Nature-Based Solutions Implementation Handbook

Deliverable 5.5

31/10/2022

Maria Dubovik[1], Ville Rinta-Hiiro[1], Arto Laikari[1], Malin zu Castell-Rüdenhausen[1], Laura Wendling[1], Kristen Jakstis[2], Leonie K. Fischer[2], Piersaverio Spinnato[3], Johannes Jermakka[1], Zarrin Fatima[1], Ana Ascenso[4], Ana Isabel Miranda[4], Peter Roebeling[4], Ricardo Martins[4], Rita Mendonça[4], Silvia Vela[5], Margherita Cioffi[5], Sophie Mok[6], Sara Botto[5], Eleonora Gambucci[5]

[1] VTT Technical Research Centre of Finland Ltd, P.O. Box 1000, FI-02044 VTT, Finland
[2] University of Stuttgart, Institut für Landschaftsplanung und Ökologie, Keplerstr. 11, D-70049 Stuttgart, Germany
[3] Engineering Ingegneria Informatica S.p.A., Via Regione Siciliana Nord Ovest, 7275, 90146 Palermo, Italy
[4] CESAM – Department of Environment and Planning, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal
[5] RINA Consulting, Via Antonio Cecchi, 6, 16129 Genoa, Italy
[6] Fraunhofer Institute for Industrial Engineering (IAO), Nobelstraße 12, 70569 Stuttgart, Germany

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Deliverable administration						
No & name	**D5.5 NBS Implementation Handbook**					
Status	Final	**Due**	M66	**Date**	2022-10-31	
Author(s)	Maria Dubovik, Ville Rinta-Hiiro, Malin zu Castell-Rüdenhausen, Laura Wendling, Arto Laikari, Kristen Jakstis, Leonie Fischer and Piersaverio Spinnato					
Description of the related task and the deliverable. Extract from DoA	D5.5 *NBS Implementation Handbook* is the final version of the UNaLab NBS handbook series. It is an updated version of the D5.3 *Preliminary NBS Implementation Handbook*, which accumulates knowledge from updated D5.1 *Interim NBS Technical Handbook* (T5.1) and updated D3.1 *NBS performance and impact monitoring protocols* (T3.1.1 & T3.1.2) with lessons learned gained during NBS co-creation and implementation in front-runner cities Eindhoven, Genova and Tampere (T5.2, T5.3 & T5.4). The *Preliminary NBS Implementation Handbook* summarises the work to date. In addition, D5.5 documents the technical specifications of the NBS implemented in UNaLab front-runner cities and provides guidance for maintenance and adaptive management of the implemented NBS. D5.3 NBS Implementation Handbook has been iteratively updated and improved (M40-M60) based upon learnings from the UNaLab front-runner cities, and issued as a final, public deliverable in M66 (D5.5 *NBS Implementation Handbook)*.					
Participants	VTT, TRE, EIN, GEN, STU					
Comments						

V	Date	Authors	Description
0.1	28.2.2020	Maria Dubovik, Ville Rinta-Hiiro, Arto Laikari, Malin zu Castell-Rüdenhausen, Laura Wendling	ToC prepared
1.0	31.5.2020	Maria Dubovik, Ville Rinta-Hiiro, Malin zu Castell-Rüdenhausen, Laura Wendling, Arto Laikari	Initial draft prepared based upon information from FRCs
1.1	31.7.2020	Maria Dubovik, Ville Rinta-Hiiro, Malin zu Castell-Rüdenhausen, Laura Wendling, Arto Laikari, Kristen Jakstis, Leonie Fischer, Piersaverio Spinnato	First draft completed
1.2	10.8.2020	Laura Wendling	Draft submitted for external review
2.0	7.9.2020	Maria Dubovik	Final draft sent for cross-WP review (WP2) & other partners for comments
2.1	23.9.2020	Spela Zalokar, Maarit Särkilahti, Luuk Postmes, Kristen Jakstis, Leonie Fischer	Comments and additional inputs received (ENoLL, STU, TRE, EIN)
3	30.9.2020	Authors & Laura Wendling	Final revision and submission
4	6.11.2020	Maria Dubovik & Laura Wendling	Additional inputs and re-submission
5	18.12.2020	Laura Wendling, Maria Dubovik, Ville Rinta-Hiiro, Sophie Mok, Sara Botto, Eleonora Gambucci	Additional inputs from VTT, FHG and RINA based on reviewers' comments, and re-submission
6	7.10.2022	Arto Laikari & al.	Updates and additions performed to upgrade D5.3 to D5.5.
7	25.10.2022	Joanna Karas & Spela Zalokar	Internal review (ENOLL)

8	25.10.2022	Arto Laikari	Internal review comments addressed
9	26.10.2022	Laura Wendling	Project coordinator review
10	31.10.2022	Arto Laikari	Project coordinator review comments addressed. Final revision and submission.

Dissemination level		
PU	Public	**X**
CO	Confidential, only for members of the consortium (including the Commission Services)	

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

About UNaLab

The UNaLab project is contributing to the development of smarter, more inclusive, more resilient and more sustainable urban communities through the implementation of nature-based solutions (NBS) co-created with and for local stakeholders and citizens. Each of the UNaLab project's three Front-Runner Cities – Eindhoven (NL), Genova (IT) and Tampere (FI) – has a strong commitment to smart, citizen-driven solutions for sustainable urban development. The establishment of Urban Living Lab (ULL) innovation spaces in Eindhoven, Genova and Tampere supports on-going co-creation, demonstration, experimentation and evaluation of a range of different NBS targeting climate change mitigation and adaptation along with the sustainable management of water resources. The Front-Runner Cities actively promote knowledge- and capacity-building in the use of NBS to enhance urban climate and water resilience within a network of committed partner cities, including seven Follower Cities – Stavanger, Prague, Castellón, Cannes, Başakşehir, Hong Kong and Buenos Aires – and the Observers, Guangzhou and the Brazilian Network of Smart Cities. Collaborative knowledge production among this wide network of cities enables UNaLab project results to reflect diverse urban socio-economic realities, along with differences in the size and density of urban populations, local ecosystem characteristics and climate conditions. Evidence of NBS effectiveness to combat the negative impacts of climate change and urbanisation will be captured through a comprehensive monitoring and impact assessment framework. Further replication and up-scaling of NBS is supported by development of an ULL model and associated tools tailored to the co-creation of NBS to address climate- and water-related challenges, a range of applicable business and financing models, as well as governance-related structures and processes to support NBS uptake. The results of the project will be a robust evidence base and go-to-market environment for innovative, replicable, and locally-attuned NBS.

Partners

Table of Contents

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

1 Executive Summary

The *Nature-Based Solutions Implementation Handbook* (Deliverable 5.5) is a handbook for practitioners involved in the implementation of nature-based solutions (NBS). This handbook has been iteratively developed and updated throughout the execution of the UNaLab project. The *Nature-Based Solutions Implementation Handbook* comprises a part of the UNaLab Replication Framework, aiming at providing guidance for NBS replication - from co-creation, through co-implementation and co-management - to a wide range of practitioners. This Handbook provides:

- An overview of NBS co-creation to address specific environmental challenges related to climate change and guidance on the technical specifications of selected NBS;
- A review of monitoring schemes to evaluate NBS performance and impact, including the selection of appropriate indicators, both process- and outcome-based;
- Guidance regarding management and use of acquired NBS data; and,
- Information about NBS operation and maintenance to support co-management of implemented NBS.

The UNaLab front-runner cities Eindhoven (EIN), Genova (GEN) and Tampere (TRE) have identified specific challenges related to climate change and resultant impacts on the local hydrologic cycle. Together with stakeholders, the UNaLab front-runner cities have co-created and implemented NBS to address identified challenges. UNaLab deliverables *D2.2 Co-creation Workshops Report* (van Dinter & Habibipour, 2019) and *D2.4 Urban Living Lab Framework* (Habibipour & Ståhlbröst, 2020) summarise the results of co-creation workshops in UNaLab front-runner cities (FRCs) and further explore the theory and execution of NBS development in an urban living lab context, respectively.

Accurate evaluation of the performance and impacts of implemented NBS and the associated processes such as co-creation is essential to understand the realised benefits and trade-offs, and to sustainably manage NBS in the long term. Nature-based solutions monitoring involves a collection of measurements used for assessing the state of environment and subsequently the change that signifies either its degradation or restoration. Evaluation of the co-creation processes inherent to NBS implementation is likewise an essential consideration address in the Handbook. Herein, we present guidance specific to the monitoring (both of outcomes and processes) and maintenance of the NBS sub-projects undertaken in each UNaLab FRC.

Prior to monitoring, goals and data analysis methods must be well defined to ensure robust data acquisition and management that supports understanding of physical, chemical and biological variables and processes occurring in the studied environment. Sampling protocols should be defined by the unique characteristics of each environment being assessed within the scope of the project. It is important to establish baseline (pre-NBS) measurements to understand the reference conditions and quantifying the actual impact, both for processes and outcomes. This supports NBS co-creation processes (i.e., through refinement of the NBS design to meet existing needs) as well as NBS impact assessment, by providing a baseline with which to compare later results to assess the impacts of NBS.

Many NBS interventions generate impact on local to sub-local scale. The impact can be assessed quantitatively and/or qualitatively by adopting Key Performance Indicators (KPIs) – a set of variables providing the means to assess particular attributes to meet an explicit objective. Identification and selection of specific KPIs to assess NBS performance is an intricate process of NBS implementation due the vast selection of potential indicators and their specific metrics. The UNaLab deliverable D3.1 *Performance and Impact Monitoring of Nature-Based*

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Solutions (Wendling *et al.*, 2019) introduces a list of nearly 400 potential KPIs for NBS impact assessment. Appendix I of the present Handbook presents updates to UNaLab deliverable *D3.1*, including KPIs and methods of their determination based on the new inputs and/or finalisation of common methodologies within the Taskforce II. Careful selection of KPIs that align with the anticipated impacts of NBS implemented and evaluation at appropriate spatial and temporal scale is essential for accurate assessment of NBS performance and impact.

The International Union for the Conservation of Nature (IUCN) recently released standards for the design and assessment of NBS in order to support mainstreaming of nature conservation and consistency of NBS application (IUCN, 2020). Whilst the IUCN standard lacks definitive thresholds, it provides a systematic framework to support consistency in NBS design and assessment based on solutions-oriented outcomes. The eight criteria and sub-indicators that comprise the standard framework for NBS design and assessment defined by the IUCN (2020) are described in Section 6 Global standards for NBS , with links to specific quantitative indicators and methods of evaluation previously identified by the UNaLab project and/or the NBS Impact Evaluation Framework Taskforce.

Following establishment of a monitoring scheme, implementing appropriate methods of data acquisition will ensure accurate data collection at relevant scales. A number of data acquisition options exist that could be employed for NBS performance and impact monitoring. In this Handbook, they are presented as the broad major categories comprising remote sensing and earth observations, ground (*in situ*) observations, statistical and legacy datasets, and citizen science. These monitoring means produce reliable quantitative and/or qualitative data only when applied at appropriate scales and periods of time. Note that fine granular data (low level of aggregation) provides greater detail than coarse granular data (high level of aggregation), making it more suitable for research and decision-making purposes. It is critical to define an appropriate level of aggregation of the measures for both time (temporal granularity) and location (spatial resolution) to accurately evaluate the performance and impact of a given NBS.

The most important, and arguably the most complex element of designing monitoring schemes for NBS is determining a realistic potential scale of impact. Considerations of the scale of NBS monitoring and the frequency of recorded intervals are of outmost importance due to their effect on the quality of monitoring efforts. Ranges of scales at which key indicators can be observed and quantified vary substantially, and the overall visibility of impacts associated with a specific NBS are scale-sensitive. Assessing the realistic scale of impact based on the scale of the NBS implemented will determine the scope of monitoring efforts, e.g., the number of monitoring stations or field surveys and the requisite frequency and duration of monitoring. It should be noted that the monitoring efforts should match the available monetary and personnel resources.

Monitoring of NBS performance and impact is an essential element of NBS sustainability, ensuring that implemented NBS are maintained in a suitable condition to deliver the expected benefits and co-benefits for the long term. Maintenance of NBS should be planned and undertaken throughout the NBS lifecycle. Initially, maintenance requirements should be considered during NBS planning (co-creation) to ensure that sufficient resources are reserved for NBS monitoring and upkeep. It is important to estimate realistic costs over the lifetime of the NBS, including design, construction, operation, and possible renewal or decommissioning. A detailed maintenance plan can make the efforts and costs of NBS maintenance lower throughout the lifetime of NBS, as well as extend the lifetime of NBS.

Readers are also encouraged to explore other related UNaLab deliverables, namely the *NBS Demonstration Site Start-Up Report* (deliverable D5.4), which broadens the view of NBS by providing early lessons learned during NBS implementation processes and the *Impacts of NBS Demonstrations* (deliverable D3.4), which provide impact assessment and initial results from the UNaLab NBS monitoring program in the project's Front Runner Cities (FRCs).

2 INTRODUCTION

2.1 Purpose and target group

The *Nature-Based Solutions Implementation Handbook* (Deliverable D5.5) is a handbook for practitioners involved with implementation of nature-based solutions (NBS) within the Urban Nature Labs (UNaLab) project. This deliverable has been iteratively updated and refined based on feedback and experiences in the FRCs during the latter months of the project and it serves as the guide for NBS implementation in urban areas. The *Nature-Based Solutions Implementation Handbook* comprises a part of the UNaLab Replication Framework aiming at providing guidance for NBS replication, from co-creation, through co-implementation and co-management, including social, environmental and economic data acquisition and management, and NBS impact evaluation, performance assessment and maintenance.

The *Nature-Based Solutions Implementation Handbook* provides:

- An overview of NBS co-creation to address specific environmental challenges related to climate change and guidance on the technical specifications of selected NBS;
- A review of monitoring schemes to evaluate NBS performance and impact, including the selection of appropriate process- and outcome-based indicators for social, environmental and economic domains;
- Guidance regarding management and use of acquired NBS data; and,
- Information about NBS operation and maintenance to support co-management of implemented NBS.

2.2 Contributions of partners

VTT led the preparation of D5.5 *Nature-Based Solutions Implementation Handbook* and updated the handbook with contributions from the Front Runner Cities (FRCs) and Follower cities (FC), particularly concerning the lessons learned chapter. VTT also led the preparation of the D5.3 *Preliminary Nature-Based Solutions Implementation Handbook,* which is the earlier version of this handbook. The preliminary version of the Handbook was used within the UNaLab project and was not a public document. In this updated D5.5 *Nature-Based Solutions Implementation Handbook,* STU contributed the discussion of NBS technical specifications to Section 4.6 and updates to NBS inspiration cards (from D5.1) to Appendix II. ENG contributed to Section 5.2 with the discussion on data granularity. FHG and RINA contributed to Section 4.3 with the discussion on Value Model and financing considerations. Inputs from the multi-project NBS Impact Evaluation Framework (IEF) Taskforce/NBS Taskforce II formed the basis for discussion and development of some of the NBS monitoring parameters and techniques described herein, which is reflected in Appendix I. Feedback from front-runner cities EIN, GEN and TRE informed selection of project-specific NBS and monitoring parameters (i.e., metrics not "common" among all SCC-02-2016-2017 projects).

2.3 Baseline

Following comprehensive internal risk assessment, significant potential impacts of COVID-19 and subsequent national regulations on environmental, social and economic parameters in UNaLab partner cities were identified. The definition of baseline conditions for NBS impact monitoring is described in detail in UNaLab D3.1, *Performance and Impact Monitoring of Nature-Based Solutions*. The present document (D5.5, *Nature-Based Solutions Implementation*

Handbook) identifies specific cases in UNaLab front-runner cities EIN, TRE and GEN where baseline conditions are likely to have been significantly affected by COVID-19 and/or measures to mitigate the spread of the virus. Alternative approaches are outlined herein as needed to accurately quantify the environmental, social and economic impacts of NBS implemented in the UNaLab front-runner cities in order to provide accurate, actionable information to the European Reference Base on NBS.

2.4 Relations to other activities

The *Nature-Based Solutions Implementation Handbook* (D5.5) is a stand-alone document that provides guidance to practitioners and stakeholders involved with implementation of nature-based solutions (NBS). The *Nature-Based Solutions Implementation Handbook* (D5.5) provides updates to *D3.1 NBS Performance and Impact Monitoring* (Wendling *et al.*, 2019) based upon the collaborative development and finalisation of common methodologies in NBS Taskforce II, and updates to *D5.1 NBS Technical Handbook* (Eisenberg & Polcher, 2018) based upon the experiences from UNaLab FRCs. The updates to UNaLab deliverables *D3.1 NBS Performance and Impact Monitoring* and *D5.1 NBS Technical Handbook* are included here as Appendices (Appendix I and Appendix II, respectively).

Additionally it is recommened to explore the *NBS Demonstration Site Start-Up Report* (deliverable D5.4), which broadens the view of NBS by providing early lessons learned during the process of implementing NBS in UNaLab Front Runner Cities (FRCs) and the *Impacts of NBS Demonstrations* (deliverable D3.4), which provides the impact assessment and results from the NBS monitoring in the UNaLab FRCs.

3 NBS TO ADDRESS CLIMATE-RELATED CHALLENGES

The concept of NBS dates to 2008 (MacKinnon, Sobrevila, & Hickey, 2008; Mittermeier et al., 2008) when they were introduced as a means to mitigate and adapt to climate change whilst protecting biodiversity and improving sustainability of livelihoods. The EU Research and Innovation policy agenda on Nature-Based Solutions and Re-Naturing Cities[1] defines nature-based solutions to societal challenges as *'solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions.'* Thus, NBS intrinsically provide biodiversity benefits and support delivery of ecosystem services.

The UNaLab front-runner cities EIN, GEN and TRE have identified specific challenges related to climate change and resultant impacts on the (local) hydrologic cycle. Together with stakeholders, the UNaLab front-runner cities co-created NBS to address identified challenges (Figure 1). The processes of challenge identification and co-creation are further discussed in Chapter 4.

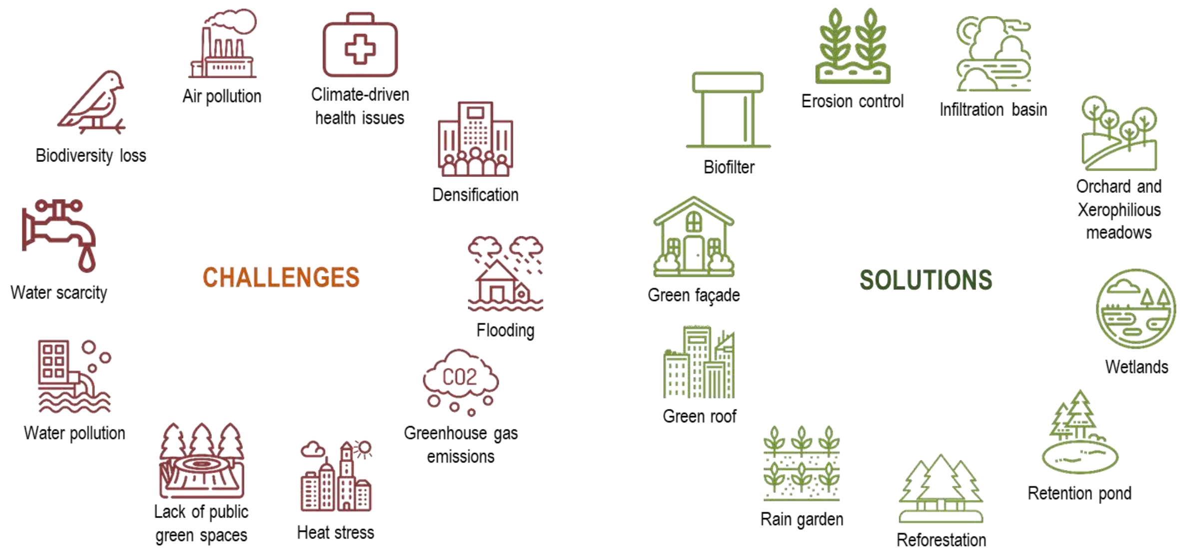


Figure 1. Identified environmental burdens and urban pressures, and examples of mitigation options adopted by the UNaLab Front-Runner Cities.

Following NBS implementation, NBS owners must establish an effective framework for NBS co-management with stakeholders, including data acquisition and reporting for assessment of NBS performance and impact. In the context of the UNaLab project, multi-stakeholder engagement and contribution of new knowledge to the EU evidence base for NBS are critical objectives to be addressed via NBS co-management in front-runner cities EIN, GEN and TRE. The present document aims to provide guidance to UNaLab front-runner cities in support of multi-stakeholder engagement in NBS co-management, and for the acquisition of local NBS

[1] https://ec.europa.eu/research/environment/index.cfm?pg=nbs. Accessed 4.6.2020.

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

performance and impact monitoring data in a format that enables comparison of NBS of different types and scales across multiple geographic locations.

In order to facilitate comparison of NBS among different projects and across multiple geographic locations, the UNaLab project has adopted the NBS classification scheme derived by the ThinkNature 2016-2019 coordination and support action, presented in detail by Somarakis, Stagakis & Chrysoulakis (2019). The NBS classification is outlined in UNaLab D3.1, *Performance and Impact Monitoring of Nature-Based Solutions* (Wendling *et al.*, 2019; Appendix I) and the NBS implemented in UNaLab front-runner cities EIN, GEN and TRE are presented within this classification scheme in Sections 4.5–4.6 of the present document.

The NBS sub-projects undertaken in each front-runner city as a part of a greater UNaLab framework generally follow a similar structure applicable to a wide variety of NBS projects (Figure 2).

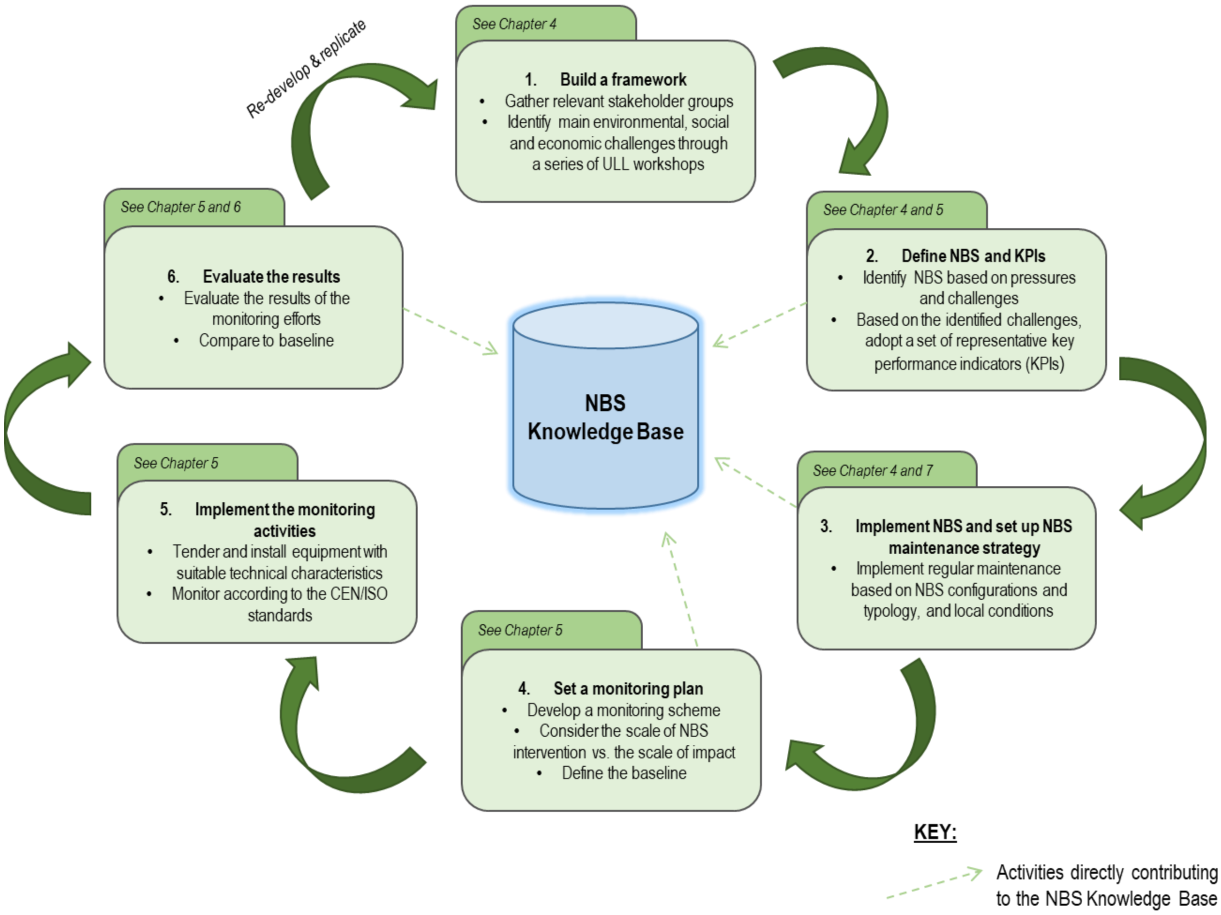


Figure 2. Lifecycle of an NBS project in relation to the content of the Handbook.

The lifecycle of an NBS project comprises six equally important steps or phases. The lifecycle begins with a framework identification phase, which will be adopted first in the project and which will drive the implementation of the next actions. The following phases - identifying the relevant NBS given the identified urban pressures and challenges and the key performance indicators (KPIs), and developing a monitoring scheme to capture the change from the baseline conditions – are crucial for evaluating the NBS performance and impact. Once the monitoring scheme is defined and monitoring equipment is tendered, a prolonged period of NBS monitoring begins. The monitoring outputs are continuously reviewed to assess NBS performance and impact, and to ensure the soundness of the equipment and the methods of data acquisition. Ideally, NBS monitoring should span several years for critical evaluation of NBS performance and impact to support future development proposals. Several phases of the NBS project lifecycle directly contribute to the NBS Knowledge Base, which can be perceived as a collection of good practices regarding NBS implementation across the EU Member States.

The structure of the present *NBS Implementation Handbook* follows the general structure presented in Figure 2, and the reader is referred to the respective Chapters for detailed information and procedures.

The UNaLab tools that complement the development of a more holistic framework for NBS initiation in urban areas follow the adaptive management cycle, or Plan-Do-Check-Act-cycle (PDCA-cycle). The UNaLab tools and knowledge (Figure 3) create a framework for NBS planning and implementation (via co-creation toolkit, ONIA, SDST), adaptively addressing the societal challenges by providing the evidence and continuous evaluation of the generated impact (via CPM) for upscaling and replication (via Replication Framework and roadmapping). The tools and their application during the NBS implementation process are highlighted throughout the Handbook.

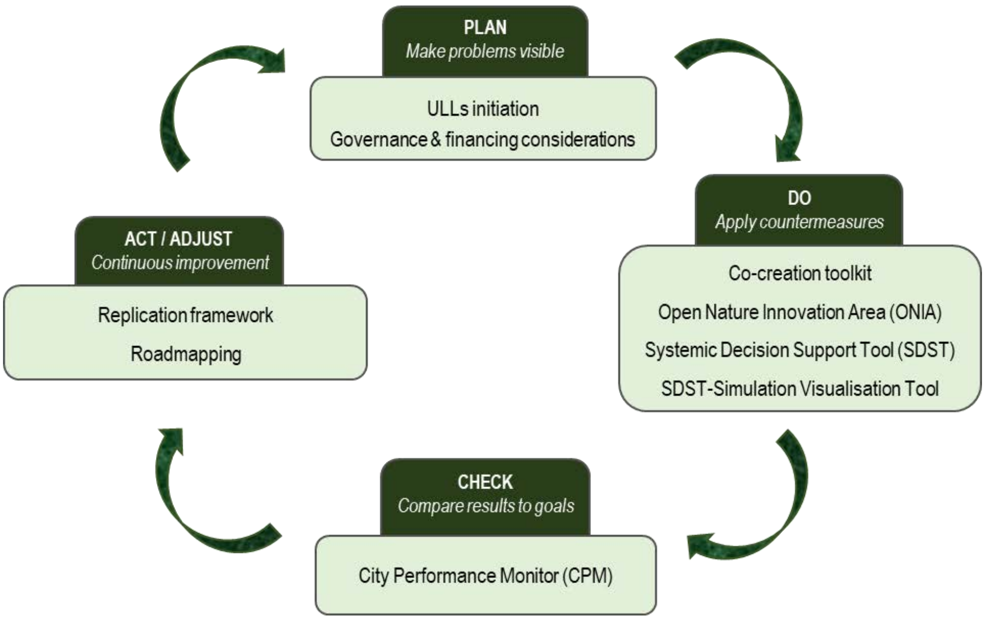
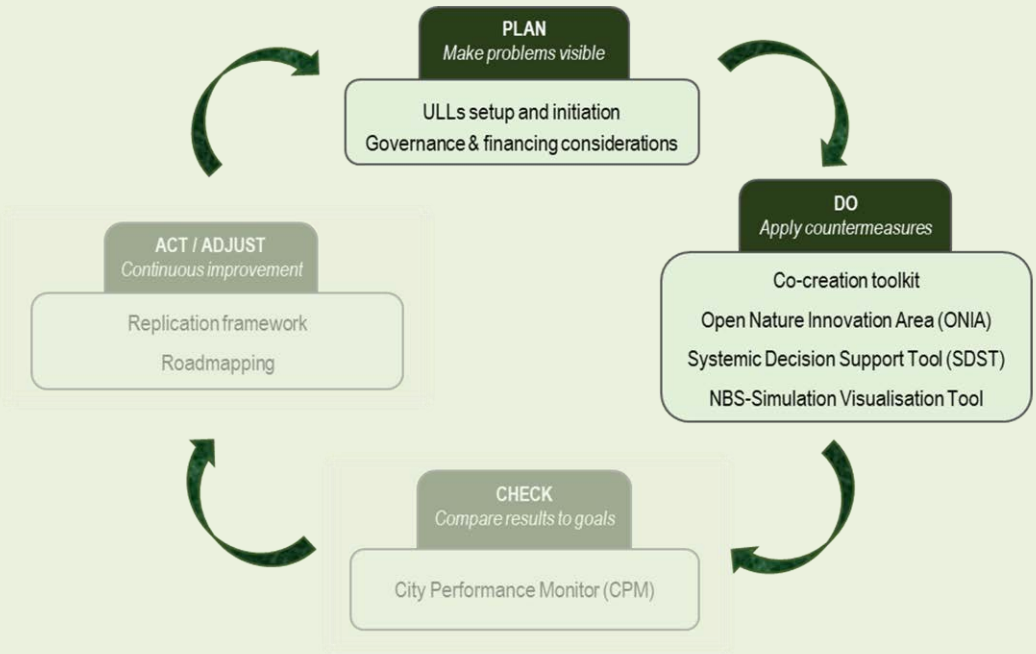


Figure 3. The UNaLab toolkit follows the Adaptive Management Cycle approach.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

4 NBS INITIATION IN UNALAB CITIES

Box 4-1: UNaLab tools for Urban Living Lab (ULL) setup and co-creation for the NBS planning and problem definition as part of the Adaptive Management (or, PDCA-) cycle



Urban Living Lab Handbook: https://unalab.eu/en/documents/living-lab-handbook

With this handbook, one can learn how to develop an Urban Living Lab, based on the experiences, research and practical experience from the UNaLab project. The tips included there are given by the Living Lab experts who have successfully set up a Living Lab in their own community. At the end of the handbook, one will find an interactive tool to guide them through the Living Lab journey.

Co-creation toolkit: https://unalab.enoll.org/

The UNaLab Toolkit collects all of the instruments used for the co-creation and experimentation of innovative solutions in a real-life urban environment together with the engagement of citizens and all relevant stakeholder groups in a city. The tools come in a wide range of formats from games, workshops to templates. The toolkit can be used as a source of inspiration and for preparing a co-creative session with various stakeholders. To ensure a truly collaborative and “co-creative” approach, one should equip themselves with various methods and tools found in this toolkit.

Open Nature Innovation Area (ONIA): https://onia.unalab.eng.it/

ONIA is collaborative tool supporting the co-creation process that can be utilised for problem identification, NBS co-creation and feedback collection. In ONIA, it is possible to identify and submit the city problems, express needs and topics relevant for the local community. ONIA enables challenge management as a public call to participation to solve a local problem, and further analyse and improve the ideas proposed by the citizens. It ensures transparency for voting and selecting the ‘best’ ideas.

Systemic Decision Support Tool (SDST) and NBS-Simulation Visualisation Tool (NBS-SVT)

SDST is a geo-visualisation tool to support understanding of NBS impacts, participatory planning and decision-making. SDST can be employed during the co-creation process allowing stakeholders to visualise and discuss the potential direct and indirect environmental, social and economic impacts of no-action as compared to implementation of selected nature-based solutions (NBS) in scenarios without (2015) or with (2030 and 2050) climate change and/or population growth. The NBS-SVT constitutes the user-interface of the SDST.

4.1 Co-creation in the Front-Runner Cities

Within the UNaLab project, a series of Urban Living Lab (ULL) NBS co-creation workshops were organised in the UNaLab front-runner cities (FRCs). The workshops aimed at engaging the stakeholders and working together to explore and implement the NBS interventions. The ULL co-creation workshops provided a starting point for the selection of NBS the UNaLab front-runner cities would develop in their respective UNaLab project locations. The workshops were attractive; in total, 361 stakeholders participated in the workshops, an average of 30 per workshop. The UNaLab Deliverable D2.2 presents the outcomes of the co-creation workshops in the FRCs, and Deliverable D2.4 encompasses the refined ULL Framework. Some of the best tips to attract and engage stakeholders based upon these two Deliverables are listed in Box 4-2.

The UNaLab front-runner cities are geographically widespread, representing diverse climates and cultures and having organisational differences. This resulted in different approaches by UNaLab FRCs to their co-creation workshops, evidenced by a mix of selected techniques, participants and results. Yet, because the co-creation process was coordinated through the UNaLab project, the execution and goals of the workshops were similar. The first workshops aimed at familiarising participants with the subject, UNaLab project methodologies and aims, and sharing views. In the second step, workshop participants mainly focused on creating NBS solutions to be implemented in the UNaLab project sites, and these were then evaluated in each of the third and final workshops.

Box 4-2: The best tips to engage people in the ULL workshops

- ✓ Citizen participation must be voluntary
- ✓ Adjust the length of the talks in the workshops, especially for children
- ✓ Connect the workshop to an existing (popular) event
- ✓ Go on walking tours
- ✓ Give detailed information in the invitation
- ✓ Work with maps
- ✓ Various communication channels are required
- ✓ If participants show hesitation about their presence, discuss this in the group
- ✓ Responsible people from the city should take part directly
- ✓ Beyond the workshops, involve the participants in site activities, managed and supported by planners and technicians
- ✓ Native language will facilitate the true engagement

Each UNaLab FRC selected either the European Awareness Scenario Workshops (EASW) method or the Design Thinking method for use in their respective ULL co-creation workshops. The steps followed by each of these methods are similar, as are the stakeholders that can be involved. In both methods, the groups get together to understand a problem, find solutions, and test them. The stakeholders that can be engaged in both cases are policy makers, technical experts, entrepreneurs/businesspeople, local citizens and designers.

In Tampere, various stakeholders participated in each workshop including residents and people connected to the sites, in addition to experts from the city and NBS practitioners. In Eindhoven, the group consisted of only professionals (Figure 4); citizens were involved through other processes of co-creation. In Genova, the group was a combination of the city representatives, citizens and experts of various fields. In total, 361 stakeholders in EIN, GEN and TRE participated in the co-creation workshops, including professionals and/or experts, NGOs, local and provincial government representatives, representatives of companies (e.g., energy companies, material producers, etc.), universities, and local associations (e.g., housing), and citizens.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Figure 4. Co-creation workshop in Eindhoven (NL).

The cities' expectations of the workshops were mostly met, and feedback from the participants in all three cities was positive. The impact from joining in the workshops was very similar in all cities; all participants learned about NBS locally and worked on creating a vision for the NBS implementation at each of the project sites. The commitment to follow up between and after the workshops was high. In Tampere, residents are already active and they want to know about the status and schedules of implementation (Box 4-4). At the Vuores NBS site in Tampere, schoolchildren have an active role monitoring water quality. In Eindhoven, participants are committed to forming a Community of Practice and support work on NBS beyond the UNaLab project. In Genova, workshop participants expressed interest and willingness to take part in the next stages of involvement in the project.

