potential paths of erosion.*



C *Tree canopies provide shade and transpirative cooling that lowers temperatures in outdoor spaces. Shade on shelters and other buildings reduces heat gain and contributes to more comfortable indoor spaces.*

D *Tree canopies can provide barriers filtering airborne dust, which can be a significant issue in arid locations where settlement disturbs existing soil and vegetation thus potentially increasing dust sources.*

Flood Risk Reduction

Trees and urban forests contribute to flood risk reduction be moderating loads on drainage systems, including grey infrastructure and nature-based drainage solutions. Specifically, interception of rainwater by trees and increased ground infiltration can reduce peak drainage loads.

Erosion reduction

Through soil stabilisation, rainwater interception and absorption, trees and urban forests can reduce soil erosion, particularly in moderately sloping terrain, which is commonly among the most visible environmental impacts of settlement development. In general, afforestation efforts can protect from various natural hazards, including landslides and rockfall.

Heat Stress Reduction

Trees and urban forests can reduce heat stress by reducing heat in outdoor spaces through provision of shade and moderation of heat island effects of buildings and paved surfaces. Reducing heat in outdoor spaces is particularly important in situations where shelter designs lead to excessively hot internal conditions.

Social Interaction

Shade from trees and urban forests can provide comfortable outdoor public spaces that support greater social interaction. Trees can define communal outdoor spaces, particularly in hot climates, where shelter designs lead to excessively hot internal conditions.

Public Health

Trees and urban forests can contribute to physical and mental health. Regulation of airborne dust by tree canopies can contribute to reducing respiratory problems and other dust-related health issues. Increased social interaction and engagement with natural environments can contribute to mental health, particularly in otherwise highly built up and densely populated settlements.

Site Restoration

Urban forestation can entail an initial step in site restoration that develops during settlement operation. Tree planting can offset loss of vegetation, which is often a highly visible environmental impact of settlements. Trees established during settlement operation continue to provide ecosystem services and benefits to host communities beyond settlements.

6 TREES & FORESTATION

Technical Considerations

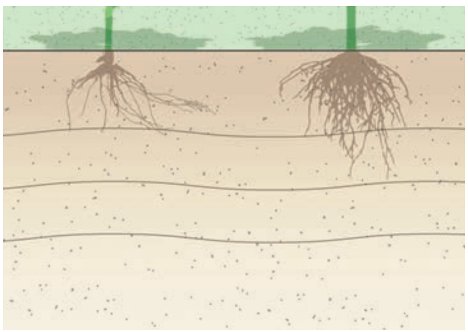
Technical considerations for trees and urban forests generally relate to providing appropriate conditions for tree growth and are particular important during earlier stages of growth when trees are less robust and at greater risk. Specific conditions required for successful tree establishment and growth differ across species and local conditions such as local climate and soil characteristics. Local knowledge from host communities may be a valuable resource when planning urban forestry initiatives, including species selection, arrangements for sapling cultivation and planning for protection, watering and maintenance.

Water

Water availability is a critical consideration and potential limitation in tree planting and forestation in and around settlements. Appropriate species selection can optimise water requirements; however, water requirements vary with other conditions including climatic and soil conditions. Water availability – from rainfall and groundwater – should be assessed to determine the forestation potential of a site.

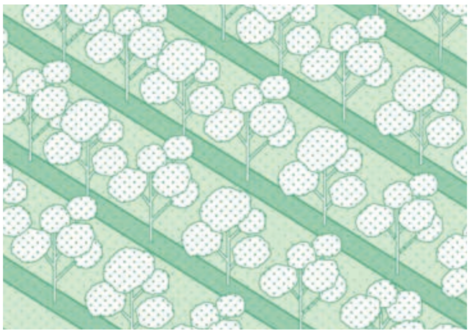
Species selection

Species selection should take into consideration water availability, soil and climatic conditions at the site as well as trees' growth rates, drought tolerance, canopy/root characteristics and protection requirements. Local indigenous tree species may be best adapted to local ecosystem conditions. In general, a mix of species encompassing different growth rates and indigenous species supports forest establishment and improves resilience.



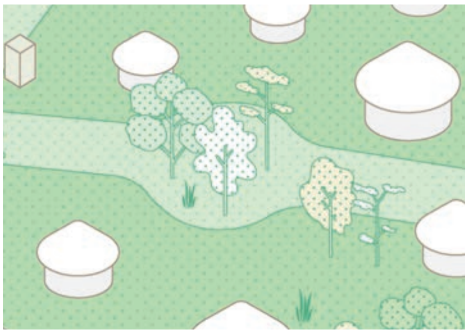
Slope and soil conditions

Soil characteristics including topsoil depth, structural quality, acidity and degree of compaction should be assessed to ensure appropriate conditions for growth. Trees can help to stabilise soil on sloping sites. However, sloping sites and rainwater can be challenging for initial stages of tree growth.



Sapling production

Initial grafting and growth of saplings in nursery conditions and planting of healthily saplings supports improved rates of tree growth. Establishment of a productive tree nursery can be integrated with other livelihoods and urban agriculture initiatives.



Tree protection

Trees face high risk of damage by humans and animals, including free-ranging livestock, particularly during earlier stages of growth. Protection may be required to prevent damage to trees until they are established and robust.

Seasonal planting

Saplings and seedlings should be planted at the correct time of year to ensure appropriate conditions – including temperature, sunlight, rainfall, and soil moisture – to support initial establishment. Correct seasonal timing of planting varies with species and local conditions. Host communities may be useful sources of knowledge for species selection and timing of planting.

Maintenance

Maintenance requirements will vary with species and with local conditions. Watering is typically the most important maintenance requirement. Watering schedules should be established with regard to tree species and local conditions. Before trees are adequately established, active watering may be required for several years, then it may be reduced or ceased. Seasonal pruning maintains the health of trees and promotes growth. Protection measures such as fencing may also require maintenance until trees are established and robust.

Costs

Both initial planting and ongoing maintenance costs are significant components of overall costs for tree planting and urban forestry. Initial planting costs include costs for saplings, which may involve costs of establishing a nursery for cultivation of saplings, which may be integrated into livelihoods and urban agriculture initiatives, and costs of protection measures. Initial planting costs also include labour for planting of saplings and seedlings and for installation of protective measures. Ongoing maintenances costs are primarily labour costs for regular watering and other maintenance such as pruning and maintenance of protective measures.

6 TREES & FORESTATION

Minawao settlement, Camaroon

At Minawao settlement in Camaroon, Nigerian refugees supported by UNHCR, French development NGO ADES and the Lutheran World Federation have planted more than 400,000 trees across 100 hectares since 2017. Minawao's limited forests were quickly stripped of trees by refugees fleeing conflict in Niegeria. Species planted in and around Minawao include cassia, neem, acacia, moringa, cashew and leucaena. Most of these are drought-resistant and their branches can be pruned and used for fuel. Some of their leaves are also used for medicine, food or fertilizer.

Further information

Saplings in the nursery at Minawao. © *UNHCR/Caroline Irby*

Refugees in Minawao planting trees. © *UNHCR/Caroline Irby*

A tree plantation at Minawao. © *UNHCR/Caroline Irby*

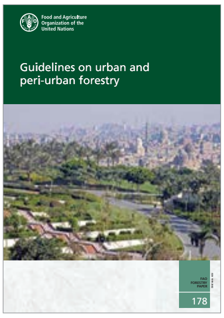
Key Take-aways

Forestation initiatives in settlements can involve dispersed networks of trees including dispersed individual trees, small groups of trees, and larger plantations.

Trees provide a range of benefits including erosion control, heat stress risk reduction and provision of comfortable outdoor space for social interaction. Trees also contribute to longer term site restoration.

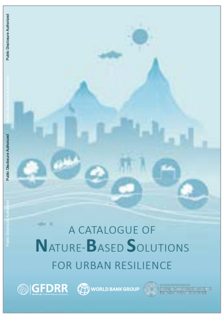
Trees have significant watering, protection and maintenance requirements that should be considered when planning forestation initiatives. Planting strategies should emphasis indigenous species and incorporate local sapling production.

Further Reading



Salbitano, F., Borelli, S., Conigliaro, M., Chen, Y., 2016. Guidelines on urban and peri-urban forestry. FAO, Rome.

This report published by the FAO provides a comprehensive explanation of issues related to forestry in urban settings and guidelines for implantation of urban forestry initiatives. While the report does not specifically address informal settlements nor displacement situations, detailed explanations of urban forestry are relevant.



World Bank, 2021. A Catalogue of Nature-based Solutions for Urban Resilience. World Bank Group, Washington, D.C.

This report from the World Bank provides a general description of NBS, a comprehensive rationale for integration of NBS in urban environments, and a catalogue that describes the characteristics, benefits and technical guidelines for implementation of a range of NBS, including trees and urban forestry. It addresses NBS in urban formal urban settings – principally well-developed cities. Nevertheless, many of the characteristics, benefits and technical guidance is relevant to less developed urban settings including settlements for displaced people.

7 URBAN FARMING

Description

Urban farming encompasses a wide range of agricultural activities, including plant cultivation and livestock husbandry, that can be accommodated within the constraints of urban settings. Plant cultivation can include crops, vegetables and fruits. Animal husbandry in settlements can include chickens, goats, pigs and cows. For people displaced from rural settings, urban farming in settlements can entail a continuation of practices, albeit modified in response to the challenges of displacement.

Farming in urban settings can occur at different scales employing different agricultural techniques. For example, plant cultivation can be undertaken by families on individual plots, or communally in larger communal spaces. The techniques employed will reflect the forms of agriculture, local environmental conditions, and normal agricultural practices in places of origin and in the local area. Communities in and around settlements will be an important source of information for planning urban farming initiatives.

The availability of water and governance arrangements are important considerations when planning urban farming initiatives. In situations of current or potential water scarcity, water requirements of different plant and animal options over time should be carefully considered. The potential economic value of farming products also requires that governance issues, including management, access and rights to products, are carefully considered.

Applicability

Farming can be undertaken in a wide range of ecosystems, including different climatic and soil conditions, with locally appropriate plants and animals and farming techniques. Availability of water for irrigation is perhaps the main limiting factor for urban farming in settlements, noting that water requirements for farming are seasonal and will increase over time if the amount of land under cultivation expands. Prior agricultural knowledge and skills of the settlement population is another important factor. Urban farming can occur in designated communal areas or dispersed in small family gardens where individual family plots include sufficient outdoor space with access to sunlight.

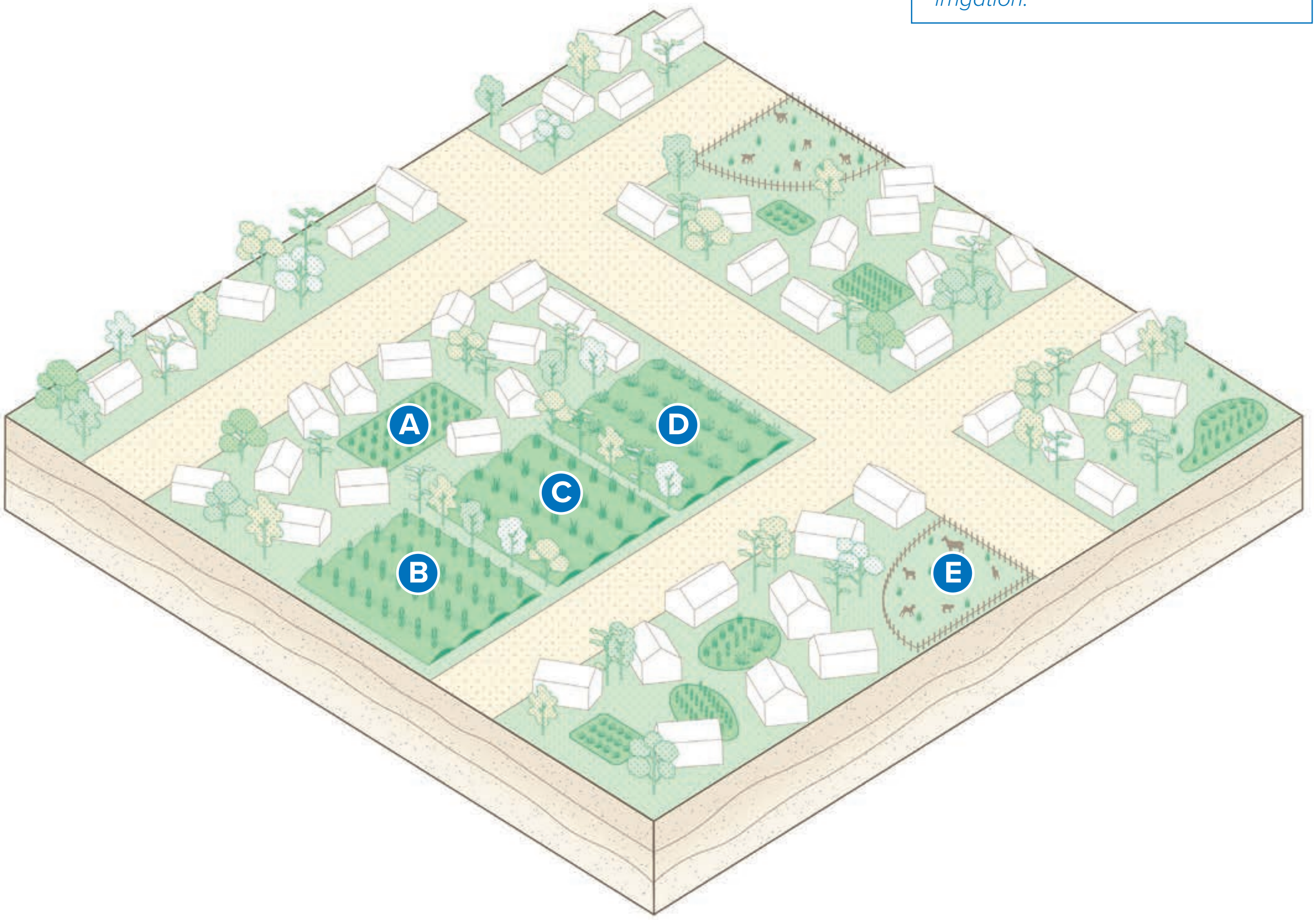
Hydroponic farming at Azzraq. © *UNHCR/Hamzeh Al-Momani*

Vegetable cultivation at Kutapalong. © *UNHCR/Fahima Tajrin*

A *Families may establish individual gardens where family plot sizes and configurations provide sufficient space with access to water and sunlight. Family garden can provide greater autonomy and security for produce.*

B *Communal gardens of different scales can be incorporated within settlement planning. Larger sizes can provide greater efficiencies and productivity of farming techniques, however appropriate governance arrangements are required for allocation of space and other resources and for distribution of produce.*

C *Raised beds may be adapted to family and communal gardens at different scales. Raised beds may be used where local ground conditions are not appropriate for cultivation. Raised beds warm quicker than natural ground and can thus increase the length of cultivation seasons. However, raised beds generally do not retain moisture as well and natural ground, thus potentially requiring more irrigation.*



D *Cultivation of natural ground requires appropriate topsoil conditions, including appropriate salinity and drainage properties. Topsoil conditions may be adapted over time with irrigation and addition of organic matter, for example through composting.*

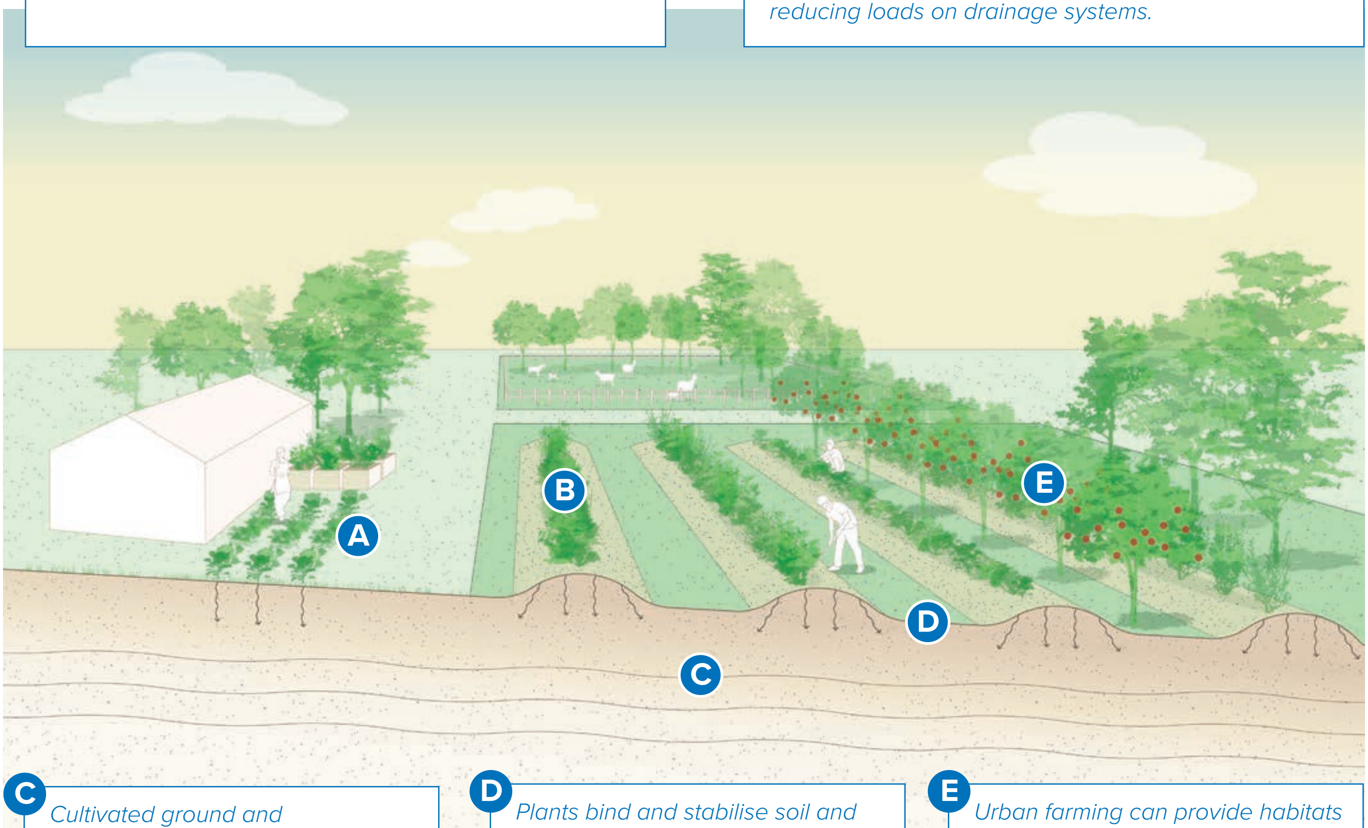
E *Animal husbandry may be a conventional component of livelihoods for displaced families. Livestock may be associated with environmental and health risks, which should be carefully considered when planning urban agriculture initiatives.*

Benefits

Urban farming can support food security and livelihoods while fostering social interaction and a continuation of normal cultural practices. Moreover, plant cultivation can contribute to flood risk mitigation and erosion control by enhancing groundwater absorption and harnessing rainwater runoff (World Bank, 2021). Alongside various benefits, animal husbandry can have negative consequences such as grazing damage to vegetation and potential to increase erosion. The potential scale and intensity of urban farming and any environmental risks this may entail should be carefully considered.

A *Cultivation of crops, vegetables and fruits provides food production that can supplement local supply chains in settlements and the surrounding areas.*

B *Irrigation systems intercept rainwater runoff while cultivated ground can readily infiltrate rainwater, increasing soil moisture availability for plants and reducing loads on drainage systems.*



C *Cultivated ground and vegetation transfer water to the atmosphere through the process of evapotranspiration and they generally store and release less heat than building and pavement materials, thus reducing heat island effects associated with buildings and grey infrastructure.*

D *Plants bind and stabilise soil and contribute to control of soil erosion. Strategic planting of cultivated land can bind soil and provide soft barriers to potential paths of erosion.*

E *Urban farming can provide habitats for local fauna including birds and insects. This maintenance of local biodiversity may be particularly relevant for site restoration following settlement closure.*

Food security

Urban agriculture within settlements generally will not yield sufficient output to meet wider food demands. Nevertheless, food production from family and communal gardens can support food security for individual families and contribute to improved nutrition.

Livelihoods and economic security

Production of food and livestock for sale can enable displaced people to utilise their agricultural knowledge, skills and labour to support family livelihoods.

Social Interaction

Communal gardens provide a structure for active community engagement and social interaction. Gardening requires cooperation in a manner that can build social cohesion with direct incentives for mutual benefit.

Public Health

Urban farming can contribute to physical and mental health, local food production and improved nutrition. Increased social interaction and engagement with communal gardening activities can contribute to mental health, particularly in otherwise highly built up and densely populated settlements.

Flood Risk Reduction

Urban cultivation can contribute to flood risk reduction by reducing runoff rates and volumes. Specifically, interception of rainwater by irrigation systems and evapotranspiration by crops and other vegetation can reduce peak loads to the drainage system.

7 URBAN FARMING

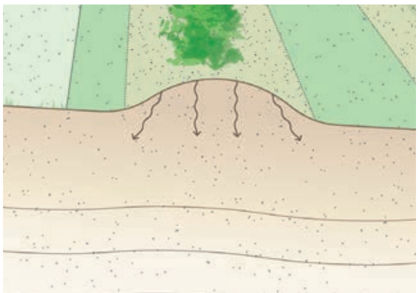
Technical Considerations

Water availability

Availability of water for irrigation may be the main limiting factor for urban farming in settlements, noting that water requirements for farming are seasonal and will increase over time if the amount of land under cultivation expands. Irrigation requirements should be planned to take into account soil conditions, forms of cultivation, and seasonal variations.

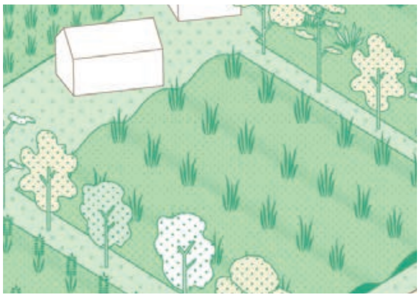
Governance

Governance arrangements for communal gardens should clearly allocate rights and responsibilities of access to land, water and other resources and provide for proper safekeeping of produce. A community committee may provide an effective and equitable mechanism for management of communal gardens and associated resources.



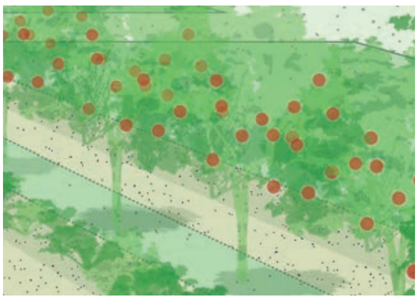
Soil characteristics

Appropriate topsoil conditions are required for cultivation of nature ground, including appropriate salinity and drainage properties. Topsoil conditions may be adapted over time with irrigation and addition of organic matter, for example through composting. Where local soil conditions are unsuitable, raised garden beds may be used with suitable soils.



Agricultural techniques

Agricultural techniques include different irrigation systems and watering patterns, garden bed formation, pruning techniques, crop rotations, use of fertilizers, etc. The techniques employed will reflect the forms of agriculture, local environmental conditions, and normal agricultural practices in places of origin and in the local area. Use of fertilizers and other nutrients should avoid pollution of water bodies. Communities in are around settlements will be an important source of information for suitable agricultural techniques.



Seasonal timing

Agriculture is seasonal, requiring different levels of engagement and output at different times of year. Planning of urban gardening initiatives should consider requirements across seasons in order to optimise use of resources and output. In addition to seasonality, development over several years of fruit trees and other plants that develop over multiple years should be considered.

Maintenance

Maintenance requirements for urban farming vary with the forms of agriculture. For cultivation, beyond planting, maintenance requirements vary with the type of crop, vegetable, fruit, etc., and may include requirements such as watering, weeding, pruning, and harvesting. Structural elements such as irrigation systems and trellising will also require regular maintenance. Beyond care for livestock, maintenance requirements for animal husbandry can include maintenance of fencing and other supporting facilities. In general, farming is labour intensive and maintenance requirements should be carefully considered during planning of urban farming initiatives.

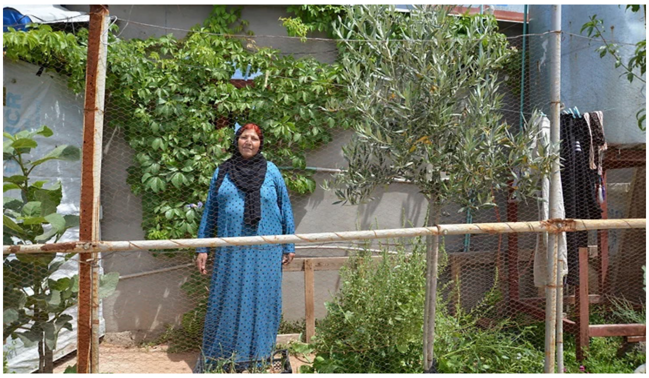
Costs

Urban farming can involve substantial upfront and ongoing costs. Labour is an important component of costs, which will usually be contributed by beneficiaries of the products. Initial preparation of land for cultivation, including in raised garden beds, can involve significant costs. In general, livestock involve substantial upfront costs. The costs of farming are generally expected to be offset by the value of produce yielded.

Dormiz 1 settlement, Iraq

In the Dormiz 1 refugee camp in the Kurdistan region of northern Iraq, many refugees have established gardens on family plots. These family gardens are adapted to limited water availability within the camp. In addition, a community garden has been established with support from NGO Lemon Tree Trust, which includes cultivation and fruits and vegetables as well as raising of chickens and rabbits, with proceeds from the sale of produce support costs of establishing and maintaining the communal garden.

Further information



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7 URBAN FARMING

Key Take-aways

Urban farming can include a wide range of plant cultivation and livestock raising undertaken at different scales, including individual family and communal efforts.

Urban farming can draw on the knowledge and skills of displaced people and host communities to build self-sufficiency and resilience while fostering communal cooperation.

Water, protection and other maintenance requirements should be carefully planned, and potential environmental impacts of livestock taken into account when considering urban farming initiatives.

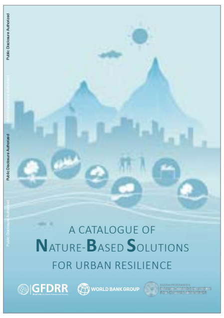
Further Reading

FAO, Rikolto, RUAF, 2022. Urban and Peri-urban Agriculture Sourcebook - From production to food systems. FAO, Rome.