Naturally, co-creation has its tangible outcomes. However, it is beneficial to evaluate and quantify its impacts on a variety of topics, including enabling participatory decision-making, inclusivity, social cohesion and justice, and gender dimension, to deeper explore the NBS impact on the social domain and the co-creation process, which is a critical part of the successful implementation of effective NBS. Co-creation is evaluated using the process-based indicators (see Section 5.2 for details), which assess the efficiency, quality, or consistency of specific actions employed to achieve the goals. Box 4-3 presents some considerations relevant to assessing the robustness and efficacy of the co-creation approach. For evaluating the success of co-creation process, it is necessary to establish a pre-co-creation baseline capturing

Box 4-3: Quantifying impacts of co-creation

Evaluating and quantifying the impacts of co-creation process is equally important as quantifying the other NBS impacts, either environmental or economic. It should adopt a similar approach that relies on adoption of a set of key performance indicators with a baseline assessment (i.e., pre-co-creation). The process-based indicators of the societal challenge areas (see Appendix 1) directly contributing to monitoring and evaluating the co-creation process include but are not limited to:

- Participatory Planning and Governance
  - Openness of participatory processes: proportion of citizens involved
  - Community involvement in planning
  - Community involvement in implementation
  - Involvement of citizens from traditionally under-represented groups
  - Active engagement of citizens in decision-making
- Social Justice and Social Cohesion
  - Citizen engagement by NBS projects
  - Participation of vulnerable or traditionally under-represented groups

the degree of stakeholder involvement or other relevant aspects. To learn more about establishing NBS monitoring for both process- and outcome-based indicators and applicable considerations, see Chapter 5.

Box 4-4: Co-creating Nature-based Solutions in Tampere (FI)

The City of Tampere has a population of 234 441, whereas the metropolitan area, also known as the Tampere sub-region, has 385 301 inhabitants in an area of 4 970 km^2. Tampere is located on narrow isthmus between two large lakes, Näsijärvi and Pyhäjärvi. Since the two lakes have an 18 m difference in water level, the Tammerkoski rapids linking them have been an important power source throughout history, most recently for generating electricity. Tampere is the former centre of Finnish industry.

The main NBS demonstration site in Tampere is located in Vuores, a green district under construction located in the centre of a forested area and natural waterbodies. The smart district, to be completed by 2030, offers innovative construction and uses cutting-edge technologies and innovative co-created NBS systems. The NBS implemented through the UNaLab project were complementary to the district's existing green infrastructure. In addition to the demonstration site located in Vuores, a second Tampere ULL site is located in Hiedanranta, a former industrial area transformed into a housing district. Selected Vuores NBS systems will be replicated in Hiedanranta.

Tampere organised co-creation workshops in both Vuores and Hiedanranta ULL locations. The co-creation process had two main goals: (i) to increase public awareness of NBS and explore innovative solutions to identified problems, and (ii) to solicit citizens' opinions on the neighbourhood and city development using NBS approaches.

Vuores
The goal of the first workshop was to create a shared vision of the Vuores NBS Living Lab: gathering needs and ideas, best practices and learning from the current NBS to develop the solutions further in Vuores, and then in Hiedanranta and the UNaLab follower cities. The second workshop aimed at educating the pupils in Vuores' elementary school about the NBS in the region, raising awareness about the NBS and urban nature, and devising innovative ways to simultaneously utilise these NBS for recreation, play and biodiversity enhancement. In the third workshop, the objective was to further develop NBS in Vuores and collect good practices for potential transfer to the Hiedanranta development.

Hiedanranta
The goal of the first workshop was to co-create ideas and vision(s) for NBS in Hiedanranta related to (storm)water management, biodiversity enhancement, and recreational opportunities. In the second workshop, the city sought input from city planners and building professionals regarding important considerations in NBS planning and implementation of ideas from the first workshop. The workshop objective was to establish a shared understanding of proposed NBS concepts and to identify potential locations for demonstration of selected co-created NBS in the near future.

The co-creation workshops with stakeholders in Tampere resulted in significant changes to the City's planned activities. Some ideas collected in the co-creation workshops were delivered to the city planners to be feasibly implemented in the master plan of the area, and many NBS will be implemented after the UNaLab project has ended. Workshop participants actively influenced local planning and decision-making. The outcomes of co-creation workshops will help frame future trainings and materials designed to support ULL activities.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

4.2 Urban Living Lab Framework

Two workshops (organised in November 2017 and November 2018) involving representatives from the front-runner and follower cities, and a follow-up open-ended questionnaire (December 2018–January 2019), aimed at refining the ULL concept based on the combined experience of the UNaLab FRCs. The resulting ULL Framework is based on theories and practices for Living Labs, Action Design Research, methods for co-creation and data from workshops with the front-runner cities. The seven key components of the ULLs (Habibipour *et al.,* 2020) are presented in Figure 5.

The key components include the *governance and management structure* as the basis for the strategic and operational management and organisation of the ULL, which requires support from the local governments and decision-makers. The governance component is followed by *financing and business models* that create and deliver value for the ULL stakeholders and that are essential for running the ULL, including the vision and scope, risk management and dissemination. Business models determine who will finance the ULL activities and whether the commitment will be supported in the long term. The *urban context* defines a physical setting, in which NBS will be implemented (street, neighbourhood, or city). The physical setting should be considered in terms of ownership and responsibility, existing infrastructure and future development plans. The *Nature-based solutions* component should be innovative and address local challenges and pressures; here, the (co-)created NBS aims and values should be clearly identified. The innovation component is followed by the partners and users, or *key stakeholders*, adopting the Quadruple Helix approach. This approach uses the innovation and collaboration model of Triple Helix (academia–authorities–industry) whilst adding a fourth pillar – a citizen perspective, which leads to more transparent and end-user-friendly innovations. The *methods* and the *ICT infrastructure* components relate to the various data collection, analysis and tool to support and engage stakeholders in the ULL activities.

Figure 5. Key components of the Urban Living Lab framework.

The Urban Living Lab Framework Toolkit followed the development of the ULL framework. The Toolkit comprises an overall white background sheets and a set of Cards that are divided into the *Main Cards* and the *Guide Cards*. The *Main Cards* include (a) the seven decks of cards, each deck representing one of the key components of the ULL framework (Figure 5), (b) the *Barrier* and *Stop* cards, and (c) the empty cards (four in each deck) for any necessary actions or descriptions identified. The larger-sized *Guide Cards* comprise seven *Key component guide* *cards* (as presented in Figure 5) and five *Development phase guide cards* (exploration, (co-)creation, implementation, evaluation, and adoption) that could be used for building a unique guide and planning sheet using the white background sheets.

Briefly, the Toolkit application begins with the familiarisation of the card decks representing the ULL components and agreeing with the participants on the NBS case considered. It is followed by placing the *Development phase guide cards* (*Guide cards)*, which address the various phases of the NBS development in the local context. Depending on the Living Lab implementation status, different sets of phases should be considered. Up to three relevant *Key component guide cards* (*Guide cards)* should be placed under each phase for building the unique guide and planning sheet on the white background paper. The *Main Cards* can be placed anywhere on the sheet regardless of the (one of the seven) decks to which they belong (e.g., city planners can be placed under the *key stakeholders* or *financing and business models* components; see Figure 5). The empty cards can duplicate the actions (e.g., risk assessment) under multiple phases (*Development phase guide cards*) of the NBS development. The *Barrier* and *Stop* cards can be used in the process to predict or identify an obstacle for any action (e.g., lack of citizen's motivation to engage in the NBS development).

The empty cards and the guide and planning sheet provide the canvas for building locally-attuned development scenarios. The cards provide the ULL users with the set of possible key components of development phases. The users, however, are not obliged to use all cards, but the ones that are relevant, and the users are also encouraged to use the empty cards for identifying other significant key components or development phases that must be considered in the local context.

For additional information, the reader is referred to UNaLab D2.4 *UNaLab Living Lab Handbook* (Habibipour & Ståhlbröst, 2020) and the publication *Living Lab Handbook for Urban Living Labs Developing Nature-Based Solutions* (Habibipour *et al.*, 2020).

4.3 NBS values, benefits and financing options

Next to the potential of nature-based solutions to directly contribute to increased climate resilience in cities, their multifunctional nature can also provide a wide range of social, environmental and economic co-benefits. Whilst this diversity of benefits and the context-specificity of NBS performance make it difficult to capture and communicate the overall value, they also hold a great potential for engaging more urban stakeholders in the planning, implementation and financing of such solutions.

Behind this background, the UNaLab Value Model seeks to explore the multiple and often intangible values of NBS and enable a structured navigation through the complex issue of NBS valuation. The underlying assumptions are that the different technical functions of NBS (as outlined in the D5.1 *NBS Technical Handbook*) can be translated into individual benefits of different urban stakeholders. Based on a given urban context and the actual type and performance of the NBS, different beneficiary structures will emerge. If the individual benefits are well communicated to those, their willingness to invest could be enhanced, opening the way to alternative co-investment and financing options.

In D6.4, *UNaLab Value Model*, these relationships and the underlying logic are further highlighted and explored. Additionally, it describes a potential clustering of different benefit types and discusses their value capture potential (see Table 1). For different types of NBS, it provides an overview of potential 'usual suspect beneficiaries' and hints at available evaluation tools for further value assessment.

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Table 1. Benefit types and characterisation.

Benefit Type	Description	Example	Value	
Revenue & Income	The beneficiary directly increases his/her income through the intervention	Increased property values, improved sales through increased foot traffic in business areas	Monetary	Higher
Cost Savings	The beneficiary saves money due to the intervention	Better insulation and reduced energy costs, flood damage mitigation		
Compliance	The intervention helps the beneficiary to fulfill a mandate or comply with regulations	Fulfilling environmental standards, achieving city goals	Non-monetary	Value Capture Potential
Active Use	The beneficiary can make direct use of the intervention	Opportunities for recreation and sports		
Local Identity & Image	The beneficiary gains recognition and visibility or identifies better with the place	Improved city marketing, CSR, sense of place		
General Wellbeing	The beneficiary's quality of life/health/wellbeing is improved through the intervention	Better air quality, increased contact with blue green spaces		Lower

The value model ultimately links potential alternative financing options to identified beneficiary structures, to encourage the mobilisation of additional resources for a given NBS project. Figure 6 summarizes different financing options in relation to private, public and civil society actors. More in-depth information and additional financing and business model considerations regarding NBS can also be found in D6.3 *Business Models & Financing Strategies*, including innovative municipal financing approaches, Public Private Partnerships, mandatory requirements and taxes, incentive programmes, as well as municipal funds. It also reflects the acknowledgement that smart and innovative financing strategies need to take into consideration the specific institutional, technical, economic and normative contexts where they are applied, and that these contexts need to be adequately understood by the parties involved, be those financial institutions, municipal governments, private companies or civil society.

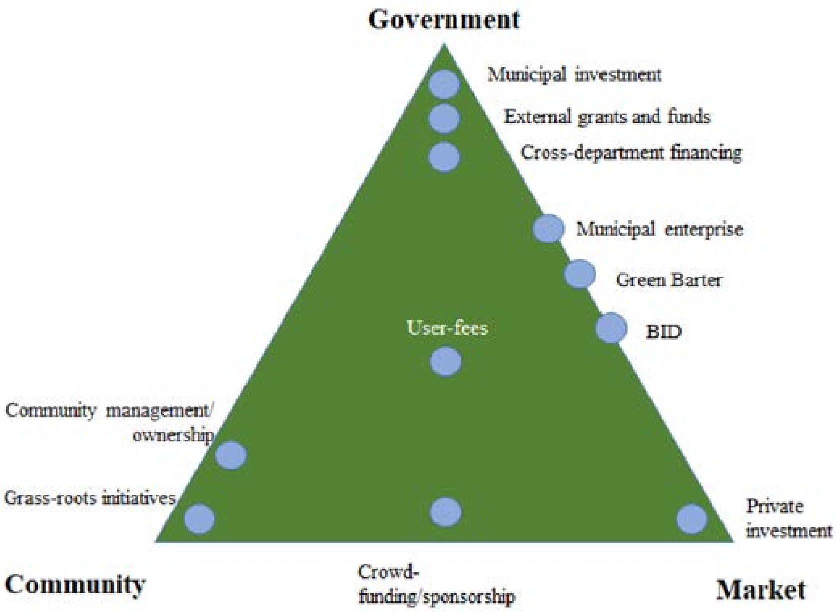


Figure 6. Financing options for NBS.

Next to the focus on financing strategies, a summary description of the NBS business model is provided for each type of investigated NBS (selected from each front-runner city), reporting the following information: main features, value proposition, conditions for implementation, main stakeholders involved, costs, financing options and limits. The UNaLab business models considered have been analysed through the Business Model Canvas methodology (A. Osterwalder concept) that consists of nine conceptual blocks which allow making explicit the most relevant aspects for the business solution. The Business Model Canvas, in particular, is a complete and systemic method that allows reducing the complexity of the business modelling activity, representing in an effective manner all the parts and internal/external dynamics that are within a Business Model, using a visual language (visual thinking logic).

The Nature-based Solutions Business Model Canvas was used to study the UNaLab NBS, because is an easy-to-use tool that helps capture the business model of NBS in a visual format. It is a tool that was already used and tested in the past in other NBS projects to support the plan of NBS implementation. In particular, the NBS Business Model Canvas was used as a tool to support the initial stages of planning the implementation of NBS in the cities engaged in the European "Connecting Nature" project. In particular, the Business Model Canvas used for NBS projects helps to communicate, plan, identify new partners, explore new sources of finance, and broaden the value proposition of NBS.

In the course of the UNaLab project, all these mentioned aspects will be further explored, developed and incorporated in the final replication framework (D6.8 *Handbook to Support NBS Implementation*).

4.4 NBS governance considerations

Tranditionally, governance has been approached as a top-down process, where managing urban challenges was administered by the public authorities. The modern cities face the transformation by involving other stakeholders, such as citizens, companies and other actors, in the urban development. A combined effort of the emerging city actors can target topics such as climate change adaptation and sustainable urban development. Although viable in their nature, these actor networks require certain rules to steer the ways city actors can act to change governance structures to better facilitate the uptake of NBS. The four key areas, or themes, considered include (1) cross-departmental communication and cooperation, (2) policies, (3) financing and procurement and (4) data governance.

The governance examination in UNaLab front-runner cities consisted of three parts:

(i) Municipal governance survey to identify the central governance-related challenges and conduct a preliminary assessment of potential key research points according to the four themes
(ii) High-level workshops to elaborate on the identified challenges and develop potential solutions for the four key themes on a more general level, and
(iii) Development and application of the assessment framework

The results of each individual front-runner city for the four key themes diverged due to the differences in the organisation structure and other local aspects. However, the key findings highlighted that NBS present an opportunity for enhanced cross-departmental cooperation, although political support is often needed to drive the development. Targets and vision, and early involvement of key actors during the NBS development were identified as critical for establishing the local long-term strategy.

The NBS development and uptake require a mix of policy instruments, both command and control mechanisms (e.g., binding regulations) and market-based instruments (e.g., tax incentives), which are also reflected in the planning tools and mechanisms to enhance the visibility of targets. Integration of policies from a variety of sectors (e.g., water, construction) was deemed beneficial to promote interdisciplinarity of NBS. The policy instruments may further prove a valuable asset for attracting private engagement and local business owners to develop and invest in NBS. Three enablers identified for the NBS-supportive policies included simple access to existing policies, good communication and stakeholder involvement, which also enables feedback mechanisms.

Regarding finance and procurement of NBS, it was concluded that EU funding currently constitutes the major share of NBS investment and funding, whereas new financial strategies are not being developed due to the current access to low-cost credit. Despite NBS concept being rapidly developed, their financial and technical feasibility is not yet demonstrated, and that prohibits the involvement of the private investors. The financial mechanisms and even the introduction of economic incentives are seen as means to encourage the private investments, once these mechanisms are well established. Public-private partnerships (PPPs) represent the way for municipalities to connect with the private sector to reduce the costs of construction and maintenance, and provide new business opportunities.

Municipalities implementing NBS ideally should define their data management strategy that aligns with the long-term development targets. Storage, management, ownership and access are among the critical issues for governing data.

Practical tools for implementing NBS, such as business and governance models and financing options (addressed in Sections 4.4–4.5) are found in the following UNaLab Deliverables:

- D6.1 *Value Chain of Selected NBS* (Cioffi, Zappia, & Raggi, 2019);
- D6.2 *Municipal Governance Guidelines* (Hawxwell *et al.*, 2018);
- D6.3 *Business Models and Financing Strategies* (Mačiulyte *et al.*, 2019); and
- D6.4 *NBS Value Model* (Mok *et al.*, 2019).

4.5 Selecting a NBS suite for specific challenges

Once the local needs have been defined, the further actions include selecting the suitable NBS to address the identified challenges. Multiple classifications of NBS exist: they can be grouped by their function, objectives, or ecosystem services provided. A widely accepted NBS typology proposed by Eggermont *et al.* (2015) includes three types of NBS based on the relation of the level of ecosystem engineering to the expansion of ecosystem services and the targeted number of stakeholders (it should be noted that the boundaries between the three types are not defined allowing for hybrid solutions, whose typology may migrate from one type to another):

- **Type 1** – No or minimal intervention in ecosystems, with objectives related to maintaining or improving delivery of ecosystem services within and beyond the protected ecosystems
- **Type 2** – Extensive or intensive management approaches that develop sustainable, multifunctional ecosystems and landscapes to improve delivery of ecosystem services relative to conventional interventions
- **Type 3** – Highly intensive ecosystem management or creation of new ecosystems

Type 3 NBS are further addressed in Section 4.6.

The NBS IEF Taskforce has identified 12 unique societal challenge areas based upon the ten challenge areas initially described in the NBS impact evaluation framework developed by the EKLIPSE Working Group on Nature-based Solutions to Promote Climate Resilience in Urban Areas (Raymond *et al.*, 2017). Each of the identified challenges can be addressed through multiple individual actions that provide holistic support for climate resilience in urban areas. The identified challenge areas are:

1) Climate Resilience (including both climate change mitigation and adaptation);
2) Water Management;
3) Natural and Climate Hazards;
4) Green Space Management;
5) Biodiversity Enhancement;
6) Air Quality;
7) Place Regeneration;
8) Knowledge and Social Capacity Building for Sustainable Urban Transformation;
9) Participatory Planning and Governance;
10) Social Justice and Social Cohesion;
11) Public Health and Well-being; and,
12) Potential for New Economic Opportunities and Green Jobs.

The use of NBS is expected to enhance climate resilience in urban areas and to mitigate impacts such as extreme temperatures, wind, drought and flooding, while also producing climate change and pollution mitigation benefits (Raymond et al., 2017). NBS targeted to a particular challenge also deliver multiple co-benefits across other challenge areas. Thus, it is important to consider the full range of potential effects of NBS to comprehensively evaluate NBS impacts. The UNaLab deliverable D5.1 *Nature-Based Solutions Technical Handbook* (Eisenberg & Polcher, 2018) presents an overview of environmental and societal challenges in UNaLab cities and the envisioned impacts of specific NBS. The direct and indirect benefits of NBS on water and climate change related challenges in UNaLab cities are illustrated in Table 2.

A broad understanding of NBS – how they work and what they look like – supports selection of the most appropriate NBS to address a particular challenge, as the application of a mechanistic understanding of NBS function enables further innovation and optimisation of co-benefits (Boxes 4-5–4-6). Table 3 provides a general indication of the applicability of each broad NBS group to selected common urban challenges.

Nature-based solutions have a spatio-temporal dependency, meaning that the impacts and benefits of the solutions are related to the specific characteristics of the local ecosystem and climate[2]. The delivery of ecosystem services by NBS is similarly influenced by their location and relative scale, as well as by NBS type, of the type and diversity of plant species used, and the level of maintenance required. Some NBS specify vegetation types (e.g., intensive and extensive green roof, green façade) but recommendations concerning species of vegetation are rare due to the wide range of climates and ecosystems wherein NBS may be implemented (Kotteck et al., 2006).

Table 2. Direct and indirect benefits of NBS associated with climate change and water-related challenges in UNaLab front-runner cities (Eindhoven, Tampere and Genova).

Main drivers	Water- and climate-related challenges	Objectives of associated NBS		Direct benefits	Co-benefits
Urban growth Climate change	Water scarcity	Water collection and reuse Wastewater remediation Water storage capacity Groundwater recharge	Water quality and flood management	Increased water use efficiency and availability	Noise reduction Improved attractiveness Recreational opportunities Social cohesion Increased awareness Increased knowledge Educational opportunities Increased energy savings Increased property value Job opportunities Eco-tourism opportunities Lower maintenance costs Reduced damages and related costs
	Flooding	Peak flow control Runoff mitigation Erosion control		Flood risk reduction	
	Water pollution	Soil erosion control Load discharge control Capture and removal of pollutants Runoff temperature regulation		Improved water quality	
	Air pollution	Carbon sequestration Removal of air pollutants (PM_{10}, NO_2, O_3, CO, SO_2)	Heat and greenhouse gases management	Improved air quality	
	Heat stress	Reduce exposure to heat stress Lower air temperature (cooling effect)		Thermal comfort	
	Loss of biodiversity	Improved habitat connectivity Biological control Wildlife and flora habitant provision	Green space management	Increased biodiversity	
	Increasing density or rapid growth	Connect and improve green and blue infrastructure Increase percentage of green spaces Reduce sealed surfaces		Green space provision	
	Climate-driven health issues	Reduce risk factors Provide health benefits		Improved public health and well-being	

[2] http://koeppen-geiger.vu-wien.ac.at/present.htm. Accessed 4.6.2020.

Table 3. Nature-based solutions grouped by form and function or mode of action, and their general applicability to exemplar challenges.

Primary mode of action†	NBS form	Variations on NBS form	Carbon emissions	Flooding	Water scarcity	Water pollution	Coastal erosion	Soil degradation	Land instability	Air pollution	Reduced biodiversity	Compromised health and well-being	Urban decline	Building inefficiency	Poor public perception of nature	Declining property values
I, D, E, P	Green space	Urban parks and gardens Cemetery Schoolyards and sports fields Meadow Green strips “Multifunctional” dry detention pond or vegetated drainage basin	●	●	●	●		●		●	●	●	●	●	●	●
E, Sh, W, P	Trees and shrubs	Forest (including afforestation) Orchard Vineyard Hedges/shrubs/green fences Street tree(s)	●	●	●			●	●	●	●	●	●	●	●	●
I, B, P (E, W)	Soil conservation and quality management	Slope revegetation Cover crops Windbreaks Conservation tillage practices Permaculture Deep-rooted perennials Organic matter enrichment Inorganic soil conditioners and amendments	●	●	●	●		●	●	●	●	●				
F, I, B	Blue-green space establishment or restoration	Riparian buffer zones Mangroves Saltmarsh/seagrass Intertidal habitats Dune structures	●	●	●	●	●	●	●		●	●				
E, F/I, Ins, Sh, S, P	Green built environment	Green roof Green wall/façade Green streets, alleys and parking lots	●	●	●	●		●		●	●	●	●	●	●	●

European Commission

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

		Temporary and/or small-scale green structures														
I, P, R/S	Natural or semi-natural water storage and transport structures	Surface wetland Floodplains and floodplain reconnection with rivers Restoration of degraded waterways/ waterbodies Retention pond/wet detention pond	(•)	•			•				•	•	•		•	•
I, F, B, P	Infiltration, filtration, and biofiltration structures	Infiltration basin Bioretention basin/cell Rain garden Vegetated filter strip/(bio)swale Infiltration planters and tree boxes Subsurface (constructed) wetland or filtration system		•	•		•					•				

† *B=biofiltration; D=peak volume reduction via detention (temporary pool); E=evaporation/evapotranspiration; F=filtration; I=infiltration; Ins=insulation; P=pollutant removal or transformation; R=peak volume reduction via retention (permanent pool); S=storage, typically for later use; Sh=shade; W=windbreak.*

The UNaLab front-runner cities EIN, GEN and TRE have implemented NBS primarily to address issues associated with climate change and alterations to the local water cycle. The six main ecological services relevant to challenges identified by EIN, GEN and TRE and the associated 17 natural processes are outlined in Table 4. These natural processes or ecological principles are further related to NBS as grouped by form and function or mode of action and potential provision of ecosystem services in Table 5.

Table 4. Primary ecological services and associated natural processes relevant to challenges identified by UNaLab front-runner cities Eindhoven, Genova and Tampere

Ecological service	Natural process or ecological principle	UNaLab front runner-cities identifying relevant challenges†
Regulation of temperature (e.g., cooling)	Evaporation Evapotranspiration Shading	EIN, GEN
Regulation of water quantity	Water conveyance Water infiltration Water retention Water storage Water reuse	EIN, GEN, TRE
Regulation of water quality	Water filtration Water bioremediation	EIN, GEN, TRE
Regulation of air quality	Pollutant deposition Pollutant absorption and sequestration/ transformation	EIN, GEN
Provision of biodiversity	Habitat creation or restoration Enhancement of habitat connectivity	EIN, GEN, TRE
Cultural amenity value	Aesthetics Usability/ functionality Fostering social interaction	EIN, GEN, TRE

† EIN=Eindhoven (NL), GEN=Genova (IT) and TRE=Tampere (FI)

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Table 5. Nature-based solutions broadly grouped by form and function or mode of action, and the potential ecosystem services provided by each

<table>
<tr><th rowspan="2">NBS form</th><th rowspan="2">Description and Function</th><th colspan="3">Potential Ecosystem Services Provided (main processes or principles)</th></tr>
<tr><th>Provisioning Ecosystem Services</th><th>Regulating Ecosystem Services</th><th>Cultural Ecosystem Services</th></tr>
<tr><td>Green space</td><td>Multifunctional open space characterised by natural vegetation & permeable surfaces. May include (isolated) trees or woody vegetation in addition to open space. Intercept precipitation, increase infiltration and evapotranspiration, shallow depressions provide temporary water storage. This type of NBS can also contribute to the improvement of air quality and to the reduction of the urban heat island effect.</td><td>Provisioning:
• food (e.g., provided by community gardens, wild foods)
• genetic resources (habitat creation or restoration; enhancement of habitat connectivity)
• fresh water (water infiltration, retention, storage and/or reuse)</td><td>Regulating:
• air quality (pollutant deposition; pollutant absorption and sequestration/ transformation)
• climate (evapotranspiration, shading)
• water quantity (water conveyance, infiltration, retention, storage and/or reuse; evapotranspiration)
• erosion (water conveyance, infiltration, retention and/or storage; soil stabilisation)
• water quality (water filtration)
• pollination (habitat creation or restoration; enhancement of habitat connectivity)
• natural hazard (water conveyance, infiltration, retention and/or storage; soil stabilisation; evapotranspiration)</td><td>Cultural:
• spiritual and religious
• aesthetic
• recreation and tourism</td></tr>
<tr><td>Trees and shrubs</td><td>Natural or semi-natural systems including perennial woody vegetation. Function to intercept precipitation, increase evapotranspiration, provide shade, stabilise slopes, absorb gaseous pollutants, capture particulate pollutants, capture and store CO_2. Trees and shrubs can affect atmospheric dispersion patters in the cities changing local air quality and affecting human comfort.</td><td>Provisioning:
• food (e.g., provided by community orchards, wild foods);
• fibre (e.g., provision of timber, wood fuel);
• genetic resources (habitat creation or restoration; enhancement of habitat connectivity);
• fresh water (water infiltration)</td><td>Regulating:
• air quality (pollutant deposition; pollutant absorption and sequestration/ transformation)
• climate (evapotranspiration; shading)
• water quantity (water infiltration; evapotranspiration)
• erosion (rainfall interception; soil stabilisation)
• water quality (water filtration, e.g. through underlying soil)
• pollination (habitat creation or restoration; enhancement of habitat connectivity)
• natural hazard (water infiltration; soil stabilisation; evapotranspiration)</td><td>Cultural:
• spiritual and religious
• aesthetic
• recreation and tourism</td></tr>
<tr><td>Soil conservation and quality management</td><td>Soil conservation and quality management actions serve to reduce soil erosion, increase water infiltration, improve quality of surface runoff and receiving waterbodies, increase</td><td>Provisioning:
• food (e.g., crops, wild foods);
• fibre (e.g., timber, wood fuel);</td><td>Regulating:
• Erosion (soil stabilisation);</td><td>Cultural:
• aesthetic</td></tr>
</table>

	biodiversity of soil flora and fauna, mitigate climate change by through C sequestration and CO_2, CH_4 and N_2O emissions reduction, enable food and fibre production, and provide genetic resources. Vegetation can also provide food and habitat for pollinators.	• genetic resources (*habitat creation or restoration; enhancement of habitat connectivity*); • fresh water (*water infiltration, filtration and/or storage*)	• air quality (*pollutant absorption and sequestration/ transformation; soil particulate stabilisation)*; • climate; • water quantity; • water quality; • pollination; • natural hazard	
Blue-green space establishment or restoration	Vegetated area of land adjacent to a watercourse or waterbody. Function to slow overland runoff and reduce flooding, increase infiltration and hyporheic exchange, stabilize soil at land-water interface and reduce erosion, & filter particulate materials.	Provisioning: food (fisheries, wild foods); fibre (timber, wood fuel); fresh water (via filtration/infiltration); genetic resources	Regulating: air quality; climate; water quantity; erosion; water quality; natural hazard; pollination	Cultural: spiritual & religious; aesthetic; recreation & tourism
Green built environment	Structural (built) elements of the urban environment that incorporate vegetation in to their design to infiltrate, evapotranspirate and/or store rainwater, provide shade, and mitigate heat and pollution. Highly variable due to differences in structure, growth media & plant species/cover.	Provisioning: fresh water (via filtration/infiltration and rainwater capture); genetic resources	Regulating: air quality; water quantity; erosion; water quality; climate; pollination; natural hazard	Cultural: aesthetic
Natural or semi-natural water storage and transport structures	Natural or constructed waterbody that increases water retention capacity and reduces flow of overland runoff by providing water storage or conveyance & facilitates particulate settling. Enhances freshwater resources via infiltration through hyporheic zone. Provides natural habitat for wildlife, and a range of recreational opportunities.	Provisioning: food (fisheries/aquaculture, wild foods); fresh water (via filtration and/or infiltration through hyporheic zone), genetic resources	Regulating: water quantity; erosion; water quality; natural hazard; climate (via particulate/organic C capture)	Cultural: spiritual & religious; aesthetic; recreation & tourism
Infiltration, filtration, and biofiltration structures	Normally dry area, possibly associated with a watercourse, which slows overland runoff water velocity and provides increased water storage capacity (reduces peak flows). Natural physical, biological and chemical processes attenuate pollutants in runoff. Captured water may infiltrate surrounding soil or engineered media and subsequently intersect with groundwater, or filtered water may be discharged via a drainage system or spillway.	Provisioning: fresh water (via runoff capture & filtration and/or infiltration)	Regulating: water quantity; erosion; water quality; natural hazard; climate	

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Box 4-5: Towards drought resiliency in Genova (IT)

Genova is the capital of the Italian region of Liguria and the sixth largest city in Italy. Approximately 580 000 people live within the city's administrative limits, and the Metropolitan City of Genova is home to nearly 855 000 residents. Genova has historically been one of the most important ports in the Mediterranean region and its port is currently the busiest in the Mediterranean Sea.

A highly urbanised city, Genova is heavily impacted by extreme weather events such as excessive precipitation and subsequent flooding, periods of intensive droughts and heat waves, and by environmental challenges such as water and air pollution. Due to a local scarcity of green and blue public spaces, the Municipality of Genova (Comune di Genova) decided to reclaim the Gavoglio barracks area of Genova's Lagaccio district as a multifunctional green space. The neighbourhood surrounding the former barracks area is characterised by disorganised post-war urbanisation mainly formed by residential multi-story buildings with a high degree of surface sealing, contributing to local heat stress.

The reclamation project involved demolition of several barracks buildings and reuse of materials onsite wherever possible, unsealing of impervious surfaces and installation of new water storage areas and nature-based drainage/infiltration systems. The reclamation of the Gavoglio barracks area increases connectivity of the Lagaccio area to the 850-hectare Peralto natural park and creates biodiversity corridors, thus increasing the overall connectedness of green areas in Genova.

The reclaimed barracks area features NBS designed to address flooding, excessive heat and air pollution challenges. Implemented nature-based water retention measures are designed to mitigate the consequences of both flood events and prolonged periods of drought, including an underground retention basin for rainwater collection (artificial aquifer), wherein the collected water is stored and used for irrigation purposes as needed. Local air quality and excessive heating are addressed by the park's new rain gardens, green wall, forested areas, drought-resilient orchard and meadow areas. Rain gardens, bioswales and retention ponds aid in heat stress reduction through enhanced evapotranspiration and also serve as runoff reduction measures. Permeable surfaces were implemented as supportive measures for enhancing rainwater infiltration whilst facilitating emergency vehicle access to the park as needed.

Box 4-6: Advancements in urban flood management in Eindhoven (NL)

The City of Eindhoven has a population of 229 126 whilst the greater region of Eindhoven is home to approximately 750 000 people. The Eindhoven landscape is characterized by sand ridges and valleys formed by the Rivers Dommel, Tongelreep and Gender. The choice for a garden city model at the beginning of the twentieth century remains visible in 2020 and offers a solid concept for further development.

Eindhoven is facing many challenges due to climate change and the rapid population growth, from ca. 220 000 inhabitants in 2014 to an estimated 300 000 in 2030. Critical issues for the city, which are exacerbated by climate change, include flooding, urban heating, air pollution and loss of biodiversity. Rapid urbanisation has not been accompanied by a proportional capacity upgrade of the wastewater and stormwater collection systems has had detrimental consequences for the urban environment, including localised flooding and, on occasion, combined sewer overflows. The City of Eindhoven has selected several locations for NBS implementation, mainly in the city centre, that represent a range of different urban characteristics. The focus of the NBS demonstration in Eindhoven is on effective integration of blue (water), green (flora) and grey (built environment) areas, to provide a comfortable, safe and aesthetically pleasing living environment for citizens.

The main approach for reduction of overland flow and pluvial flooding in Eindhoven was the extensive removal of sealed surfaces to enable natural rainfall infiltration and runoff reduction. For example, locations with increased permeability include the City Hall area, Waagstraat and Bilderdijklaan streets and the Nutsbedrijven Regio Eindhoven (NRE; former electricity, heat and gas distribution company) site. The City Hall features a lightweight green roof due to the limited bearing capacity of the existing structure. The green roof ensures delayed discharge of rainfall runoff as compared with conventional rooftops, additionally providing co-benefits such as enhanced biodiversity, an equally important target in Eindhoven. The water retention system implemented in the vicinity of the City Hall temporarily retains stormwater from the roof and other parts of the City Hall square. Another important advancement is the development of the Clausplein Square, which was transformed into an urban green space. An underground water retention structure in the Clausplein Square allow for additional buffering capacity against storm events as well as water supply for the plants.

Envisioned future NBS developments in Eindhoven include river daylighting and requalification of existing green spaces as means to reduce runoff and promote other co-benefits, such as enhanced heat mitigation and increased urban biodiversity.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

4.6 NBS technical specifications

The *NBS Technical Handbook* (D5.1; Eisenberg & Polcher, 2018) was created in the beginning of the UNaLab project in 2018 by STU in an iterative process together with UAV, VTT, FHG and the front-runner cities. Its main objective was to provide front-runner cities with accurate information about potentially applicable NBS to support climate and water resilience, and therefore facilitate informed decision making during the NBS co-creation process.

Since the publication of UNaLab's *NBS Technical Handbook* in 2018, the EC has adopted a more robust definition of NBS with a greater emphasis on biodiversity. The EC currently defines NBS as follows (European Commission, 2020a):

> *'Nature-based Solutions to societal challenges are solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systematic interventions. Nature-based Solutions must benefit biodiversity and support the delivery of a range of ecosystem services.'*

The *NBS Technical Handbook* has been updated (Appendix II), as the definition of NBS has evolved and UNaLab project members have gained additional experience implementing and monitoring NBS. Additionally, a standalone new version of "*Nature-based Solutions, Technical Handbook Factsheets*" has been generated.

Rather than offer an exhaustive catalogue and summarise of all existing NBS, the *NBS Technical Handbook* aims to provide inspiration and easily-digestible information directed towards practitioners. Because of this focus on practitioners, the NBS Factsheets were originally organized according to planning and construction terminology. However, since the publication of the *NBS Technical Handbook* in 2018, a unified classification system for NBS has been adopted (Eggermont *et al.*, 2015), and it is used in other recent UNaLab Deliverables (see D3.1; Wendling *et al.*, 2019). Therefore, the NBS Factsheets are organized in this Deliverable at hand following the new classification system.

According to this new classification system, there are three main types of NBS that are categorized by function and increasing level of ecosystem intervention, with Type 1 involving the least intervention, and Type 3 the greatest amount of ecosystem intervention (Eggermont *et al.*, 2015). All NBS described in the Factsheets are Type 3 – highly intensive ecosystem management or the creation of new ecosystems. Type 3 NBS, and therefore the following NBS Factsheets, are further subdivided into seven main categories:

i. Green space
ii. Trees and shrubs
iii. Soil conservation and quality management
iv. Blue-green space establishment or restoration
v. Green built environment
vi. Natural or semi-natural water storage and transport structures
vii. Infiltration, filtration and biofiltration structures

For the D5.1 *NBS Technical Handbook*, each NBS Factsheet is presented in a consistent tabular layout, to ensure comparability between methods, general benefits and performances. Each NBS Factsheet is structured as follows:

i. Basic Information
   What kind of NBS is considered?
ii. General description
   What is it and what does it consist of?
iii. Role of nature
   How does it work? How is it inspired by or make use of nature?
iv. Technical and design parameters
   Which are the main technical/design considerations?
v. Conditions for implementation
   Which site conditions should be considered?
vi. Benefits and limitations
   How does it contribute to/limit urban ecosystems?
vii. Performance
   What is the performance of the NBS? (P: performance of NBS with regard to ecological services; P1: cooling service; P2: water regulation service; P3: water purification service; P4: air purification service; P5: biodiversity; P6: amenity value service.)

The updated factsheets of NBS technical specifications (Appendix II) mainly focus on the NBS and the supporting measures implemented in the UNaLab front-runner cities (Figure 7), and they are re-grouped according to the seven-category classification adopted in D3.1 and throughout this Handbook.

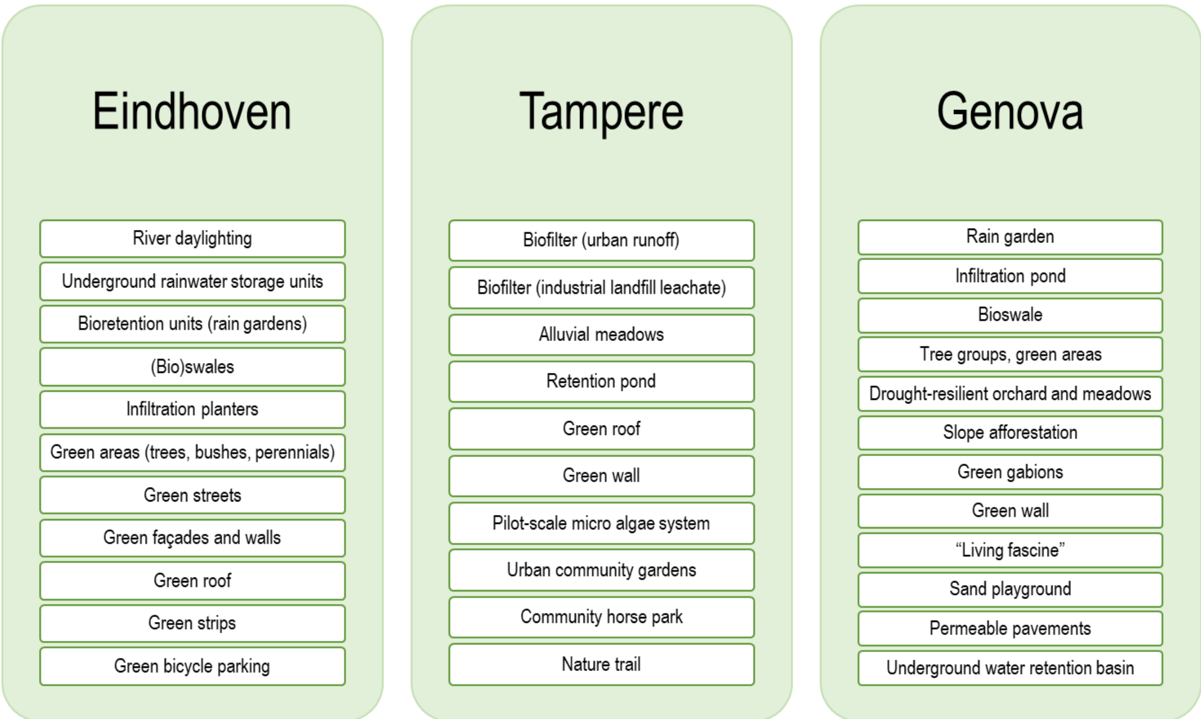


Figure 7. Nature-based solutions and supporting measures implemented in the UNaLab front-runner cities: Eindhoven (NL), Genova (IT) and Tampere (FI).

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Since the publication of the first NBS Technical Handbook, twelve categories have been identified (WP2) as challenge areas the FRC want to address with NBS. The most recently updated version of the Factsheets from the Technical Handbook (see Appendix II), consider if a particular NBS addresses seven out of these twelve challenges. The remaining challenges (Green space management, Place regeneration, Knowledge and social capacity building for sustainable urban transformation, Participatory planning and governance, and New economic opportunities and green jobs) are not intrinsic qualities of the NBS themselves, but dependent on the intention, creation process and management of the NBS, and are therefore outside the scope of the technical handbook.

The UNaLab project (WP3 and WP5) has developed a set of indicators for measuring performance of NBS in general, on the city and on the neighbourhood/project level (Wendling *et al.*, 2019). The general NBS indicators try to ascertain what can be measured in different cities to compare overall performance. For example, the indicator 'heat reduction' at the city scale is measured by the temperature difference between the inner city heat island effect and the surrounding rural areas. After implementation of the NBS, effectiveness can be measured by comparing the temperature difference of city and rural areas before and after implementation (see D5.1).

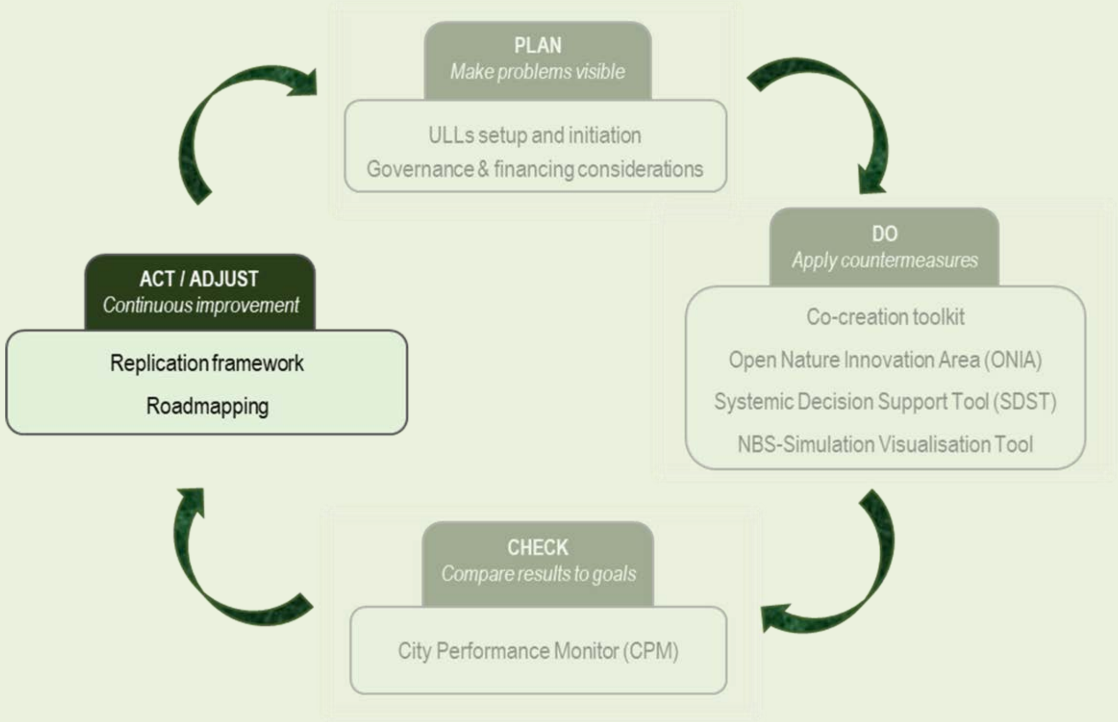
Evaluating the overall success of NBS in a city can be done with these performance indicators, however, a different form of evaluation is needed to identify differences between various NBS. Therefore, a detailed performance evaluation was created for the *NBS Technical Handbook*, based on ecological services and processes. Six relevant ecological services in terms of NBS performance (see P1–P6 above) with 18 specifications were selected for the performance evaluation. For example, ecological service P5 (biodiversity service) has two associated specifications: habitat provision and connectivity. While slightly different than the previously mentioned general indicators for measuring NBS performance, each of the services and specifications can be related back to the key performance indicators (Wendling *et al.*, 2019; Appendix I) at the city or neighbourhood level.

As NBS performance is dependent on the climate and geomorphological conditions (e.g., soil conditions, slope and aspect of a surface, etc.) of each city or even site, a location-specific evaluation of NBS considering all relevant factors would be ideal. However, this is not feasible for all three UNaLab front-runner cities and five follower cities for each permutation of conditions, and is outside the scope of the *NBS Technical Handbook*. Therefore, a panel of experts, following a general approach, evaluated the potential performance of each NBS in suitable conditions. The performance in those conditions is rated as *good* (1) or *very good* (2). It is also indicated if a performance criterion is *not applicable* (-).

The *NBS Technical Handbook* is fundamentally a 'living document' whose purpose and construction continued to evolve with the progression of UNaLab. For example, while its original intent was to provide information about potentially applicable NBS to front-runner cities, Inspiration Cards were developed from the NBS Technical Handbook and used in Road Mapping Workshops (WP6) to inform follower cities about NBS relevant to their identified challenges. Additionally, information from the NBS Technical Handbook was used in the production of the NBS Replication Framework Draft (D6.6, M24).

4.7 Roadmapping in UNaLab Follower Cities

Box 4-7: UNaLab tools for NBS replication for continuous improvement as part of the Adaptive Management (or, PDCA-) cycle



Replication Framework

The Replication Framework is a set of best practices developed throughout the UNaLab project to support NBS implementation in cities. In its final form, it will include the following key elements: municipal governance guidelines, ULL co-creation tools (see Box 4-1), SDST and linked tools (see Box 4-1) and an NBS Technical Handbook (see Section 4.5). The Replication Framework is developed as an iterative process and takes form of knowledge exchange between the UNaLab cities.

Roadmapping

Roadmapping is a part of the Replication Framework. During the roadmapping activities, the follower cities develop roadmaps envisioning the city development under the existing pressures. Inspiration Cards, which aim to inspire new ideas and enrich discussions within cities looking to adopt nature-based solutions, were developed from the work and findings in the project.

The roadmapping activities in the UNaLab follower cities (FCs) developed roadmaps for the future scenarios of cities exploring the ways of connecting the current situation to the vision of the city in a co-creative way. The UNaLab EU follower cities Başakşehir (TR), Cannes (FR), Castellón (ES), Prague (CZ) and Stavanger (NO), and the non-EU replication stakeholders Buenos Aires (AR), the network of Brazilian cities and Hong Kong (CN) are widely geographically distributed and represent differences in culture, urban structure, governance organisation and climate. The follower cities work together with the front-runners, focusing on the cities' individual NBS roadmaps. The activities have included training sessions, workshops, meetings and staff exchange.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

An NBS Replication Framework for the replication of NBS in follower cities has been developed within the UNaLab project. Barriers to NBS implementation have been addressed, and strategies, models, and frameworks for use by municipalities to overcome these barriers have been developed by and with the follower cities during the roadmapping process (Boxes 4-8 through 4-14; Den Ouden *et al.*, 2019; Den Ouden *et al.*, 2020). The UNaLab D5.1 *NBS Technical Handbook* (Eisenberg & Polcher, 2018) was used to identify suitable solutions as well as remaining needs.

The roadmapping activities emphasised the involvement of local stakeholders; workshops were held in the UNaLab follower cities to support each step of the roadmapping process. Stakeholder participation is essential for a lasting commitment to long-term cooperation and shared of responsibility throughout the implementation of co-developed plans.

The UNaLab roadmapping follows a five-step approach, including (Den Ouden *et al.*, 2019; Den Ouden *et al.*, 2020):

1. Systems Analysis
2. Ambition Setting
3. Vision Development
4. Replication framework
5. Roadmapping

The roadmapping beings with the *systems analysis* tool aiming at evaluating the 'point of departure' for the EU follower cities, including social, economic and environmental pressures, and barriers and opportunities in the local context. The tool enables stakeholder mapping and identification of the potential sites for NBS implementation. The *ambition setting* step comprises the ambition workshops involving stakeholders such as policymakers, internal and external stakeholders to develop an understanding of the ambitions and their context in each of the follower cities. The results are reported in a unified format to facilitate the knowledge exchange between the cities. The *vision development* phase aims at developing the ambitions into the specific scenarios, the input for which is collected via interviews with experts, visits to front-runner cities ULLs and the ambitions workshops. The future scenarios are developed in a series of workshops involving internal and external stakeholders. The last two steps, *replication framework* and *roadmapping*, build upon the previous steps. In addition, the *replication framework* builds upon other UNaLab knowledge, e.g., the *NBS Technical Handbook*, *Municipal Governance Guidelines* and *Business Models and Financing Strategies*, the outcomes of which are presented in the form of 'inspiration cards' serving as guidance for NBS identification and implementation. *Roadmapping* summarises and builds upon the knowledge generated in the previous steps by creating the roadmaps for each follower city, including opportunities in the short-, mid- and long-term planning.

Box 4-8: Roadmapping activities in Prague (CZ)

The City of Prague has population of around 1.27 million people, concentrating approximately 12% of the Czech population. Another 300 000-400 000 people commute to Prague daily for work, study, treatment or tourism. Prague faces a challenge in flood adaptation in the urban areas and air quality improvement. The city has extensive historical protected areas and many protected natural parks and monuments. Prague has a good water quality and has been revitalising small water courses, ponds, orchards and parks. The city aims to address their challenges by implementing NBS such as expansion of the green spaces and improving water infiltration. To address air quality, the city has developed public transportation systems and has increased number of green spaces and the amount of trees in the public spaces. In the ambitions workshop, Prague identified the opportunity to increase awareness of the NBS concept and to develop a value model for Prague's ecosystem services.

Box 4-9: Roadmapping activities in Stavanger (NO)

The City of Stavanger is the fourth largest city of Norway and the country's most densely populated municipality with ca. 133 000 inhabitants. Together with surrounding municipalities Sandnes, Sola and Randaberg, Stavanger represents the country's third largest urban area with around 300 000 inhabitants. Stavanger is a coastal town, with nearly 170 yearly days of rain that lead to stormwater and flooding issues. An increase in rainfall and sea level rise is foreseen due to the effects of climate change. The city has already transitioned to the use of alternative solutions for climate change adaptation and the use of NBS will aid in increasing the urban resilience of already developed areas. The city envisions that the project outcomes will increase awareness of the importance of climate adaptation within the municipality and amongst the policy makers.

Box 4-10: Roadmapping activities in Başakşehir (TR)

The City of Başakşehir is one of 39 second-level districts of Istanbul. The population is estimated to grow from ca. 340 000 in 2014 to ca. 800 000 in 2020. The city is experiencing rapid population growth and related environmental pressures, such as heat stress, pollution, biodiversity loss and water scarcity. Başakşehir aims at improving the citizens' quality of life by providing the highest quality of public services. The city envisions to become a green city by 2050; Başakşehir's primary focus in UNaLab is on the implementation of public green spaces and NBS to reduce energy consumption and CO_2 emissions, and mitigate climate change effects in the city, additionally focusing on recycling and treating 100% of wastewater.

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Box 4-11: Roadmapping activities in Cannes (FR)

Cannes is a city of 75 000 inhabitants in the south of France, which triples its population in summer or during major events such as the international film festival. Cannes is a town particularly exposed to frequently occurring natural hazards: flooding due to overflowing rivers, urban runoff, coastal flooding, forest fires, shrinking-swelling clay and landslides. For Cannes, NBS seem to be the best solution to prevent the devastating effects of these risks, and allow the city to become more resilient. Integrated stormwater management solutions and community rooftop gardens are some of the key elements of Cannes' current strategy to improve urban living. Cannes aims to improve risk mitigation by taking into account specific topography and climate of the town in urban planning. The new urban plan preserves the natural and historical districts of the city (no new buildings allowed there) and develop the density in other districts to support their re-qualification.

Box 4-12: Roadmapping activities in Castellón (ES)

The City of Castellón has almost 200 000 inhabitants and is situated at the east coast of Spain. Castellón is highly affected by climate change through flooding due to rising sea level and heavy rains. Castellón has an objective to reduce energy consumption and increase energy efficiency while maintaining the quality of life and the future opportunities in the city. Castellón aims to employ a range of NBS in planned landscape-scale integrated urban water management using the roadmap developed during the UNaLab activities. Castellon is aiming to become a Green city, aiming to increase biodiversity, green economy, blue economy and circular economy. Castellón has defined a structural urban plan based on the existing and future green infrastructure and aiming to protect wetlands. Castellón is testing pilots to improve sustainable drainage and water management and is also starting to implement solutions to re-use water for public services and intelligent irrigation of green areas.

Box 4-13: Roadmapping activities in Hong Kong (CN)

Hong Kong is the fourth most densely populated area in the world with over 7.4 million people inhabiting 1 104 km^2. The city is regularly exposed to seasonal air pollution and other environmental challenges, such as water scarcity, flooding, biodiversity loss and climate-driven health issues. The Hong Kong city centre forms a dense urban area with numerous skyscrapers. Despite the densification and intensive urbanisation, the city strives to promote greening of the city environment focusing on implementing stormwater retention ponds, permeable pavements and green spaces and façades. That will enable the green and grey infrastructure integration promoting the improved urban drainage and stormwater harvesting to further address water scarcity in the city.

Box 4-14: Roadmapping activities in Buenos Aires (AR)

Buenos Aires is a capital and largest city of Argentina with almost three million inhabitants (and almost 16 million in the Buenos Aires Metropolitan area). Buenos Aires constitutes a large economy, with extensive agricultural and industrial activities outside the city limits. The city faces several climate-change related challenges, such as flooding, biodiversity loss, pollution and densification. To address them, the city strives to implement NBS such as green façades, street trees and green spaces. Since Buenos Aires is situated in the low-lying area with frequent rainfall events, it is envisioned to implement NBS aiming at flood control and stormwater management, including permeable pavements and green spaces.

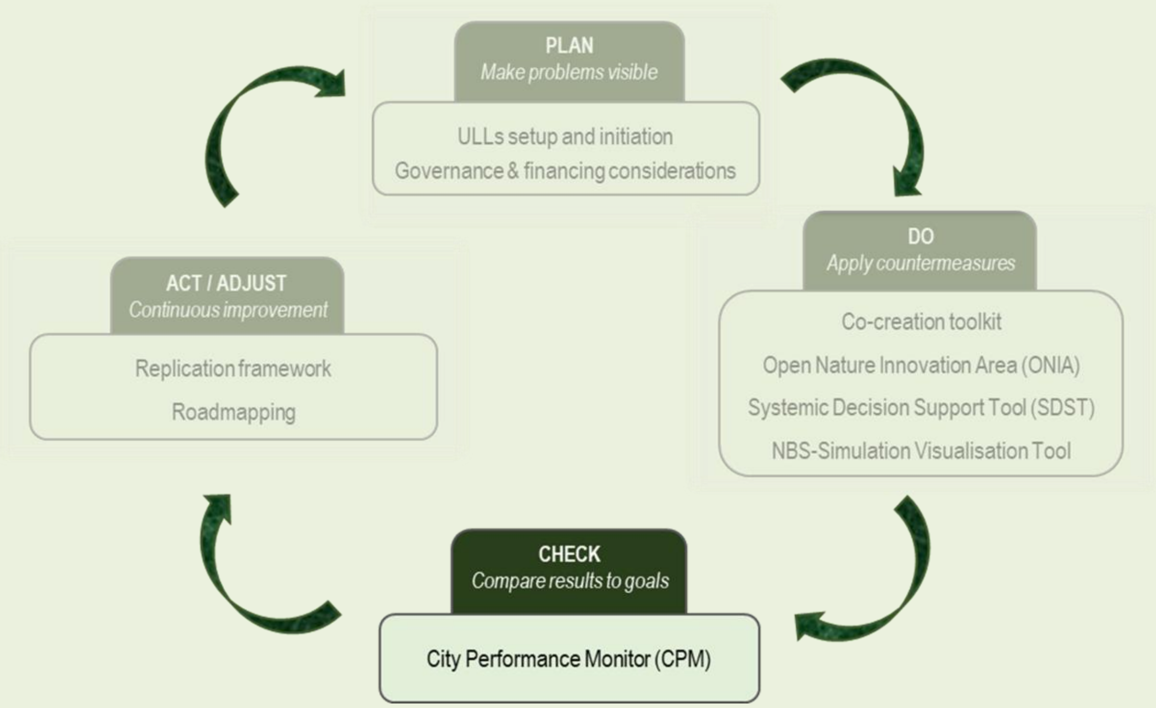
As highlighted in Den Ouden *et al.* (2020),

> *'The results [of the roadmapping activities] are comprehensive roadmaps for NBS replication (one per follower city) tailored to the specific context of each city and describing a set of projects to be implemented. These projects are placed on a timeline to provide insight into the required steps, together with a set of clear milestones towards the desired future scenario.'*

The reader is referred to UNaLab D6.5 *Visions of UNaLab Follower Cities* (Den Ouden *et al.*, 2019) and D6.7 *Replication Roadmaps for UNaLab Follower Cities* (Den Ouden *et al.*, 2020) for additional information about the NBS roadmapping in the UNaLab follower cities.

5 NBS MONITORING AND IMPACT ASSESSMENT

Box 5-1: UNaLab tools for NBS impact assessment for meeting the targets and objectives as part of the Adaptive Management (or, PDCA-) cycle



City Performance Monitor (CPM): https://unalab.eng.it/cpm_v2/

CPM aims to facilitate the participatory planning process along the NBS co-creation process synthesising and presenting environmental and social indicators in a manner that can be used readily by a wide range of individuals, including citizens and non-expert users. In CPM, it is possible to track the progress towards the goals and objectives set during the co-creation and target setting phases of NBS implementation. Evidence generated thanks to CPM can be used for informing decision-making and securing the future investments for the NBS replication.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

5.1 Purpose of monitoring

Box 5-2: Monitoring of the nature-based solutions in a nutshell

Monitoring of nature-based solutions (NBS) comprises several steps that are equally important for the development of a holistic monitoring strategy. Once the NBS have been (co-)defined, these steps include the identification and development of the baseline and the representative key performance indicators, accounting for the scale of impact, which will dictate the monitoring scale. After the scale, at which the impact will be most visible, has been defined, the data acquisition mode considerably influences the ability to capture the impact in terms of its temporal and spatial resolution, and granularity. The evaluation framework determines the thresholds and the overall evaluation scheme of the NBS performance and impact.

A simple 'recipe' outlining a successful monitoring strategy can be presented as:

In times of rapid urbanization and anthropogenic climate change, urban areas face an increasing number of extreme weather events and other environmental burdens such as water and air pollution. NBS are associated with distinct impacts on ecosystem services and improvement of a range of environmental aspects hindered by urban growth (Figure 1). However, a selection of NBS to address the identified challenges and pressures (Table 2, Table 3, and Table 5) should prove its impact and indicate whether the anticipated outcomes are achieved, including monetary and environmental targets, to consolidate the future investments into wider NBS implementation. Monitoring is one of the central factors determining the success of the NBS impact assessment as it provides quantitative and qualitative evidence of the impact generated by the NBS interventions (Raymond *et al.*, 2017).

NBS monitoring involves a collection of measurements used for assessing the state of environment and subsequently the change that signifies either its degradation or restoration. Prior to monitoring, goals and data analysis methods must be well defined to ensure accurate monitoring and understanding of physical, chemical and biological variables and processes occurring in the studied environment (Figure 8). Sampling protocols should be defined by the unique characteristics of each environment being assessed within the scope of the project (Pepper, Brusseau, & Artiola, 2004).

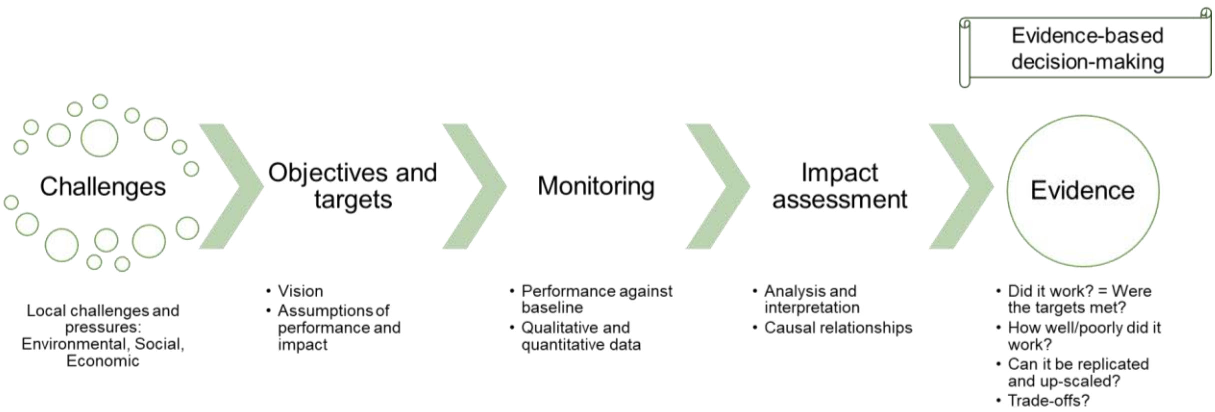


Figure 8. From challenges to evidence: setting targets and aligning monitoring activities to generate evidence of NBS performance and impact leading to evidence-based decision-making.

However, monitoring solely the NBS performance is usually not sufficient to ensure the most holistic evaluation. It is equally important to establish baseline (pre-NBS) measurements for understanding the reference conditions and quantifying the actual impact, i.e., the change, further refining the NBS design (Strosser *et al.*, 2015). Ideally, the baseline measurements should be ongoing prior to NBS implementation. Nevertheless, in cases, when the baseline measurements are not available from the area of interest, a similar reference area without NBS can be employed as a "baseline". Naturally, the latter approach has its limitations, including the impossibility of a reference site to have the same exact conditions and, thus, a comprehensively observed contrast. The baseline data can additionally be derived from spatial and non-spatial historical and statistical data (see Section 5.2.2), although special attention should be given to data resolution (both spatial and temporal) and its granularity to obtain comparable measurements and assessments (see Section 5.2.3). However, the historical data may be variable, and its spatial and temporal resolution may not suit the needs or be inconsistent within a single urban area. To overcome these complications, data modifications and aggregations may be necessary.

Individual NBS may have multiple (co-)benefits on various aspects of a city environment, and their performance may be affected by a range of different attributes based on the initial design and implementation. For an NBS, considering the scale of impact versus the scale of intervention (see Section 5.2.3) has a considerable impact on answering the question whether that particular NBS addresses the identified urban challenges, and whether future investments are feasible and provide multiple (co-)benefits compared to investments into conventional grey infrastructure (Raymond *et al.*, 2017).

For the NBS to become a widespread feature in the urban environments, it is critical to generate evidence of NBS performance and impact through informed monitoring activities. The following chapters describe the process of establishing monitoring for NBS interventions, briefly covering the selection of indicators but thoroughly describing the actual implementation of the monitoring schemes and evaluation of outcomes of the monitoring efforts.

5.2 Establishing NBS monitoring

5.2.1 Selecting appropriate indicators

Many NBS interventions generate impact on local to sub-local scale. The impact can be assessed quantitatively and/or qualitatively by adopting Key Performance Indicators (KPIs) – a set of variables providing the means to assess particular attributes to meet an explicit objective. Identification and selection of specific KPIs to assess NBS performance is an intricate process of NBS implementation due the vast selection of potential indicators and their specific metrics. Prior to initiation the discussion with the stakeholder groups, it may be beneficial to limit the number of indicators by assembling a local expert group, who are familiar with the local challenges and pressures and who will recommend a narrowed list to further the discussion

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

(Figure 9). A number of frameworks exist from which it is possible to extract relevant indicators, such as:

- NBS impact evaluation framework developed by the EKLIPSE Working Group on Nature-based Solutions to Promote Climate Resilience in Urban Areas (Raymond *et al.*, 2017);
- Mapping and Assessment of Ecosystems and their Services-Urban Ecosystems technical report and indicator framework (Maes et al., 2016; Maes, Zulian, Günther, Thijssen, & Raynal, 2019);
- CITYkeys assessment framework for smart city projects and smart cities (Bosch *et al.*, 2017; Huovila *et al.*, 2017);
- Global indicator framework for UN Sustainable Development Goal 11 'Make cities and human settlements inclusive, safe, resilient and sustainable' (United Nations General Assembly, 2015, 2017; UN-Habitat *et al.*, 2016);
- Key environmental indicators identified by the Organization for Economic Development and Co-Operation (OECD) (OECD, 2008); and,
- Various other NBS evaluation schemes and assessment frameworks published in the scientific literature (e.g., Calliari, Staccione & Mysiak, 2019; Faivre, Sgobbi, Happaerts, Raynal, & Schmidt, 2017; Kabisch *et al.*, 2016; Nel, du Plessis & Landman, 2018; Wendling, Huovila, zu Castell-Rüdenhausen, Hukkalainen, & Airaksinen, 2018)

Figure 9. Schematic representation of NBS performance and impact indicator and metric selection.

The UNaLab Deliverable D3.1 *Performance and Impact Monitoring of Nature-Based Solutions* (Wendling *et al.*, 2019) introduces a list of nearly 400 potential KPIs for the NBS performance and impact assessment. The updated version of D3.1, as a part of the present Handbook (Appendix I), presents several additional indicators and the supplementary details for the previously identified indicators relevant for NBS monitoring and impact assessment. Careful matching between the anticipated NBS impacts and KPIs selection is crucial for securing the holistic NBS performance evaluation.

The process through which NBS are co-created, co-implemented and co-managed with stakeholders is equally as important as the environmental, social and economic outcomes achieved. Indicators selected to evaluate NBS outcomes should, therefore, include a mixture of both outcome-based and process-based indicators. The indicators of NBS performance and impact employed in UNaLab partner cities can be classified as structural, process or outcome based (Donabedian, 1966) indicators to support the selection of a tailored suite of different NBS indicators specific to a given NBS implementation that holistically address the the process of NBS co-creation, co-implementation and co-management. The three basic classes of indicators are:

- Structural indicators (S) – refer to all the factors that affect the context in which NBS are implemented. This typically includes the supporting infrastructures and resources in place to achieve the desired goals (e.g., physical facilities, equipment, human resources, organisational characteristics, policies and procedures).
- Process indicators (P) – refer to the actions that are involved in NBS co-creation, co-implementation and co-management. These indicators are used to assess the efficiency, quality, or consistency of specific procedures employed to achieve the desired goals.
- Outcome indicators (O) – refer to all the effects of NBS. These include social, enviromental and economic effects or impacts. Outcome-based indicators comprise the greatest proportion of the indicators presented in Appendix I.

Indicators of NBS performance and impact presented in Appendix I are grouped by the respective societal challenge area they address. At the beginning of each indicator section, tables indicate the class of each indicator (i.e., structural, process or outcome based) and also show the applicability of each indicator to different types of NBS. Nature-based solutions can be broadly grouped based upon their primary objective or function and by the level of ecosystem intervention, as previously described in UNaLab Deliverable 3.1 (Wendling *et al.*, 2019). In summary:

- **Type 1 NBS** – minimal or no intervention in ecosystems, with objectives related to maintaining or improving delivery of ecosystem services within and beyond the protected ecosystems
- **Type 2 NBS** – extensive or intensive management approaches seeking to develop sustainable, multifunctional ecosystems and landscapes in order to improve delivery of ecosystem services relative to conventional interventions
- **Type 3 NBS** – characterised by highly intensive ecosystem management or creation of new ecosystems

Practitioners are advised to utilise the tables preceding each group of indicators in Appendix I to ensure the selection of an appropriate suite of indicators for the holistic assessment of both the processes involved with and outcomes achieved by NBS interventions.

5.2.2 Means of data acquisition

Once the monitoring scheme is defined and set, establishing the appropriate data acquisition means will ensure careful data collection at relevant scales. A number of data acquisition options exist that could be employed for NBS performance and impact monitoring. In this Handbook, they are presented as the broad major categories comprising remote sensing and earth observations, ground (*in situ*) observations, statistical and legacy datasets, and citizen science. These monitoring means produce reliable quantitative and/or qualitative data only when applied at appropriate scales and periods of time (see Section 5.2.3).

Varying data outputs from a multitude of the data acquisition means provide ample evidence of the NBS impacts, if the data produced meets the certain conditions. Data granularity is one of the most critical parameters for the successful evaluation of the NBS performance and impact. Depending on the dimensioning relevance, it allows to identify the effectiveness of an implemented solution, or it can impede the achievement of the project goals by generating futile outputs. Granularity indicates the level of details expressed by each observation, and the levels of data aggregation in a dataset. Examples of aggregation relevant to the NBS monitoring include but are not limited to:

- Temporal aggregations: year, month, minute
- Spatial aggregations: hectares, kilometres, metres
- Geographic aggregations: world, region, country, city, street

Fine granular data (low level of aggregation) provides more details than coarse granular data (high level of aggregation) making it more suitable for the research and decision-making. In fact, the greater amount of fine-granular data generated permits to focus better on the challenge being addressed (i.e., flooding, heat islands, service inefficiency), making the correlation between causes and effects more discernible. To obtain a reliable evaluation, the granularity of all the different data acquisition means must match the scale of the impact of the NBS interventions. The parties deciding on the acceptable granularity and the correct aggregation should rely on their experience when considering the variability of the monitored phenomenon and the level of details required for the performance evaluation. Table 6 presents a non-exhaustive set of examples of the possible granularity ranges for the NBS impact evaluation.

Box 5-3: On data outputs.

Granularity is different from *accuracy*, the degree of correctness of the outputs with respect to the true value, and from *precision*, the accuracy when the observations are repeated.

Instead, *resolution* is a specification of *granularity*, and it indicates the size of the minimum unit/area in a data output (e.g., spatial data).

Table 6. Examples of possible data granularity associated with the NBS monitoring.

Challenge	Exemplar parameter	Possible data granularity
Urban heat	Minimum and maximum temperature recorded in an urban area	Acceptable granularity: • Fine grain: 30 minutes • Medium grain: 60 minutes • Coarse grain: 180 minutes Erroneous granularity: • Over-sampled: second, millisecond • Under-sampled: on daily scale no changes can be observed
Flooding events	Number of the flooding events per year	Acceptable granularity: • Fine grain: 1 day • Medium grain: 5 days • Coarse grain: 30 days Erroneous granularity: • Over-sampled: minute, second, millisecond • Under-sampled: on yearly scale no changes can be observed
Green areas in the city	Density of green spaces in an urban area	Acceptable granularity: • Fine grain: 10 m^2 • Medium grain: 200 m^2 • Coarse grain: 1 km^2 Erroneous granularity: • Over-sampled: centimetre, millimetre • Under-sampled: 30 km^2

It is critical to define the correct level of aggregation of the measures for both time (temporal granularity) and location (spatial resolution) to accurately evaluate the NBS performance and impact.

a) *In situ* observations

In situ observations and measurements are the most widespread means of data acquisition. They provide the most reliable and accurate measurements if applied to the collection of the environmental constituents, such as those related to biodiversity, water and air quality. *In situ* data acquisition comprise manual and automated sampling, the advantages and limitations of both approaches are described in Section 5.2.4. The fine-grain and high-resolution local monitoring sensors are more suitable to record the changes required to evaluate the impact of an NBS.

b) Statistical and legacy datasets

Statistical and legacy datasets comprise a collection of datasets gathered by a city or a municipality over a prolonged time period prior to NBS implementation. The datasets may include measurements of environmental constituents, such as air and water quality, or economic and demographic records and changes. Statistical data can be employed for the baseline data collection and assessment of the pre-NBS conditions. Special considerations should be made regarding the spatial and temporal scales of datasets and their granularity as it may lead to ambiguous or erroneous results and conclusions. At times when statistical and legacy data have varying granularity, aggregation of data points may be deemed necessary. It should be noted that aggregation (scaling up) of data points often excludes the element of randomness (unlike dis-aggregation, or downscaling), but it nevertheless should be applied cautiously to avoid the statistical issues and heterogeneity of the outcomes (Scholes *et al.*, 2013).

c) Remote sensing and earth observations

Earth observation approaches, including aerial- and satellite-based monitoring, provide sound evidence of ecosystem changes on a larger scale. Satellite-based monitoring produces images of low spatial resolution (30–300 m), i.e., the amount of pixels included in the image that is determined by the ability of a sensor to detect details of complex environments. Low spatial resolution sensors produce adequate results at large scales, although they are incapable of capturing greater amount of details as high spatial resolution outputs (<30 m).