This book published by the FAO provides an in-depth review of urban farming, including comprehensive guidance on urban farming techniques and issues such as land and water management, labour and financing.

Miralles-Wilhelm, F., Iseman, T., 2021. Nature-based solutions in agriculture: The case and pathway for adoption. FAO and The Nature Conservancy.

This report published by the FAO provides a comprehensive overview of relationships between NBS and agriculture. It does not specifically address urban agriculture; however is provides a detailed explanation of nature-based farming practices, including many issues relevent ot urban contexts.



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8 DRAINAGE SOLUTIONS IN ARID & SEMI-ARID ZONES

Description

Arid and semi-arid zones are generally characterised by low annual precipitation, with long dry seasons interrupted by heavy rainfall during short wet seasons. According to quantifications of aridity by the Intergovernmental Panel on Climate Change (IPCC), arid zones are defined by a ratio of average annual precipitation to annual evapotranspiration of 0.05-0.20, while semi-arid zones are defined by a ratio of 0.20-0.50 (UN Habitat, 2023). In Africa, arid and semi-arid zones include a band spanning Mali, Chad, Sudan, Somalia, Kenya and Tanzania and other locations of displacement operations.

Numerous nature-based drainage solutions have been developed in societies inhabiting arid and semi-arid zones that respond to local environmental and social conditions. Many of these NBS involve harvesting rainwater for direct use, including drainage solutions such as spate irrigation, road runoff and spreading bunds. Others focus on catchment-scale interventions for water storage or groundwater replenishment, including micro-basins, planting bunds and terraces.

Considering the inherent unpredictability and annual variability of wet-season rainfall in arid and semi-arid zones, the effectiveness of such nature-based drainage solutions is difficult to quantify and varies from year to year. Also, considering the importance of rainfall in arid places, impacts of NBS on land users downstream should be considered to ensure that drainage solutions don't negatively impact downstream access to water (UN Habitat, 2023).

Applicability

Nature-based drainage solutions for arid and semi-arid zones have, in general, been developed in response to specific climatic conditions of long dry seasons separated by short wet seasons with intense rainfall events. Most of these solutions involve labour intensive construction of structural elements and regular labour-intensive maintenance. Design of specific drainage solutions should be informed by knowledge about local rainfall and flood patterns.

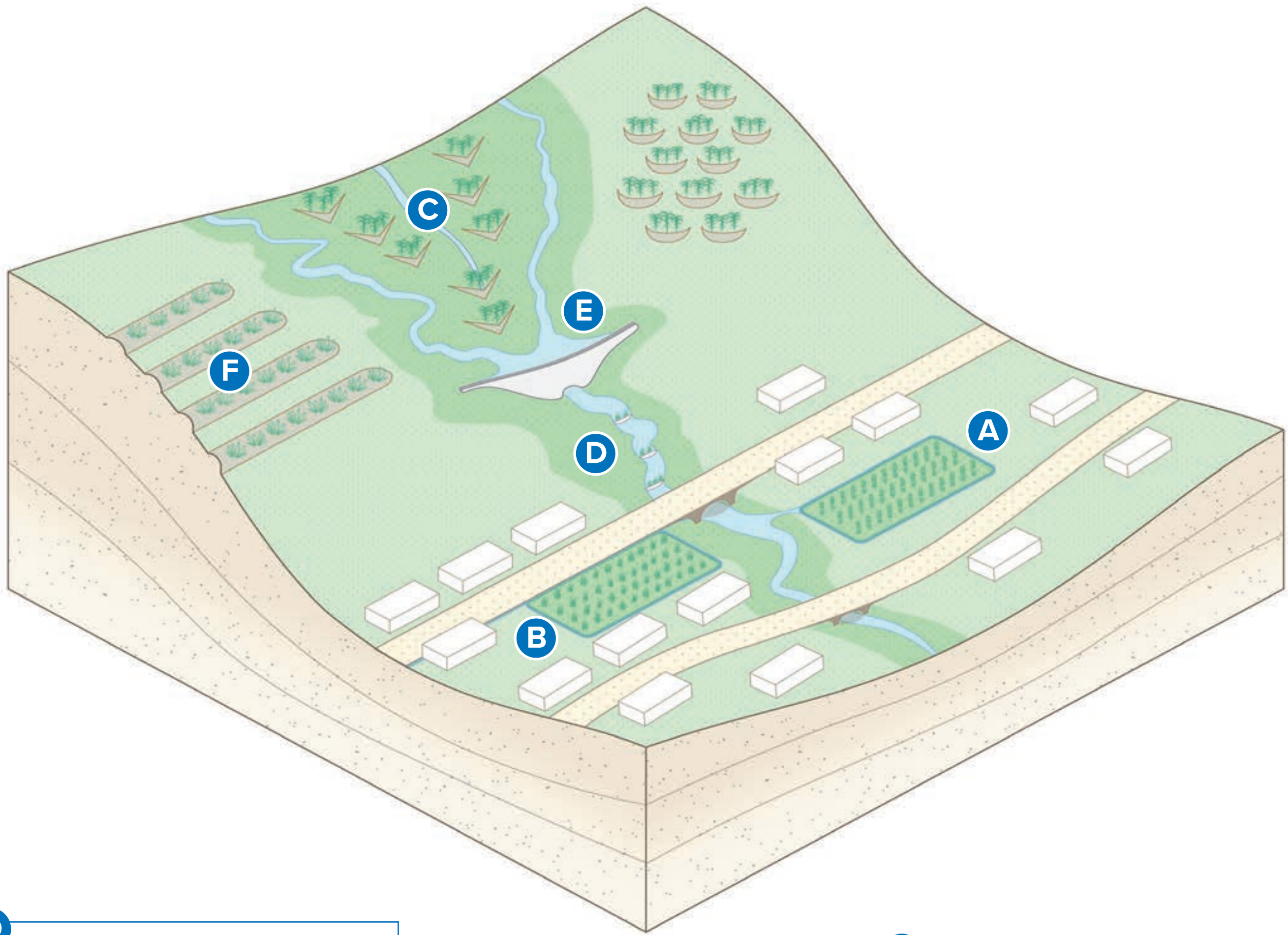
Irrigation channels near Melkadida settlement, Ethiopia. © *UNHCR/Tiksa Negeri*

8 DRAINAGE SOLUTIONS IN ARID & SEMI-ARID ZONES

A *Spate irrigation systems divert seasonal floodwater from intermittent rivers for distribution across cultivated land. Infiltration of intensive rainfall into cultivated land may provide sufficient moisture for multiple harvests depending on residual soil moisture. Elements of spate irrigation systems include a diversion structure in the intermittent river, a canal directing water to fields, and fields featuring a system of distribution canals and surrounding earthen embankments.*

B *Road runoff systems capture and divert seasonal floodwater from roads, paths and other paved or unpaved surfaces that collect rainwater. As with spate irrigation, road runoff systems make water available for agricultural use and include similar elements: diversion structures, transmission canals, and field distribution systems. As water is harvested from roads and paved surfaces and may contain pollutants, care should be taken to avoid direct human consumption.*

C *Spreading bunds divert floodwater from a natural intermittent water course or flood plain and spread it over a wider cultivated area where it can be readily absorbed. Spreading bunds are typically trapezoidal earth embankments positioned in a network across and down slopes, with the size and shape of embankments designed to suit the gradient of the slope and anticipated volume of rainwater.*



D *Checking dams intercept and store floodwater in intermittent rivers and flood channels, making floodwater available for direct agricultural use and for absorption to increase soil moisture and support cultivation. Checking dams should be designed to suit local conditions and anticipated water volumes and may be made from locally available materials including stone, earth, and branches.*

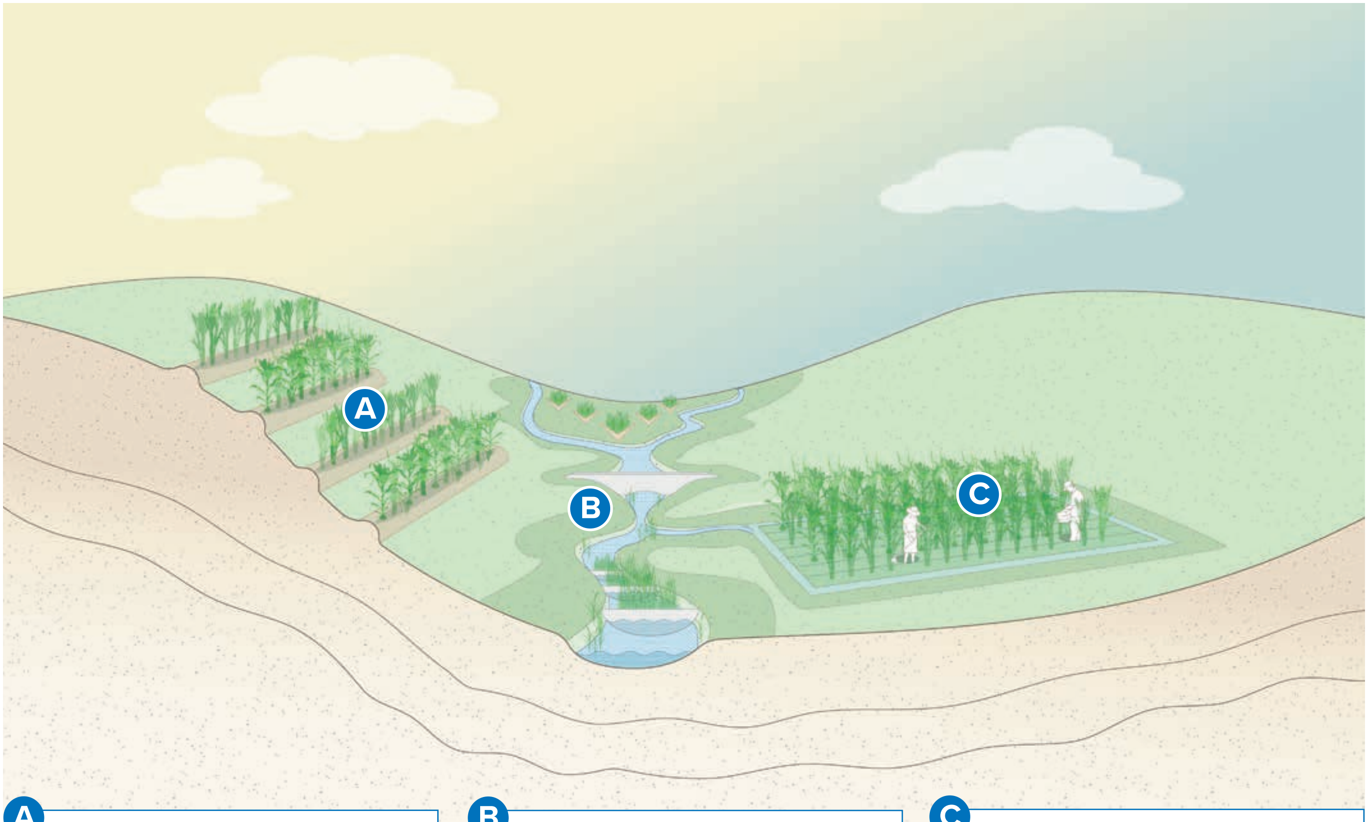
E *Permeable rock dams are positioned across valleys in order to control flow rates and spread floodwater across the base of valleys. Excess floodwater filters through or over permeable rock dams and continues in a more restrained flow. Usually, series of permeable rock dams are positioned along valleys to optimise infiltration.*

F *Contour earth bunds are small embankments formed with soil excavated from a slope and arranged in a sequence running along the slope contours. They are suited to shallow gradients. Embankments are typically around 30cm high and 75 cm wide and spaced to suit the gradient. Contour earth bunds intercept rainwater in order to irrigate adjacent crops.*

8 DRAINAGE SOLUTIONS IN ARID & SEMI-ARID ZONES

Benefits

Nature-based drainage solutions for arid and semi-arid zones generally involve the interception and harnessing of seasonal floodwater. Support for agriculture is the principle use for captured floodwater, either directly through the irrigation of crops and other plants, or through ground infiltration and increased soil moisture content that can support plant growth. In parallel, these drainage solutions mitigate the effects of erosion that accompanies seasonal flooding, which is often concentrated in gullies and intermittent rivers. While the damaging effects of such concentrated erosion can be difficult to address in the short term, nature-based drainage solutions can provide a means of remediating effects of erosion in the medium and long-term.



A *Various NBS for drainage intercept intense seasonal floodwater, which may then be harnessed for direct or later agricultural use, or distributed in a manner that supports infiltration and increases soil moisture content, again supporting agricultural production.*

B *Interception and control of floodwater by various NBS for drainage entails interception of sediments and control of erosion. For many nature-based drainage solutions, the capture of sediment supports floodwater absorption and supports plant growth, with plant root systems supporting soil stability and further control of erosion.*

C *Nature-based drainage solutions are generally related to traditional agricultural techniques in arid and semi-arid zones. Harnessing seasonal floodwater supports agriculture and food production through direct use of water or absorption to increase soil moisture for cultivation.*

Flood risk reduction

Interception of floodwater and control of flow rates along flood channels and intermittent rivers enables the harnessing of floodwater and reduction of flood risks, which can be significant during intense rainfall during wet seasons in arid and semi-arid zones.