Coarse-grain data and low spatial resolution datasets, such as those originating from satellite sensors, are suitable only for having an overview of the context without information about a specific aspect or dynamic. High resolution data that can be produced by remote sensing, e.g., LiDAR, is essential for characterisation and interpretation of complex environments and models, as example the urban flood and hydraulic studies of river and floodplain interactions where topographic details significantly influence the flow path interactions with the underlying terrain (Krebs *et al.*, 2014; Mason *et al.*, 2007).

However, given the low resolution of a large extent of the spatial data, it is a valuable asset for generating knowledge about the ecosystem changes. For example, spatial observations are capable of capturing the extent of extreme events, such as floods and wildfires. EU-wide spatial datasets, such as those provided by Copernicus Earth Observation and Monitoring Programme, are capable of providing information on, for example, changes in land uses, agricultural practices and forest dynamics, and climate-related datasets, such as Earth's surface albedo

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

(sunlight reflected by the Earth's surface) on global and pan-European scales (European Parliament, Council of the European Union, 2014; https://www.copernicus.eu/en).

The Copernicus Land Monitoring Service produces multiple datasets, including those on land cover, energy and water cycle, in spatial resolutions ranging from 100 m (medium) to >1 km (coarse) and near-real-time temporal resolutions of 10 days (Copernicus Global Land Service, n.d.; Taramelli *et al.*, 2019). However, the pan-European and global datasets at high spatial resolution (<30 m) are being developed (Copernicus Land Monitoring Service, 2020; Pekel *et al.*, 2016).

The pan-European scale appears advantageous for inter-regional data collection and comparability since the adoption and subsequent updates of NUTS (Nomenclature of Territorial Units for Statistics), the official division of the EU, UK and several additional countries into specific territorial units (Statistical Office of the European Union, 2020). Table 7 lists several EU-wide databases and open datasets that could be employed for various needs. The major worldwide databases include those of OECD (https://data.oecd.org), FAO (http://www.fao.org/statistics/databases/en), the United Nations (http://data.un.org), and the World Bank (https://data.worldbank.org).

Table 7. A few EU-wide open databases and datasets.

Database	Brief overview	Web source
EU Open Data Portal	The EU Open Data Portal contains publicly available data on multiple domains, including health, energy, environment and other, from the EU institutions and other EU bodies, including European Commission, European Parliament and others.	https://data.europa.eu/euodp/en/home
Infrastructure for spatial information in Europe (INSPIRE) Knowledge Base	The INSPIRE Knowledge Base was developed as a result of the adoption of the INSPIRE Directive (2007/2/EC) that aims at developing an EU-wide spatial data infrastructure and common standards for 34 spatial data themes (e.g., administrative units, transport networks) for the transboundary usability. The Knowledge Base comprises of datasets on multiple environmental domains, e.g., air, water, noise and waste, and on protected sites, geology and habitats, and many more.	https://inspire.ec.europa.eu
Copernicus services (European Union's Earth Observation Programme)	The Copernicus services provide near-real-time data from the Sentinel-family satellites and *in situ* measurements for marine, land, atmosphere, climate change and emergency management domains.	https://www.copernicus.eu/en/access-data/conventional-data-access-hubs
	CORINE Land Cover developed by the Copernicus services is a pan-European land cover inventory consisting of 44 land use classes (from 1990 to date). The dataset includes the land use change for the periods of 1990–2000, 2000–2006, 2006–2012, and 2012–2018.	https://land.copernicus.eu/pan-european/corine-land-cover

	Urban Atlas developed by the Copernicus services provides the pan-European land cover and land use for the 17 urban classes the Functional Urban Areas including the street tree layer and the building heights for the core urban areas. The dataset includes the land use change for the periods of 2006–2012 and 2012–2018.	https://land.copernicus.eu/local/urban-atlas
Eurostat	Eurostat is the Statistical office of the European Union that provides the EU-wide statistical data (at times aggregated from several data providers) on a variety of topics such as demographics, unemployment, circular economy and economic status, science and environment. The regional statistics follow the NUTS regional division.	https://ec.europa.eu/eurostat/data/database
Climate-ADAPT platform	Climate-ADAPT is the European Climate Adaptation Platform maintained by the EEA targeting the climate change adaptation support for the EU. The platform features the adaptation case studies and adaptation strategies for the whole EU, and national and transnational regions.	https://climate-adapt.eea.europa.eu/#t-database
European Environmental Agency (EEA) data and maps	The EEA provides data and maps on the environment for science-based policymaking and policy evaluation. The EEA service additionally provides interactive maps and data viewers, e.g., for state of bathing waters and climate change impacts. The EEA additionally contributes to the Copernicus service and the Climate-ADAPT platform.	https://www.eea.europa.eu/data-and-maps
Joint Research Centre (JRC) Data Catalogue	The JRC Data Catalogue includes a compilation of more than 2000 datasets for a multitude of science areas, including environment, nuclear safety, innovation, and safety. The JRC constantly produces new datasets to inform the EU-level science-based policies.	https://data.jrc.ec.europa.eu

Spatial data collection has a considerable advantage for assessing the changes at larger scales, i.e., city- or regional-scale; remote-sensed data collection can be applied for obtaining better outputs at finer scales. In addition, both methods have a potential to be employed for and complement the baseline data collection and pre-NBS assessment when combined and compared (i.e., validated) against the ground-based (*in situ*) monitoring (e.g., Orgiazzi *et al.*, 2017; Statistical Office of the European Union, 2019).

d) Citizen science initiatives

Citizen science initiatives are an evolving field aiming at engaging the public, who have not been trained for collecting or analysing the scientific data, into scientific activities through the environmental and ecological monitoring. Citizen science projects bridge the gap between science and citizens, contributing to knowledge production and increasing citizens' awareness

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

through voluntary participation, which should be designed in an intentional and transparent manner (Dickinson, Zuckerberg, & Bonter, 2010; Shirk *et al.*, 2012). The latter is a prerequisite for adoption of the citizen science approach, prior to which the volunteer motivation, precise aims, resource availability (to support the project and volunteers), sampling extents and scales, and the complexity and practicality of the sampling protocols must be evaluated to ensure that citizen science "fits the purpose" of one's project (Pocock *et al.*, 2014).

Instead of purely environmental education, it sets multiple shared goals, such as collection of scientifically valuable information, what additionally sets a solid agenda for attracting and retaining the participants (Dickinson & Bonney, 2012), although the interests of researchers and participants may diverge (Hecker *et al.*, 2018; Shirk *et al.*, 2012). Shirk *et al.* (2012) note that public involvement in the scientific research generally endeavours to achieve the outcomes that fall into three major categories: producing the scientific findings, generating new skills or knowledge, and/or influencing policies and decision-making. It is further recognised as one of the actions that is capable of fostering the 'Open Science' framework, involving the open access of the research results (European Commission, 2016), as citizen science implies that the scientific findings are made public (Hecker *et al.*, 2018).

Although citizen science is a broad field with projects ranging from being contributory (led by professionals) to collaborative and co-created (participant-driven) (Bonney *et al.*, 2009), it provides the means for collecting data at greater spatiotemporal extents and finer resolutions, and in a more cost-effective manner than the traditional scientific approaches (Dickinson & Bonney, 2012; Gardiner *et al.*, 2012; Shirk *et al.*, 2012). Naturally, the drawbacks of the citizen science approach include the challenges in participant retention (Dickinson *et al.*, 2012), the reliance on the data acquisition means beyond one's control and subsequent challenges with validating the data quality, and the need for data collection in a controlled way, e.g., by establishing an online database (Pocock *et al.*, 2014).

Error and bias in the citizen science data collection have been associated with the training received, complexity of sampling protocols and labour-insensitivity of the sampling efforts, age of the participants, and the previous experience in similar initiatives. Bias in environmental and ecological studies adopting citizen science can be diminished by the appropriate training, development of clearer protocols (Dickinson & Bonney, 2012), larger number of samples (Gardiner *et al.*, 2012), and by adopting more advanced statistical analyses (Dickinson, Zuckerberg, & Bonter, 2010; Pocock *et al.*, 2014). These challenges, however, drive forth the development and build the capacity in citizen science by creating and integrating the new ways of data interpretation, analysis and collection (Bonney *et al.*, 2014; Hecker *et al.*, 2018).

5.2.3 Considerations for monitoring scale and frequency

The most important, and arguably the most complex element of designing the NBS monitoring schemes is determining a realistic potential scale of impact. Considerations of the scale of NBS monitoring and the frequency of recorded intervals are of outmost importance due to their effect on the quality of monitoring efforts. Ranges of scales at which KPIs can be observed and quantified vary substantially, and usually the overall visibility of impacts associated with certain NBS are scale-sensitive. Often, the scale of NBS interventions do not match the scale of either economic, social or environmental impact, so assessing the realistic scale of impact based on the scale of the NBS implemented will determine the need for additional monitoring efforts, e.g., the number of monitoring stations or field surveys. It should be noted that the monitoring efforts should match the available monetary and personnel resources.

Box 5-4: On monitoring scales.

The choice of scale and resolution/granularity is subjective and is typically informed by prior experience, but they should not be selected arbitrarily or haphazardly (Scholes *et al.*, 2013). Careful considerations for the suitability of scales and their interactions will produce the most reliable outcomes.

Owning the viable attribute of the nature-based solutions in delivering the environmental, social and economic benefits, and a multitude of ecosystem services, a single-scale evaluation may not suffice the assessment of the cross-scale interactions between the ecosystem components (Faehnle *et al.*, 2015). A multi- and/or cross-scale assessment enables identification of trade-offs, interactions between spatial and temporal scales of the studied phenomena, and understanding the relationship and patterns between parts of a larger "system" at various spatial and temporal scales (Scholes *et al.*, 2013; Kremer *et al.*, 2016).

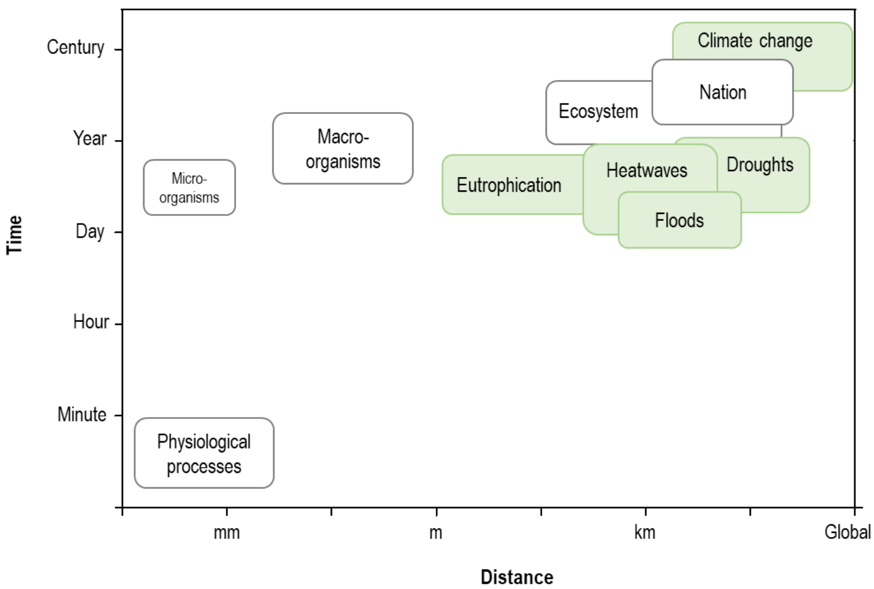


Figure 10. Exemplar temporal and spatial characteristics of processes relevant for NBS monitoring (adapted from Scholes et al., 2013). White boxes denote changes in ecological and social entities; green boxes denote environmental pressures.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

When an indicator can only be measured at a sub-local scale, multiple measurements can be combined to yield information on a broader scale (Raymond *et al.*, 2017). Alternatively, modelling can provide approximations and projections for a larger scale or various modifications. However, the *in situ* monitoring should be adopted as the main means of data collection; and the models should be validated against real measurements whenever possible to provide the realistic estimates. Table 8 provides a comprehensive but not exhaustive list of scales at which it would be possible to capture the anticipated impacts of the NBS interventions. The spatial scales division adopted therein (Table 8) include:

- Micro (fine scale)
    - Plot/NBS site
    - Building
- Meso (medium scale)
    - Street
    - Neighbourhood/district
- Macro (large scale)
    - City
    - Municipality
    - Region

Here, the 'monitoring scale' denotes the spatial extents at which the impact of the NBS interventions is measured and/or captured; the 'scale of NBS interventions/implementation' or 'small/large-scale NBS' denotes the spatial distribution (i.e., size) of the NBS interventions. The reader is referred to the Deliverable D3.1 *Performance and Impact Monitoring of Nature-Based Solutions* (Wendling *et al.*, 2019; Appendix I) for the detailed descriptions of environmental, social and economic indicators and their monitoring scale that aid in assessing the NBS performance and impact.

Table 8. Recommendations for appropriate scales for NBS monitoring. Micro-scale denotes plot/NBS site and building scales; Meso-scale denotes street and district/neighbourhood scales; Macro-scale denotes city, municipal and regional scales.

NBS category	Variations of NBS form	Suitable monitoring scales (spatial)†									Rationale
		Environmental indicators			Social indicators			Economic indicators			
		Micro	Meso	Macro	Micro	Meso	Macro	Micro	Meso	Macro	
Green space	Urban parks and gardens of all sizes Heritage park Botanical garden Community garden Cemetery Schoolyards and sports fields Meadow Green strips "Multifunctional" dry detention pond or vegetated drainage basin	X	X	(X)	X	X	X	(X)	X	X	Environmental: The performance of the grassed units and urban gardens for surface runoff reduction (Armson, Stringer, and Ennos, 2013; Gittleman *et al.*, 2017) and particulate matter immobilisation (Weber, Kowarik, & Säumel, 2014) has been reported at micro-scale. The effect of the community gardens, parks and other large-sized NBS on for example carbon sequestration can be evaluated at macro-scale by aggregating their impact (Davies *et al.*, 2011), while habitat patchiness and subsequent biodiversity assessment is typically applied at meso- to macro-scale (Shanahan *et al.*, 2010). Social: The social aspects of the green public spaces such as those related to health and wellbeing, perceived restorativeness, accessibility, use and cohesion (Jennings & Bamkole, 2019) can be evaluated at any of the scales (Peschardt & Stigsdotter, 2013). This enables the social value assessment at different viewpoints, i.e., the benefits/drawbacks of the particular space and the role of the green space in the context of a larger area (Carrus *et al.*, 2015) including the community involvement in managing the green spaces (Dennis & James, 2016). Economic: The economic changes due to the implementation of green spaces such as those related to land value and retail activity should be evaluated at meso- to macro scale by establishing an areal context (i.e., proximity to the NBS) as a proxy for the economic changes (Gore *et al.*, 2013; Roebeling *et al.*, 2017).
Trees and shrubs	Forest (including afforestation)	(X)	X	X	X	X	X	(X)	X	X	Environmental: Natural forests and urban forests represent larger areas with multi-layered vegetation, and their ecosystem services or impact on the environmental constituents, such as biodiversity (Sandström, Angelstam, & Mikusiński, 2006), heat fluxes (Feigenwinter *et al.*, 2018), water management or air quality, are generally accessed at larger scales (meso to macro) using the remote sensing approaches, e.g., LiDAR, which however should be validated against a series of *in situ* measurements (Giannico *et al.*, 2016). The effects on some indicators, such as those related to carbon sequestration, could nevertheless be evaluated at micro-scale (Ward *et al.*, 2015).

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

NBS category	Variations of NBS form	Suitable monitoring scales (spatial)†									Rationale
		Environmental indicators			Social indicators			Economic indicators			
		Micro	Meso	Macro	Micro	Meso	Macro	Micro	Meso	Macro	
											Social: Citizen wellbeing and the restorative capacity of the urban forests due to various reasons (e.g., weather extremes or restorative capacity of urban nature) can be assessed at micro- to meso-scale (over the areal extent of the forested area) using a large respondent sample size (Hauru *et al.*, 2012; Panno *et al.*, 2017). The accessibility evaluated as distance or time is typically assessed and reported at macro-scale (Zhang *et al.*, 2019). Economic: The economic effects in terms of increased land or property value or valuation of the regulating ecosystem services provided by urban forests has been reported at macro-scale (Tammi, Mustajärvi, & Rasinmäki, 2017).
	Orchard Vineyard Hedges/shrubs/green fences Street tree(s)	X	X	(X)	X	X	X	X	X	(X)	Environmental: The performance of the individual or a cluster of street trees and shrubs in for instance reducing surface runoff (Armson, Stringer, and Ennos, 2013) and reducing ambient air temperature (Streiling & Matzarakis, 2003) has been studied predominantly at the NBS level (micro-scale), although meso- and macro-scale assessments exist for carbon sequestration potential (Nowak, Crane, & Stevens, 2006; Velasco *et al.*, 2016). In cases when the street trees are many, or they comprise a denser area, such as those of an orchard or vineyard, the impact can be assessed at meso-scale. Social: While the recreational and restorative value of the orchards, street trees and vineyards are typically assessed at micro- to meso-scales (Peschardt & Stigsdotter, 2013), the assessment on macro-scale is feasible in studies of the community involvement and the impact of their health and wellbeing (Dennis & James, 2016). The macro-scale is feasible for studying the green space accessibility in terms of distance and/or time. Economic: The economic changes due to the implementation of green spaces such as those related to land value and retail activity should be evaluated at meso- to macro scale by establishing an areal context (i.e., proximity to the NBS) as a proxy for the economic changes (Gore *et al.*, 2013; Roebeling *et al.*, 2017).
Soil conservation and quality management	Slope revegetation Cover crops Windbreaks Conservation tillage practices Permaculture Deep-rooted perennials	X	X	(X)	X	–	–	(X)	X	X	Environmental: Soil restoration has the potential for increased soil organic carbon sequestration though, e.g., planting of perennials and reforestation (Conant, Paustian, & Elliott, 2001), which can be directly evaluated at the micro-scale (Nelson & Sommers, 1996) or modelled at macro-scale (Mohareb & Kennedy, 2012). The inorganic soil amendments can be used to

NBS category	Variations of NBS form	Suitable monitoring scales (spatial)†									Rationale
		Environmental indicators			Social indicators			Economic indicators			
		Micro	Meso	Macro	Micro	Meso	Macro	Micro	Meso	Macro	
	Organic matter enrichment Inorganic soil conditioners and amendments										inactivate the contaminants and to improve the physical qualities of soil, such as infiltration and water holding capacity for clayey and sandy soils, respectively; slope revegetation generally reduces erosion (Allen *et al.*, 2007). These types of soil quality management practices are typically evaluated at micro- to meso-scale. The macro-scale effects could be evaluated in case of biodiversity and changes to sediment input in the waterbodies. The up-scaling opportunities for perennial crops have been reported at macro-scale (Peter *et al.*, 2017). Social: Health & wellbeing have been associated with the soil biota (micro-scale). Economic: Soil conservation and quality management can be translated into the economic benefits, such as those related to 'avoided costs' due to reduced risk of erosion, landslides, more resilience against flooding and improved biodiversity, but furthermore to the food security in the region.
Blue-green space establishment or restoration	Riparian buffer zones Mangroves Saltmarsh/seagrass Intertidal habitats Dune structures	(X)	X	X	X	X	X	(X)	X	X	Environmental: Riparian vegetation and mangroves play a substantial role in reducing the flood risks and enhancing air pollutant immobilisation (e.g., Haase, 2017). The coastal measures act as carbon pools sequestering carbon in living biomass or as soil organic carbon (Murray *et al.*, 2011), which can be evaluated at larger scales. Social: The social indicators, such as those related to green space accessibility and distribution of green spaces are typically evaluated at meso- to macro-scales. Economic: The economic benefits of the coastal interventions, such as mangroves and saltmarsh/seagrass can be translated into the net economic returns to carbon fluxes, provisioning ecosystem services, such as fisheries and aquaculture, or flood-avoided casualties or property damage (Murray *et al.*, 2011), which are typically evaluated at larger scales for total area assessments. However, local economic benefits can potentially be evaluated at micro- to macro-scale.
Green built environment	Green roof Green-blue roof Green wall/façade Green streets, alleys and parking lots	X	(X)	(X)	X	X	(X)	X	X	(X)	Environmental: Small-scale NBS interventions often have the detectable impact on micro-scale (i.e., building) due to their size. It is deemed reasonable to monitor the aggregated impact on a larger scale (e.g., district) having a greater number of similar NBS implemented (Raymond et al., 2017). Typically, the impact of green roofs and walls/façades on particulate matter capture

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

NBS category	Variations of NBS form	Suitable monitoring scales (spatial)†									Rationale
		Environmental indicators			Social indicators			Economic indicators			
		Micro	Meso	Macro	Micro	Meso	Macro	Micro	Meso	Macro	
	Temporary and/or small-scale green structures (green furniture, green living room, etc.)										(Speak *et al.*, 2012), runoff reduction (Kuoppamäki & Lehvävirta, 2016; Perales-Momparler *et al.*, 2017) and energy savings (Coma *et al.*, 2017) are evaluated at micro-scale due to their size. The roadside vegetative barriers are similarly reported at micro-scale (Al-Dabbous & Kumar, 2014; Hagler *et al.*, 2012). The evaluation of larger NBS, such as green streets and alleys, can be performed at all scales. Social: The effects of green streets, alleys and parking lots, and even green roofs on the social domain, including accessibility, 'sense of place', restorativeness and wellbeing, have been reported at micro- (Peschardt & Stigsdotter, 2013; Mesimäki, Hauru, & Lehvävirta, 2019) scales; they can equally be evaluated at larger scales. Economic: The economic benefits of green roofs, walls and façades can be evaluated at micro-scale, e.g., for assessing the change of the energy demand of the building, which are directly related to monetary savings. The other economic changes are typically evaluated at meso- to macro scale.
Natural and semi-natural water storage and transport structures	Surface wetland (marsh, reed bed, etc.) Floodplains and floodplain reconnection with rivers Restoration of degraded waterbodies Restoration of degraded waterways, including re-meandering of streams and river daylighting Retention pond/wet detention pond	X	X	X	X	X	X	X	X	X	Environmental: Restoration of degraded watercourses can be monitored at micro-scale to detect the fine changes in, e.g., water quality and bank erosion. Restoration of wetlands, floodplains and watercourses is an important addition to a catchment water balance, so their impact on flood risk management in terms of reduced peak flows or runoff can be evaluated at meso- to macro-scales (Krysanova *et al.*, 2008). The impact of wetlands and floodplains on local biodiversity (ecosystem complexity) and nutrient dynamics has been evaluated at micro- to meso-scales (Hassall & Anderson, 2015), although the spatial and functional connectivity of the habitats are generally evaluated at meso- to macro-scales. Retention ponds, generally being shallower than the natural waterbodies, can be successfully monitored at a micro-scale (e.g., water quality) as well at the larger ones (e.g., for flood risk) especially if combined with other water management measures. Social: The social aspects related to the increased blue and blue-green spaces can be evaluated at all scales (e.g., Vierikko & Niemelä, 2016). Economic: The economic impact can be translated into avoided costs for flooding, restoration of watercourses and damaged

NBS category	Variations of NBS form	Suitable monitoring scales (spatial)†									Rationale
		Environmental indicators			Social indicators			Economic indicators			
		Micro	Meso	Macro	Micro	Meso	Macro	Micro	Meso	Macro	
											property that are typically evaluated at meso-scale due to direct influence on the downstream locations (Barth & Döll, 2016).
Infiltration, filtration and biofiltration structures	Infiltration basin Bioretention basin/bioretention cell Rain garden Vegetated filter strip/bioswale Wet/dry grassed swale, with or without check dams Infiltration planters and tree boxes Subsurface (constructed) wetland or filtration system	X	(X)	(X)	X	X	X	(X)	X	X	Environmental: Structures enhancing infiltration are generally relatively small in size (e.g., Yuan, Dunnett, & Stovin, 2017), so their monitoring of water quality and runoff reduction is most feasible at micro-scale (Hatt, Fletcher, & Deletic, 2009; Flynn & Traver, 2013; Yuan, Dunnett, & Stovin, 2017). However, if multiple NBS comprise a 'network', larger scale evaluation is feasible (Shuster *et al.*, 2017). The constructed wetlands systems may be significantly larger in size (Greenway, 2017). However, their performance for water quality and quantity has been as well reported at micro (i.e., NBS) scale (Adyel, Oldham & Hipsey, 2016; Greenway, 2017). Social: The social indicators can be evaluated at all scales. Economic: The economic impact can be translated into avoided costs for flooding and damaged property, or changing land value that are typically evaluated at meso- to macro-scale.

† X = most advantageous; (X) = possible; – = not applicable

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

5.2.4 Considerations for monitoring equipment

After the monitoring schemes have been defined and revised to match the available resources, a selection of monitoring equipment is the next step toward establishing the NBS monitoring. Local monitoring equipment suppliers are often the preferred option for city planners, and their selection is subject to tendering. While municipalities and city planners are free to select any supplier, careful considerations must be made on the degree of data precision and the continuity of data collection that is required to meet the level of the expected impact to be considered "successful" (Pepper, Brusseau, & Artiola, 2004). It is advised that the internationally recognised sampling and measurement methods (CEN/ISO standards) are selected during the design and implementation of the monitoring schemes.

A variety of the equipment that can be employed for monitoring of various environmental constituents provide different detection limits, require different calibration procedures and times between subsequent calibrations, and they can produce erroneous results due to poor calibration, operating ranges or magnitude of the change of the phenomena (Pepper, Brusseau, & Artiola, 2004). The selection of the monitoring equipment should consider precision, accuracy and resolution of the generated outputs (Box 5-5). Regular inspections of the *in situ* monitoring equipment may be necessary to ensure the equipment integrity.

Box 5-5: On monitoring equipment.

The selection of the monitoring equipment should consider:

- Precision
- Accuracy
- Resolution
- Detection limits
- Sampling frequency
- Sensitivity
- Units of measurement
- Data transmission or retrieval
- Device unit cost
- Device calibration
- Device maintenance schedule
- Device lifetime
- Operational environment (e.g., temperature, humidity, vibrations)

Figure 11 illustrates the various possibilities for NBS monitoring. Generally, it is advisable to employ continuous automatic measurements for environmental indicators, such as ambient temperature, water and air quality, whenever possible, as they provide the robust evidence of changes in the natural systems over fine time intervals. Intermittent automated measurements may prove beneficial at times of limited resources and can provide equally useful results using less effort and simpler equipment. However, if the intermittent measurements are employed for environmental constituents, the most suitable measurement intervals must be considered prior to initiation of monitoring. All of the mentioned monitoring equipment can be placed temporarily or for a limited time period depending on the duration of the anticipated measurement period and the available maintenance resources.

Manual intermittent data collection is typically applied to health and well-being assessments, and to those measurements that are impossible to perform over a prolonged period, e.g., soil or permeable surface infiltration rate and biodiversity studies. Manual water quality (grab) sampling is a simple and economical possibility, yet it increases manual labour and occupational safety, and it may reduce the overall quality of produced datasets (Pepper, Brusseau, & Artiola, 2004).

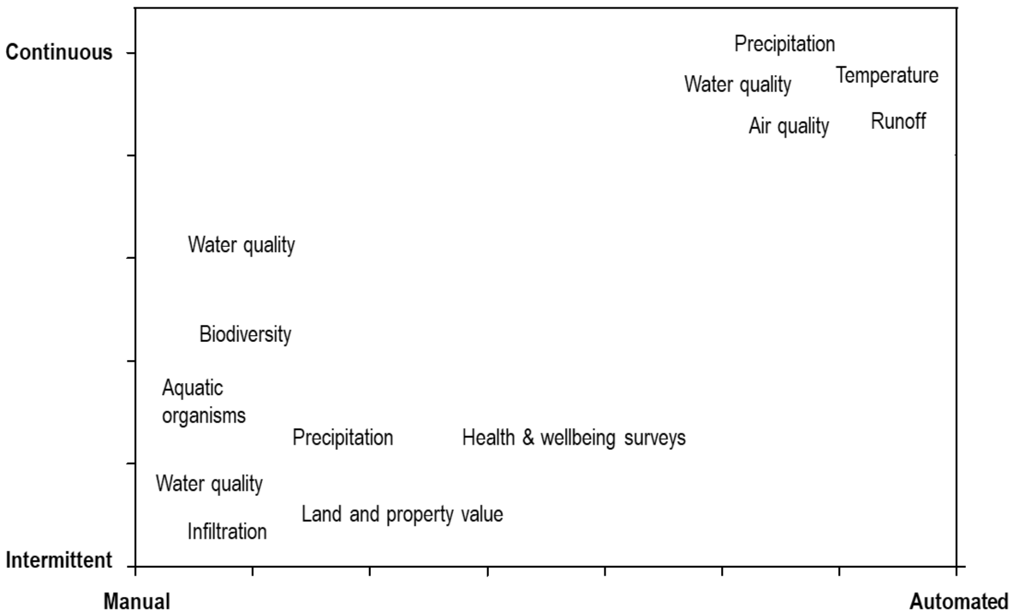


Figure 11. Types of NBS monitoring. Continuous monitoring implies the data collection at regular intervals; intermittent monitoring implies the data collection not happening regularly. Several parameters, e.g., water quality, appear multiple times due to the possibility of various sampling activities.

When selecting the ways and means to implement the monitoring schemes, the placement of the monitoring equipment to reflect the scale of NBS impact requires careful thinking. The city planners may consider using various sources of data collection, including citizen science (see Section 5.2.2 for details) and wearable sensors, or combine them with the modelling approaches to complement the data generation.

5.3 Framework for monitoring activities

NBS performance and impact assessment evaluation is crucial for determining the overall success of the NBS implementation, and consequently feasibility of the current and future investments. NBS performance assessment must always rely on limit and target values specified by the EU-level legislative documents (Table 9) that inform the national-level policies.

The Air Quality Directive (2008/50/EC) determines the limit values for Particulate Matter ($PM_{2.5}$, PM_{10}), Nitrogen dioxide (NO_2) and Ozone (O_3) and their permitted exceedances each year for protection of human health (European Parliament, Council of the European Union, 2008). Physicochemical, hydromorphological and ecological statuses of surface waters and groundwater are addressed by the Water Framework Directive (2000/60/EC) (European Parliament, Council of the European Union, 2000) while the Floods Directive (2007/60/EC) (European Parliament, Council of the European Union, 2007) target the holistic national flood management strategies. The Water Framework- and Floods Directives enforce the implementation of the local river basin management plans and flood risk management plans, respectively, to which NBS contribute directly or indirectly (European Commission, 2013). Water quality and environmental pollution are further regulated by a number of other legislative acts that limit the discharge of pollutants into the environment or waterbodies from various activities, including agriculture and urban wastewater treatment (Table 9).

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

The biodiversity challenge targets follow the Birds- (79/409/EEC) and Habitats Directives (92/43/EEC) and the EU Biodiversity strategy (European Commission, 2020b), which are likewise essential and additionally targeted by the EU Green infrastructure strategy (see European Commission, 2013). The latter heavily relies on Natura 2000 network that aims at conserving Europe's habitats and wildlife (European Commission, 2020c).

Table 9. Challenge categories and their reference EU-level policies and strategies.

Challenge category	Reference EU-level policies and strategies
Air quality	• Air Quality Directive (2008/50/EC) as amended by Directive 2015/1480/EC
Water management: quality	• Water Framework Directive (2000/60/EC) • Bathing Water Directive (76/160/EEC) • Drinking Water Directive (98/83/EC) • Urban Waste-water Treatment Directive (91/271/EEC) • Nitrates Directive (91/676/EEC) • Groundwater Directive (2006/118/EC) • Integrated Pollution Prevention Control Directive (2010/75/EU) • Environmental Impact Assessment Directive (85/337/EEC) • Priority Substances Directive (2013/39/EU)
Water management: quantity	• Water Framework Directive (2000/60/EC) • Floods Directive (2007/60/EC)
Droughts and water scarcity	• As part of Member States' River Basin Management Plans (RBMPs) enforced by the Water Framework Directive (2000/60/EC) • Water Scarcity and Droughts Policy (2012)
Biodiversity, ecosystem services and green infrastructure	• Birds Directive (79/409/EEC) • Habitats Directive (92/43/EEC) • Regulation on Invasive Alien Species (Regulation (EU) No 1143/2014) • EU Biodiversity strategy • Natura 2000 network • EU Green infrastructure strategy

Many EU-level legal acts ensure coordination within and across the policies and strategies, all aiming at enhancing the regional development. Coordinated implementation of these policies directly influence the adoption of the NBS measures in various local contexts (Strosser *et al.*, 2015). For instance, the Floods Directive (2007/60/EC) aims at managing the flood risks whilst targeting the Water Framework Directive (2000/60/EC), thus simultaneously aiming at achieving good statuses for water bodies. The Water Framework Directive itself encompasses the links to the EU climate change strategy and other policies, such as those related to agriculture (Common Agricultural Policy) and green infrastructure. Strosser *et al.* (2015) note that the stakeholder participation and awareness-rising further contributes to a more successful implementation of the strategies outlined in the Directives (see Section 4.1), which in fact legally promote the public involvement for achieving the favourable outcomes of those acts.

5.4 Processing of monitoring data

Quantitative and qualitative data generated throughout the NBS monitoring periods via *in situ* observations, questionnaires or other means may have different access rights depending on the degree of confidentially originally outlined in the legal or data management plans. Most of the personal data collected during, for example, Urban Living Lab (ULL) sessions, health and well-being surveys or other studies involving data that can be associated with a person are subject to access restrictions imposed by governing bodies or EU-level regulations, such as General Data Protection Regulation (GDPR) (European Parliament, Council of the European Union, 2016).

Naturally, not all data generated during an NBS project can be made public, so any personally identifiable information, which can be potentially generated during the project, should be carefully considered before and throughout NBS implementation. Despite the restricted access to some of the data generated in the NBS projects, most of the output is accessible through project dissemination activities or via aggregation of outcomes.

Box 5-6: On data governance.

The amount of data generated throughout the duration of the NBS implementation process, including co-creation, co-implementation, co-management, and monitoring of NBS performance and impact, is vast. Storage, management, ownership and access are among the critical issues for governing data at a municpal scale. To ensure the smooth management of data, municipalities should define a data management plan during the intial stages of NBS implementation.

Although some data owners may be reluctant to make their data open access, open data has numerous benefits as it can be widely utilised by research institutes and universities by applying it in research and education, or data-informed decision- and policymaking (European Commission, 2016). The possibility to use open datasets for producing various simulations and utilising them for NBS baseline conditions assessment brings an added value to the datasets and their owners. Openness of data generated via citizen science is a prerequisite for promoting the activities and encouraging volunteer participation by producing scientifically valuable data (e.g., Hecker *et al.*, 2018; see Section 5.2.2). Here, it should be noted that 'availability' and 'accessibility' mean 'existence' and 'possibility and ease of retrieval', respectively. While accessible data is concomitantly available, 'availability' does not imply 'accessibility'.

Data accessibility is of outmost importance for data- and research-informed decision- and policymaking, additionally for a wider NBS implementation. Not only open data provides such attributes to urban development, it encourages greater collaboration in NBS implementation through ample evidence of benefits and issues recorded and obtained via the open data sources.

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

6 Global standards for NBS

The International Union for the Conservation of Nature (IUCN) recently released standards for the design and assessment of NBS in order to support mainstreaming of nature conservation and consistency of NBS application (IUCN, 2020). Whilst the IUCN standard lacks definitive thresholds, it provides a systematic framework to support consistency in NBS design and assessment based on solutions-oriented outcomes. The eight criteria and sub-indicators that comprise the standard framework for NBS design and assessment defined by the IUCN (2020) are described below, with links to specific quantitative indicators and methods of evaluation previously identified by the UNaLab project and/or the IEF Taskforce.