Erosion reduction

Nature-based drainage solutions for arid and semi-arid zones control erosion on floodplains, intermittent rivers and gullies where the effects of erosion are most damaging. Over time, the capture of sediment can redress effects of erosion, which is often the most visible impact of settlement development.

Site restoration

Nature-based drainage solutions for arid and semi-arid zones can redress concentrated effects of erosion at gulley and intermittent water courses by capturing sediment and supporting plant growth and can further control erosion. Nature-based solutions also support floodwater drainage and increased soil moisture, supporting plant growth and contributing to longer term ecosystem restoration.

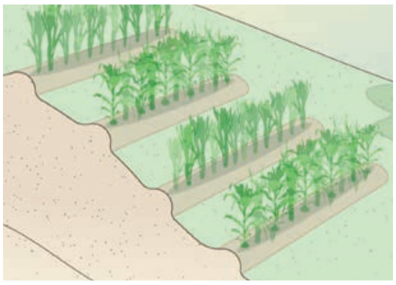
Food security

Support for agriculture provided by nature-based drainage solutions in arid and semi-arid zones can contribute to food security and nutrition in settlements. The capacity for agricultural production supported by floodwaters to meet general food demand in settlements is limited. However, storage or infiltration of floodwater may support multiple annual crop cycles.

Technical Considerations

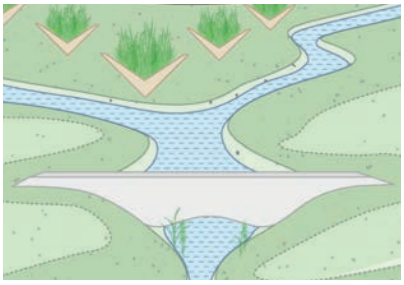
Labour

Nature-based drainage solutions generally involve landscape interventions that are labour intensive for construction and maintenance. Excavation and other labour-intensive tasks require only basic skills and equipment and may be integrated into cash-for-work or other livelihoods programs.



Geometry

The geometry and design of different nature-based drainage solutions depends upon local conditions including slope gradients, rainfall intensity and soil characteristics. Displaced and host communities may be an important source of information for selection and design of specific interventions.

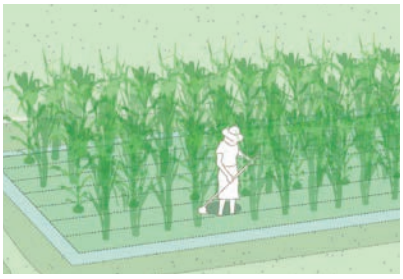


Materials

Materials for construction of nature-based drainage solutions – such as soil, stone and branches – will typically be available locally. Selection and design of specific interventions should consider the local availability of materials for construction and maintenance and ensure that ongoing material requirements do not contribute to other environmental problems such as loss of vegetation and erosion from uncontrolled excavation.

Rainfall

Local rainfall patterns should be considered in the selection and design of specific nature-based drainage systems. Seasonal flooding in arid and semi-arid zones may be unpredictable. The design of drainage systems should carefully consider impacts during extreme flooding events, including landslide risks and other risks associated with the structural failure of drainage interventions.



Planting

Selection of plant species integrated into nature-based drainage solutions should take into consideration water requirements, local soil and climatic conditions, growth rates, and protection requirements. Indigenous plants may be best adapted to local ecosystem conditions. Displaced and host communities may be important sources of knowledge about appropriate planting.

Maintenance

Many nature-based drainage solutions require significant maintenance. Floodwater can cause significant damage to dams, bunds and other water diversion infrastructure. Regular inspection and maintenance of drainage systems, including after flood events, may be required to maintain proper functions. In general, excavation and other basic maintenance requirements are labour intensive and may require labour contributions from displaced people.

Costs

Labour for excavations and other basic construction tasks is generally the principal costs item for nature-based drainage solutions. Financial costs may thus be defrayed with labour contributions from displaced communities. Ongoing costs for maintenance labour may be significant and should be considered when selecting and planning specific drainage solutions.

Kakuma Settlement, Kenya

At Kakuma refugee settlement in north Kenya, spate irrigation and other techniques for floodplain irrigation have been employed to support significant agricultural production, including crops of sorghum and cowpea.

Further information:

UN Habitat, 2023. Designing for Displacement: A Spatial Guide for Planning Along Seasonal Rivers in Drylands. UN Habitat, Nairobi.

UN Habitat, 2023. Kakuma Regeneration Strategy. UN Habitat, Nairobi

UN Habitat, 2023

UN Habitat, 2023

UN Habitat, 2023

UN Habitat, 2023

8 DRAINAGE SOLUTIONS IN ARID & SEMI-ARID ZONES

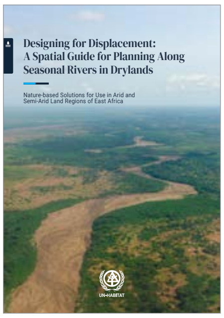
Key Take-aways

Drainage solutions for arid and semi-arid zones involve the harnessing of intense wet-season rainfall for agriculture and for replenishment of ground moisture. With proper selection and design they can support cultivation and long-term site restoration while controlling erosion.

Various local techniques are often developed in response to specific climatic and geological conditions. Displaced and host communities may be important sources of information for designing and implementing drainage initiatives.

Many techniques include significant maintenance requirements and will vary in effectiveness from year to year depending on rainfall conditions.

Further Reading



UN Habitat, 2023. Designing for Displacement: A Spatial Guide for Planning Along Seasonal Rivers in Drylands. UN Habitat, Nairobi.

This report published by Un Habitat describes the increasing prevalence of displacement operations in arid and semi-arid zones and describes the range of issues and challenges these zone present. The report includes an overview of a wide range of NBS suitable for arid and semi-arid zones, including nature-based drainage solutions. Descriptions include technical guidelines, drawings and images.

Irrigation and planting systems at Bogo relocation site for IDPs at Maroua, Cameroon. © *UNHCR/Colin Delfosse*

9 DRAINAGE SOLUTIONS IN NON-ARID ZONES

Description

Nature-based drainage solutions for non-arid zones provide alternatives to conventional grey infrastructure. In general, conventional drainage infrastructure is characterised by impervious elements such as pipes, channels, and reservoirs that transmit rain and floodwater away from urban areas.

Nature-based drainage solutions also mitigate flood risks by channelling rainwater. Though in contrast to conventional grey infrastructure, NBS integrate permeable surfaces and vegetation to facilitate infiltration and conveyance of rainwater. Nature-based drainage solutions seek to manage flood risks while maintaining the natural water cycle driven by infiltration and evapotranspiration (Woods Ballard et al., 2015). They also seek to manage water quality and reduce pollution risks through filtration of runoff before it enters groundwater and natural water courses. Beyond these conventional drainage functions, nature-based drainage solutions can contribute to public amenity by providing drainage infrastructure that is more aesthetic and has other public functions compared to conventional drainage systems.

Nature-based drainage solutions include a range of systems intended to intercept, store, and transmit rainwater runoff. Swales are shallow, vegetated, open channels that can replace conventional drainage pipes and channels. While swales collect and transmit rainwater runoff, grassed surfaces and shallow geometries facilitate infiltration of rainwater and filtration of sediment. Detention basins are landscaped depressions that remain dry under normal conditions though are connected with drainage networks to receive rainwater runoff during normal storm events. Detention basins are designed to quickly return to dry conditions following rainfall via infiltration through vegetated (usually grassed) surfaces or onward transmission of runoff. Bioretention systems are shallow landscaped depressions that remain partially filled under normal dry conditions and accept and attenuate runoff during rain events. Bioretention systems integrate vegetation to filter runoff, which is then infiltrated or transmitted via an underdrain system.

Different nature-based drainage solutions may be combined in drainage systems and may be integrated with elements of conventional drainage infrastructure. As with conventional infrastructure, nature-based drainage systems must be designed in response to prevailing conditions and clear performance requirements that consider specific design storm characteristics (i.e., return period, rainfall intensity and duration).

Applicability

Local conditions affecting soil hydraulic properties and plant growth are fundamental considerations affecting the applicability of nature-based drainage solutions in settlements. Sufficient ground moisture and/or water for irrigation should be available to support vegetation, particularly during early stages of growth. Local soils should support infiltration or should be modified at the sites of drainage infrastructure to facilitate infiltration.

Protection of grass and other vegetation in the context of relatively high population densities and accessibility of public spaces, especially during early stages of growth, should also be considered when selecting and planning nature-based drainage solutions.

Availability of land is also an important consideration, noting for example that swales and bioretention systems occupy more land than conventional drainage channels and reservoirs. For new planned settlements in open locations, land requirements can be accommodated within existing settlement planning standards.

A

Swales are shallow, vegetated, open channels that collect and transmit rainwater runoff while grassed surfaces and shallow geometries facilitate infiltration of rainwater and filtration of sediment. Swales are typically 40-60cm deep with gently sloping sides planted with grass and may follow straight or meandering routes, enabling them to be integrated into a variety of urban landscapes. The soil subsurface of swales may be modified, for example with organic material and coarser grained soils, to enhance infiltration.

B

Bioretention systems are shallow vegetated ponds that are partially filled under normal dry conditions. Bioretention systems accept runoff from surrounding areas during rain events, generally through surface collections. Runoff is filtered through vegetation and soil then infiltrated or transmitted from the bioretention pond via an underdrain system. Bioretention systems thus facilitation increased infiltration, attenuation, and filtration of runoff.

C

Detention basins are landscaped depressions that remain dry under normal conditions when they may be used as public recreational spaces. Detention basins collect and attenuate runoff during rain events. Grassed surfaces facilitate infiltration and return to a dry state following rainfall. Detention basins may be connected to drainage transmission systems, including swales or conventional drainage systems, to facilitate intake of runoff during rain and subsequent return to dry conditions.

D

Nature-based drainage systems incorporate vegetation and permeable surfaces in a manner that enables integration with public spaces. For example, the shallow geometry of swales makes them easily traversable and does not provide a barrier to pedestrian movement. Detention basins may be used as parks and sports fields under dry conditions, with precautions to ensure that compaction of soil and loss of vegetation does not reduce infiltration capacities.

E

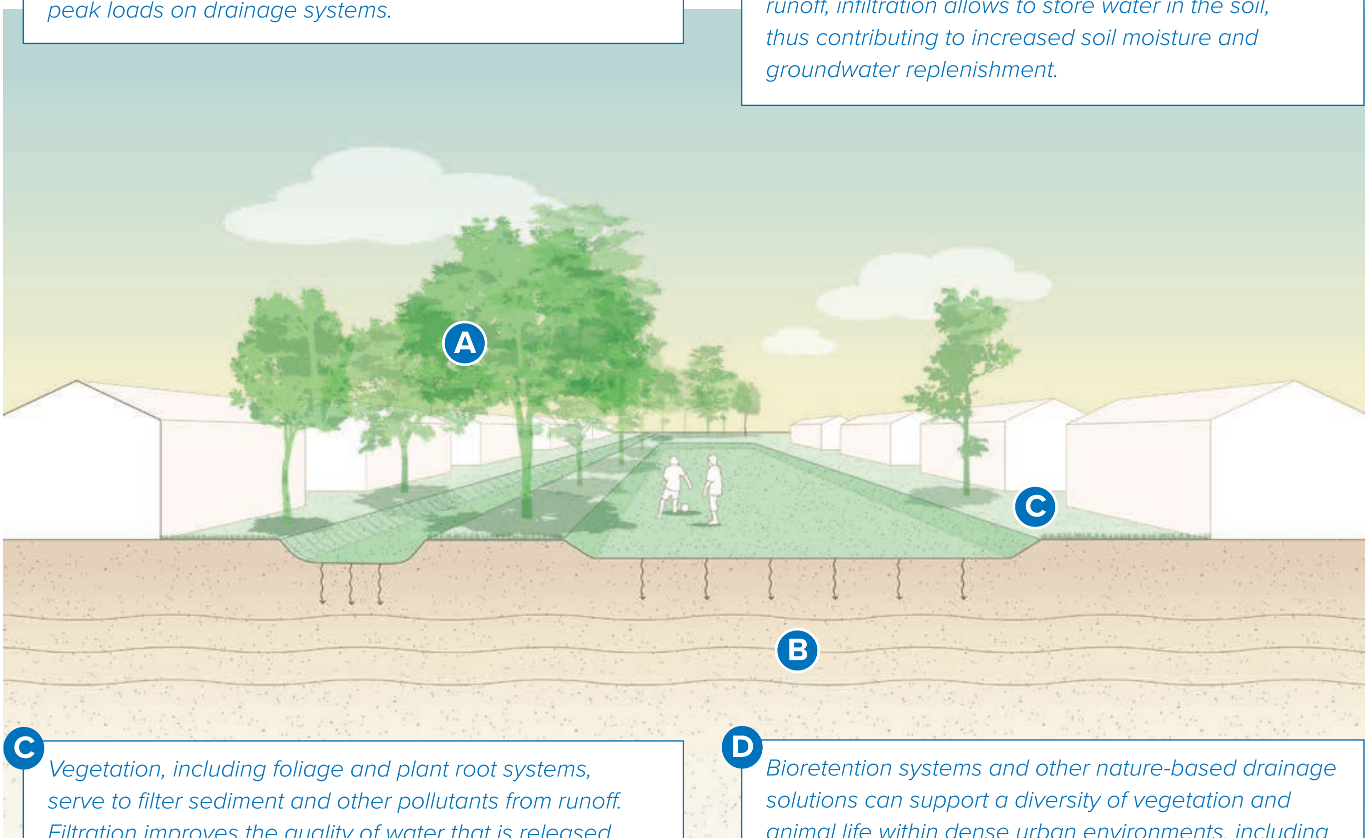
Various nature-based drainage solutions can be integrated with conventional drainage infrastructure. For example, detention basins and bioretention systems may be integrated with conventional drainage channels. Swales may be integrated with conventional drainage channels in transmission systems, facilitating increased infiltration while accommodating peak drainage loads and flood risks. As with conventional infrastructure, nature-based drainage systems must be designed in respond to prevailing conditions and clear performance requirements that consider anticipated rainwater loads.