6.1 Criterion 1: NBS effectively address societal challenges

A core concept of NBS is that they respond to one or more societal challenges that have been identified as a priority by the local community. Three indicators have been identified to assess this criterion (IUCN, 2020):

IUCN Indicator 1.1 The most pressing societal challenge(s) for rights-holders and beneficiaries are prioritized

The EU R&I policy agenda for NBS and re-naturing cities focuses on 'innovating with nature' to enhance societal resilience and sustainability via the main thematic areas of (1) climate change adaptation and mitigation and (2) risk management and resilience. Within these thematic and spatial areas, ten key challenge areas were identified by the EKLIPSE expert working group on NBS (Raymond et al., 2017). The NBS IEF Taskforce (Taskforce II) has since built upon the EKLIPSE framework to identify 12 key societal challenges that can be addressed by NBS, including:

- Climate Resilience
- Water Management
- Natural and Climate Hazards
- Green Space Management
- Biodiversity
- Air Quality
- Place Regeneration
- Knowledge and Social Capacity Building for Sustainable Urban Transformation
- Participatory Planning and Governance
- Social Justice and Social Cohesion
- Health and Well-being
- New Economic Opportunities and Green Jobs

Within these challenge areas, a number of indicators have been identified that evaluate stakeholder involvement in NBS planning, implementation and management. The indicators and brief methods of assessment provided herein under the category of Participatory Planning and Governance (Appendix I) are particularly relevant to evaluate the extent to which NBS processes are driven by stakeholders.

IUCN Indicator 1.2 The societal challenge(s) addressed are clearly understood and documented

Indicators related to environmental awareness (i.e., Challenge Knowledge and Social Capacity Building for Sustainable Urban Transformation; Appendix I) can support evaluation of citizens' understanding. Stakeholders' understanding of risks and risk mitigation measures can be enhanced through multi-stakeholder disaster resilience planning (Challenge Natural and Climate Hazards, Appendix I). At the municipality level, disaster-risk informed development, the presence of a climate resilience strategy and its alignment with UNISDR-defined elements and the adaptation of local policies to include NBS are indicative of understanding how NBS address societal challenges (Challenge Natural and Climate Hazards and Challenge Participatory Planning and Governance, Appendix I).

IUCN Indicator 1.3 Human well-being outcomes arising from the NBS are identified, benchmarked and periodically assessed

Indicators of human well-being outcomes impacted by NBS implementation can broadly be grouped as those addressing (1) vulnerability, risk and exposure, (2) impacts on population health and on health systems, and (3) the adaptation and resilience of human populations and health systems (Ebi *et al.*, 2018).

Note that direct impacts of NBS on human well-being can be difficult to evaluate in the short term. Rather, precursor or indirect indicators of well-being such as air quality, air temperature or heatwave, human comfort, flooding and water quality (e.g., indicators of vulnerability, risk and exposure to well-being hazards), and access to green space may be useful indicators. Appendix I provides a brief overview of selected indicators and methods related to the assessment of NBS impacts on human health and well-being. The *NBS Impact Evaluation Handbook* (*in progress*, IEF Taskforce) will present a more comprehensive list of potential indicators of NBS impacts on health and wellbeing, along with methods of assessment.

6.2 Criterion 2: Design of NBS is informed by scale

This criterion refers to both spatial scale as well as the relative level of complexity of the local biophysical, sociocultural, economic and governance contexts. Notably, this criterion specifies that NBS design should maintain or enhance the productive capacity of ecosystems as well as promote the generation of benefits for human well-being (IUCN, 2020).

IUCN Indicator 2.1 The design of the NBS recognises and responds to interactions between the economy, society and ecosystems

Fundamentally, this indicator refers to the multiple benefits expected from NBS by referencing "how well the interactions between people, the economy and the ecosystem are understood and responded to" (IUCN, 2020, pg. 8). The application of multiple individual indicators across several of the identified challenge areas is necessary to determine how well an NBS intervention addresses interactions between society, the economy and local ecosystems:

- A variety of different indicators within the New Economic Opportunities and Green Jobs challenge area can be used to assess the economic impacts of NBS, such as land or property values in proximity to NBS, retail and commercial activity or number of new businesses established, the value of rates paid by businesses located near NBS, new jobs in the green sector, or the value of subsidies applied for private NBS measures.
- Social impacts can be evaluated via indicators of social justice and social cohesion. Here, indicators may assess the engagement of citizens in NBS co-co-co processes (e.g., citizen engagement by NBS projects, the participation of vulnerable or traditionally

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

under-represented groups), or specific outcomes of NBS implementation (e.g., perceived ownership and sense of belonging, changes in local crime rates, availability and equitable distribution of public green space).

- Impacts of NBS on the built environment can be assessed using indicators within the Place Regeneration challenge category, such as the reclamation of derelict land, quantity of blue-green space as a ratio to built form, the area devoted to roads, the preservation of cultural heritage, incorporation of environmental design in buildings, or extent of design for sense of place.
- Impacts of NBS related to interactions between people and the natural environment can be evaluated using indicators from the category Green Space Management. In particular, indicators of green space accessibility, the distribution of green space within an urban area, and the proportion of the road network dedicated to 'green transport' (i.e., pedestrians and bicyclists).

IUCN Indicator 2.2 The design of the NBS is integrated with other complementary interventions and seeks synergies across sectors

Engineering projects, information technology and financial instruments are mentioned as relevant complementary interventions where integration with NBS can support cross-sectoral synergies. For example, this could relate to the integration of blue-green with conventional grey infrastructure for stormwater management, or the use of financial instruments to incentivise NBS implementation.

Information technology, in particular the use of data management platforms, plays an important role in managing NBS by making available the necessary data to observe changes brought about as a result of NBS implementation. In the UNaLab project, the Open Nature Innovation Arena (ONIA) online tool facilitates on-going citizen engagement in NBS co-creation through problem definition, challenge identification, and collaborative idea generation. Transparent monitoring and evaluation of NBS performance and impact is facilitated by UNaLab's online City Performance Monitor (CPM). See UNaLab deliverable *D4.7 Refined Open Innovation/ Crowdsourcing and Performance Measurement Tools* (Tuomisto, Spinnato & Roebeling, 2020) for additional information about the ONIA and CPM tools.

IUCN Indicator 2.3 The design of the NBS incorporates risk identification and risk management beyond the intervention site

Risk management is cited as a critical element for incorporation during NBS design in order to support long-term durability and sustainability of selected solutions. This could be realised by implementing the UNISDR disaster resilience scorecard for cities during NBS planning and design to gain an understanding of local disaster risks, and following up by implementing a multi-hazard early warning system to help mitigate the consequences of natural and climate hazards (Challenge 3 Natural and Climate Hazards, Appendix I).

6.3 Criterion 3: NBS result in a net gain to biodiversity and ecosystem integrity

Implemented NBS should seek to enhance ecosystem function and connectivity, both to support biodiversity and ecosystem integrity and to ensure the long-term resilience and durability of the NBS.

IUCN Indicator 3.1 The NBS actions directly respond to evidence-based assessment of the current state of the ecosystem and prevailing drivers of degradation and loss

A baseline assessment of the local ecosystem is essential to identify critical needs for intervention. In the UNaLab project, the systemic decision support tool (SDST) enables visualization of outcomes based on existing baseline data and projected climate and population change scenarios in the front-runner cities Tampere, Genova and Eindhoven. The City Performance Monitor (UNaLab D4.7; Tuomisto, Spinnato & Roebeling, 2020) enables real-time evaluation of environmental parameters relevant to assessment of ecosystem function.

IUCN Indicator 3.2 Clear and measurable biodiversity conservation outcomes are identified, benchmarked and periodically assessed

Specific biodiversity targets should be determined that are specific to individual NBS, and progress towards these targets assessed regularly. Appendix I provides several examples of biodiversity indicators and methods of assessment, such as green space connectivity, species diversity and species evenness, the proportion of natural areas within a specified area, number of native bird species, and the City Biodiversity Index. A more comprehensive list of biodiversity indicators and associated methods will be presented in the *NBS Impact Evaluation Framework Handbook* currently in preparation by members of the IEF Taskforce (Taskforce II). The Handbook is scheduled to be released in the latter part of 2020.

IUCN Indicator 3.3 Monitoring includes periodic assessments of unintended adverse consequences on nature arising from the NBS

Ecosystems are inherently complex, and changes to one or more elements of an ecosystem may have unintended and unforeseen negative impacts. For example, NBS implementation could result in the unintentional introduction of non-native species – either directly or indirectly – or changes to species composition as a consequence of increased human activity in the area. Regular assessment of the diversity and evenness of floral and faunal community composition per, e.g., Shannon diversity and evenness indices, can be used to monitor changes to local biodiversity as a result of NBS implementation.

IUCN Indicator 3.4 Opportunities to enhance ecosystem integrity and connectivity are identified and incorporated into the NBS strategy

The fragmentation of open spaces into smaller and more isolated patches is a major impact of urbanisation that can reduce intra- and inter-species connectivity and lead to biodiversity loss. Higher-level urban planning should take into consideration the connectivity of blue-green spaces by adopting a green infrastructure approach, wherein urban green spaces are linked (connected). The physical linking of blue-green spaces in urban areas is referred to as structural connectivity and can easily be assessed using maps or satellite images. Functional connectivity refers to the ability of organisms to move between blue-green spaces in cities, and is species-specific in that some species require direct, linear connectivity whereas others can use areas in proximity to one another as 'stepping stones' to move across a wider area. Threshold values for functional connectivity must be defined for target species then applied to land use maps to measure potential corridors of connectivity.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

6.4 Criterion 4: NBS are economically viable

The sustainability of NBS is closely related to the balance of short-term costs against longer-term gains. In many cases, NBS benefits are realised over decades and involve significant intangible or less-tangible benefit in the form of provisioning and regulating ecosystem services. For this reason, it is important to clearly identify potential direct and indirect economic benefits of NBS and utilize evidence-based tools to estimate economic benefit during the planning stages, and to monitor and document economic benefits following NBS implementation. In particular, socioeconomic impacts of NBS implementation must be continuously assessed and actions taken to mitigate "green gentrification" must be continuously evaluated to mitigate any resultant inequalities.

IUCN Indicator 4.1 The direct and indirect benefits and costs associated with the NBS, who pays and who benefits, are identified and documented

A number of indicators in the challenge 12 New Economic Opportunities and Green Jobs can be used to quantify direct and indirect benefits of NBS (Appendix I). In addition, the SDST will provide detailed information about changes to land or property value in proximity to NBS in UNaLab FRCs. Indicators under Challenge 10 Social Justice and Social Cohesion (Appendix I), such as perceived owndership of space and sense of belonging to the community, can also provide insights regarding the potential impacts of "green gentrification". A more comprehensive list of economic and social indicators and associated methods will be presented in the *NBS Impact Evaluation Framework Handbook* currently in preparation by members of the IEF Taskforce (Taskforce II). The Handbook is scheduled to be released in the latter part of 2020.

IUCN Indicator 4.2 A cost-effectiveness study is provided to support the choice of NBS including the likely impact of any relevant regulations and subsidies

A lifecycle assessment or similar analysis of cost-effectiveness comparing planned NBS with alternatives, e.g., conventional engineered or 'grey' solutions, can provide important information about the longer-term economic sustainability of NBS in comparison with other options. A comprehensive lifecycle assessment of NBS and analogous grey infrastructure requires in-depth knowledge of both NBS and engineered infrastructure design and operation, including maintenance; however, a number of online tools are available to estimate long-term costs and benefits of NBS and can serve as a good starting point (e.g., the Green infrastructure valuation toolkit GI-Val, https://www.merseyforest.org.uk/services/gi-val/). In addition, the UNaLab deliverable *D6.1 Value Chain Analysis of Selected NBS* (Cioffi, Zappia & Raggi, 2019) provides critical information on the replication and/or upscaling potential of many of the NBS implemented during the UNaLab project.

IUCN Indicator 4.3 The effectiveness of the NBS design is justified against available alternative solutions, taking into account any associated externalities

Many factors influence the appropriateness of NBS design. Both the type and scale of planned NBS interventions should be modelled in order to optimize design parameters, and the resultant NBs options compared with one another with respect to environmental outcomes and economic efficiency. The SDST-SVT will provide UNaLab FRCs with the opportunity to define and simulate impacts of various NBS at different scales to support co-creation and decision-making. In addition to technical specifications (i.e., performance considerations), cultural and aesthetic values should be considered. Some relevant indicators under Challenge 7 Place Regeneration

(Appendix I) include metrics related to design for a sense of place, the incorporation of environmental deisgn in buildings and the preservation of cultural heritage.

IUCN Indicator 4.4 NBS design considers a portfolio of resourcing options such as market-based, public sector, voluntary commitments and actions to support regulatory compliance

It is important for the long-term sustainability of NBS that a range of different financing options are explored and implemented. Combinations of different financial mechanisms can help to achieve an equitable distribution of risks and returns. The UNaLab deliverable *D6.3 Business Models and Financing Strategies* (Mačiulyte *et al.*, 2019) provides important information about business models and financing strategies for different types of NBS based on their anticipated co-benefits. UNaLab deliverable *D6.4 NBS Value Model* (Mok, Hawxwell, Kramer & Mačiulyte, 2019) provides guidance on the national and international policies to leverage financing for NBS projects.

6.5 Criterion 5: NBS are based on inclusive, transparent and empowering governance processes

Core characteristics of NBS include the delivery of multiple co-benefits and the ownership of NBS by stakeholders. The social license to operate is largely based upon adoption of governance mechanisms that actively engage and empower local communities and other stakeholders.

IUCN Indicator 5.1 A defined and fully agreed upon feedback and grievance resolution mechanism is available to all stakeholders before an NBS intervention is initiated

The Challenge 9 Participatory Planning and Governance indicator openness of participatory processes provides a means to evaluate the openness of processes managed by the municipality (Appendix I). It is also important here to consider the involvement of vulnerable or traditionally under-represented groups in order to understand whether feedback and grievance resolution mechanisms are available to all stakeholders. IUCN indicator 5.1 states that effective feedback and grievance resolution mechanisms that are transparent, accessible and adhere to rights-based approaches should be implemented before initiation of an NBS intervention.

IUCN Indicator 5.2 Participation is based on mutual respect and equality, regardless of gender, age or social status, and upholds the right of Indigenous Peoples to Free, Prior and Informed Consent (FPIC)

Challenge 9 Participatory Planning and Governance indicators that are particularly relevant to this sub-criterion are those that explore stakeholder involvement in governance processes. In particular, the openness of participatory processes, community involvement in planning and implementation, and the involvement of citizens from vulnerable or traditionally under-represented groups (Appendix I).

IUCN Indicator 5.3 Stakeholders who are directly and indirectly affected by the NBS have been identified and involved in all processes of the NBS intervention

In addition to the Challenge 9 Participatory Planning and Governance indicators mentioned above, for IUCN indicator 5.2, another relevant Challenge 9 indicator to IUCN indicator 5.3 is

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

active engagement of citizens in decision-making. The citizen engagement by NBS projects indicator under Challenge 10 Social Justice and Social Cohesion (Appendix I) can also provide important information about the quality of citizen engagement.

IUCN Indicator 5.4 Decision-making processes document and respond to the rights and interests of all participating and affected stakeholders

Documentation of all steps in the NBS decision-making procedures should be transparent and accessible to stakeholders in order to maintain accountability and provide the basis for recourse in any disputes. The IUCN note that "specific attention should be paid to noting which stakeholders were involved in decision-making and the role they played" (IUCN, 2020, pg. 14). Documentation of decision-making processes is particularly important where inequalities exist so that more participatory processes can be developed and adopted. Indicators regarding policy learning (i.e., adaptation of local plans and regulations to include NBS, development of a climate resilience strategy or alignment of climate resilience strategy with UNISDR-defined elements, Challenge 9 Participatory Planning and Governance, Appendix I) can be applied to evaluate the adaptation of local plans and regulations to include NBS and linked participatory processes.

IUCN Indicator 5.5 Where the scale of NBS extends beyond jurisdictional boundaries, mechanisms are established to enable joint decision-making of the stakeholders in affected jurisdictions

Management of ecosystems may require transboundary cooperation and joint decision-making. In this case, establishment of transboundary cooperation agreements can support joint NBS planning, implementation and management and promote achievement of the desired outcomes.

6.6 Criterion 6: NBS equitably balance trade-offs between achievement of their primary goal(s) and the continued provision of multiple benefits

The provision of multiple co-benefits is a key characteristic of NBS; however, not all benefits are equally valued by different stakeholders. It is important to determine a minimum condition for proposed NBS aligned with acknowledged social and ecological limits such that the proposed NBS and associated ecosystems remain sustainable in the longer term and ecological boundaries are not transgressed.

IUCN Indicator 6.1 The potential costs and benefits of associated trade-offs of the NBS intervention are explicitly acknowledged and inform safeguards and any appropriate corrective actions

Accurate, transparent assessment of co-benefits, associated trade-offs and changes to costs and benefits over the lifecycle of the proposed NBS is necessary to initiate dialogue among stakeholders. In particular, safeguards should be applied to ensure that any necessary trade-offs do not disproportionately impact disadvantaged members of society, or that disadvantaged, vulnerable and traditionally under-represented groups are not denied access to the NBS. For this reason, open dialogue with all stakeholders regarding the potential costs and benefits of various NBS scenarios is essential. Safeguards should be determined based upon the environmental conditions that limit that limit natural productivity and ecosystem structure, functioning, and diversity.

Numerous metrics listed under Challenge 7 Place Regeneration, Challenge 9 Participatory Planning and Governance, Challenge 10 Social Justice and Social Cohesion, Challenge 11 Health and Wellbeing and Challenge 12 New Economic Opportunities and Green Jobs can be applied to assess baseline (pre-NBS) and to periodically evaluate NBS impacts in order to track cost, benefits and trade-offs (Appendix I). In addition, a more comprehensive list of economic and social indicators and associated methods will be presented in the *NBS Impact Evaluation Framework Handbook* currently in preparation by members of the IEF Taskforce (Taskforce II). The Handbook is scheduled to be released in the latter part of 2020.

IUCN Indicator 6.2 The rights, usage of and access to land and resources, along with the responsibilities of different stakeholders, are acknowledged and respected

Stakeholder analysis and mapping can be used to develop a preliminary plan regarding the rights, use and responsibilities of various stakeholder groups. In particular, the rights to NBS access, use and management control of Indigenous communities and vulnerable or marginalised groups needs to be considered. Where management practices involve trade-offs such as limiting traditional uses of a given area, it is necessary to negotiate compensation among potentially affected parties in a fair and transparent manner.

IUCN Indicator 6.3 The established safeguards are periodically reviewed to ensure that mutually-agreed trade-off limits are respected and do not destabilize the entire NBS

Established limits to agreed trade-offs should be subject to periodic review throughout the lifecycle of the NBS to anticipate and mitigate adverse consequences. It is important to both explicitly define the benefits and costs to be addressed, and to consider changes to trade-offs or affected groups with time per regularly planned reviews. These reviews should be fair and transparent with clear mechanisms in place for stakeholder consultations, addressing grievances, appeals, etc.

6.7 Criterion 7: NBS are managed adaptively, based on evidence

Adaptive management is a structured, iterative process of assessment and decision making aimed at reducing uncertainty about processes affecting resource dynamics. Regular monitoring and evaluation of NBS performance and impact, with a focus on structure, processes, functions and interactions enables evidence-based adaptive management (FAO, 2003). An ecosystem approach to adaptive management supports balancing resource conservation, sustainable use and the fair and equitable sharing of benefits.

IUCN Indicator 7.1 A NBS strategy is established and uses as a basis for regular monitoring and evaluation of the intervention

All stakeholders should jointly define long-term NBS management objectives within the boundaries of ecosystem structure and function, as well as the applicable economic and social conditions, in order to maintain ecosystem services. The processes implemented to co-define management objectives can be evaluated using Challenge 9 Particpiatory Planning and Governance indicators, such as openness of participatory processes, involvement of citizens from traditionally under-represented groups, and community involvement in planning. Objectives need to be specific such that the intended outcomes and proposed actions to achieve

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

the desired outcomes are clear. Individual indicators to evaluate specific parameters at appropriate spatial and temporal scale to determine whether the objectives are met should be selected or defined based upon jointly-defined NBS (see Appendix I).

IUCN Indicator 7.2 A monitoring and evaluation plan is developed and implemented throughout the intervention lifecycle

Develop and implement with stakeholders a clear management plan, decentralizing management to the lowest appropriate level to involve all stakeholders and balance local interests with those of the wider public. The extent to which stakeholders are involved in NBS management can be assessed using the Challenge 9 Participatory Planning and Governance indicator community engagement in NBS implementation. Monitoring plans must explicitly consider the spatial and temporal resolution of acquired data and address functional relationships and processes within ecosystems. Regular evaluation of monitoring data is necessary to review the balance between conservation and use of ecosystem services and progress towards NBS objectives, and to revise NBS management actions as needed to align with NBS objectives. Scientific as well as indigenous, traditional and local knowledge should be utilised to establish the NBS evidence base and inform NBS evaluations.

IUCN Indicator 7.3 A framework for iterative learning that enables adaptive management is applied throughout the intervention lifecycle

IUCN indicators 7.1 and 7.2 provide guidance on the continuous feedback loop necessary to adaptively manage NBS. A formalised or institutionalised learning approach to the iterative adaptive management approach (problem assessment → solution design → implementation → monitoring → evaluation → adjustment → …) is beneficial as it supports both the analysis of management outcomes in light of the original objectives as well as the incorporation of results into future decisions.

For additional information about ecosystem based adaptive management see Annex 7 of the FAO report *Biological Management of Soil Ecosystems for Sustainable Agriculture* (2003; http://www.fao.org/3/y4810e/y4810e0f.htm#bm15).

6.8 Criterion 8: NBS are sustainable and mainstreamed within an appropriate jurisdictional context

IUCN Criterion 8 seeks to foster mainstreaming of NBS through alignment with sectoral, national and other policy frameworks, supported by strategic communication and outreach.

IUCN Indicator 8.1 The NBS design, implementation and lessons learnt are shared to trigger transformative change

NBS replication and up-scaling requires that the lessons learned throughout the NBS co-creation and implementation process are documented and accessible to all those potentially interested in replicating the process. The extent to which mainstreaming of NBS is successful may be evaluated using the Challenge 9 Participatory Planning and Governance indicator of policy learning, adaptation of local plans and regulations to include NBS (Appendix I).

IUCN Indicator 8.2 The NBS informs and enhances facilitating policy and regulation frameworks to support its uptake and mainstreaming

Because NBS address cross/cutting challenges such as climate resilience, biodiversity conservation and public health, and actors from different sectors, it is important to become familiar with the full range of existing policies and sectoral regulations that are applicable to the NBS. During the NBS planning process, close collaboration among decision makers and other key stakeholders is needed highlight policy barriers to successful NBS implementation and identify an appropriate response that will enable achievement of the desired environmental, social and economic outcomes. From this point, stakeholders must continue to ensure the alignment of NBS plans (design, implementation, management) with applicable policy instruments.

IUCN Indicator 8.3 Where relevant, the NBS contributes to national and global targets for human well-being, climate change, biodiversity and human rights, including the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP)

NBS can have significant positive economic, social and environmental impacts and support national commitments regarding climate change mitigation, sustainable development, biodiversity conservation and human rights. IUCN indicator 8.3 recommends making explicit linkages between NBS objectives and national targets in order to secure both societal support and durable political commitment to the NBS project. For example, review the national commitments to the following international processes, document linkages with proposed NBS project(s) and communicate this to decision makers and other key stakeholders:

- The UN Framework Convention on Climate Change Paris Agreement[3] and nationally determined contributions (UN FCCC, 2016)
- The European Green Deal, COM(2019) 640 final (EC, 2019)
- The UN Sustainable Development Goals[4] (UNGA, 2015) and associated targets, indicators and evaluation metrics (UNGA, 2017)
- The UN Declaration on the Rights of Indigenous Peoples[5] (UN, 2007)
- The EU Biodiversity Strategy for 2030, COM(2020) 380 (EC, 2020b)

[3] https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

[4] https://www.un.org/sustainabledevelopment/sustainable-development-goals/; http://unhabitat.org/sdg-goal-11-monitoring-framework/; https://unstats.un.org/sdgs/indicators/database/

[5] https://www.un.org/development/desa/indigenouspeoples/declaration-on-the-rights-of-indigenous-peoples.html

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

7 NBS MAINTENANCE RECOMMENDATIONS

The EKLIPSE Working group has defined that reliable NBS are NBS whose performance are guaranteed over time with a certain defined maintenance strategy. The ThinkNature project (https://platform.think-nature.eu/) defines that ideally NBS should function with minimal maintenance. Therefore, it is important that appearance and functionality of the NBS solution are recognized to be able to estimate the need for maintenance. Further, different materials and construction techniques should be evaluated in terms of their sustainability and resource consumption during and after the building phase of NBS.

It is easy to agree that minimal maintenance can be considered as a desirable target, but certain limitations in this kind of thinking should be kept in mind. One of the most important functional target of NBS is that they are resilient and can be designed for a long-term function. Therefore, minimising the costs of maintenance should not be the main driver when planning the maintenance. Sometimes designing NBS to function "as close to nature as possible" can be advantageous both for their long-term performance and also to reduce the need for maintenance. However, minimal maintenance in terms of maintenance activities might not be the same as minimal costs since the target of minimal maintenance can require high-quality of NBS and maintenance design as well as high-quality of implementation. In addition, often high-quality technology is needed for effective maintenance. These can lead to higher costs in the initial phases but are more economical in the long-term. After all, if the maintenance of NBS can be proven to be cost-effective it can have positive impacts for the decisions regarding the implementation of NBS.

As NBS remain to be a somewhat new concept, there is an existing need for support and encouragement for the implementation of NBS. In general, knowledge gaps still exist for the implementation of NBS and one of the knowledge gaps that may still exist is maintenance of different types of NBS. There are some knowledge gaps especially related to the costs of NBS maintenance. This and other knowledge gaps in the maintenance might be one of the barriers for the larger scale of NBS implementation. When the knowledge of maintenance needs increases, it simultaneously increases the knowledge of the NBS concept as a whole. Maintenance of NBS has also potential to have positive impacts on the labour market by providing new types of jobs in the green sector. Design and development of the maintenance procedures and also high-quality technologies are some of those jobs that have potential to have bigger role in the labour market.

Knowledge and technology for the NBS maintenance should be supported in different levels of decision-making. ThinkNature project (Somarakis, Stagakis, & Chrysoulakis, 2019) listed drivers and actions that could increase and provide knowledge and new methods for NBS maintenance at various levels, including local, national, EU, and global levels (Table 10).

Table 10. Technical drivers and examples of possible actions for NBS maintenance at various levels (Modified from Somarakis, Stagakis, & Chrysoulakis, 2019).

Drivers/Actions	Local	National	EU	Global
Knowledge and technical support for the maintenance of NBS	Following instructions and standards developed in National level	Provide information and instructions	Support the development of standards and performance assessment	Spread knowledge of devices supporting maintenance in a sustainable way
Cost effectiveness of NBS techniques (including maintenance)	Cost effective technologies through digital technologies		Support the implementation of digital technologies.	

Maintenance of NBS should be considered throughout the lifecycle of NBS. Maintenance should ideally be involved already in the planning process of NBS. Needs for maintenance might even affect the decisions whether the NBS should be implemented and which type of the NBS should be chosen. Usually, NBS do not have high maintenance needs. However, some NBS require a lot of maintenance for them to work properly. In each case, sufficient maintenance is desirable to enable proper functioning and long lifetime of NBS which is why long-term maintenance strategy should be created for each NBS. Naturally, some NBS require constant and extensive maintenance action whereas some NBS only need minimal maintenance. However, it should be noted that all types of NBS require regular maintenance.

Maintenance of NBS requires resources and other financial investments. In many cases, maintenance costs are the most important factor when creating a maintenance plan. Additionally, the maintenance costs are sometimes the most important factor in the decision if NBS should be implemented and if they should replace the conventional grey solutions. It is important to estimate the costs for the lifetime of NBS, including design, construction, operation, and possible dismantling. Thus, it is important to consider the maintenance costs, and they should always be included in the life cycle cost analysis for NBS. There is a high variance for how much maintenance and financial investments certain NBS require, which is why extensive databases and knowledge for the required costs are needed when creating a maintenance cost analysis. As it was mentioned earlier, maintenance needs for NBS, including costs, are often smaller than they are for grey infrastructure solutions. Due to some lack of knowledge and missing technology in the NBS maintenance, there is a lot of potential to develop the technology (digitalisation and smart technologies) and methods for maintenance activities. This could potentially create more cost-effective solutions for the NBS maintenance.

NBS maintenance activities can have participatory and well-being aspects. For example, property owners can maintain vegetation and other green solutions around their houses. These kinds of activities can increase social interaction among the residents which can have positive impacts on the property maintenance in general and increase the flow of information. Increased social interaction and activities done outside can also have positive impacts on mental and physical well-being. In addition, proper maintenance can potentially impact positively on the property values.

Some publicly available guidance for NBS maintenance exists at the moment. However, there are some knowledge gaps, for example related to the costs of NBS implementation. This can make the estimation of maintenance costs and comparison to grey infrastructure solutions more difficult. In this chapter, general guidelines for the NBS maintenance are given. More detailed guidelines should always be made by the NBS designers. As a part of the NBS design, there should always be a long-term maintenance plan involved. A detailed maintenance plan can make the efforts and costs of NBS maintenance lower throughout the lifetime of NBS, as well

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

as extend the lifetime of NBS. With more publicly available general guidance, awareness of the NBS and their function is increased. This could encourage cities and other potential users of NBS to use NBS as part of their plans and possibly create more jobs in the green sector.

7.1 General guidance for NBS maintenance

Proper maintenance plan should be produced for each NBS before the NBS is constructed. The maintenance plan can be modified and optimized afterwards, when knowledge and experience have been gathered and more efficient ways for maintenance have been found. Maintenance can often be included in the construction or installation contract, especially during the first years after construction or installation of NBS. In general, maintenance activities during the first years are the most important regarding proper NBS operation.

In a manual for Sustainable Urban Drainage Systems (SuDS), Woods Ballard *et al.* (2015) list examples of elements to be included in an operation and maintenance manual:

- Location of all SuDS components on the site
- Brief summary of the design intent, how the SuDS components work, their purpose and potential performance risks
- Visual indicators that will trigger maintenance
- Maintenance requirements (i.e., the Maintenance Plan) and a maintenance record
- Explanation of the objectives of the maintenance proposed and potential implications of not meeting those objectives (it may be useful to split into planted and hard elements, for clarity)
- Identification of areas where certain activities are prohibited (e.g., stockpiling materials on pervious surfaces)
- An action plan for dealing with accidental spillages of pollutants
- Advice on what to do if alterations are to be made to a development or if service companies need to undertake excavations or other similar works that could affect the SuDS
- Details of whom to contact in the event that pollution is seen in the system or if it is not working correctly

To complement the list of things that could be added to the maintenance plans, Melbourne Water (2013) lists things to be included in the maintenance plan of Water Sensitive Urban Design (WSUD) assets:

- A description or plan showing the location of assets that require maintenance
- Required maintenance tasks
- Maintenance procedure and any specific equipment that may be required
- Materials list and supplier details
- Manufacturers documents, warranties and schedules
- Plant lists
- Monitoring method
- Maintenance access
- Any site-specific requirements
- An estimate of the on-going maintenance costs to be included in budgets

Woods Ballard *et al.* (2015) further list factors that influence the type and frequency of maintenance required for a SuDS component or a scheme at any particular site:

- The type of SuDS components
- The size of the contributing catchment in relation to the area of the SuDS components (this will affect the likely sediment loading rates and potential for erosion etc.)

- The land use associated with the contributing catchment (this will affect the likely build-up of contamination)
- The level of continuing construction within the contributing catchment
- The SuDS planting scheme
- The habitat types that have been created as part of the scheme and how they are anticipated to evolve into a mature landscape
- The amenity and visual requirements of the area

As it was noticed, frequency of the NBS maintenance activities depends on a variety of factors. Needed maintenance activities, including the maintenance frequency, depend mostly on the NBS type. Maintenance frequency can vary from monthly maintenance activities to once a year maintenance activities. In some cases, more frequent than once a month or less frequent than once a year maintenance activities can be conducted. Often, in the early phases, for example during the first year after the NBS construction, more frequent maintenance is recommended. It is beneficial that the newly constructed NBS are checked after rainfall events in the initial phases whereas in the later phases more seldom frequency is sufficient.

Usually, different maintenance tasks are planned to be done in regular intervals. Examples of these kind of tasks are grass cutting and vacuuming of permeable surfaces. These maintenance activities serve as examples of maintenance activities having a different need for maintenance frequency. While grass cutting is often done approximately once a month, a quite common vacuuming frequency of permeable pavements is once a year. It should be noted that frequency of these maintenance activities can vary depending on not only functional but also aesthetic requirements. In addition certain things like high loads of litter and debris can increase the need for more frequent maintenance activities.

Grass cutting and vacuuming of permeable pavements additionally serve as examples of regular maintenance activities. Some maintenance activities are done irregularly. However, irregular maintenance activities usually include regular monitoring of the NBS function to be able to perform needed maintenance activities when needed. The monitoring will be based on certain indicators which then trigger the need for maintenance (e.g. removing excess litter or debris).

In addition to regular and irregular maintenance work done for NBS, repairing work is a part of the maintenance activities. It is difficult to estimate the need for repairing work beforehand but it is beneficial to reserve budget for the it. Range of possible costs for the repairing work can vary greatly and depends heavily on the NBS type and especially on the equipment (pumps, valves etc.) used.

As mentioned, maintenance can be divided into aesthetic and functional maintenance. Requirements set for aesthetics of NBS can heavily affect the maintenance requirements whereas functional requirements usually do not vary that much among similar NBS types. These two types of maintenance requirements are usually shared but sometimes aesthetic requirements might have negative impacts on the functionality of NBS. However, it should be noted that aesthetic values can lead to better public acceptance of NBS.

A great variance exist in the needed expertise of different maintenance activities. Some of the maintenance activities can be conducted without any special skills or education. These are often regularly performed simple activities (e.g., removing litter and debris). Maintenance activities that require more skills and experience can be for example more complex NBS structures or tasks that require using of special equipment. Repairing activities are a type of tasks that typically require more expertise. In all maintenance activities, it is beneficial that people or at least the same companies are performing the maintenance activities for the same NBS. It is also possible that different companies need to perform different maintenance tasks for the same

NBS, especially if special equipment are needed in some parts of the maintenance work. Proper instructions for all maintenance activities should always be given in the maintenance campaigns.

7.2 Maintenance costs

Costs of the NBS operation and maintenance should be estimated for the whole lifecycle of NBS. The cost estimation should be done in the early phases of NBS design and the cost estimation should be updated when more data and knowledge are available, during design, construction, and operation of NBS. Update of the cost estimation is important due to the difficulty in estimating the accurate costs of many NBS during the design phase. However, some data and knowledge gathered from experiences in NBS maintenance exist, which can help in estimating the costs before the NBS implementation. This information could be received for example from designers or maintenance companies. Some publicly available data and guidelines already exist but it should be noted that there are many things affecting the maintenance costs and the initial cost estimations may differ from the realised costs.

Maintenance costs are dependent on the NBS type and size. In most cases, smaller NBS require less maintenance work and budget for the maintenance works. There are also some specific cases that can increase the costs compared to standard NBS structures, for example special equipment used, challenging access of NBS or contaminated sediments that need processing after their removal. Besides functional requirements of NBS, also aesthetic requirements of NBS play a role in maintenance costs as more strict requirements (e.g. more frequent maintenance work) need greater maintenance budget.

Maintenance costs are usually higher during the first years after construction or installation of maintenance. The costs can also differ between different years, since some maintenance actions are done less often than yearly and also some irregular, unexpected maintenance actions can increase the costs in some years. These unexpected maintenance costs can originate for example from unexpected repairing activities.

Maintenance work can often be included in the construction or installation contract, especially during the first years after the NBS construction or installation. When preparing the maintenance plan and contracts for the maintenance, it is important to carefully define the responsibilities for costs related to the maintenance actions.