Benefits

When properly designed and maintained, nature-based drainage systems provide the same flood risk mitigation as conventional drainage systems. In addition, nature-based drainage solutions help to maintain the natural water cycle by supporting improved infiltration and replenishment of groundwater and by integrating vegetation to enhance evapotranspiration. Nature-based drainage solutions integrate grasses and other vegetation types to filter sediment and pollutants from runoff, thus improving water quality. Nature-based drainage solutions can also extend the function and public amenity of drainage systems by providing infrastructure that can be integrated aesthetically into public spaces and serve additional recreational functions.

A *Integration of vegetation in nature-based drainage solutions increases interception of rainwater before it enters drainage transmission channels. Interception attenuates drainage loads during rainfall events, reducing peak loads on drainage systems.*

B *Nature-based drainage solutions emphasis infiltration of rainwater. Vegetation such as grasses serve to slow surface flows while appropriate soil conditions facilitate infiltration. Rather than only transmitting runoff, infiltration allows to store water in the soil, thus contributing to increased soil moisture and groundwater replenishment.*



C *Vegetation, including foliage and plant root systems, serve to filter sediment and other pollutants from runoff. Filtration improves the quality of water that is released into conventional drainage systems or the receiving water bodies. Filtration of sediment reduces sedimentation within drainage systems, reducing maintenance requirements and improving system performance.*

D *Bioretention systems and other nature-based drainage solutions can support a diversity of vegetation and animal life within dense urban environments, including a range plant species and attraction of birds and insects.*

Flood risk reduction

As with drainage systems in general, the principal benefit of nature-based drainage solutions is flood risk reduction through control, infiltration, and transmission of rainwater. To ensure flood risk reduction, nature-based drainage systems must be designed in response to prevailing conditions and clear performance requirements that consider anticipated rain loads.

Site restoration

In situations where settlements are closed and sites returned to former functions, conventional drainage systems endure unnecessarily. Nature-based drainage solutions can readily reintegrate into restored environments. During operation, nature-based drainage solutions increase soil moisture, groundwater replenishment and plant growth, which contribute to later site restoration. Maintenance of biodiversity during settlement operation can also support later site restoration.

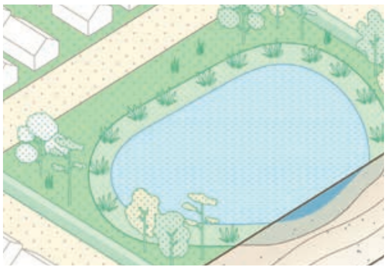
Public amenity

The aesthetic character of nature-based drainage solutions enables integration into parks and other urban spaces. Detention basins can be utilised as public open space and playing fields during dry periods, with proper attention to soil compaction and maintenance of grass and other vegetation. Bioretention systems can also serve as attractive landscape features and places for recreation.

A small detention pond in an urban park

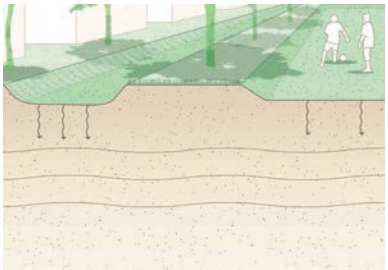
9 DRAINAGE SOLUTIONS IN NON-ARID ZONES

Technical Considerations



Hydrology

Local hydroclimate should be carefully assessed to identify the right design storm (i.e., rainfall intensity and duration for different return periods). Climate and water availability are also fundamental information to ensure the establishment and maintenance of vegetation and determine the applicability of nature-based drainage solutions. Increased ground moisture provided by the operation of the NBS will support plant growth, however additional watering may be required depending on local conditions.

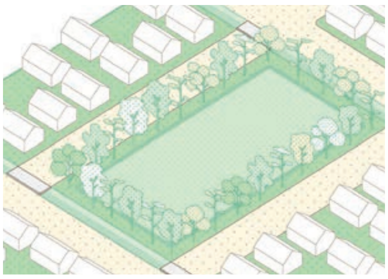


Geology

Soil hydraulic properties affect the infiltration process while biological and chemical properties (e.g., soil acidity) can influence plant growth. The infiltration capacity of local soils should be carefully assessed. Soil characteristics may be modified with the addition of nutrients and other suitable soils; however, the feasibility of such interventions should be considered in the context of costs and proximity of materials/soils. Excessive compaction of the ground should be avoided to maintain the infiltration capacity of the nature-based drainage solutions.

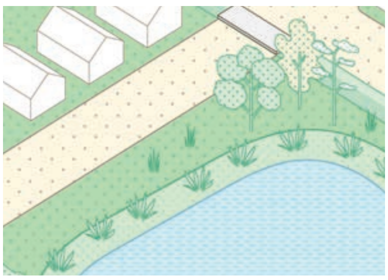
Planting

Plant species should be selected considering local conditions, growth and maintenance requirements, and plant characteristics to optimise drainage functions, public amenity and maintenance. Species should be selected considering life-cycle water requirements. In general, plant species should be selected that are robust to damage and minimise requirements for protection and maintenance.



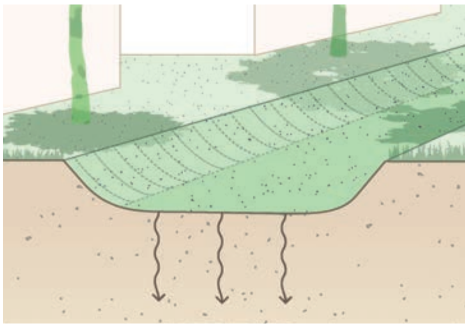
Geometry

Swales, detention basins, bioretention systems and other nature-based drainage solutions can take a variety of shapes and sizes. In general, swales, detention basins, and bioretention systems are shallow. Dimensions should be determined with engineering criteria considering drainage functions (e.g., conveyance, storage, infiltration) and public amenity.



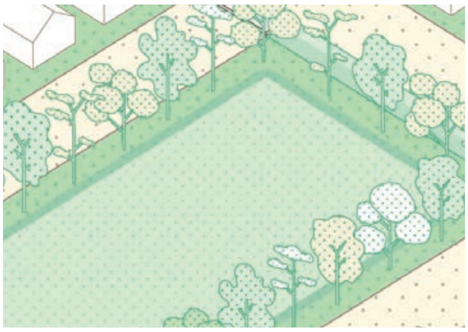
Mosquitos

Bioretention systems and some other nature-based drainage solutions maintain static pools of water, which may provide conducive environments for mosquitoes. Mosquito-borne diseases can be significant public health problems in settlements. Mosquito-related risks should be taken into account when considering specific nature-based drainage solutions in settlements.



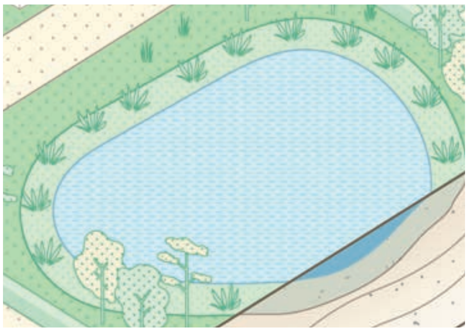
Design of swales

Swales are normally around 50cm deep with gently sloping sides and flat bases that may be around 50-200cm wide. Bases should be graded at around 0.5-6% in the direction of flow, with intermittent checking dams recommended for gradients greater than 3%. Swales may follow straight or meandering paths and may vary in width to give a more natural appearance. Topsoil or engineered soil at the base of swales should facilitate infiltration. Grassed base and side surfaces should be maintained with a grass length of less than 10cm.



Design of detention basins

Detention basins are relatively shallow. The depth and area of a detention basin and the resulting storage volume may be designed considering a storm with 10 or 30 year return period. Gently sloping sides should enable safe public access and growth and maintenance of vegetation. Topsoil or engineered soil at the base should facilitate infiltration. Grassed bases should generally be flat facilitate even infiltration. Care should be taken to avoid concentration of pedestrian traffic and other uses that could damage vegetation and compress base soil thus hindering infiltration.



Design of bioretention systems

Bioretention systems feature shallow ponds with a maximum depth that should not exceed 2m during extreme rainfall events. The geometry of a pond is flexible and should be designed to accommodate a 100-year rainfall event. Generally, the surface area should be around 2-4% of the area to be drained. The pond base serves as a filter with less permeable base layers and more permeable upper filtration layers. Vegetation should be selected for filtration and removal of nutrients, considering indigenous species and maintenance requirements. Shallow edges should ensure public safety and accessibility.

Maintenance

Nature-based drainage solutions generally require a period of establishment prior to proper functioning. The establishment period usually spans at least one seasonal cycle, enabling initial development of vegetation and enabling appropriate levels of soil moisture and compaction to be achieved following construction work. Regular inspection and maintenance is required to ensure proper functioning of drainage systems throughout operation. Cutting of grass and other maintenance requirements for vegetation are required. For swales, grass should be maintained at a length of around 8-15cm. Use of livestock to maintain grass should be avoided, considering this length requirement and the potential to excessively compact soil, however cut grass may provide feed for livestock.

Costs

Any comparison of costs between nature-based drainage and conventional grey drainage solutions will depend upon local environmental conditions such as soil characteristics, drainage area, etc., and economic factors such as material and labour costs. While NBS may require less construction materials such as concrete and steel, they may require greater expertise and attention to some design parameters. In the cost-benefit analysis, additional functions and the non-monetary benefits of NBS should be carefully considered.

9 DRAINAGE SOLUTIONS IN NON-ARID ZONES

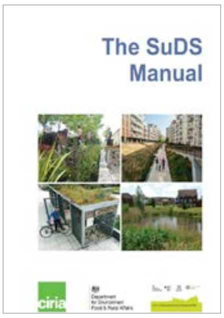
Key Take-aways

A range of nature-based drainage solutions for non-arid zones offer alternatives to conventional grey infrastructure that can optimise site restoration and public amenity benefits while mitigating flood risks. Nature-based solutions may be integrated with conventional drainage infrastructure.

Nature-based drainage solutions generally include vegetation that has ongoing watering, protection and maintenance requirements that should be planned and implemented to ensure proper operation.

Selection, design and construction of nature-based drainage solutions should engage expert hydraulic engineering advice to ensure proper functions and drainage capacities to mitigate risks.

Further Reading

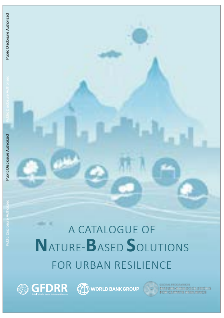


Woods Ballard, B., Wilson, S., Udale-Clarke, S., Illman, S., Scott, T., Ashley, R., Kellagher, R., 2015. The SUDS Manual. CIRIA, London.

This manual published by the UK Construction Industry Research and Information Association contains detailed technical guidance on the design and implementation of a wide range of nature-based drainage solutions. The technical guidance includes design parameters and specifications. While the information relates specifically to the UK, it provides relevant and useful technical guidance for design of nature-based drainage solutions in settlements.

United Nations World Water Assessment Programme, 2018. The United Nations World Water Development Report 2018: Nature-Based Solutions for Water. UNESCO, Paris.

This report published by UNESCO provides an overview of NBS in relation to water availability and water quality. The wide-ranging report includes sections on nature-based drainage solutions, including contributions to preservation of water quality and natural water cycles.



World Bank, 2017. Implementing nature-based flood protection - Principles and implementation guidance. World Bank, Washington, DC.

This report published by the World Bank provides an overview of principles underpinning nature-based flood prevention and guidelines for implementation and nature-based flood prevention measures. The report does not specifically address drainage solutions, though the principles it describes are useful for defining and implementing nature-based drainage solutions alongside more detailed technical guidance.

A drainage swale integrated with a carpark

10 PONDS & WETLANDS

Description

Ponds and urban wetlands are engineered water bodies intended to capture and treat stormwater and wastewater, support biodiversity, and provide spaces for public amenity and recreation. Ponds and wetlands are similar to bioretention systems that are a nature-based drainage solution. Yet they differ in that ponds and wetlands are generally less sophisticated in the engineering of filtration media, including vegetation, and, unlike bioretention systems, ponds and wetlands are not necessarily connected with broader drainage systems.

Ponds and wetlands can remove pollutants from surface waters via physical, biological, and chemical processes (e.g., sediment trapping, nutrient removal, chemical detoxification) (Woods Ballard et al., 2015).

The selection of vegetation should focus on indigenous species, reducing maintenance requirements and optimising local biodiversity through attraction of local fauna including birds and insects. Integration of ponds and wetlands within parks and other public spaces can provide attractive spaces for recreation alongside other environmental benefits. In arid and semi-arid zones, ponds may be used to capture and store rainwater runoff.

Ponds and inland wetlands maintain static bodies of water that could provide breeding grounds for mosquitos in urban settings. Hence, any potential integration of ponds and wetlands in settlement planning should carefully consider public health risks of mosquito-borne diseases.

Applicability

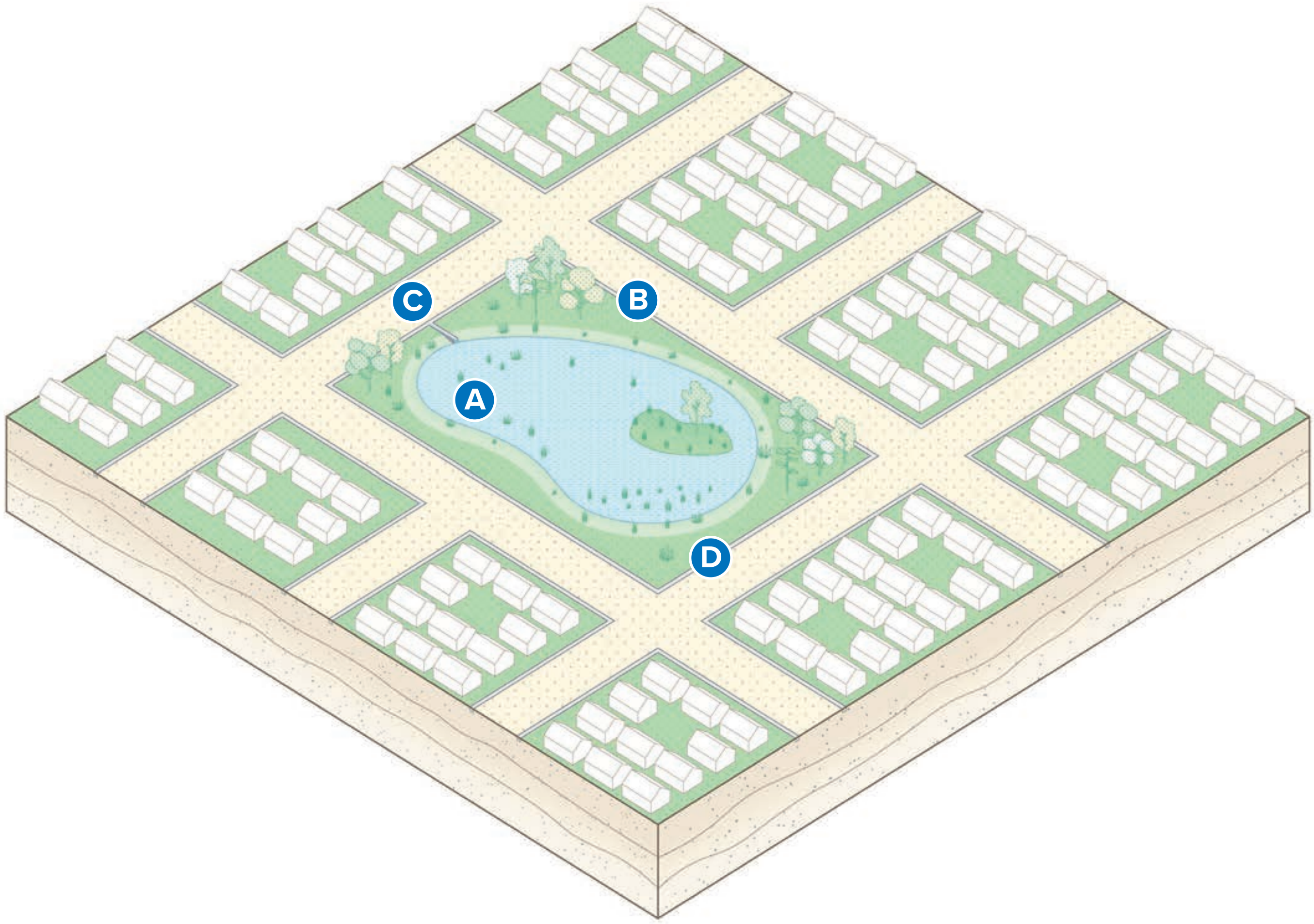
Ponds and urban wetlands are generally suitable for use in tropical and temperate zones. In colder zones, lower temperatures reduce biological activity including anaerobic processes that support water purification. In hotter zones, sufficient runoff may not be available to maintain water within ponds and wetlands. In arid and semi-arid zones, ponds may be integrated with other drainage solutions to capture and store runoff, although selection of plant species and filtration functions should consider intermittent dry-wet states.

Public health risks associated with mosquitos and static water should be carefully considered before planning any integration of ponds and wetlands within settlements.

Partially filled retention pond

A *Vegetation supports filtration of water and removal of nutrients through anaerobic processes. Planting of indigenous species can support biodiversity by attracting local animal, bird, and insect species while optimising maintenance requirements.*

B *Ponds and wetlands provide attractive sites for public recreation. Increased soil moisture from infiltration can support growth of trees and other vegetation.*

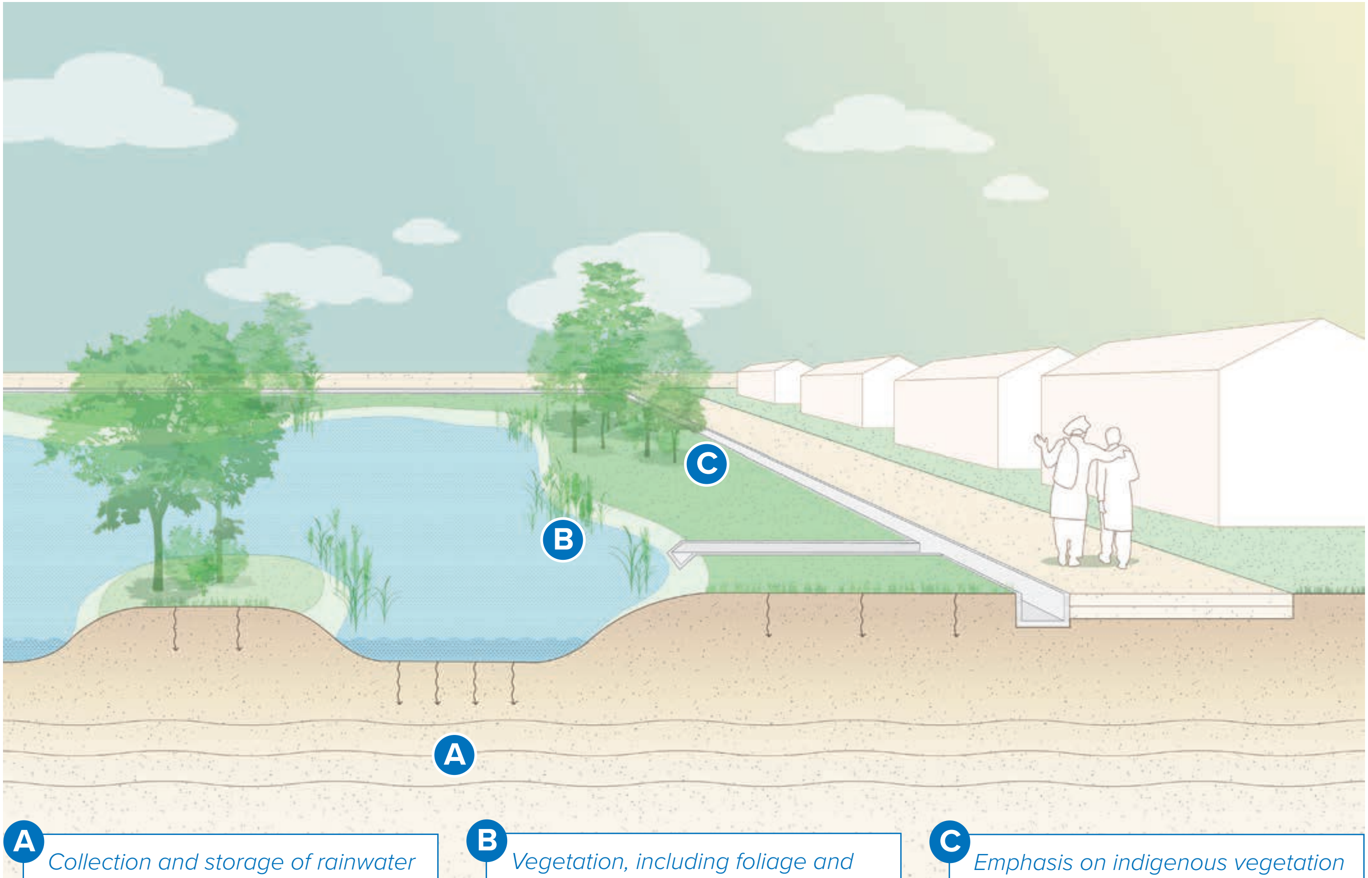


C *Ponds and wetlands are closely related with urban drainage solutions, though involve less-sophisticated engineering design that solutions such as bioretention systems. Ponds and wetlands may be connected with nature-based or grey drainage infrastructure to attenuate drainage loads and store excess runoff during extreme rainfall events.*

D *Ponds and wetlands can provide central features of urban landscaping. Water bodies provide natural sites for relaxation and recreation.*

Benefits

Ponds and wetlands can provide both environmental and social benefits. Environmental benefits are similar to those of nature-based drainage solutions such as bioretention systems; they support filtration and infiltration of rainwater runoff and other grey wastewater thus reinforcing natural water cycles. Ponds and wetlands often emphasise the integration of indigenous plant species, which can support biodiversity and, in turn, later site restoration efforts. Social benefits of ponds and wetlands primarily relate to the provision of public amenity and attractive recreation spaces, which can contribute to social interaction and mental health.



A *Collection and storage of rainwater runoff and other grey wastewater at ponds and wetlands supports increased infiltration. In arid and semi-arid zones, ponds can be used to store seasonal intense rainfall and facilitate infiltration that can support cultivation and other plant growth on adjacent land.*

B *Vegetation, including foliage and plant root systems, serve to filter sediment and other pollutants from rainwater runoff and other grey wastewater. Filtration improves the quality of water entering water courses and natural water cycles.*

C *Emphasis on indigenous vegetation in ponds and wetlands can support a diversity of vegetation and animal life within dense urban environments, including a range of plant species and attraction of birds and insects.*

Flood risk reduction

Ponds and wetlands may be integrated with nature-based or conventional grey drainage infrastructure to store and attenuate peak drainage loads. To ensure flood risk reduction, pond and wetland volumes must be designed considering extreme rainfall events such as a 100-year storm.

Site restoration

Ponds and wetlands increase soil moisture, groundwater replenishment and plant growth, which contribute to later site restoration. Attraction of local animal, bird, and insect species maintains biodiversity during settlement operation and can support later site restoration.

Public amenity

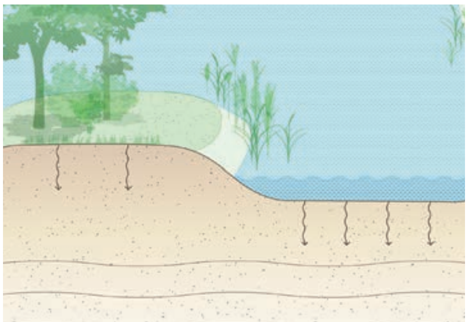
Ponds and wetlands provide attractive urban spaces that can support recreation and social interaction that can in turn contribute to mental health and community wellbeing.

Partially filled retention pond

Technical Considerations

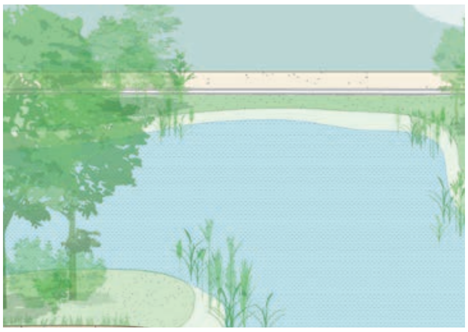
Ponds and wetlands are generally flexible in relation to technical requirements. Geological and hydrological conditions should ensure appropriate water levels to maintain operation and vegetation, noting that ponds in arid and semi-arid zones will feature regular dry states.

Planting should focus on indigenous species in order to optimise biodiversity benefits and reduce maintenance requirements. The potential for ponds and wetlands to provide breeding grounds for mosquitos is a critical consideration.



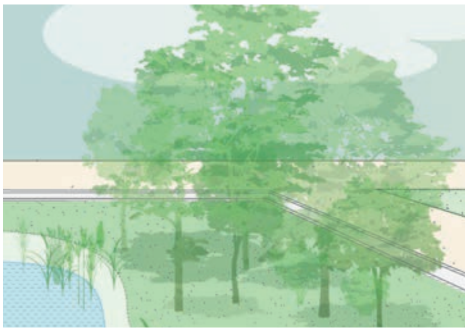
Geology

In temperate and tropical zones, local soil characteristics including permeability and moisture levels should support retention of water at a minimum level to maintain planting and gradual infiltration of additional water. Soil characteristics may be engineered with addition of other appropriately grained soils, considering soil availability and excavation and transportation costs. In arid zones, a dry state of ponds during dry seasons should be considered.