Woods Ballard *et al.* (2015) list factors that normally comprise the operation and maintenance costs:

- labour and equipment costs
- material and/or replacement product costs
- replacement and/or extra planting costs
- disposal costs of, for example, contaminated sediments and vegetation

Costs of different operation and maintenance activities can vary substantially and is dependent on (Woods Ballard *et al.* 2015):

- location (influences material, labour and equipment charges)
- ease of access (confined sites might require special equipment which increases costs)
- upstream activities (can influence the rate of sediment accumulation in the system)
- type of use (multifunctional use, such as an additional amenity or ecological function, requires specific maintenance)
- quality of on-site construction or off-site manufacture of products
- the need for off-site disposal of waste
- the effectiveness of the design of the scheme to mitigate the above costs

In Table 11, some examples maintenance for different types of NBS are given. It should be noted that the costs are dependent on multiple different factors that the maintenance cost estimations should always be case-specific.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Table 11. Typical maintenance costs of different NBS types and supporting measures. Note that the costs can vary remarkably depending on the structure of NBS or supporting measure (e.g., type of permeable pavement) and their maintenance needs.

	Green roof	Rain garden	Daylighted river	Bioswale	Trees	Residential park	Vertical greening	Infiltration basin	Permeable pavements	Biofilter
Maintenance costs	0.5 - 3 €/m²/a[(1)]	~2,5 €/m² (grassed systems) ~8 €/m² (native vegetation)[(1)] 5-7 % of the construction costs to maintain each year[(1)]	Can vary a lot depending on many factors, including the size, and the plantings established	Similar to rain gardens	15-23 €/street tree/a[(2)] 5-7 % of the construction costs to maintain each year[(1)]	0.4-2.7 €/m²/a[(3)]	Direct green façade: Pruning: 2.81 €/m² Cladding renovation: 1224 €/m² (once in 50 years)[(4)]	1-5 €/m²/a[(5)] 5-20 % of the construction costs to maintain each year[(1)]	0.05-0.21 €/m²/a[(6)]	As a subsurface wetland type of filter, the maintenance costs can be somewhat similar to rain gardens, bioswale, and infiltration basins.

References:

(1) Eisenberg & Polcher, 2018
(2) McPherson *et al.*, 2006
(3) Tempesta, cited in Tempesta, 2015
(4) Perini & Rosasco, 2013
(5) Iwaszuk *et al.*, 2019
(6) Morello *et al.*, 2019

7.3 Maintenance operations for different NBS

In Table 12, a list of typical NBS maintenance activities is presented and the activities are linked with typical NBS types. The table is an exemplar, detailed list of needed maintenance activities should always be produced for each NBS that is planned to be implemented. Table 13 describes general maintenance recommendations and maintenance frequency for typical NBS types.

Table 12. Typical maintenance activities of different NBS (modified from Woods Ballard et al. 2015).

	Green roof	Rain garden	Daylighted river	Bioswale	Trees	Residential park	Vertical greening	Infiltration basin	Permeable pavements	Wetland	Biofilter
Regular maintenance											
Inspection	x	x	x	x	x	x	x	x	x	x	x
Litter and debris removal	(x)	x	x	x	x	x	x	x	x	x	x
Grass cutting	(x)	x	(x)	x	(x)	x	--	x	(x)	x	(x)
Weed and invasive plant control	x	x	x	x	x	x	x	(x)	(x)	(x)	(x)
Shrub management	-	(x)	(x)	(x)	(x)	(x)	-	(x)	(x)	(x)	(x)
Shoreline vegetation management	-	-	x	-	-	(x)	-	-	-	x	(x)
Aquatic vegetation management	-	-	x	-	-	(x)	-	-	-	x	(x)
Vacuum sweeping and brushing	-	-	-	-	-	-	-	-	x	-	-
Checking mechanical devices	(x)	-	(x)	-	-	(x)	(x)	(x)	-	(x)	(x)
Irregular/occasional maintenance											
Sediment management	-	x	(x)	x	x	(x)	-	x	x	x	x
Vegetation replacement	x	(x)	(x)	(x)	(x)	(x)	(x)	(x)	-	(x)	(x)
Repairing maintenance											
Structure rehabilitation/repair	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)
Infiltration surface reconditioning	-	(x)	-	(x)	(x)	(x)	-	(x)	(x)	-	(x)
Erosion damage control	(x)	x	(x)	x	(x)	(x)	-	x	-	(x)	(x)

Key:
x denotes "Required maintenance action"
(x) denotes "Possible maintenance action"
\- denotes "Usually not needed"

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Table 13. NBS maintenance recommendations.

NBS type	Maintenance considerations	Maintenance regularity
Green roof	Need for maintenance of the green roofs depends heavily on the type of green roof. According to Woods Ballard *et al.* (2015), intensive green roofs require regular inspection and maintenance with regular mowing, weeding, removing litter and debris etc., whereas extensive green roofs normally require only biannual or annual visits to remove litter, check any damage or unwanted drains and erosion channels etc. As it is for the most NBS, green roofs require more intensive maintenance during the early phases after implementation (approximately 12 months), including for example watering, weeding, and fertilisation. And as it is for the most NBS, the green roofs should be inspected after severe storms.	During the first year after implementation of the green roof, the inspection and maintenance routines should be more intensive (1-3 months) and afterwards, most of the maintenance activities are recommended to be performed biannually or annually.
Rain garden	According to Department of Planning and Government (2010a), rain gardens typically do not need intensive maintenance (e.g. watering, mowing, fertilising) if there is appropriate vegetation planted. However, in dry conditions or periods, watering of the rain gardens might be needed and retaining of moisture with mulch is recommended. Weeding might be necessary until the plants have matured. Regular inspections are important for checking the plant conditions (might need to be replaced), removing litter, debris, and sediment, and checking possible erosion damages. In general, it is important to detect possible clogging of the rain garden surface.	Inspections should be done once in 1-6 months, more regularly during the first 1-2 years and also after heavy rain events. Cleaning of the surface should be regular and performed at least biannually as well as the most of the other maintenance activities. Watering might need to be done more often in the early phases after the rain garden implementation.
Daylighted river	One of the potential benefits of river daylighting is reduction of maintenance needs compared to buried systems. River daylighting reduces the need for intensive water treatment. Daylighted river requires more intensive maintenance during the first years after its implementation, when the plants are established and their condition is inspected. Replanting, weeding, and in some cases also irrigation might be necessary especially in the initial phase. Regular debris, litter, and sediment removal might also be needed. Also the conditions of the channel and the riverbanks should be inspected especially during the first years after daylighting the river.	Regular inspections and maintenance are required for the daylighted rivers. The inspections and maintenance are more important and need to be done more intensively (once in 1-3 months) during the first years after implementation of river daylighting.
Bioswale	Bioswales are similar type of structures than rain gardens. The bioswales usually do not need very intensive maintenance but especially during the 1-2 first years after the implementing a bioswale, weeding and plant control might need to be done. Watering might also need to done during the plant establishment period. Regular inspections are important also for bioswales to check plant conditions, remove litter, debris, and sediment, check possible erosion damages, and to detect possible clogging of the surface. For dry bioswales, mowing should be done regularly.	Inspections should be done once in 1-6 months, more regularly during the first 1-2 years and also after heavy rain events. Cleaning of the surface should be regular and performed at least biannually as well as the most of the other maintenance activities. Watering might need to be done more often

		in the early phases after the bioswale implementation.
Trees (including green corridors)	Trees do not require as much maintenance as many other NBS. However, some maintenance especially during the first years is required. Woods Ballard (2015) suggests that maintenance tasks for the trees include removal of invasive vegetation as well as irrigation during long dry periods. Also, regular removing of litter and debris is required in an appropriate maintenance plan.	Monthly inspections are recommended especially during the first years after planting of trees. Regular (once in 1-3 months) removal of litter and debris as well as invasive vegetation is required.
Residential park	Parks can be diverse and multifunctional NBS that combine many different kinds of functions. Parks can contain trees, shrubs, and other kinds of plantings. Many different kinds of maintenance activities can be required for parks and they include mowing, irrigation, fertilization, weeding, pest control, maintenance of trees and all kinds of plants, litter and debris removal, raking leaves, maintenance of streams, and maintenance of trails.	Maintenance of residential parks should be regular and depending on the maintenance tasks and the functional and aesthetic requirements set for the park, the regularity of most the maintenance activities can be from monthly to annually. Some maintenance activities can require more frequent regularity especially in the early phases of the park after its implementation.
Vertical greening	Maintenance activities of vertical greening are somewhat dependent on the type of the vertical greening. Due to the verticality and considerable heights of this greening solution, maintenance activities can be time-consuming and costly. Therefore, it is beneficial to choose plants which require only little maintenance. Some vertical greening solutions can be almost maintenance free. However, some green facades can require intensive maintenance, including regular watering and fertilising. Maintenance actions for different types of vertical greening systems can include pruning, cladding renovation, irrigation, pipes maintenance/replacement of the irrigation system, and plant species replacement (Perini & Rosasco 2013).	Most of the regular maintenance activities (inspection, pruning, weeding etc.) are recommended to be done biannually or annually. In the initial phases after installing the vertical greening, more frequent maintenance is required for the plants. Cladding renovation is recommended to be done once in 50 years (Perini & Rosasco 2013).
Infiltration basin	Infiltration basins, as all infiltration systems, infiltrate water and therefore their infiltration capacity should be retained at a sufficient level by regular maintenance. Removing litter, debris, and sediments helps to prevent clogging of the infiltration systems. Condition of vegetation as well as erosion damages should be inspected and maintained regularly. Mowing might be needed at the access routes.	Regular inspections and maintenance (once in 1-6 months) is needed for sediment etc. removal, cleaning of the surface, and checking of erosion damages, etc. Vegetation should be maintained biannually.
Permeable pavements	Permeable pavements require regular maintenance activities. The need for maintenance originates mostly from the decline in the infiltration capacity of the pavement. The maintenance can be regular or it can be performed only when the infiltration rate has declined to a level that triggers the maintenance. If the	Regular inspections (once in 1-12 months) are needed for the permeable pavement condition and infiltration capacity (visual

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

	maintenance is performed only when the infiltration rate has declined, it is important to conduct regular measurements to test the infiltration capacity of the pavements. In general, it is important to conduct regular infiltration capacity testing to follow the condition of the pavement regarding its infiltration capacity. It is possible that despite the regular maintenance, the pavement becomes clogged. In this kind of situation, more intense or different type of maintenance should be done. At some point, the clogged pavement needs to be replaced by a new pavement. In certain cases and in long-term, also aggregate layer should be replaced. Clogging rate of the permeable pavements depends on many factors, including the type of pavement. Mostly the pavements become clogged due to debris, litter etc. but often the most clogging originates from fine sediment. For cleaning the pavements, the recommended maintenance actions include vacuuming, sweeping, and hosing.	inspection and infiltration capacity testing). Regularity of the maintenance activities can vary between 1-12 months.
Wetland	For simpler wetlands, the maintenance work requires maintaining and inspecting the banks, inspecting inlet and outlet structures for signs of clogging and need for sediment removal. More complex wetlands may include mechanical devices (valves, pumps etc.) which require more detailed maintenance recommendations. The most intensive period of maintenance is during the plant establishment period, which is approximately the first two years, during which weed removal, replanting, and more intensive sediment removal may be required (Department of Planning and Local Government, 2010b). The following things should be taken into account in maintaining wetlands (US EPA, 1995): • providing ample opportunity for contact of the water with the microbial community and with the litter and sediment • assuring that flows reach all parts of the wetland • maintaining a healthy environment for microbes • maintaining a vigorous growth of vegetation The operation and maintenance plan should address (US EPA, 1995): • setting of water depth control structures • schedule for cleaning and maintaining inlet and outlet structures, valving and monitoring devices • schedule for inspecting embankments and structures for damage • depth of sediment accumulation before removal is required • operating range of water levels, including acceptable ranges of fluctuation • the supplemental water source to be used to ensure adequate water levels during establishment and operation • wastewater application schedule, if this is part of the system design	Inspections should be done monthly as well as some of the maintenance activities, e.g. removing litter and debris. Some maintenance activities can be considered to be performed annually and repairing work when needed.

	• scheduling discharges to or from the wetland, recycling/redirecting flows, or rotating between cells, if such are part of the design	
Biofilter (sub-surface wetland/filter)	Where geochemically reactive materials are used as treatment media, the material should be replaced when its sorption capacity has been reached and effluents from the filter no longer meet water quality objectives. Clogging is a major issue with subsurface flow treatment wetlands; flow should be monitored to assess potential clogging of porous media. Both TSS and chemical oxygen demand (COD) loading rates are correlated with the occurrence of clogging. Intermittent operation, and the restoration of aerobic conditions within the filter, accelerates the mineralisation of organic material within filter media and is used to reduce clogging of subsurface filters. The duration of the resting period required depends upon the local climate, but typically is in the range of days to weeks (Knowles *et al.*, 2011).	Evaluations should occur annually based on regular flow and water quality monitoring data.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

7.3.1 Examples from partner cities

In the following tables (Table 14, Table 15 and Table 16) existing and planned maintenance procedures in the UNaLab Front Runner Cities (FRCs) are outlined.

Table 14. Maintenance of NBS in Tampere (FI).

NBS	Existing maintenance	Planned maintenance
Biofilter in Vuores	Maintenance has been started according to the plan	• Comprehensive maintenance is done to ensure optimal performance of the NBS • Maintenance card/plan is done • Cutting the vegetation will be done once a year in late summer • Inspections of underdrains/manholes (grey infra related to the NBS) once a year • Flushing of underdrains every 5 years • Inspection of sedimentation on top of the filter once a year. When sediment thickness is more than 10 cm, it is removed purification performance is monitored (when there is enough water coming in) twice a year
Retention pond	Not maintenance work done yet as the NBS is so new	• Comprehensive maintenance is done to ensure optimal performance of the NBS • No maintenance card yet, but we are going to make one based on the maintenance plans/cards in central park Vuores • Inspection of sedimentation once a year. When sediment thickness is more than 10 cm, it is removed in dry season • Inspection of pipes once a year in spring
Alluvial meadows	Not maintenance work done yet as the NBS is so new	• Comprehensive maintenance is done to ensure optimal performance of the NBS • No maintenance card yet, but we are going to make one based on the maintenance plans/cards in central park Vuores • Cutting the vegetation will be done once a year in late summer (September when flower seeds are ready)
Biofilter for seepage waters	• All the planned maintenance in done more often than planned in the beginning due to the capacity problems	• Maintenance card/plan is done • Comprehensive maintenance is done to ensure optimal performance of the NBS • Underdrains/ventilation pipes are inspected once a year • Sedimentation from manholes is inspected once a year and emptied when needed • Cutting the perennials will be done once a year in early spring when soil is frozen • Flushing of underdrains every 5 years • Activated carbon filter of the odour removal unit is changed once a year • Weeds are uprooted during the 2 first years

Pilot-scale micro algae system	• Maintenance has been done according to the plans	• Process inspection every work day during the microalgae growing season • Emptying the waste containers when needed • Emptying the system in late autumn • Starting the system in early spring
Small-scale NBS in Vuores: Urban garden 1	• Maintenance has been done according to the plans	• Maintenance of composts • Maintenance of fruit trees and berry bushes • Growing vegetables in urban gardening boxes • Irrigation with harvested rainwater • Fertilizing with compost • Uprooting the weeds • All voluntary work of residents
Small-scale NBS in Vuores: Urban garden 2	• Maintenance has been done according to the plans	• Maintenance of fruit trees and berry bushes • Uprooting the weeds • Growing vegetables in urban gardening boxes • All voluntary work of residents
Small-scale NBS in Vuores: "Community horse park"	• Maintenance has been done according to the plans	• Inspecting and fixing the fences in spring • Collecting and composting horse manure • Cutting the vegetation if needed • Horses do maintenance by grazing • Work done by local horse stable and supported by city
Lake Koukkujärvi nature trail	• The path has been in heavy use during the first months and eroded • Subsequently, maintenance measures (more duckboards, benches and wood chips) have been done already • Residents have participated on the maintenance	• Condition is inspected once a year and needed maintenance measures are done if needed • Adding woodchips to wet parts if needed • Duckboard removal in ca. 15 years • Possibly cutting the vegetation that grows on top of the path if needed • This is a suitable site for residents to participate on maintenance
Green roof/wall	Green roof/wall is not yet implemented	• Under planning, but aim is low need of maintenance such annual visit (more often in the beginning) • Plan is not to irrigate green roof • Green wall is going to be irrigated with harvested rain water

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Table 15. Maintenance of NBS in Genova (IT).

NBS	Planned maintenance
Draining pavements	Regular visual inspections (once in 3 months). Maintenance activities once in 12 months.
Sand playground	Regular visual inspections (once in 3 months). Maintenance activities once in 12 months.
Rain garden	Inspections once 6 months. Cleaning surface biannually.
Infiltration pond	Regular visual inspections (once in 6 months). Maintenance activities once in 24 months.
Bioswale	Inspections once 6 months. Cleaning surface biannually.
Tree groups and green areas	Inspections once 1 month for the first year. Regular removal of litter and debris once 3 months
Drought-resilient orchard and meadows	Inspections once 1 month for the first year. Regular removal of litter and debris once 3 months
Slope afforestation	Regular visual inspections (once in 3 months). Maintenance activities once in 12 months.
Natural engineering for slope securing	Regular visual inspections (once in 3 months). Maintenance activities once in 12 months.
Gabions	Regular visual inspections (once in 6 months). Maintenance activities once in 24 months.
Underground water retention basin	Inspections once 6 months. Cleaning biannually.
Green wall	Inspections once 1 month for the first year. Maintenance activities once in 12 months.

Table 16. Maintenance of NBS in Eindhoven (NL).

NBS	Existing maintenance (before introduction NBS)	Planned maintenance (after introduction NBS)
Grote Beek	Mowing, brushing pavements removing weeds	Mowing, brushing pavements removing weeds. Once every 3 to 5 years removing bushes and shrubs
Green zones (Clausplein)	Brushing pavement, and removing weed	Watering the plants, removing weeds, cutting the grass
Rainwater storage (Clausplein)	-	Cleaning the sand collector several times per year.
Green roof (Stadhuis plus)	Cleaning roof and replacing every 10 to 20	Removing weed once or twice per year
Green terrace (Stadhuis plus)	Brushing pavement, and removing weed	Mowing maintaining the plants (removing dead parts and planting)
Green entrance (Stadhuis plus)	Brushing pavements	Mowing removing weed brushing walking path
Vestdijk	Brushing pavements removing weeds	Mowing, brushing pavements removing weeds
Waagstraat	Brushing pavements removing weeds	Mowing, brushing pavements removing weeds
Bilderdijklaan	Brushing pavements removing weeds	Mowing, brushing pavements removing weeds
Willemstraat	Brushing pavements removing weeds	Mowing, brushing pavements removing weeds
H.Boexstraat/ Nieuwstraat	Brushing pavements removing weeds repairing the tree canopies	Watering plants in very dry periods removing weed Brushing pavement
Dommelstraat	Brushing pavements removing weeds repairing the tree canopies	Brushing pavement removing weed
Mathildelaan	Painting facade	Trimming green
Green facade (NRE terrein)	Painting every 5-10 years	Trim the green façade repairing the construction
Green zones (NRE terrein)	Mowing, brushing pavements removing weeds	Removing weed watering plants In very dry periods
Vestdijk/ Oude Stadsgracht (Kop smalle haven)	Brushing pavement Walls: Little maintenance necessary	Trimming green.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

8 LESSONS LEARNED AND POTENTIAL BARRIERS PREVENTING ADOPTION OF NBS

During the UNaLab project, good practices, lessons learned and information about realised and potential barriers to the adoption of Nature-Based Solutions have been collected. The *UNaLab NBS Demonstration Site Start-Up Report* (deliverable D5.4) illustrates the development and implementation of NBS and supporting actions in the UNaLab project FRCs Tampere (FI), Eindhoven (NL) and Genova (IT). The *UNaLab NBS Demonstration Site Start-Up Report* provides also good practices and early lessons learned and recommendations, which have been gained during the co-creation, design and early initiation on NBS in the UNaLab front runner cities, with which the reader is encouraged to become acquainted. The *UNaLab NBS Demonstration Site Start-Up Report* outlines both joint outcomes, which have been common to all UNaLab partner cities, but also locally specific outcomes, which concern a certain city. Some of the lessons learned that are highlighted in the document describe good practices. In addition, specific case examples of behaviour analysis of an NBS implementation has been provided. It has been noted that the life cycle of NBS from co-creation to implementation and maintenance involves several stakeholders and multisectoral knowledge. In order to ensure a successful result, knowledge and information transfer among actors and process phases is a key factor. Figure 12 outlines the process proposed by the city of Tampere to ensure information flow, from the ordering of the work through to maintenance and monitoring and documentation of the NBS. This process description has also been presented in deliverable D5.4.

Good practices help to replicate and accelerate the creation of NBS, but potential barriers can slow or prevent their implementation and should also be carefully taken into account. During the UNaLab project execution, information has been collected both from the FRCs and follower cities (FCs) about the potential barriers, which might inhibit NBS actions. Such barriers can be political, economic, social, technological, environmental, legal or ethical. Sometimes the observed barriers do not fall only into a single category, but the same or similar barrier may overlap several fields. In this chapter, we have summarised some of the observed barriers and mitigation measures found to overcome them in an effort to help other NBS actors avoid these or similar obstacles. Some of the barriers have already been discussed earlier in this document, but in this chapter, we summarise and collect some of the barriers discussed in the project into one section for quick reference. This chapter is based on the findings reported by all UNaLab partner cities, both the FRCs and the FCs.

One important lesson learned across the project has been that UNaLab ULL's have provided valuable data for municipal desicion making and strongly supported NBS implementation, both for public areas and private developers, when NBS actions have been replicated in UNaLab partner cities. Some NBS replication actions were inspired by the cities' own NBS actions, whilst others were inspired by NBS actions of other UNaLab cities.

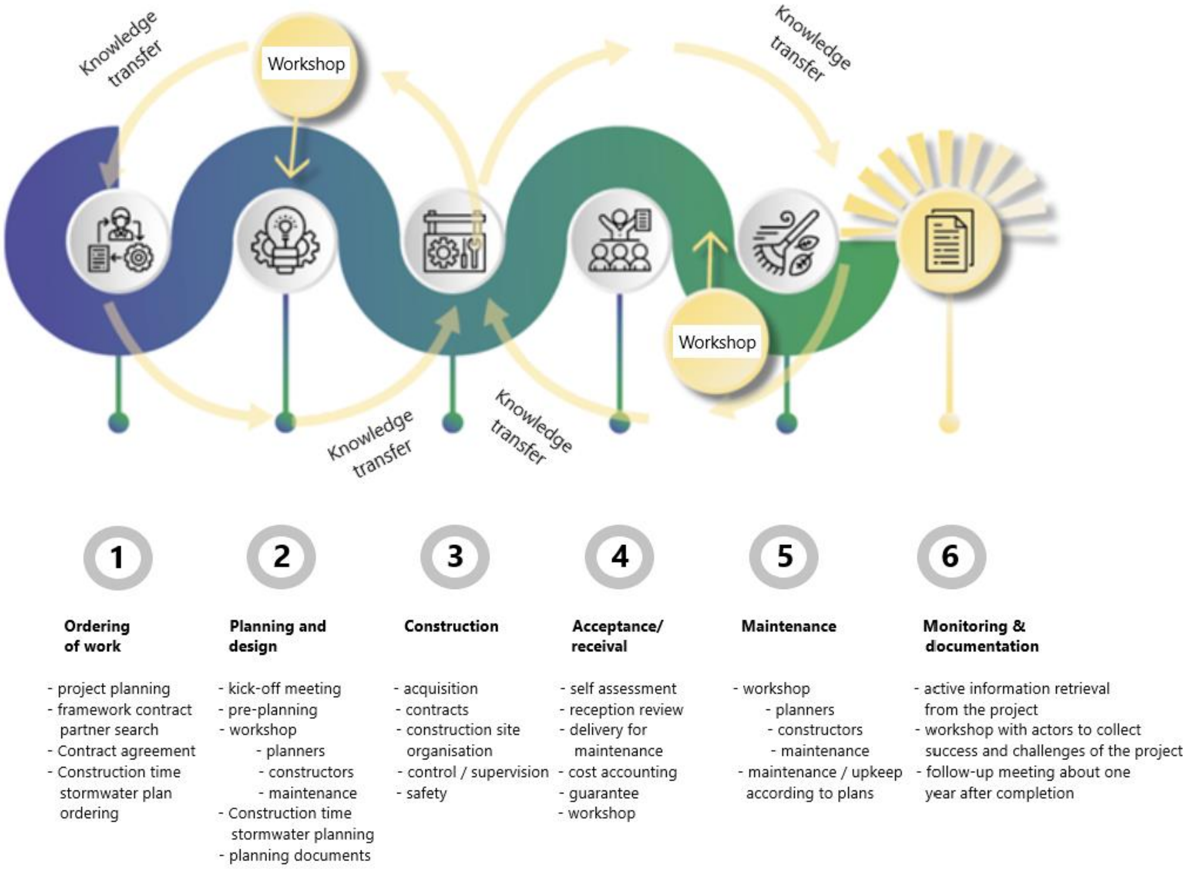


Figure 12 Importance of knowledge transfer in NBS project. Development of planning-implementation-maintenance chain of nature-based (storm water management) solutions (Luhtaniemi, 2020).

8.1 Organisational barriers and countermeasures

As the concept of NBS remains novel to the general public, the lack of knowledge concerning NBS has been encountered as an organisational barrier to the adoption of NBS. Municipal structures are generally department oriented and groups or departments can be siloed to a greater or lesser extent, making it hard to co-operate. In contrast to this traditional municipal structure, multisectoral actions are needed to implement NBS. When NBS and their benefits are unclear, it can result in a lack of commitment among the requisite stakeholders. A lack of an innovation mindset can also sometimes be a barrier in municipal organisations with respect to NBS adoption.

The primary countermeasure to mitigate these barriers is to increase the knowledge regarding NBS and the awareness of their benefits. When positive experiences are gained around the implementation of NBS, initiating, up-scaling and replicating NBS will become easier in the future. Creating municipal guidance and a coordinated NBS implementation strategy is also recommended as a good practice. In addition, fostering co-operation among municipal

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

departments should be enhanced to mitigate the silo mentality. Various national and international climate change adaptation and mitigation programs, along with sustainability, biodiversity enhancement and “greening” initiatives connected with a range of multi-level policy instruments support lowering of barriers associated with siloed organisational structures.

8.2 Social barriers and countermeasures

Similar to organisations, the lack of public awareness can also be a barrier to widespread NBS adoption. Although urban greening is almost universally viewed in a positive light, there are types of NBS that are less visible, making it harder to justify the need of them. In the dense urban areas with limited space, citizens might not appreciate Nature Based Solutions, if they would lose some of their achieved benefits, like parking places. Implementing Nature-Based Solutions can make the district more attractive impacting to rise of property prices and rents in the neighbourhood. Some can see this as a source of social inequality. Depending on the district socioeconomic problems, public policy priorities can higher in other fields than Nature-Based Solutions. Lack of public understanding of NBS benefits and insufficient practices of public participation at the local government level can in some cases cause false perception of NBS being an add-on option or greenwashing.

Lessons learned have shown that implementation take time and it is good to give people time to get use to new ideas and design. Public awareness about NBS is still quite low, so it is seen important to communicate actively about targets, what the city want to achieve with the NBS implementations. These actions can include e.g. public awaneress campaigns and engaging schools to educate and participate in the process. Schools and organisations can be engaged to participate in the monitoring phase to see the functionality and assist municipalities via citizen science programs, but they can be exposed also to NBS already in the co-creation phase using UNaLab co-creation toolkit. To gain social acceptance, cultural heritage should be conserved, and programs should be inclusiveness oriented creating community spaces for all, not only for specific limited group of residents.

8.3 Legal barriers and countermeasures

Legislation guides many things in societies. On one hand it has been mentioned that there is weak support for NBS in legislation, but on the other hand, legal framework is seen complex. Despite NBS is not yet visible in legislation, other area legislation brings boundary conditions to NBS implementation. NBS implementation require changes into urban environment and many legal frameworks are concerned. Such areas are e.g. the cultural heritage, flora and fauna legislation, zoning plans, waterboard regulations and construction regulations. Procurement regulations for tendering can cause also extra challenges and acquiring necessary permissions can take a lot of time. NBS will be a local implementation, but national or province wide decisions can interfere with them. In the limited available area, ownership of land property can cause constraints to available implementation options or bring ethical or economical barriers involved in the process. Some people have also mentioned that lack of interdisciplinary standards can be a barrier. In case land expropriation would be needed, other barriers and considerations will be involved in the process.

To lower the the potential legal barriers, liaisoning with legislature is seen important, because in the long run legislation can adapt better to take into account the requirements of NBS, when people with NBS knowhow are involved in the change process. It has been seen beneficial to start in time applying needed permission, because the approval process can be very long. Although NBS would not directly be mentioned in the legislation, the climate change mitigation and adaptation changes bring up the need for needed countermeasures, where NBS can be the answer. These include the e.g. the requirements for rainwater management or heat stress reduction in legislation for urban construction.

8.4 Ethical barriers and countermeasures

Although ethical barriers have not foreseen as major obstacles during the project for NBS, some potential barriers have been raised. Using public money to implement NBS on the private property might require ethical inspection. In the dense urban areas, available public space might not be sufficient for larger NBS implementations. Available resources are often limited, which require balancing between NBS and other investments. Some ethical issues can follow from designing the monitoring programs to ensure the functionality of the NBS and/or impact of the NBS, GDPR and privacy issues need to be taken into account e.g. when using cameras, surveys or other monitoring techniques, which could result to recognition of persons using the NBS.

8.5 Political barriers and countermeasures

Politics can bring uncertainty to the long term NBS implementation plans, because repeatedly occurring elections can both change the strategies in the municipal decision making, but also induce periods, when decision making is slowed down for a certain time. These can occur both before elections, when new bigger issues are not anymore decided, or after elections, when the new elected representatives are starting their term and concentrating to urgent pending issues. Politicians promote their own agenda and Nature-Based Solutions don't necessarily have high priority in their program resulting to lack of political commitment or leadership for NBS the implementation or speedy adoption. Political decisions can also be connected to agreements and compromises between the institutions and parties in power and in opposition. Some decisions are politically hard to make. like less space for cars in favour of greening the city or land and site expropriation when there is not enough space for a certain implementation. Local authorities and politicians have to follow also national regulations and guidelines. Convincing other local and government authorities for land provisioning might be needed when available space is insufficient and agreements with private landowners is not possible.

Awareness about climate change adaptation is increasing, which starts to impact the politicians, who start giving higher priority to environmental issues. Despite this shift, the challenge is still to keep politician committed to NBS programs, when they face competing interests. Gradually NBS is moving to the long-term environmental plans in several cities and districts, which promise increase of NBS implementation in the future. When piloting and pioneering NBS in new areas, some of the cities have started with "easy to realize" projects and collected references from successful example projects to increase awareness and acceptance among stakeholders and inhabitants for the next larger NBS projects. Another channel to lower the political barriers is to lobby for changes in rules & regulations to enforce NBS and to turn NBS into a politically winning asset. As well as the implementation requires a project leader, a political project leader can assist the NBS promotion significantly. When the NBS awareness of the public increases, it reflects also to the politician awareness making attitudes towards NBS more favourable.

8.6 Environmental barriers and countermeasures

During the UNaLab project, project partners have encountered several environmental barriers, which delay or extend the implementation time of NBS much longer and increase severely the costs. In the worse case the barriers can even prevent the NBS implementation completely. These encountered barriers include among others:

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

- Polluted soil
- Archeological findings
- Hidden war time explosives and ordnances
- Reconstruction of heavy existing infrastructure, like tram rails, sidewalks or streets
- Available space
- Conflicting objectives: more water elements to reduce heat island effect vs less water elements to avoid mosquitoes
- Danger of impact or contamination to the aquifer
- Local weather conditions, e.g. long dry periods followed by extreme rain periods
- Seasonal restrictions (e.g. winter in the Nordic countries vs. winter in Southern countries)
- Same NBS solutions don't always fit to other location, atleast not without modifications.
- Some decision makers are expecting to have quantified environmental benefits of NBS to support their decisions.

To avoid these barriers, extensive surveys already during the design phase are needed for potential polluted areas, archeological findings, cabels and pipes etc. It should be still remembered that unexpected issues during the implementation can and most likely will happen and changes or delays to the implementation occur. Long term environmental programs and related city plans need to be connected together but changing priorities can result to swift decisions. E.g. in case some specific challenge emerges to be a risk factor. Different climate regions require sometimes also some adaptation and all solutions cannot be directly copied from another city or location. Education about NBS and how they work is needed to ensure successful implementation.

8.7 Technological barriers and countermeasures

As in many other barrier categories, lack of knowledge or experience is a barrier. Adding NBS to existing grey infrastructure can lead to unwanted side effects with air or water flow changes, either increasing or decreasing the flow. Different climate and weather regions require also different or adapted solutions and one solution, which fits everywhere does not exist. Lack of knowledge of successful NBS pilot projects in your own climate region keep municipalities careful. Access to and procurement knowledge of the multisectoral technologies are needed both in the buyer and provider side to overcome these obstacles. Some novel technological solutions might need further development or research which overlaps with the ecomic barriers, e.g. who is going to pay for the development, which later can be used by others. Examples of encountered challenges have been e.g.

- How to create a parc on top of an existing parking house
- How to green the façade of parking house
- How to repair a broken biofilter
- Improving soil conditions can be a big separate project and require special expertise
- What are suitable environments for biodiversity micro-organisms
- Lack of experience among NBS providers / not enought experts in the field of NBS
- Lack of experience, when scaling small scale NBS to large scale

Sometimes it has been found out that there is lack of commitment over the area once the project has been completed when the next instance should take over the maintenance responsibility. The technological benefits versus challenges have not always been fully tested (e.g., the robustness, mosquito issues, etc.) and more research about the NBS effectiveness, biodiversity benefits and hybrid solutions has been asked for.

Deliverable D5.4, the *UNaLab NBS Demonstration Site Start-Up Report,* reports several technological lessons learned, which has been gained from the the UNaLab implementations concerning experienced difficulties and suggestions for improvements in certain NBS. Many quarters have demanded standards, manuals, and textbooks to be developed to better guide practices with proven sound NBS solutions. This document together with the D5.4 deliverable aims to provide answers to this gap from its own part. Involvement of universities and research institutes to educate students through learning about NBS to increase awareness has been also seen beneficial.

8.8 Economic barriers and countermeasures

Economic barriers are often tied together with the political and partly to the technological barriers, because they are tightly connected in the public domain. Funding is probably the most limiting resource drawing the border lines to what will be carried out. It is important to remember that implementation is not the only cost incurred from Nature-Base Solution, which need to be secured, but the whole lifetime of the NBS from design and operation up to the continuous maintenance including needed human resources. If the available space is too small, increasing the required space will lead to cost implications and can in some cases prevent the NBS implementation, because the space used for another use will provide better profit or benefits. Securing funding for the whole service life of NBS has been seen as a barrier. Economic challenges exist not only on the procurement side, but also on the production side. Stakeholders producing NBS (tools, services, etc.) need to have a sound business plan to justify their operations. Being a novel area, NBS has in some regions challenges to show the incentives or benefits, which can be acquired with NBS. Amount of skilled NBS personnel is still limited both on the provider and acquisition side causing bottlenecks for the projects and sometimes also increasing costs in a rivalry situation.