Hydrology

Local hydroclimate is a central consideration in pond design. Anticipated minimum and maximum storage levels should be considered. Minimum levels will impact dimensions and planting design, while maximum levels based on extreme rainfall events such as a 100-year storm will influence dimensions and any overflow arrangements. Overflow arrangements should consider flood risks is adjacent areas.

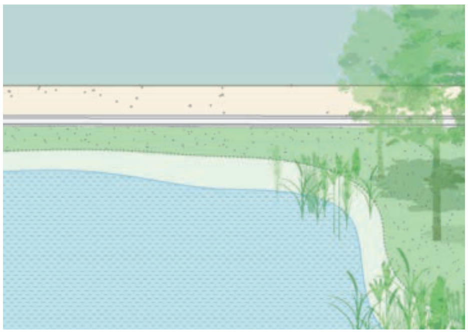


Planting

Ponds and wetlands should emphasise use of indigenous species to optimise biodiversity outcomes and maintenance requirements. Species should be selected considering water requirements. In general, plant species should be selected that are robust to damage and minimise requirements for protection and maintenance.

Geometry

Ponds and wetlands may be designed in a wide range of shapes and sizes. Dimensions to consider minimum operational water volumes and maximum operational volumes resulting from extreme rainfall events such as a 100-year storm. In general, shallow ponds with gently sloping edges enhance public access and safety.



Mosquitos

Ponds and wetlands maintain static pools of water, which may provide conducive environments for mosquitoes. Mosquito-borne diseases can be significant public health problems in settlements. Mosquito-related risks should be addressed when considering specific nature-based drainage solutions in settlements.

Maintenance

Ponds and wetlands require an initial establishment period during which soil conditions including compaction and moisture content will adapt to operating requirements and newly planted vegetation will become established. Regular inspection is required through operation to ensure that anaerobic processes are maintaining appropriate conditions and preventing, for example, algae blooms.

After establishment, the principal maintenance requirement for ponds and wetlands are associated with maintenance of vegetation, which may include seasonal weeding and clearing.

Costs

The principal initial costs for ponds and wetlands relate to excavation and ensuring appropriate soil conditions, which may require modifications through addition of other appropriately grained soils. Planting is another significant initial cost, which may be optimised through use of local plants and through local cultivation of seedlings and saplings in greenhouse conditions. Ongoing costs primarily relate to maintenance of vegetation including grass and other plants.

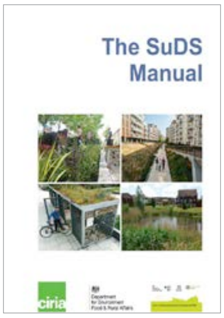
Key Take-aways

Ponds and created wetlands are related to nature-based drainage solutions and can provide some of the same flood prevention and environmental benefits while also providing recreational spaces for public amenity.

Ponds require particular soil and rainfall conditions to enable consistent wet states that can support vegetation. Planting should emphasise indigenous species to optimise growth and maintenance requirements.

Mosquito-borne diseases can be significant public health problems in settlements. Mosquito-related risks should be addressed when considering specific nature-based drainage solutions in settlements.

Further Reading



Woods Ballard, B., Wilson, S., Udale-Clarke, S., Illman, S., Scott, T., Ashley, R., Kellagher, R., 2015. The SUDS Manual. CIRIA, London.

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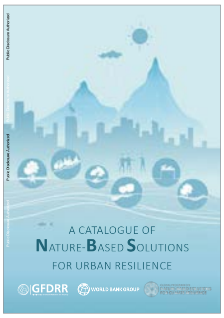


World Bank, 2017. Implementing nature-based flood protection - Principles and implementation guidance. World Bank, Washington, DC.

This report from the World Bank provides a general description of NBS, a comprehensive rationale for integration of NBS in urban environments, and a catalogue that describes the characteristics, benefits and technical guidelines for implementation of a range of NBS, including ponds and wetlands. It addresses NBS in urban formal urban settings – principally well-developed cities. Nevertheless, many of the characteristics, benefits and technical guidance is relevant to less developed urban settings including settlements for displaced people.

Bamboo planting around water retention ponds at Cox's Bazaar, Bangladesh. © *UNHCR/Kamrul Hasan*

Description

Nature-based building solutions usually refer to planted surfaces on building roofs and facades, also known as green roofs and green facades. Both forms of NBS generally comprise the plants and a substrate for planting – usually engineered layers of soil. In addition, green roofs and green facades may incorporate water storage and irrigation systems and, for green facades, secondary structural systems to support growing plants (World Bank, 2021).

Green roofs include two categories: extensive and intensive. Extensive green roofs feature shallower substrates of 2-15cm that may comprise several engineered layers of soil that support dense planting of smaller plant species including grasses. Extensive green roofs are usually not accessible for other functions. Intensive green roofs are distinguished by substrates deeper than 15cm, comprising several layers of engineered soils and often integrating systems for water storage. Intensive green roofs support a wider variety of plants, are accessible, and may be used for other activities such as gardening and other forms of recreation.

Green facades also include two general categories: ground based, and facade bounded. Ground based green facades involve plants rooted in the ground or in planters located on the ground adjacent to the building. Facade bounded green facades use walling systems to support substrates that typically integrate irrigation systems.

Green roofs and facades may be integrated into new buildings or retrofitted onto existing flat roofs. They entail additional loads that should be considered in structural designs. Green roofs also entail specific waterproofing requirements. In general, the additional requirements of green roofs and facades increase building costs compared to conventional approaches.

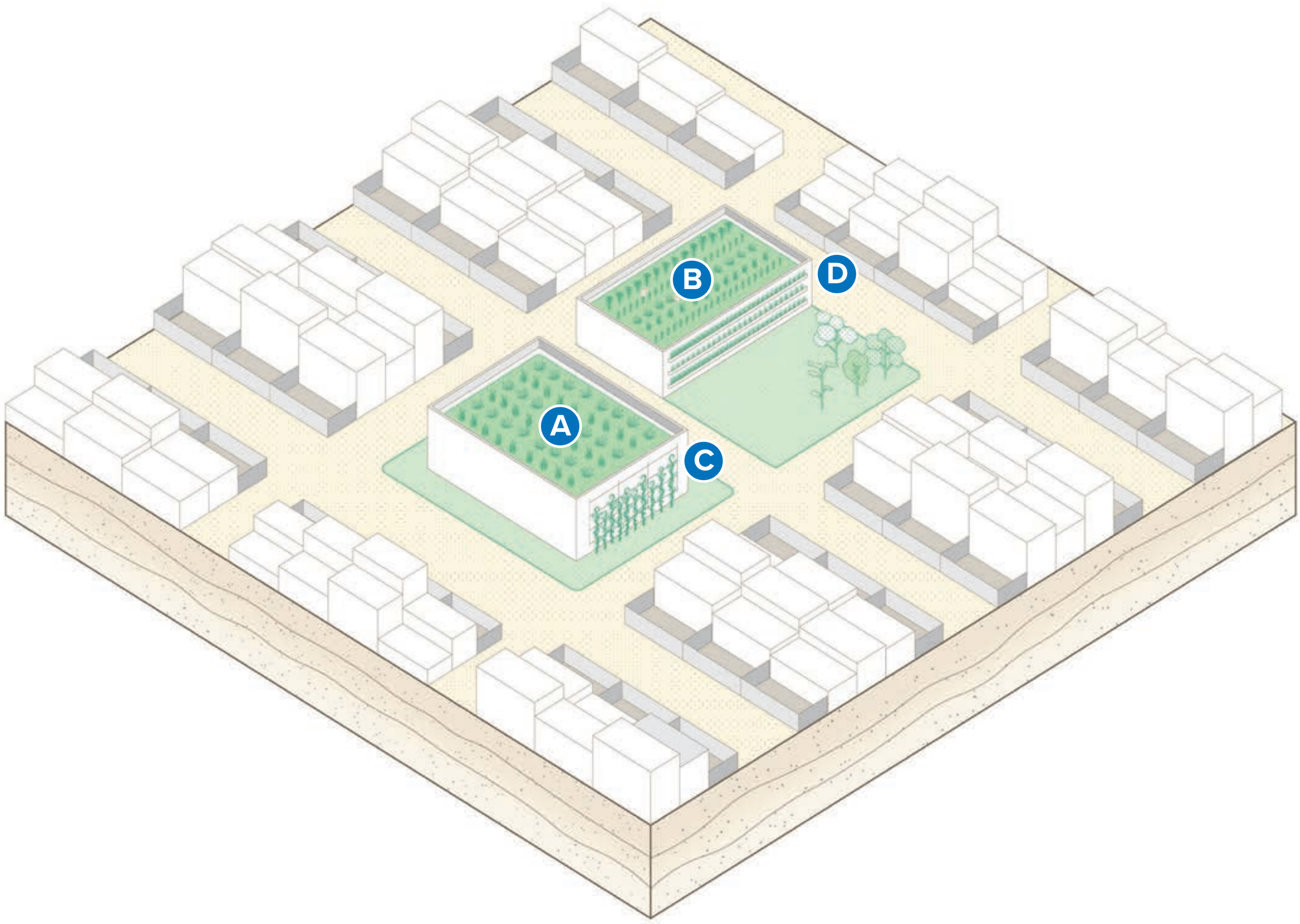
Applicability

For successful implementation of green roofs and facades, local climatic conditions must be conducive to plant growth. Consideration must be given to the degree of exposure of growing plants to sunlight, moisture, heat and cold.

Several factors may limit the applicability of green roofs and facades in settlements. Buildings may be designed for relatively short lifespans such that building envelope materials and structures may be unsuitable for green roofs and facades. Additional structural and waterproofing requirements and associated additional costs may not be feasible in the context of constrained building budgets and nominally short-term investment horizons. Engineered substrates, waterproofing systems, and water storage and irrigation systems may rely on knowledge and skills that are not readily available.

A *Extensive green roofs feature shallower substrates of 2-15cm that may comprise several engineered layers of soil that support dense planting of smaller plant species including grasses. Extensive green roofs are usually not accessible for other functions.*

B *Intensive green roofs are distinguished by substrates deeper than 15cm, comprising several layers of engineered soils and often integrating systems for water storage. Intensive green roofs support a wider variety of planting, are accessible, and may be used for other activities such as gardening and other forms of recreation.*



C *Ground based green facades involve plants rooted in the ground or in planters located on the ground adjacent to the building. Light structural systems such as cabling can support growth of plants up and across building facades.*

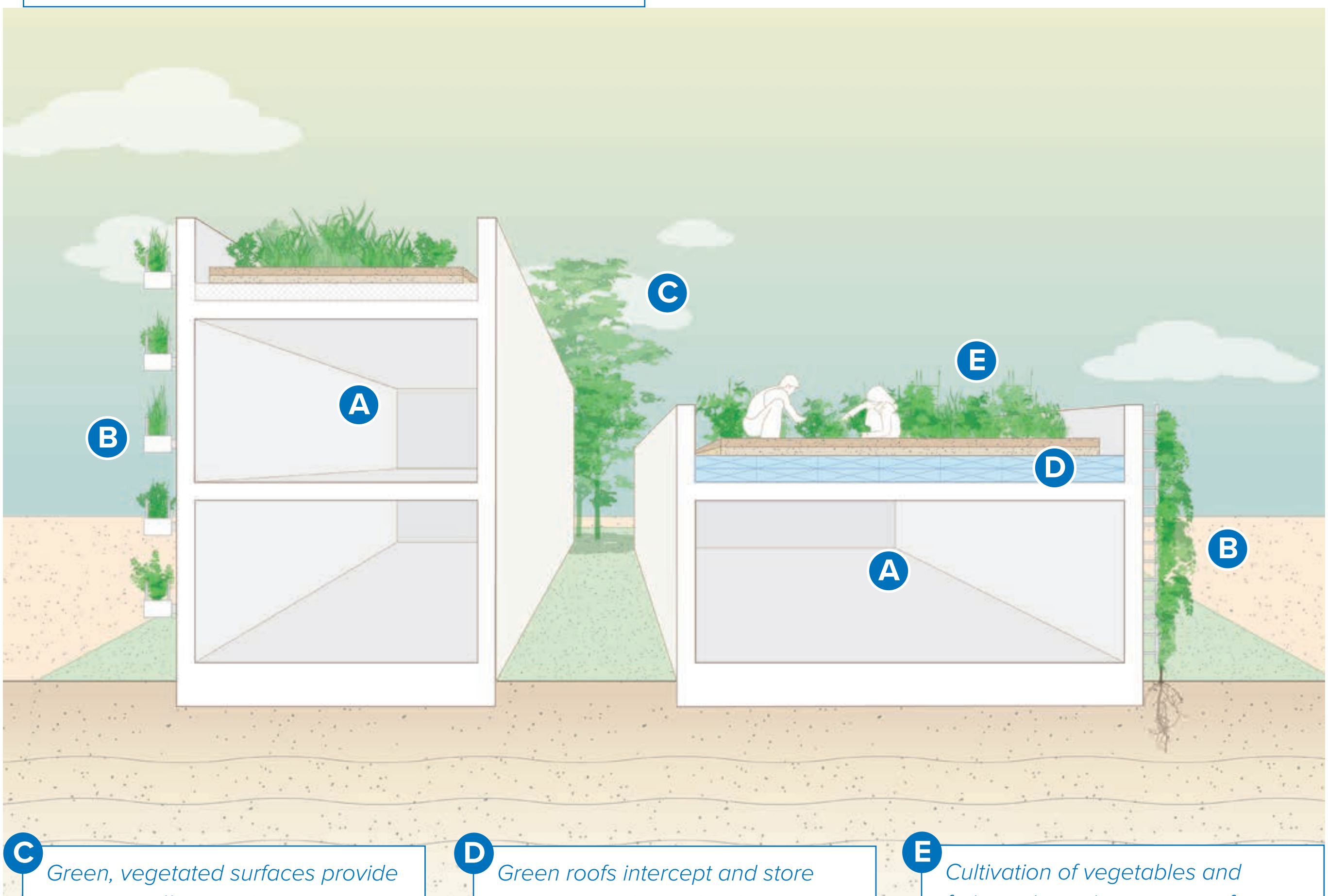
D *Facade bounded green facades use walling systems to support substrates that typically integrate irrigation systems. Facade-bounded substrate systems are typically more complex and expensive compared to ground based green facades.*

Benefits

Green roofs and facades can provide both environmental and social benefits. They can improve the thermal (insulation) performance of buildings, reducing heat gain and improving comfort in inside buildings. They can also reduce heat storage and release, thereby reducing heat island effects and temperatures outside and adjacent to buildings. Beyond aesthetic considerations, green roofs can provide secure outdoor spaces for recreation, which may be particularly useful in very dense urban settings.