During the project good practises and lessons learned have been gained also to overcome the economic barriers. It has been said as a general comment that climate adaptation actions doesn't have to increase costs, but especially in the transition phase cost often increase, because removing old structures can be very expensive as reported in the previous barrier chapters. On the other hand, the maintenance of the ready NBS can sometimes be more cost efficient than the maintenance of the old grey infrastructure. New strickter design requirements concerning the climate adaptation and climate change need to be taken into account in all new projects, which open the opportunity for the NBS to solve some of the existing challenges. Increase of NBS awareness and provision of incentives can assist the NBS adoption in larger scale. NBS can be implemented afterwards, but if there is the opportunity to include the NBS in the bigger scale project as an integral part already from the beginning, some of the potential barriers can be avoided. This will also ensure the budget allocations. Project management and division to well lead sub-projects with skilled professionals is one of the key factors for successful result. It should be remembered that some of the larger NBS design and implementation require multisectoral knowledge, which might not be found from the buyer's organisation or even from one solution provider. To gain economic acceptability, cost benefit analysis and comparison of NBS and grey solutions can be beneficial. Volunteer groups and public participation can be engaged in the projects both with awareness increase and using vouchers. Last but not least, public tendering in the bigger scale projects can bring additional challenges in the procurement of services.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

9 CONCLUSIONS

The *Nature-Based Solutions Implementation Handbook* explores the various dimensions of the NBS implementation in the urban areas. The Handbook presents the examples and best practices of co-creation, Urban Living Lab implementation, NBS monitoring, including scales and equipment, and the NBS maintenance. It additionally includes amendments to D3.1 *Performance and Impact Monitoring of Nature-Based Solutions* (Appendix I) and D5.1 *NBS Technical Handbook* (Appendix II). This Handbook has been iteratively updated with new knowledge and learnings from the UNaLab project front-runner cities Eindhoven, Genova and Tampere. Other recommended reading with this handbook from the UNaLab project are the *NBS Demonstration Site Start-Up Report* (deliverable D5.4) and the *Impacts of NBS Demonstrations* (deliverable D3.4), which enhance the topics discussed in this document.

10 Acronyms and Terms

C/N ratio	Carbon-to-nitrogen ratio
CN	Curve number
CO_2	Carbon dioxide (gas)
DRR	Disaster risk resilience
EC	European Commission or Electrical conductivity (see context)
EEA	European Environment Agency
EIN	City of Eindhoven (NL)
ET	Evapotranspiration
EU	European Union
FAO	Food and Agriculture Organization (of the United Nations)
FC	Follower city
FRC	Front-runner city
GEN	City of Genova (IT)
GI	Green infrastructure
GIS	Geographic Information System
IDF	Intensity-frequency-duration
IEF	Indicator Evaluation Framework
ISO	International Organization for Standardization
IUCN	International Union for the Conservation of Nature
JRC	Joint Research Centre
KII	Key Impact Indicator
KPI	Key Performance Indicator
LiDAR	Light detection and ranging
NBS	Nature-based solution
NO_2	Nitrogen dioxide (gas)
NOAA	National Oceanic and Atmospheric Administration
N_{tot} or TN	Total nitrogen
NTU	Nephelometric turbidity units
O_3	Ozone (gas)
OECD	Organisation for Economic Co-operation and Development
PAHs	Polycyclic aromatic hydrocarbons
PET	Physiological equivalent temperature
PM_{10}	Particulate matter less than 10 µm in diameter (atmospheric)

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

$PM_{2.5}$	Particulate matter less than 2.5 µm in diameter (atmospheric)
PMV-PPT	Predicted Mean Vote-Predicted Percentage Dissatisfied
P_{tot} or TP	Total phosphorus
SO2	Sulphur dioxide (gas)
SOC	Soil organic carbon
SuDS	Sustainable urban drainage systems
SWMM	Stormwater Management Model
TOC	Total organic carbon
TRE	City of Tampere (FI)
TSS	Total suspended solids
UHI	Urban heat island
ULL	Urban Living Lab
UNDRR	United Nations Office for Disaster Risk Reduction
US EPA	United States Environmental Protection Agency
UTCI	Universal Thermal Climate Index
WEI	Water Exploitation Index
WFD	Water Framework Directive
WHO	World Health Organisation
WMO	World Meteorological Organization
WSUD	Water-sensitive urban design
YLL	Years of life lost

11 References

Adyel, T. M., Oldham, C. E., & Hipsey, M. R. (2016). Stormwater nutrient attenuation in a constructed wetland with alternating surface and subsurface flow pathways: event to annual dynamics. Water Research, 107, 66-82.

Al-Dabbous, A.N., & Kumar, P. (2014). The influence of roadside vegetation barriers on airborne nanoparticles and pedestrians exposure under varying wind conditions. *Atmospheric Environment*, *90*, 113-124.

Allen, H.L., Brown, S.L., Chaney, R.L., Daniels, W.L., Henry, C.L., Neuman, D.R., ... & Toffey, W. (2007). The use of soil amendments for remediation, revitalization and reuse. *United States Environmental Protection Agency, EPA 542-R-07-013.* 59 pp.

Armson, D., Stringer, P., & Ennos, A.R. (2013). The effect of street trees and amenity grass on urban surface water runoff in Manchester, UK. *Urban Forestry & Urban Greening*, *12*(3), 282-286.

Barth, N.C., & Döll, P. (2016). Assessing the ecosystem service flood protection of a riparian forest by applying a cascade approach. *Ecosystem Services*, *21*, 39-52.

Bonney, R., Ballard, H., Jordan, R., McCallie, E., Phillips, T., Shirk, J., & Wilderman, C.C. (2009). *Public Participation in Scientific Research: Defining the Field and Assessing Its Potential for Informal Science Education. A CAISE Inquiry Group Report.* Center for Advancement of Informal Science Education (CAISE), Washington D.C.

Bonney, R., Shirk, J.L., Phillips, T.B., Wiggins, A., Ballard, H.L., Miller-Rushing, A.J., & Parrish, J.K. (2014). Next steps for citizen science. *Science*, *343*(6178), 1436-1437.

Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). *CITYkeys indicators for smart city projects and smart cities*. CITYkeys D1.4. Retrieved from http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf

Calliari, E., Staccione, A., & Mysiak. J. (2019). An assessment framework for climate-proof nature-based solutions. *Science of the Total Environment*, *656*, 691-700.

Carrus, G., Scopelliti, M., Lafortezza, R., Colangelo, G., Ferrini, F., Salbitano, F., ... & Sanesi, G. (2015). Go greener, feel better? The positive effects of biodiversity on the well-being of individuals visiting urban and peri-urban green areas. *Landscape and urban planning*, *134*, 221-228.

Cioffi, M., Zappia, F., & Raggi, E. (2019). *Value Chain Analysis of Selected NBS*. Urban Nature Labs (UNaLab) Deliverable D6.1. Available from: https://unalab.eu/en/documents/d61-value-chain-analysis-report

Coma, J., Pérez, G., de Gracia, A., Burés, S., Urrestarazu, M., & Cabeza, L.F. (2017). Vertical greenery systems for energy savings in buildings: A comparative study between green walls and green facades. *Building and environment*, *111*, 228-237.

Conant, R.T., Paustian, K., & Elliott, E.T. (2001). Grassland management and conversion into grassland: effects on soil carbon. *Ecological applications*, *11*(2), 343-355.

Copernicus Global Land Service. (n.d.). *Overview of the product portfolio*. Retrieved from: https://land.copernicus.eu/global/products/. Accessed on 15.7.2020.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Copernicus Land Monitoring Service. (2020). *High Resolution Layers*. Retrieved from https://land.copernicus.eu/pan-european/high-resolution-layers. Accessed on 15.7.2020.

Davies, Z.G., Edmondson, J.L., Heinemeyer, A., Leake, J.R., & Gaston, K.J. (2011). Mapping an urban ecosystem service: quantifying above-ground carbon storage at a city-wide scale. *Journal of applied ecology*, *48*(5), 1125-1134.

Den Ouden, E., Valkenberg, R., Ershad Sharabi, S., Mok, S., Hawxwell, T., & Maciulyte, E. (2020). *Replication Roadmaps for UNaLab Follower Cities*. Urban Nature Labs (UNaLab) Deliverable D6.7 Replication Roadmaps Report.

Den Ouden, E., Valkenberg, R., Hawxwell, T., Suska, P., Padilla, M., Mok, S., & Schaufler, C. (2019). *Visions of UNaLab Follower Cities.* Urban Nature Labs (UNaLab) Deliverable D6.5 Joint Vision Report.

Dennis, M., & James, P. (2016). User participation in urban green commons: Exploring the links between access, voluntarism, biodiversity and well being. *Urban Forestry & Urban Greening*, *15*, 22-31.

Department of Planning and Local Government. (2010a). *Chapter 6: Rain Gardens, Green Roofs and Infiltration Systems*. In: Water Sensitive Urban Design Technical Manual for the Greater Adelaide Region. Government of South Australia, Adelaide. Retrieved from: https://www.sa.gov.au/__data/assets/pdf_file/0011/11540/WSUD_chapter_6.pdf

Department of Planning and Local Government. (2010b). *Chapter 13: Constructed Wetlands.* In: Water Sensitive Urban Design Technical Manual for the Greater Adelaide Region. Government of South Australia, Adelaide. Retrieved from: https://www.sa.gov.au/__data/assets/pdf_file/0010/19099/WSUD_chapter_13.pdf

Dickinson, J.L., & Bonney, J.R.E. (Eds.). (2012). *Citizen science: Public participation in environmental research*. Cornell University Press.

Dickinson, J.L., Shirk, J., Bonter, D., Bonney, R., Crain, R.L., Martin, J., Phillips, T., & Purcell, K. (2012). The current state of citizen science as a tool for ecological research and public engagement. *Frontiers in Ecology and the Environment*, *10*(6), 291-297.

Dickinson, J.L., Zuckerberg, B., & Bonter, D.N. (2010). Citizen science as an ecological research tool: challenges and benefits. *Annual review of ecology, evolution, and systematics*, *41*, 149-172.

Ebi, K.L., Boyer, C., Bowen, K.J., Frumkin, H., & Hess, J. (2018). Monitoring and evaluation indicators for climate change-related health impacts, risks, adaptation, and resilience. *International Journal of Environmental Research and Public Health* 15(9), 1943.

Eggermont, H., Balian, E., Azevedo, J.M.N., Beumer, V., Brodin, T., Claudet, J., …Le Roux, X. (2015). Nature-based solutions: New influence for environmental management and research in Europe. *GAIA*, *24*(4), 243-248.

Eisenberg, B., & Polcher, V. (2018). *Nature-Based Solutions Technical Handbook.* Deliverable 5.1. Urban Nature Labs (UNaLab). Available from https://unalab.eu/index.php/en/documents/unalab-technical-handbook-nature-based-solutions

Environment Protection Authority (EPA) Victoria. (2008). *Maintaining water sensitive urban design elements*. Retrieved from: https://www.epa.vic.gov.au/about-epa/publications/1226

European Commission. (2013). *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Green Infrastructure (GI) — Enhancing Europe's Natural Capital. COM(2013) 249 final*. Brussels: European Commission. Available from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52013DC0249

European Commission. (2013). *Individual NWRM: Rain gardens*. Natural Water Retention Measures, European Commission. Retrieved from: http://nwrm.eu/sites/default/files/nwrm_ressources/u11_-_retention_ponds.pdf

European Commission. (2016). *Open Innovation, Open Science, Open to the World – A vision for Europe.* Luxembourg: Publications Office of the European Union. Available from http://publications.europa.eu/resource/cellar/3213b335-1cbc-11e6-ba9a-01aa75ed71a1.0001.02/DOC_2http://publications.europa.eu/resource/cellar/3213b335-1cbc-11e6-ba9a-01aa75ed71a1.0001.02/DOC_2

European Commission. (2019). *Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions, The European Green Deal, COM(2019) 640 final*, 11 December 2019, available from https://ec.europa.eu/info/sites/info/files/european-green-deal-communication_en.pdf

European Commission. (2020a). *Biodiversity and Nature-based Solutions: Analysis of EU-funded projects.* Luxembourg: Publications Office of the European Union. Available from https://op.europa.eu/en/publication-detail/-/publication/d7e8f4d4-c577-11ea-b3a4-01aa75ed71a1

European Commission. (2020b). *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: EU Biodiversity Strategy for 2030. Bringing nature back into our lives. COM(2020) 380 final*. 20 May 2020. Brussels: European Commission. Available from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0380

European Commission. (2020c). *Natura 2000*. Retrieved from https://ec.europa.eu/environment/nature/natura2000/index_en.htm. Accessed on 15.7.2020.

European Parliament, Council of the European Union. (2000). Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. *Official Journal of the European Union* L 327, 22.12.2000, 1-73. Available from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32000L0060

European Parliament, Council of the European Union. (2007). Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks (Text with EEA relevance), COD 2006/0005, EEA relevance. *Official Journal of the European Union* L 288, 6.11.2007, 27-24. Available from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32007L0060

European Parliament, Council of the European Union. (2008). Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe. *Official Journal of the European Union* L 152, 11.6.2008, 1-44. Available from https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:32008L0050

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

European Parliament, Council of the European Union. (2014). Regulation (EU) No 377/2014 of the European Parliament and of the Council of 3 April 2014 Establishing the Copernicus Programme and Repealing Regulation (EU) No 911/2010 (Text with EEA Relevance). *Official Journal of the European Union* L 122, 24.4.2014, 44-66. Available from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32014R0377

European Parliament, Council of the European Union. (2016). Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC. *Official Journal of the European Union* L 119, 4.5.2016, 1-88. Available from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32016R0679

Faehnle, M., Söderman, T., Schulman, H., & Lehvävirta, S. (2015). Scale-sensitive integration of ecosystem services in urban planning. *GeoJournal*, *80*(3), 411-425.

Faivre, N., Sgobbi, A., Happaerts, S., Raynal, J., & Schmidt, L. (2017). Translating the Sendai Framework into action: the EU approach to ecosystem-based disaster risk reduction. *International Journal of Disaster Risk Reduction*, *32*, 4-10.

FAO, 2003. Biological Management of Soil Ecosystems for Sustainable Agriculture. World Soil Resources Reports 101. Report of the International Technical Workshop organised by EMBRAPA-Soybean and FAO, Londrina, Brazil, 24-27 June 2002. Rome: Food and Agriculture Organization of the United Nations.

Feigenwinter, C., Vogt, R., Parlow, E., Lindberg, F., Marconcini, M., Del Frate, F., & Chrysoulakis, N. (2018). Spatial distribution of sensible and latent heat flux in the city of Basel (Switzerland). *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *11*(8), 2717-2723.

Flynn, K. M., & Traver, R. G. (2013). Green infrastructure life cycle assessment: A bio-infiltration case study. *Ecological engineering*, *55*, 9-22.

Gardiner, M.M., Allee, L.L., Brown, P.M., Losey, J.E., Roy, H.E., & Smyth, R.R. (2012). Lessons from lady beetles: accuracy of monitoring data from US and UK citizen-science programs. *Frontiers in Ecology and the Environment*, *10*(9), 471-476.

Giannico, V., Lafortezza, R., John, R., Sanesi, G., Pesola, L., & Chen, J. (2016). Estimating stand volume and above-ground biomass of urban forests using LiDAR. *Remote Sensing*, *8*(4), 339.

Gittleman, M., Farmer, C. J., Kremer, P., & McPhearson, T. (2017). Estimating stormwater runoff for community gardens in New York City. *Urban ecosystems*, *20*(1), 129-139.

GIZ, UNEP-WCMC and FEBA. (2020). *Guidebook for Monitoring and Evaluating Ecosystem-based Adaptation Interventions*. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Bonn, Germany.

Gore, T., Ozdemiroglu, E., Eadson, W., Gianferrara, E., & Phang, Z. (2013). *Green Infrastructure's contribution to economic growth: A review. A Final Report for Department for Defra and Natural England*. London: eftec.

Greenway, M. (2017). Stormwater wetlands for the enhancement of environmental ecosystem services: case studies for two retrofit wetlands in Brisbane, Australia. Journal of Cleaner Production, 163, S91-S100.

Haase, D. (2017). *Urban Wetlands and Riparian Forests as a Nature-Based Solution for Climate Change Adaptation in Cities and Their Surroundings*. In: Kabisch, N., Korn, H., Stadler, J., & Bonn, A., Nature-based solutions to climate change adaptation in urban areas: Linkages between science, policy and practice. Springer Nature.

Habibipour, A. & Ståhlbröst, A. (2020). *UNaLab Living Lab Handbook*. Urban Nature Labs (UNaLab) Deliverable D2.4.

Habibipour, A., Ståhlbröst, A., Zalokar, S., & Vaittinen, I. (2020). *Living Lab Handbook for Urban Living Labs Developing Nature-Based Solutions*. Urban Nature Labs (UNaLab) project.

Hagler, G.S., Lin, M.Y., Khlystov, A., Baldauf, R.W., Isakov, V., Faircloth, J., & Jackson, L. E. (2012). Field investigation of roadside vegetative and structural barrier impact on near-road ultrafine particle concentrations under a variety of wind conditions. *Science of the Total Environment*, *419*, 7-15.

Hassall, C., & Anderson, S. (2015). Stormwater ponds can contain comparable biodiversity to unmanaged wetlands in urban areas. Hydrobiologia, 745(1), 137-149.

Hatt, B.E., Fletcher, T.D., & Deletic, A. (2009). Hydrologic and pollutant removal performance of stormwater biofiltration systems at the field scale. *Journal of Hydrology*, *365*(3-4), 310-321.

Hauru, K., Lehvävirta, S., Korpela, K., & Kotze, D. J. (2012). Closure of view to the urban matrix has positive effects on perceived restorativeness in urban forests in Helsinki, Finland. *Landscape and Urban Planning*, *107*(4), 361-369.

Hawxwell, T., Mok, S., Mačiulyte, E., Sautter, J., Theobald, J.A., Dobrokhotova, E. & Suska, P. (2018). *Municipal Governance Guidelines*. Urban Nature Labs (UNaLab) Deliverable D6.2.

Hecker, S., Haklay, M., Bowser, A., Makuch, Z., Vogel, J., & Bonn, A. (Eds.). (2018). *Citizen science: innovation in open science, society and policy*. UCL Press.

Huovila, A., Airaksinen, M., Pinto-Seppä, I., Piira, K., Bosch, P., Penttinen, T., … Kontinakis, N. (2017). CITYkeys Smart City Performance Measurement System. *International Journal for Housing Science*, *41*(2), 113–125.

IUCN. (2020). *IUCN Global Standard for Nature-based Solutions. A user-friendly framework for the verification, design and scaling up of NbS. First Edition.* Gland, Switzerland: International Union for the Conservation of Nature. Available from https://www.iucn.org/theme/nature-based-solutions/iucn-global-standard-nbs

Iwaszuk, E., Rudik, G., Duin, L., Mederake, L., Davis, M., Naumann, S., Wagner, I. (2019). *Addressing Climate Change in Cities. Catalogue of Urban Nature-Based Solutions*. Ecologic Institute, the Sendmizir Foundations: Berlin, Krakiw. Available from: https://www.ecologic.eu/17229

Jennings, V., & Bamkole, O. (2019). The Relationship between Social Cohesion and Urban Green Space: An Avenue for Health Promotion. *International Journal of Environmental Research and Public Health*, *16*(3), 452.

Kabisch, N., Frantzeskaki, N., Pauleit, S., Naumann, S., Davis, M., Artmann, M., … Bonn, A. (2016). Nature-based solutions to climate change adaptation and mitigation in urban areas: perspectives on indicators, knowledge gaps, barriers, and opportunities for action. Ecology and Society, 21(2), 39.

Knowles, P., Dotro, G., Nivala, J. & García, J. (2011). Clogging in subsurface-flow treatment wetlands: Occurrence and contributing factors. *Ecological Engineering*, 37, 99-112.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Krebs, G., Kokkonen, T., Valtanen, M., Setälä, H., & Koivusalo, H. (2014). Spatial resolution considerations for urban hydrological modelling. *Journal of Hydrology*, *512*, 482-497.

Kremer, P., Hamstead, Z., Haase, D., McPhearson, T., Frantzeskaki, N., Andersson, E., ... & Baró, F. (2016). Key insights for the future of urban ecosystem services research. *Ecology and Society*, *21*(2).

Kuoppamäki, K., & Lehvävirta, S. (2016). Mitigating nutrient leaching from green roofs with biochar. *Landscape and Urban Planning*, *152*, 39-48.

Laikari, A., Dubovik, M., Rinta-Hiiro, V., Wendling, L., Postmes, L., van Dinter, M., den Hollander, M., van der Putten, P., Särkilahti, M., Leppänen, S., Palmolahti, E., Inha, L., Mustajärvi, K., Kettunen, A., Zarino, S., Campailla, S., Balestrini, A., Chirulli, I., Facco, L., Vela, S., Cioffi, M., Gambucci, E., Botto, S., Hapuoja, A., Hannonen, P. (2021). NBS Demonstration Site Start-Up Report. Urban Nature Labs (UNaLab) Deliverable D5.4. Available from: https://unalab.eu/en/documents/d54-nbs-demonstration-site-start-report

Mačiulyte, E., Cioffi, M., Zappia, F., Duce, E., Ferrari, A., Kelson Batinga de Mendonça, M.F., Loriga, G., Suska, P., Vaccari Paz, B.L., Zangani, D., & Hein Bult, P. (2019). *Business Models & Financing Strategies*. Urban Nature Labs (UNaLab) Deliverable D6.3. Available from: https://unalab.eu/en/documents/d63-business-models-and-financing-strategies

Maes, J., Zulian, G., Günther, S., Thijssen, M., & Raynal, J. (2019). *Enhancing Resilience of Urban Ecosystems through Green Infrastructure. Final Report, EUR 29630 EN.* Luxembourg: Publications Office of the European Union.

Maes, J., Zulian, G., Thijssen, M., Castell, C., Baró, F., Ferreira, A.M., ... Teller, A. (2016). *Mapping and Assessment of Ecosystems and their Services – Urban Ecosystems.* Luxembourg: Publications Office of the European Union. Retrieved from: https://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/pdf/102.pdf

Mason, D. C., Horritt, M. S., Hunter, N. M., & Bates, P. D. (2007). Use of fused airborne scanning laser altimetry and digital map data for urban flood modelling. *Hydrological Processes: An International Journal*, *21*(11), 1436-1447.

McPherson, E. G., Simpson, J. R., Peper, P. J., Gardner, S. L., Vargas, K. E., Maco, S. E. & Xiao, Q. (2006). *Piedmont Community Tree Guide: Benefits, Costs, and Strategic Planting. General Technical Report 200*. Albany, CA: US Department of Agriculture, Forest Service, Pacific Southwest Research Station, 99 p. Available from: https://www.fs.fed.us/psw/publications/documents/psw_gtr200/psw_gtr200.pdf

Melbourne Water. (2013). *Water Sensitive Urban Design Guidelines*. Retrieved from: https://www.melbournewater.com.au/sites/default/files/South-Eastern-councils-WSUD-guidelines.pdf

Mesimäki, M., Hauru, K., & Lehvävirta, S. (2019). Do small green roofs have the possibility to offer recreational and experiential benefits in a dense urban area? A case study in Helsinki, Finland. *Urban Forestry & Urban Greening*, *40*, 114-124.

Mohareb, E., & Kennedy, C. (2012). Gross direct and embodied carbon sinks for urban inventories. *Journal of Industrial Ecology*, *16*(3), 302-316.

Mok, S., Hawxwell, T., Kramer, M., & Mačiulyte, E. (2019). *NBS Value Model.* Urban Nature Labs (UNaLab) Deliverable D6.4. Available from: https://unalab.eu/en/documents/d64-nbs-value-model

Morello, E., Mahmoud, I., Colaninno, N., (eds.). (2019). *Catalogue of Nature-based solutions for urban regeneration*. *Energy & Urban Planning Workshop*. School of Architecture Urban Planning Construction Engineering, Politecnico di Milano. Available from: http://www.labsimurb.polimi.it/nbs-catalogue/

Murray, B.C., Pendleton, L., Jenkins, W.A., & Sifleet, S. (2011). *Green payments for blue carbon: Economic incentives for protecting threatened coastal habitats.* Report NI R 11-04. Durham: Nicholas Institute for Environmental Policy Solutions, Duke University.

Nel, S., du Plessis, C., & Landman, K. (2018). Planning for dynamic cities: introducing a framework to understand urban change from a complex adaptive systems approach. *International Planning Studies*, *33*(3), 250-263.

Nelson, D.W., & Sommers, L.E. (1996). Total Carbon, Organic Carbon, and Organic Matter. In D.L. Sparks (Ed.), *Methods of Soil Analysis Part 3, Chemical Methods* (pp. 961-1010). Madison, WI: Soil Science Society of America, Inc.

Nowak, D.J., Crane, D.E., & Stevens, J.C. (2006). Air pollution removal by urban trees and shrubs in the United States. *Urban forestry & urban greening*, *4*(3-4), 115-123.

Organisation for Economic Co-operation and Development (OECD). (2008). *Key Environmental Indicators*. Paris, France: OECD Environment Directorate. Retrieved from https://www.oecd.org/env/indicators-modelling-outlooks/37551205.pdf

Orgiazzi, A., Ballabio, C., Panagos, P., Jones, A., & Fernández-Ugalde, O. (2018). LUCAS Soil, the largest expandable soil dataset for Europe: a review. *European Journal of Soil Science*, *69*(1), 140-153.

Panno, A., Carrus, G., Lafortezza, R., Mariani, L., & Sanesi, G. (2017). Nature-based solutions to promote human resilience and wellbeing in cities during increasingly hot summers. *Environmental research*, *159*, 249-256.

Pekel, J.-F., Cottam, A., Gorelick, N., & Belward, A.S. (2016). High-resolution mapping of global surface water and its long-term changes. *Nature*, *540*(7633), 418-422.

Pepper, I.L., Brusseau, M.L., & Artiola, J. (2004). *Environmental monitoring and characterization*. Elsevier Science & Technology.

Perales-Momparler, S., Andrés-Doménech, I., Hernández-Crespo, C., Vallés-Morán, F., Martín, M., Escuder-Bueno, I., & Andreu, J. (2017). The role of monitoring sustainable drainage systems for promoting transition towards regenerative urban built environments: a case study in the Valencian region, Spain. *Journal of Cleaner Production*, *163*, S113-S124.

Perini, K. & Rosasco, P. (2013). Cost-benefit analysis for green facades and living wall systems. *Building and environment 70*, 110-121.

Peschardt, K. K., & Stigsdotter, U. K. (2013). Associations between park characteristics and perceived restorativeness of small public urban green spaces. *Landscape and urban planning*, *112*, 26-39.

Peter, B.G., Mungai, L.M., Messina, J.P., & Snapp, S.S. (2017). Nature-based agricultural solutions: Scaling perennial grains across Africa. *Environmental research*, *159*, 283-290.

Pocock, M.J.O., Chapman, D.S., Sheppard, L.J., & Roy, H.E. (2014). *A Strategic Framework to Support the Implementation of Citizen Science for Environmental Monitoring. Final report to SEPA*. Centre for Ecology & Hydrology, Wallingford, Oxfordshire.

Raymond, C.M., Berry, P., Breil, M., Nita, M.R., Kabisch, N., de Bel, M., Enzi, V., Frantzeskaki, N., Geneletti, D., Cardinaletti, M., Lovinger, L., Basnou, C., Monteiro, A., Robrecht, H., Sgrigna, G., Munari, L. and Calfapietra, C. (2017). *An Impact Evaluation Framework to Support Planning and Evaluation of Nature-based Solutions Projects*. Report prepared by the EKLIPSE Expert Working Group on Nature-based Solutions to Promote Climate Resilience in Urban Areas. Centre for Ecology & Hydrology, Wallingford, United Kingdom.

Roebeling, P., Saraiva, M., Palla, A., Gnecco, I., Teotónio, C., Fidélis, T., … Rocha, J. (2017). Assessing the socio-economic impacts of green/blue space, urban residential and road infrastructure projects in the Confluence (Lyon): a hedonic pricing simulation approach. *Journal of Environmental Planning and Management*, *60*(3), 482-499.

Sandström, U. G., Angelstam, P., & Mikusiński, G. (2006). Ecological diversity of birds in relation to the structure of urban green space. *Landscape and urban planning*, *77*(1-2), 39-53.

Scholes, R.J., Reyers, B., Biggs, R., Spierenburg, M.J., & Duriappah, A. (2013). Multi-scale and cross-scale assessments of social–ecological systems and their ecosystem services. *Current Opinion in Environmental Sustainability*, *5*(1), 16-25.

Shanahan, D. F., Miller, C., Possingham, H.P., & Fuller, R.A. (2011). The influence of patch area and connectivity on avian communities in urban revegetation. *Biological Conservation*, *144*(2), 722-729.

Shaw, R., Colley, M., & Connell, R. (2007). *Climate change adaptation by design: a guide for sustainable communities*. Town and Country Planning Association, London.

Shirk, J.L., Ballard, H.L., Wilderman, C.C., Phillips, T., Wiggins, A., Jordan, R., ... & Bonney, R. (2012). Public participation in scientific research: a framework for deliberate design. *Ecology and society*, *17*(2).

Shuster, W.D., Darner, R.A., Schifman, L.A., & Herrmann, D.L. (2017). Factors contributing to the hydrologic effectiveness of a rain garden network (Cincinnati OH USA). *Infrastructures*, *2*(3), 11.

Somarakis, G., Stagakis, S., & Chrysoulakis, N. (Eds.). (2019). *ThinkNature Nature-Based Solutions Handbook.* ThinkNature project funded by the EU Horizon 2020 research and innovation programme under grant agreement No. 730338. https://doi.org/10.26225/jerv-w202

Speak, A.F., Rothwell, J.J., Lindley, S.J., & Smith, C.L. (2012). Urban particulate pollution reduction by four species of green roof vegetation in a UK city. *Atmospheric Environment*, *61*, 283-293.

Statistical Office of the European Union. (2019). *LUCAS – Land use and land cover survey*. Retrieved from: https://ec.europa.eu/eurostat/statistics-explained/index.php/LUCAS_-_Land_use_and_land_cover_survey. Accessed on 15.7.2020.

Statistical Office of the European Union. (2020). *Statistical regions in the European Union and partner countries: NUTS and statistical regions 2021.* Luxembourg: Publications Ofce of the European Union.

Streiling, S., & Matzarakis, A. (2003). Influence of single and small clusters of trees on the bioclimate of a city: a case study. *Journal of Arboriculture*, *29*(6), 309-316.

Strosser, P., Delacámara, G., Hanus, A., Williams, H., & Jaritt, N. (2015). *A guide to support the selection, design and implementation of Natural Water Retention Measures in Europe - Capturing the multiple benefits of nature-based solutions*. Luxembourg: Publications Office of the European Union.

Tammi, I., Mustajärvi, K., & Rasinmäki, J. (2017). Integrating spatial valuation of ecosystem services into regional planning and development. *Ecosystem Services*, *26*, 329-344.

Taramelli, A., Lissoni, M., Piedelobo, L., Schiavon, E., Valentini, E., Nguyen Xuan, A., & González-Aguilera, D. (2019). Monitoring green infrastructure for natural water retention using Copernicus global land products. *Remote Sensing*, *11*(13), 1583.

Tempesta, T. (2015). Benefits and costs of urban parks: a review. *AESTIMUM 67*, 127-143. Available from https://core.ac.uk/download/pdf/228543399.pdf

Tuomisto, M., Spinnato, P. & Roebeling, P. (2020). *Refined Open Innovation/ Crowdsourcing and Performance Measurement Tools*. Urban Nature Labs (UNaLab) Deliverable 4.7. Amended and resubmitted 13/11/2020.

United Nations (UN) General Assembly (2017). Resolution adopted by the General Assembly on 6 July 2017. 71/313 Work of the Statistical Commission pertaining to the 2030 Agenda for Sustainable Development. 10 July 2017, A/RES/71/313. Retrieved from https://undocs.org/A/RES/71/313

United Nations (UN) General Assembly. (2015). *Transforming Our World: The 2030 Agenda for sustainable development. A/RES/70/1.* New York: United Nations. Retrieved from http://www.unfpa.org/sites/default/files/resource-pdf/Resolution_A_RES_70_1_EN.pdf

United Nations Environment Programme (UNEP), United Nations Educational, Scientific and Cultural Organization (UNESCO), World Health Organisation (WHO), United Nations (UN) Women, United Nations Office on Drugs and Crime (UNODC), World Bank Group … United Nations Statistics Division. (2016). *A Guide to Assist National and Local Governments to Monitor and Report on SDG Goal 11+ Indicators: Monitoring Framework, Definitions, Metadata, UN-Habitat Technical Support.* Nairobi, Kenya: UN-Habitat. Available from http://unhabitat.org/sdg-goal-11-monitoring-framework/

United Nations Framework Convention on Climate Change (2015). *Report of the Conference of the Parties on its twenty-first session, held in Paris form 30 November to 13 December 2015, FCCC/CP/2015/10/Add.1,* 29 January 2016, available from https://unfccc.int/process/conferences/pastconferences/paris-climate-change-conference-november-2015/paris-agreement.

United Nations General Assembly (2017). Resolution adopted by the General Assembly on 6 July 2017. 71/313 Work of the Statistical Commission pertaining to the 2030 Agenda for Sustainable Development. A/RES/71/313, 10 July 2017, available from https://unstats.un.org/sdgs/indicators/Global%20Indicator%20Framework%20after%202020%20review_Eng.pdf

United Nations. 2007. United Nations Declaration on the Rights of Indigenous Peoples, A/RES/61/295, 13 September 2007, available from https://www.un.org/esa/socdev/unpfii/documents/DRIPS_en.pdf.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

US EPA. (1995). *A Handbook of Constructed Wetlands*. United States Environmental Protection Agency, USA. Retrieved from: https://www.epa.gov/sites/production/files/2015-10/documents/constructed-wetlands-handbook.pdf

van Dinter, M. & Habibipour, A. (2019). *Co-creation Workshops Report*. Urban Nature labs (UNaLab) project deliverable D2.2. Available from: https://unalab.eu/en/documents/d22-co-creation-workshops-report

Van Wesenbeeck, B.K., Iff, S., Jongman, B., Balog-Way, S.A.B., Kaupa, S.M., Bosche, L. V., ... & Kurukulasuriya, P.H. (2017). *Implementing nature based flood protection: principles and implementation guidance* (No. 120735, pp. 1-32). The World Bank.

Velasco, E., & Roth, M. (2010). Cities as net sources of CO_2: Review of atmospheric CO_2 exchange in urban environments measured by eddy covariance technique. *Geography Compass*, *4*(9), 1238-1259.

Velasco, E., Roth, M., Norford, L., & Molina, L. T. (2016). Does urban vegetation enhance carbon sequestration?. *Landscape and urban planning*, *148*, 99-107.

Vierikko K., & Niemelä, J. (2016). Bottom-up thinking – Identifying socio-cultural values of ecosystem services in local blue-green infrastructure planning in Helsinki, Finland. Land Use Policy, 50, 537-547.

Ward, H.C., Kotthaus, S., Grimmond, C.S.B., Bjorkegren, A., Wilkinson, M., Morrison, W.T.J., ... & Iamarino, M. (2015). Effects of urban density on carbon dioxide exchanges: Observations of dense urban, suburban and woodland areas of southern England. *Environmental Pollution*, *198*, 186-200.

Weber, F., Kowarik, I., & Säumel, I. (2014). Herbaceous plants as filters: Immobilization of particulates along urban street corridors. *Environmental Pollution*, *186*, 234-240.

Wendling, L., Huovila, A., zu Castell-Rüdenhausen, M., Hukkalainen, M., & Airaksinen, M. (2018). Benchmarking Nature-Based Solution and Smart City assessment schemes against the Sustainable Development Goal indicator framework. *Frontiers in Environmental Science, 6*, 69.

Wendling, L., Rinta-Hiiro, V., Jermakka, J., Fatima, Z., Ascenso, A., Miranda, A.I., Roebeling, P., Martins, R., & Mendonça, R. (2019). *Performance and Impact Monitoring of Nature-Based Solutions*. Urban Nature Labs (UNaLab) Deliverable D3.1. Available from: https://unalab.eu/en/documents/d31-nbs-performance-and-impact-monitoring-report

Woods Ballard, B., Wilson S., Udale-Clarke, H., Illman, S., Scott, T., Ashley, R. & Kellagher, R. (2015). *The SuDS Manual*. Retrieved from: https://www.ciria.org/ItemDetail?iProductCode=C753F&Category=FREEPUBS

Yuan, J., Dunnett, N., & Stovin, V. (2017). The influence of vegetation on rain garden hydrological performance. *Urban Water Journal*, *14*(10), 1083-1089.

Zhang, R., Chen, J., Park, H., Zhou, X., Yang, X., Fan, P., ... & Ouyang, Z. (2019). Spatial Accessibility of Urban Forests in the Pearl River Delta (PRD), China. *Remote Sensing*, *11*(6), 667.