A *Green roofs provide additional roofing layers that can insulate against external heat gain in hot conditions and against internal heat loss in cold conditions. Where buildings are heated and/or air conditioned, improved thermal performance can reduce building energy consumption.*

B *Green facades can shade building facades from direct sunlight, reducing heat gain and thereby improving internal building comfort in hot conditions. Where buildings are air-conditioned, reduced heat gain can reduce building energy consumption.*



C *Green, vegetated surfaces provide a cooling effect via the transpiration process, and they store less heat that conventional building materials such as concrete, brick and glass, thereby reducing heat island effects and reducing external temperatures around buildings.*

D *Green roofs intercept and store rainwater, reducing loads on drainage systems and harvesting rainwater for other uses.*

E *Cultivation of vegetables and fruits on intensive green roofs can provide limited food production that can supplement local supply chains in settlements.*

Flood risk reduction

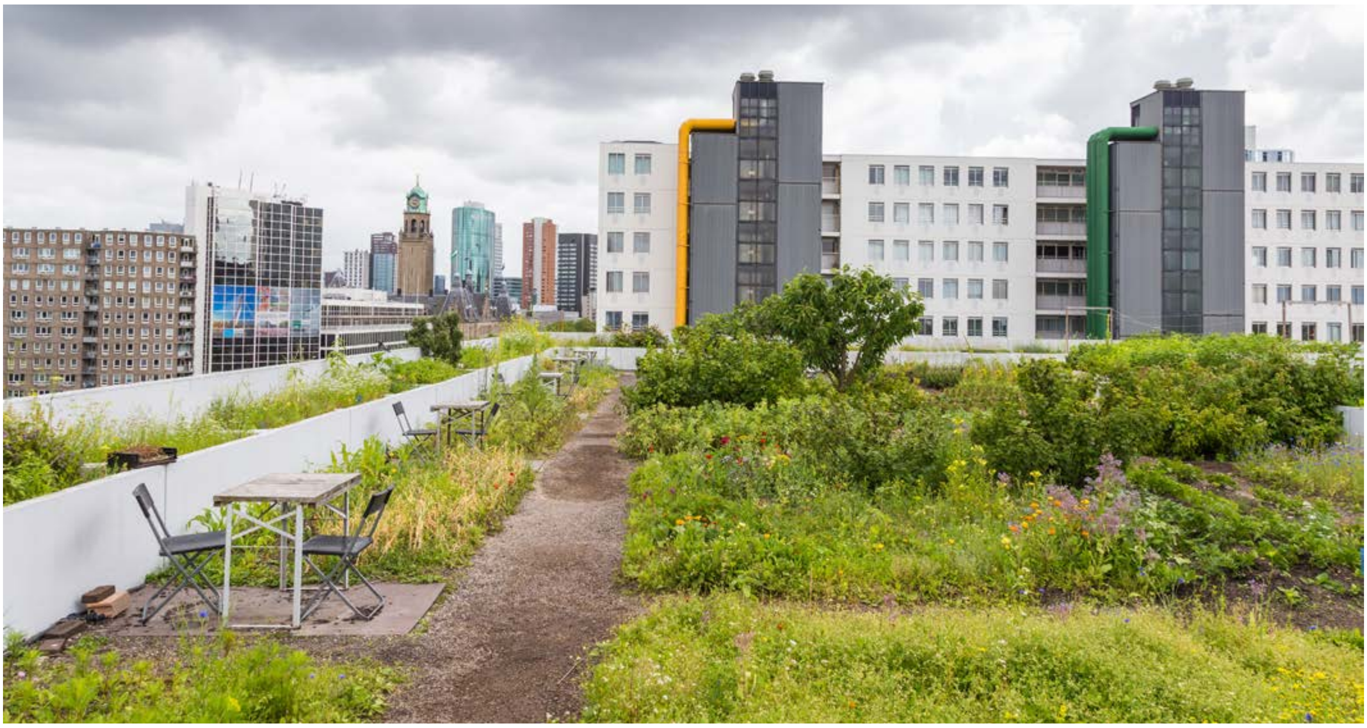
Interception of rainwater reduces loads on drainage systems and contributes to flood risk reduction. Combined effects of multiple green roofs can contribute significantly to reduced drainage loads and reduced flood risks.

Heat stress reduction

Improved building thermal performance and reduced heat island effects from green roofs and facades contributes to heat stress reduction in dense urban environments.

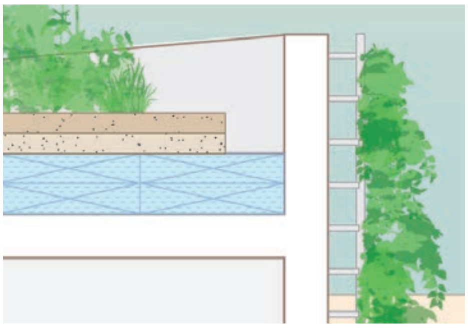
Social interaction

Intensive green roofs provide places for social interaction that may be limited in dense urban environments. Rooftop locations provide a degree of removal and potentially safety and security that may be important for vulnerable groups in dense settlement settings.



Intensive green roof on an office building in Rotterdam, Netherlands

Technical Considerations

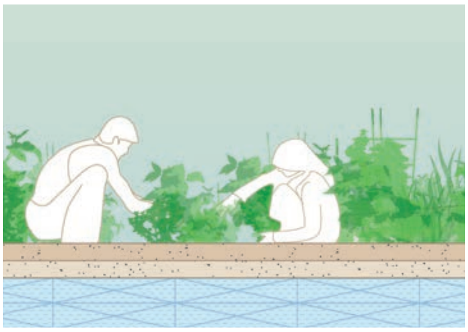


Structural loads

Green roofs and façades entail additional structural loads on Green roofs and facades entail additional structural loads on buildings that should be incorporated within structural designs. Additional loads depend on the design and specification of the green roof or facade system. Extensive green roofs generally contribute additional loads of around 20-190 kgs/m2. Intensive green roofs can contribute additional loads of around 190-680 kg/m2. Green facades place additional loads on primary and secondary structures of external walls.

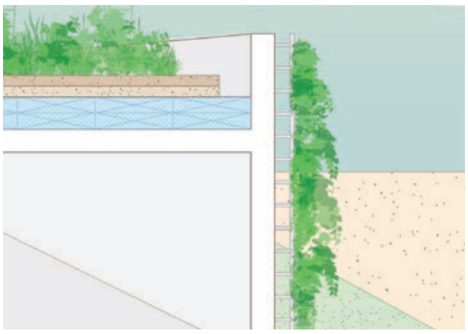
Waterproofing

Reliable and robust waterproofing must be provided below the growing substrate of green roof systems. Waterproofing should be tested thoroughly prior to installation of the substrate and should be protected to ensure it remains intact and undamaged until it is fully protected by the substrate and other layers. Robust and durable waterproofing systems may be expensive and require specialist skills and care for proper installation.



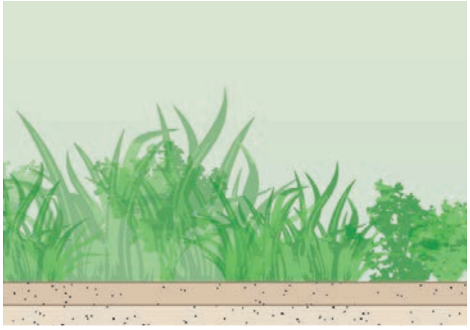
Watering and irrigation

Adequate watering is critical for successful development of green roofs and facades. Reliable irrigation systems will be required for inaccessible plants or to ensure regular watering. Systems for rainwater capture and storage can support irrigation. Drainage systems should include reliable overflow outlets and connection to ground drainage to accommodate exceptional rainfall events.



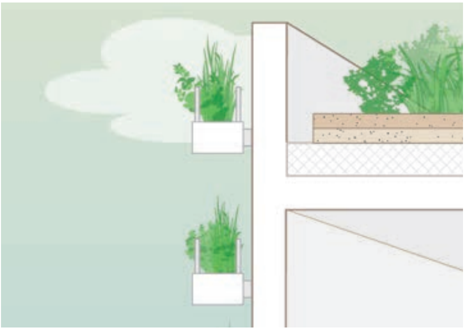
Building orientation

Access to sunlight and, conversely, excessive sunlight may be important limiting factors for plant growth. Building orientation and the effects of any overshadowing from nearby buildings should be considered to ensure that plants are located on roofs and facades with appropriate access to sunlight.



Planting

Plants should be selected considering local climatic conditions, growing conditions of the green roof or facade, and maintenance requirements. In general, robust plants with reliable growth and minimal maintenance requirements should be selected.



Secondary structural systems

Green facades may require secondary structural systems to support growth of plants up and across facades. These systems may involve rigid or flexible elements such as cables. Secondary structural systems should be designed to suit anticipated loads and should be fixed secured to building wall structures.

Maintenance

Planting in green roofs and facades requires regular inspection and maintenance to ensure that plants thrive in challenging environments. In light of substantial investment in these additional building features and the challenging environments they entail for plants, it is critical that regular inspection identifies problems that can be addressed promptly, particular during earlier stages of growth. Ongoing regular and seasonal maintenance of vegetation is required including cutting of grass, weeding and pruning.

Costs

Green roofs and facades involve additional costs compared to conventional building approach. In addition to the cost of engineered substrates and planting and any water storage, irrigation and secondary structural systems, additional structural loads and waterproofing requirements also entail additional costs. Additional maintenance requirements, compared to maintenance requirements of conventional building envelop systems, also entail additional costs.

Kindergarten at Biên Hòa Nai, Vietnam

A kindergarten for the children of workers of a nearby shoe factory in Biên Hòa Nai, Vietnam designed by Vo Trong Nghia Architects and built in 2015 included a continuous roof over the innovative architectural form. The roof garden includes play spaces and areas for gardening and other educational activities.

Further information

Kindergarten at Biên Hòa Nai, Vietnam

Kindergarten at Biên Hòa Nai, Vietnam

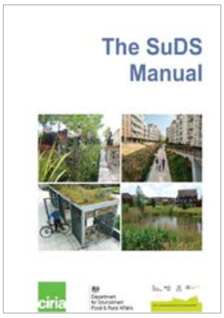
Key Take-aways

Nature-based building solutions include intensive green roofs, extensive green roofs, ground-based green façades, and façade-bounded green façades, each with different technical requirements.

Green roofs and façades can improve thermal conditions in internal and external environments and provide public amenities that may be particularly useful in very dense urban settings.

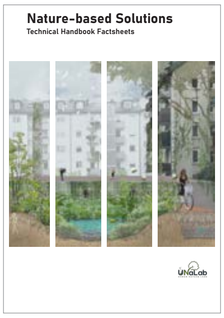
Green roofs and façades can be integrated into many new or existing buildings, however careful design and installation is required to ensure robust structural and waterproofing requirements are met.

Further Reading



Woods Ballard, B., Wilson, S., Udale-Clarke, S., Illman, S., Scott, T., Ashley, R., Kellagher, R., 2015. The SUDS Manual. CIRIA, London.

This manual published by the UK Construction Industry Research and Information Association contains detailed technical guidance on the design and implementation of a wide range of nature-based drainage solutions. The technical guidance includes design parameters and specifications. While the information relates specifically to the UK, it provides relevant and useful technical guidance for design of nature-based drainage solutions in settlements.



Eisenberg, B., Chiesa, C., Fischer, L., Jakstis, K., Polcher, H.G., 2022. Nature-based Solutions - Technical Handbook Factsheets. UNaLab Urban Nature Labs, Stuttgart.

This report from an EU-funded research program provides descriptions and technical parameters for a range of NBS in urban settings, including green corridors. Consistent formatting of technical datasheets supports simple comparisons of benefits and performance across different NBS.

Vegetable garden incorporated in an intensive green roof

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