12 Appendix I: Update to D3.1 Performance and Impact Monitoring of Nature-Based Solutions

Table of Contents

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

12.1 Introduction

The updated D3.1 *Performance and Impact Monitoring of Nature-Based Solutions* contains information contributed by UNaLab to the European Handbook on NBS Impact Assessment (Dumitru & Wendling, Eds., *in preparation*) as well as minor updates to information presented in UNaLab D3.1 *Performance and Impact Monitoring of Nature-Based Solutions* (Wendling *et al*., 2019). Herein, we present updated methods of determination for indicators of NBS performance and impact, grouped by the societal challenge addressed. The tables at the forefront of each section indicate the class of each indicator (i.e., structural, process or outcome based) and also show the applicability of each indicator to different types of NBS.

The three basic classes of indicators are:

- **Structural indicators (S)** – refer to all the factors that affect the context in which NBS are implemented. This typically includes the supporting infrastructures and resources in place to achieve the desired goals (e.g., physical facilities, equipment, human resources, organisational characteristics, policies and procedures).
- **Process indicators (P)** – refer to the actions that are involved in NBS co-creation, co-implementation and co-management. These indicators are used to assess the efficiency, quality, or consistency of specific procedures employed to achieve the desired goals.
- **Outcome indicators (O)** – refer to all the effects of NBS. These include social, enviromental and economic effects or impacts. Outcome-based indicators comprise the greatest proportion of the indicators presented in Appendix I.

The tables preceding each group of indicators also show the applicability of each indicator to different types of NBS. There is no single definitive list of NBS; however, NBS can be broadly grouped based on their objectives, or function, and level of ecosystem intervention. Eggermont et al. (2015) proposed the following NBS typology that has since been widely adopted:

- **Type 1** – no or minimal intervention in ecosystems, with objectives related to maintaining or improving delivery of ecosystem services within and beyond the protected ecosystems.
- **Type 2** – extensive or intensive management approaches that develop sustainable, multifunctional ecosystems and landscapes to improve delivery of ecosystem services relative to conventional interventions.
- **Type 3** – Highly intensive ecosystem management or creation of new ecosystems.

Type 1 NBS include protection and conservation strategies, urban planning strategies, and (environmental) monitoring strategies. Type 1 NBS by nature fall largely within the domain of governance, with implementation of Type 1 NBS strategies potentially limited or driven by various biophysical, social and institutional factors. Type 2 NBS are comprised of a range of different sustainable management practices. As newly-created ecosystems, Type 3 NBS are the most "visible" solutions. Examples of Types 1-3 NBS may include (Cohen-Shacham et al., 2016; Eggermont et al., 2015; European Commission, 2015; Nicolaides et al., 2019):

Type 1 NBS

- **Protection and conservation strategies**
    - Establishment of protected areas or conservation zones
    - Limitation or prevention of specific land uses and/or practices
    - Ensured continuity of the ecological network (protection of natural areas from fragmentation)

    - Maintenance or enhancement of natural wetlands
- **Urban planning strategies**
    - Ensured continuity of the ecological network
    - Control of urban expansion
- **Monitoring**
    - Regular monitoring of physical, chemical or biological indicators to ensure maintenance of ecosystem function

Type 2 NBS

- **Sustainable management protocols**
    - Integrated management of pests/weeds
    - Spatial and/or time and frequency aspects of integrated and ecological management plans
    - Creation and preservation of habitats and shelters to support biodiversity (e.g., insect hotels for wild bees, next boxes for native bats and birds, stopover habitat/"rest stops" for migratory birds)
    - Installation of apiaries
    - Sustainable use of fertiliser
    - Control of soil erosion through management of grazing animal stocking density and exclusion of grazing animals from riparian areas
    - Composting of organic wastes and reuse of composted organic materials
    - Integrated water resource management (IWRM)
    - Integrated coastal zone management (ICZM)
    - Protection of plant resources from pest and disease
    - Aquifer protection from pollution and sustainable management of withdrawals

Type 3 NBS

- **Green space** - multifunctional open space characterised by natural vegetation & permeable surfaces
    - Urban parks and gardens of all sizes
    - Heritage park
    - Botanical garden
    - Community garden
    - Cemetery
    - Schoolyards and sports fields
    - Meadow
    - Green strips
    - Green transport track
    - "Multifunctional" dry detention pond or vegetated drainage basin
- **Trees and shrubs**
    - Forest (including afforestation)
    - Orchard
    - Vineyard
    - Hedges/shrubs/green fences
    - Street tree(s)
- **Soil conservation and quality management**
    - Slope revegetation
    - Cover crops
    - Windbreaks
    - Conservation tillage practices

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

- Permaculture
- Deep-rooted perennials
- Organic matter enrichment (manure, biosolids, green manure, compost, etc.)
- Inorganic soil conditioners and amendments (biochar, vermiculite, etc.)

- **Blue-green space establishment or restoration**
  - Riparian buffer zones
  - Mangroves
  - Saltmarsh/seagrass
  - Intertidal habitats
  - Dune structures
- **Green built environment**
  - Green roof
  - Green-blue roof
  - Green wall/façade
  - Green alley
  - Infiltration planters and tree boxes
  - Rainwater harvesting systems
  - Temporary and/or small-scale interventions including green furniture, green living rooms, etc.
- **Natural or semi-natural water storage and transport structures**
  - Surface wetland (marsh)
  - Floodplains, floodplain reconnection with rivers
  - Restoration of degraded waterbodies
  - Restoration of degraded waterways, including re-meandering of streams and river daylighting
  - Retention pond/wet detention pond
- **Infiltration, filtration, and biofiltration structures**
  - Infiltration basin
  - Vegetated filter strip
  - Rain garden
  - Wet/dry grassed swale, with or without check dams
  - Surface wetland (marsh)
  - Subsurface (constructed) wetland or filtration system
  - Bioretention basin/bioretention cell

The indicators and associated methods of determination presented herein are organised by the societal challenge addressed, across twelve societal challenge areas (Dumitru and Wendling. Eds., *in preparation*; Raymond *et al.*, 2017):

1. Climate Resilience
2. Water Management
3. Natural and Climate Hazards
4. Green Space Management
5. Biodiversity Enhancement
6. Air Quality
7. Place Regeneration
8. Knowledge and Social capacity Building for Sustainable Urban Transformation
9. Participatory Planning and Governance
10. Social Justice and Social Cohesion
11. Health and Wellbeing
12. New Economic Opportunities and Green Jobs

The suite of indicators and methods presented herein are designed to support the development of a European Reference Base on NBS Performance and Impact by enabling the acquisition of comparable data about a wide range of different NBS, implemented by different project teams at varying spatial scales and in different environments. These indicators represent a sub-set of the extended catalogue of NBS performance and impact indicators generated by the group of experts representing 17 individual EU-funded NBS projects and collaborating institutions such as the EEA and JRC as members of the NBS Impact Evaluation Taskforce (Taskforce 2) between 2017 and 2020 (Dumitru and Wendling, Eds., *in preparation*). Note that the indicators and associated methods of determination described here are non-exhaustive. There are a number of frameworks from which it is possible to source potential indicators of NBS performance and impact, such as:

- the NBS impact evaluation framework developed by the EKLIPSE Working Group on Nature-based Solutions to Promote Climate Resilience in Urban Areas (Raymond et al., 2017);
- the Mapping and Assessment of Ecosystems and their Services-Urban Ecosystems technical report and indicator framework (Maes et al., 2016; Maes, Zulian, Günther, Thijssen, & Raynal, 2019);
- the CITYkeys assessment framework for smart city projects and smart cities (Bosch et al., 2017; Huovila et al., 2017);
- the global indicator framework for UN Sustainable Development Goal 11 'Make cities and human settlements inclusive, safe, resilient and sustainable' (United Nations General Assembly, 2015, 2017; UN-Habitat et al., 2016);
- key environmental indicators identified by the Organization for Economic Development and Co-Operation (OECD) (OECD, 2008); and,
- various other NBS evaluation schemes and assessment frameworks published in the scientific literature (e.g., Calliari, Staccione & Mysiak, 2019; Faivre, Sgobbi, Happaerts, Raynal, & Schmidt, 2017; Kabisch et al., 2016; Nel, du Plessis & Landman, 2018; Wendling, Huovila, zu Castell-Rüdenhausen, Hukkalainen, & Airaksinen, 2019)

The Taskforce 2 handbook, *Evaluating the Impact of Nature-based Solutions: A Handbook for Practitioners* (Dumitru and Wendling, Eds., *in preparation*), designates particular indicators as "recommended" in order to develop a holistic understanding of NBS performance and impact. The Taskforce 2 recommended indicators are also highlighted herein.

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

12.2 Climate Resilience

Nature-based solutions can enhance resilience to the impacts of climate change by providing ecosystem services and increasing social awareness and actions to combat climate change. The co-benefits delivered by NBS support climate change mitigation and adaptation efforts. NBS performance and impact indicators in the Climate Resilience category mainly address:

- The direct impacts of NBS on greenhouse gas emissions through carbon storage and sequestration
- The indirect impacts of NBS on greenhouse gas emissions through the provision of passive cooling, insulating and/or water treatment
- The impacts of NBS on microclimate (temperature, humidity) and human comfort

Table 17. Indicators of NBS performance and impact related to Climate Resilience

Nr.	Indicator	Units	Class	Applicability to NBS		
				Type 1	Type 2	Type 3
11.2.1†	Total carbon removed or stored in vegetation and soil	kg/ha/y	O	●	●	●
11.2.2†	Avoided greenhouse gas emissions from reduced building energy consumption	kWh/y or t C/y saved	O		●	●
11.2.3†	Heatwave incidence: Number of combined tropical nights and hot days	Nr./y	O	●		●
11.2.4	Total C stored in vegetation per unit area per unit time	t/ha/y	O	●	●	●
11.2.5	Total C stored in soil per unit area per unit time	t/ha/y	O	●	●	●
11.2.6	Soil carbon to nitrogen ration (C/N)	unitless	O	●	●	●
11.2.7	Total surface area of wetlands	ha	O	●	●	●
11.2.8	Surface area of restored and/or created wetlands	ha	O	●	●	●
11.2.9a	Human comfort: Universal Thermal Climate Index	°C	O	●	●	●
11.2.9b	Human comfort: Physiological Equivalent Temperature	°C	O	●		●
11.2.9c	Human comfort: Predicted Mean Vote-Predicted Percentage Dissatisfied	unitless	O	●		●
11.2.10	Urban Heat Island effect	°C	O	●		●
11.2.11a	Mean or peak local daytime temperature: direct measurement	°C	O	●		●

11.2.11b	Mean or peak local daytime temperature: temperature modelling	°C	O	●		●
11.2.12	Daily temperature range	°C	O	●		●
11.2.13	Rate of evapotranspiration	mm/day	O	●	●	●
11.2.14	Land surface temperature	°C	O	●	●	●
11.2.15	Surface reflectance - albedo	0-1, unitelss	O	●	●	●
11.2.16	Carbon emissions from vehicle traffic	t C/y reduction	O	●		●

† Indicators designated "recommended" by NBS Impact Evaluation Taskforce (Taskforce 2; Dumitru and Wendling, Eds., *in preparation*)

12.2.1 Total carbon removed or stored in vegetation and soil per unit area per unit time

Metric: *Total carbon removed or stored (tonnes/ha/y or similar units)*

Strengths: *Quantifying removal and sequestration can give the opportunity to mitigate GHG effects*

Weaknesses: *Requires other metrics to evaluate the indicator*

Accounting for C stored in soil and vegetation in an urban area can indicate the condition of natural green spaces, total free surface area and total quantity of vegetation in the area examined. Measures of C storage and sequestration also provide a tangible connection to climate change mitigation, and the impacts of local land use, planning and management decision-making. It is important to note the substantial variation in C sequestration and storage capacity of different types of NBS.

To evaluate C removal or storage per unit area per unit time:

- Determine C storage in vegetation or soil as described in Carbon storage and sequestration in vegetation or Carbon storage and sequestration in soil indicators, respectively, for the same area at two different points in time
- Divide each C storage value obtained by the area assessed to determine C storage per unit area
- Subtract the earlier value obtained for C storage and sequestration/unit area from the more recent value, then divide by the length of time between measures to obtain an estimate of C removal or storage per unit area per unit time.

The growth rate of a forest has significant impact on its C storage potential. Forest C sequestration (FCS) is usually estimated as a function of forest area, forest type, and forest age:

$$FCS = \left(FIA_{rate}/FOREST_{mean-pct}\right) \times NONF_{mean-pct,i} \times NONF_{area,i}$$

Where:

FIA_{rate} is net forest growth rate for the most common type group in county i,

$FOREST_{mean\text{-}pct}$ is mean canopy cover percentage for all forested pixels in the county i,

$NONF_{mean\text{-}pct}$ is mean canopy cover percentage for all non-forest pixels in county i, and

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

$NONF_{area}$ is area sum of all non-forest pixels in county *i*

The sum of FCS in both forested and non-forest pixels is the total net FCS by urban and community trees in county *i* (Zheng, Ducey, & Heath, 2013). Studies have shown that more accurate estimates of FCS are obtained by classifying forests as recently afforested or mature/remnant forest as tree growth rates vary substantially between these forest types (Smith, Heath, Skog & Birdsey, 2006; Zheng, Heath, Ducey & Smith, 2011).

Scale of measurement: Plot scale to regional scale

Required data: Requires C storage to be determined from either *Carbon storage and sequestration in soil* or *Carbon storage and sequestration in vegetation* indicators

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually

Level of expertise required: Low – requires the ability to determine C storage from other metrics and follow the calculation procedure

Connection to other indicators: Requires C storage to be determined from either *Carbon storage and sequestration in soil* or *Carbon storage and sequestration in vegetation* indicators

Connection to SDGs: SDG 11 Sustainable cities and communities, SDG 13 Climate action

Key References

Smith, J.E., Heath, L.S., Skog, K.E., & Birdsey, R.A. (2006). *Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States.* USDA Forest Service Report GTR-NE-343. Newtown Square, PA: Northeastern Research Station, United States Department of Agriculture, Forest Service.

Zheng, D., Ducey, M.J. & Heath, L.S. (2013). Assessing net carbon sequestration on urban and community forests of northern New England, USA. *Urban Forestry & Urban Greening*, 12, 61-68.

Zheng, D., Heath, L.S., Ducey, M.J. & Smith, J.E. (2011). Carbon changes in conterminous US forests associated with growth and major disturbances: 1992–2001. *Environmental Research Letters*, 6, 014012.

12.2.2 Avoided greenhouse gas emissions from reduced building energy consumption

Metric: *CO_2 emissions related to building energy consumption (direct via, e.g., residential combustion and indirect via, e.g., electric heating and cooling) with and without NBS implementation (kWh/y and t C/y saved)*

Strengths: *Can be fairly easily measured; Indicates changes in building heating and cooling needs*

Weaknesses: *Not sensitive to energy production details. Analysis can be lacking accuracy and comparability between different communities and regions*

Building energy consumption is the fraction of greenhouse gas (GHG) emissions that can be affected by nature-based solutions in an urban environment.

First, the community housing energy sources are identified and methods for their quantification on yearly basis are recorded (IPCC, 2006). These energy sources include electrical energy use, as well as supplemental energy sources such as district heating and local combustion for heating. Numerical values for the community as a whole (MWh), as well as population equivalent (MWh/person), are recorded, thus allowing for compensation for population change.

All forms of energy need to be taken into account, including electricity consumption, natural gas or thermal energy for heating and cooling, and fuels.

CO_2 emissions related to building energy consumption are calculated as follows:

$$Emissions_{buildings} = Energy\ (MWh/a) \times National\ emission\ factor\ (t\ CO_2/MWh)$$

$$Decrease\ (\%) = 100\% - \left(\left(\frac{Emission_{buildings\ (after)}}{Emission_{buildings\ (before)}} \right) \times 100\% \right)$$

Scale of measurement: Building, street and district scale

Required data: Information about building energy sources and electrical energy use, as well as supplemental energy sources such as district heating and local combustion for heating. These data can typically be obtained from municipal sources or from records of building- or district-level energy consumption from the building owner or utility company.

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually to enable tracking of changes to CO2 emissions due to building energy consumption with time; at minimum before and after NBS implementation

Level of expertise required: Low – requires ability to follow the calculation procedure and to convert different units of energy to kWh of energy to achieve the total energy consumption

Connection to other indicators: Possibility to combine with *CO_2 emissions related to vehicle traffic* indicator to obtain the total decrease due to NBS implementation

Connection to SDGs: SDG 11 Sustainable cities and communities, SDG 13 Climate action

Key References

Intergovernmental Panel on Climate Change (IPCC). (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories.* Prepared by the National Greenhouse Gas Inventories Programme, Eggleston, S., Buendia, L., Miwa, K., Ngara, T., & Tanabe, K. (Eds.). Hayama, Japan: Institute for Global Environmental Strategies (IGES). Retrieved from https://www.ipcc-nggip.iges.or.jp/public/2006gl/.

12.2.3 Heatwave incidence

Metric: *Number of combined tropical nights (>20°C) and hot days (>35°C)*

Strengths: *Easy and straightforward assessment*

Weaknesses: *Requires substantial amount of external data for modelling*

Heatwave is a period of prolonged abnormally high surface temperatures relative to those normally expected. Heatwaves can be characterized by low humidity, which may exacerbate drought, or high humidity, which may exacerbate the health effects of heat-related stress such as heat exhaustion, dehydration and heatstroke. Heatwaves in Europe are associated with significant morbidity and mortality. Furthermore, climate change is expected to increase average summer temperatures and the frequency and intensity of hot days (Russo et al., 2014). In cities and urban areas, the UHI tends to exacerbate heatwave episodes.

This indicator is assessed through continuous monitoring of temperature, and/or estimated by applying meteorological models such as the Weather Research and Forecasting WRF model (NCAR & UCAR, n.d.; NOAA, n.d.)

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

"Tropical nights" are defined as days when the daily minimum temperature is >20°C. The number of tropical nights is equal to the number of days annually when the daily minimum temperature is >20°C (ETCCDI; http://etccdi.pacificclimate.org/list_27_indices.shtml). For the purposes of this indicator, "hot days" are defined as days when the daily maximum temperature is >35°C.

Scale of measurement: Neighbourhood to regional scale

Required data: For modelling: initial and boundary conditions, topography, land use and urban parameters (building height, width, number of road lanes) (Emmons et al., 2010; Pineda, Jorba, Jorge & Baldasano, 2004). These data can be obtained through national statistics, municipal departments, Corine Land Cover, and a mapping application such as OpenStreetMap.

For direct measurements: hourly mean values of ambient air temperature

Data generation specifications: Quantitative; participatory data collection is feasible through sample collection, e.g., air temperature measurements if these are not automated

Data generation/collection frequency: Annually, and before and after NBS implementation

Level of expertise required: Low – for continuous temperature monitoring; high – for applying meteorological models

Connection to other indicators: Assessed from *Mean or peak daytime temperature* indicator and connected with *Urban Heat Island* indicator

Connection to SDGs: SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action

Key References

Emmons, L.K., Walters, S., Hess, P.G., Lamarque, J.-F-, Pfister, G.G., Fillmore, D. … Kloster, S. (2010). Description and evaluation of the Model for Ozone and Related chemical Tracers, version 4 (MOZART-4). *Geoscientific Model Development*, *3*, 43-67.

National Center for Atmospheric Research (NCAR) & University Corporation for Atmospheric Research (UCAR). (n.d.). Weather Research and Forecasting (WRF) Model Users' Page. Retrieved from http://www2.mmm.ucar.edu/wrf/users/

National Oceanic and Atmospheric Administration (NOAA). (n.d.). Weather Research and Forecasting model coupled to Chemistry (WRF-Chem). Retrieved from https://ruc.noaa.gov/wrf/wrf-chem/

Pineda, N., Jorba, O., Jorge, J. & Baldasano, J.M. (2004). Using NOAA AVHRR and SPOT VGT data to estimate surface parameters: application to a mesoscale meteorological model. *International Journal of Remote Sensing*, *25*(1), 129–143.

Russo, S., Dosio, A., Graversen, R., Sillmann, J., Carrao, H., Dunbar, M.B. …Vogt, J.V. (2014). Magnitude of extreme heat waves in present climate and their projection in a warming world. *Journal of Geophysical Research: Atmospheres*, 119(22), 12500–12512.

Weather Research and Forecasting Model (WRF): https://www.mmm.ucar.edu/weather-research-and-forecasting-model

12.2.4 Total carbon storage and sequestration in vegetation per unit area per unit time

Metric: *Total amount of carbon (tonnes) stored in vegetation, described per unit area and unit time*

Strengths: *The modelling tool can be used to model potential effects of changes to be made or situation if changes were not made by creating parallel scenarios of the same area with different tree inventories. The inventory can be created from maps and sample measurements*

Weaknesses: *Access to reliable and accurate data may be limited. Analyses may require an external laboratory*

Accounting for C stored in soil and vegetation in an urban area can provide an indication of the condition of natural green spaces, total free surface area and total quantity of vegetation in the area examined. Measures of C storage and sequestration also provide a tangible connection to climate change mitigation, and the impacts of local land use, planning and management decision-making. It is important to note the substantial variation in C sequestration and storage capacity of different types of NBS.

There are several tools for modelling carbon in trees including the U.S. Forest Service Forest Inventory and Analysis Database, such as the suite of i-Tree tools (USDA Forest Service, 2019). The i-Tree Eco model inputs a database of city trees with information on location, size and species to a geographic information system platform.

Alternatively, an estimate of C storage or sequestration in above-ground vegetation can be manually determined using a similar approach to the i-Tree Eco application. First, each above-ground vegetation polygon in a digital cartographic dataset can be classified per light detection and ranging (LiDAR) data as, e.g., herbaceous vegetation (grasses and non-woody plants), shrub (woody bushes and trees with mean height typically <2 m), tall shrub (woody bushes and trees with mean height generally 2-5 m), or tree (trees >5 m in height) after Davies, Edmonson, Heinemeyer, Leake, & Gaston (2011). Davies et al. (2011) recommend surveying to ground-truth map data and classification estimates.

Species-specific allometric equations are available from the scientific literature to estimate above-ground dry weight biomass of the classified vegetation, and carbon storage calculated using conversion factors also available from the scientific literature. Where there are multiple equations for a given species, the equations can be combined to obtain a general result. Total above ground tree biomass can be converted to C storage using conversion factors based on tree type. The dry-weight of above-ground biomass of each class of vegetation along with the mean C content can also be determined via laboratory analysis.

Scale of measurement: District to regional scale

Required data: Requires data on extent of vegetation cover & characteristics of vegetation (e.g., type, age and height), land use, air quality data, and meteorological and other local information for modelling. These can be obtained from forest inventory analysis (FIA), a national land cover database (NLCD) or databases for housing density mapping. Users may need permission to gain access to national databases unless the data are open (freely available).

Data generation specifications: Quantitative; participatory data collection is feasible through sample collection, e.g., air quality measurements

Data generation/collection frequency: Annually to enable tracking of changes to C storage and sequestration with time before and after NBS implementation

Level of expertise required: Moderate – requires understanding of the C storage concept, and ability to combine and apply allometric equations and modelling tools

Connection to other indicators: Used for evaluating C storage necessary for *Carbon removed or stored per unit area per unit time* indicator

Connection to SDGs: SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land

Key References

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Davies, Z.G., Edmonson, J.L., Heinemeyer, A., Leake, J.R., & Gaston, K.J. (2011). Mapping an urban ecosystem service: quantifying above-ground carbon storage at a city-wide scale. *Journal of Applied Ecology*, 48, 21125-1134.

Fong, W.K., Sotos, M., Doust, M., Schultz, S., Marques, A., & Deng-Beck, C. (2015). *Global Protocol for Community-Scale Greenhouse Gas Emission Inventories.* Washington, D.C.: World Resources Institute. Retrieved from https://www.wri.org/publication/global-protocol-community-scale-greenhouse-gas-emission-inventories

Intergovernmental Panel on Climate Change (IPCC). (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Prepared by the National Greenhouse Gas Inventories Programme, Eggleston, S., Buendia, L., Miwa, K., Ngara, T., & Tanabe, K. (Eds.). Hayama, Japan: Institute for Global Environmental Strategies (IGES). Retrieved from https://www.ipcc-nggip.iges.or.jp/public/2006gl/.

Intergovernmental Panel on Climate Change (IPCC). (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Core Writing Team, R.K. Pachauri and L.A. Meyer (Eds.). Geneva, Switzerland: IPCC.

United States Department of Agriculture (USDA) Forest Service. (2019). *i-Tree Eco Manual*. Northern Research Station, USDA Forest Service. Retrieved from https://www.itreetools.org/resources/manuals/Ecov6_ManualsGuides/Ecov6_UsersManual.pdf

12.2.5 Total carbon storage and sequestration in soil per unit area per unit time

Metric: *Total amount of carbon (tonnes) stored in soil per unit area and unit time*

Strengths: *Physical sampling and laboratory analysis of soil C yields accurate information, with improved accuracy of estimated C storage in soil with increasing sampling intensity. Combustion-based analytical methods are relatively simple and widely applicable*

Weaknesses: *Small changes in soil C may be difficult to quantify in carbonate-rich soils, in which case multiple analytical steps may be required to obtain reliable measurements. Soil sample collection is relatively labour-intensive; analyses typically require an external laboratory (rather than analysed in-house)*

Accounting for C stored in soil and vegetation in an urban area can provide an indication of the condition of natural green spaces, total free surface area and total quantity of vegetation in the area examined. Measures of C storage and sequestration also provide a tangible connection to climate change mitigation, and the impacts of local land use, planning and management decision-making. It is important to note the substantial variation in C sequestration and storage capacity of different types of NBS.

The most reliable and accurate method of determining soil C content is field sampling followed by laboratory analysis. Combustion is an accurate, commonly used analytical technique to quantify total C in soil – including both organic and inorganic soil C. Combustion analysis involves converting all forms of C in the soil to CO_2 by wet or dry combustion, then measuring evolved CO_2. Change in soil C content occurs most readily in the SOC fraction, so observed changes in total soil C content with time are most likely to represent changes to SOC content.

Sampling is performed using a measuring tape (for establishment of sampling transect or grid), soil corer, and plastic bags.

It may be challenging to detect small changes in soil C content in soils that contain substantial inorganic (mineral) C. A rapid field test of the soil's reactivity to acid can indicate whether it may be necessary to undertake more intensive analyses of soil samples to quantify both the organic and inorganic C fractions, rather than total (inorganic + organic) C by combustion. Rapid assessment of soil carbonate content involves reacting a small sample (ca. 1 g) of soil with 1-2 drops of 1 M hydrochloric acid (HCl) in a glass or porcelain container and observing the reaction for ~5 min. The reaction between soil carbonate minerals and HCl is visible as bubbles/effervescence as bubbles of CO2 are produced.

If the HCl 'field test' indicates the presence of inorganic C then the soil sample should be pre-treated to remove inorganic C prior to determination of organic C content by wet digestion. A sample of the carbonate-containing soil should be treated at room with a mixture of dilute sulphuric acid (H_2SO_4) and ferrous sulphate ($FeSO_4$) for at least 20 min or until effervescence appears to cease. The flask containing the soil and $H_2SO4/FeSO_4$ mixture should then be heated over a flame and boiled slowly for 1.5 min to destroy any remaining carbonate. Finally, pulverised potassium dichromate ($K_2Cr_2O_7$) should be added to the mixture and organic C determined by chromic acid digestion (wet combustion) (Nelson & Sommers, 1996).

Scale of measurement: Plot scale; it is possible to extrapolate results from small number of field samples based on soil maps to approximate soil C storage at landscape (regional) scale

Required data: Site characteristics, including maps of soil type, topography, and vegetative cover. Average soil bulk density (in kg/m^3; can be measured or estimated based on soil type). Obtainable from local municipality, department of environment, geological survey.

Data generation specifications: Quantitative; participatory data collection is feasible through soil sample collection

Data generation/collection frequency: Annually, including at a minimum measurement before and after NBS implementation

Level of expertise required: Low to Moderate – field sampling; Moderate – combustion analysis in laboratory conditions; High – soil sample pre-treatment for determination of organic C content

Connection to other indicators: Used for evaluating C storage necessary for *Carbon removed or stored per unit area per unit time* indicator

Connection to SDGs: SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land

Key References

Nelson, D.W., & Sommers, L.E. (1996). Total Carbon, Organic Carbon, and Organic Matter. In D.L. Sparks (Ed.), *Methods of Soil Analysis Part 3, Chemical Methods* (pp. 961-1010). Madison, WI: Soil Science Society of America, Inc.

Rowell, D.L. (2014). *Soil Science: Methods & Applications*. New York: Routledge.

Soil Survey Staff. (2009). *Soil Survey Field and Laboratory Methods Manual. Soil Survey Investigations Report No. 51, Version 2.0. R. Burt (Ed.).* Lincoln, NE: United States Department of Agriculture, Natural Resources Conservation Service.

12.2.6 Soil carbon to nitrogen ratio (C/N ratio)

Metric: *The ratio between the total mass of carbon and the total mass of nitrogen in soil*

Strengths: *Physical sampling and laboratory analysis of soil C and N yields accurate information, with improved accuracy of estimated C and N content of soil with increasing sampling intensity. Combustion-based analytical methods are relatively simple and widely applicable*

Weaknesses: *Small changes in soil C may be difficult to quantify in carbonate-rich soils, in which case multiple analytical steps may be required to obtain reliable measurements. Soil* *sample collection is relatively labour-intensive; analyses typically require an external laboratory (rather than analysed in-house)*

The respective quantities of carbon and nitrogen in soil is critical to soil microbial activity and a fundamental indicator of biogeochemical cycling in ecosystems. Changes to soil C/N ratio impacts nutrient cycling in soils and the structure and function of plant communities, thereby affecting ecosystem service functions. Soils with higher C/N ratio are better able to buffer soil and water N pollution, because soils with greater C/N ratio generally exhibit slower rates of N mineralisation and nitrification, and greater capacity for N immobilisation (Groffman et al., 2006). The accumulation of C and N in urban green space soils is determined both by the length of time following urbanisation that an area is managed as a green space and the structural composition of green space vegetation. Factors such as the presence of trees, an understory, and surface litter are key to soil C and N accumulation. Urban green space soils under tree canopies have been shown to have significantly greater soil C and N content and higher C/N ratios compared with grassed areas (Livesley et al., 2015). Planting and placement of trees within urban green spaces should facilitate accumulation of understory vegetation and litter to promote high C/N ratios and C and N storage in soils.

Soil microorganisms require C and N in a ratio of about 24:1 to support metabolic processes (USDA-NRCS, 2011). The majority of N in soil is present in organic form. Organic N is mineralised to ammonium (NH_4^+) via organic matter breakdown, then, under oxygenated conditions, oxidised to nitrate (NO_3^-). Plants are able to take up both NH_4^+ and NO_3^-, with some evidence for direct plant uptake of organic N, particularly in N-limited environments. Microbiological uptake of all forms of N is called immobilisation because the N is taken up or 'immobilised' in microbial biomass. Nitrogen mineralisation/ immobilisation reactions in soil are dependent upon the total N content and the C/N ratio. If decomposing organic material contains more N than microorganisms need for cell growth (i.e., where C/N < 24:1), surplus nitrogen is excreted as NH_4^+. Conversely, if decomposing organic materials contain less N than required by soil microorganisms for cell growth (i.e., C/N >24:1), the soil microorganisms must acquire additional N from the soil. In the longer term, this can lead to reduced soil fertility due to a deficit of N.

Management of urban landscapes can disrupt C and nutrient cycling through irrigation, litter removal, fertiliser or mulch addition, or other practices. Studies have shown that soil C/N ratios of urban green spaces increase with time since green space establishment, or with the duration of altered management intensity (Golubiewski, 2006; Livesley et al., 2015). Understanding the C/N ratio can promote C storage whilst maintaining adequate soil fertility, as well as management of soil N to minimise leaching of nitrate (NO_3^-) to local waterbodies and/or gaseous losses (i.e., as N_2, N_2O, NO, NH_3).

Nitrogen accumulates in soil through fixation of atmospheric N to organic forms. Soil organic matter is typically 5-6% N, so N levels in soil closely follow soil organic matter content. The N content of soil parent materials is low because N does not form stable minerals. Soil N pools:

- Gaseous: N_2, N_2O, NO, NH_3
- Mineral N: NH_4^+, NO_2^-, NO_3^- (<2% of total N but very important)
- Fixed N: NH_4^+ trapped in vermiculite-like clays (4-8% of total N)
- Organic N: 80-95% of total soil N, needs to be mineralised prior to biological uptake

Soil N moves between pools via a series of reactions. Soil organic matter is mineralised to form ammonium (NH_4^+). In the presence of oxygen, the NH_4^+ undergoes nitrification to form nitrate (NO_3^-). Both NH_4^+ and NO_3^- are forms of N available for plant and microbial uptake. Excess NH_4^+ in soil may be bound to soil clay minerals. If not taken up by plants or microorganisms, soil nitrate (NO_3^-) may be lost from the system by leaching to local waterways or through volatilisation as N2, N_2O, NO or NH_3 gas.

The most reliable and accurate method of determining soil C and N content is field sampling followed by laboratory analysis. Sampling is performed using a measuring tape (for establishment of sampling transect or grid), soil corer, and plastic bags. Soil cores should be taken to a depth of at least 0.3 m, and up to 1.0 m depth depending on the rooting depth of local vegetation.

Combustion is an accurate, commonly used analytical technique to quantify C and N in soil. A carbon-nitrogen combustion analyser can provide measures of total carbon, total organic carbon and total inorganic carbon (after sample acidification), total nitrogen, and C/N ratio.

Scale of measurement: Plot scale

Required data: Site characteristics, including maps of soil type, topography, and vegetative cover. Average soil bulk density (in kg/m^3; can be measured or estimated based on soil type). Obtainable from local municipality, department of environment, geological survey.

Data generation specifications: Quantitative; participatory data collection is feasible through soil sample collection

Data generation/collection frequency: Annually, including at a minimum measurement before and after NBS implementation

Level of expertise required: Low to Moderate – field sampling; Moderate – combustion analysis in laboratory conditions; High – soil sample pre-treatment for determination of organic C content

Connection to other indicators: Similar method used to determine *Carbon removed or stored per unit area per unit time* indicator

Connection to SDGs: SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land

Key References

Bremner, J.M. (1996). Nitrogen – total. In D.L. Sparks (Ed.), *Methods of Soil Analysis Part 3, Chemical Methods* (pp. 961-1010). Madison, WI: Soil Science Society of America, Inc.

Golubiewski, N.E. (2006). Urbanization increases grassland carbon pools: Effects of landscaping in Colorado's Front Range. *Ecological Applications*, 16(2), 555-571.

Groffman, P.M., Pouyat, R.V., Cadenasso, M.L., Zipperer, W.C., Szlavecz, K., Yesilonis, I.D., Band, L.E. & Brush, G.S. (2006). Land use context and natural soil controls on plant community composition and soil nitrogen and carbon dynamics in urban and rural forests. *Forest Ecology and Management*, 236(2-3), 177-192.

Livesley, S.J., Ossala, A., Threlfall, C.G., Hahs, A.K. & Williams, N.S.G. (2015). Soil carbon and carbon/nitrogen ratio change under tree canopy, tall grass, and turf grass areas of urban green space. *Journal of Environmental Quality*, 45, 215-223.

Nelson, D.W., & Sommers, L.E. (1996). Total Carbon, Organic Carbon, and Organic Matter. In D.L. Sparks (Ed.), *Methods of Soil Analysis Part 3, Chemical Methods* (pp. 961-1010). Madison, WI: Soil Science Society of America, Inc.

Rowell, D.L. (2014). *Soil Science: Methods & Applications*. New York: Routledge.

Soil Survey Staff. (2009). *Soil Survey Field and Laboratory Methods Manual. Soil Survey Investigations Report No. 51, Version 2.0. R. Burt (Ed.).* Lincoln, NE: United States Department of Agriculture, Natural Resources Conservation Service.

USDA-NRCS. (2011.) Carbon to Nitrogen Ratios in Cropping Systems. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd331820.pdf

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

12.2.7 Total surface area of wetlands within a defined area

Metric: *Total surface area covered with wetlands within a defined area (ha)*

Strengths: *Straightforward assessment of the surface area occupied by wetlands*

Weaknesses: *Requires access to local records or international/local spatial datasets*

Wetlands are unique ecosystems that occur in places where the water table is close to the ground level, or where land is covered by water, either seasonally or permanently. Convention on Wetlands (Ramsar, Iran, 1971), or Ramsar Convention, defines wetlands as *"… a wide variety of inland habitats such as marshes, peatlands, floodplains, rivers and lakes, and coastal areas such as saltmarshes, mangroves, intertidal mudflats and seagrass beds, and also coral reefs and other marine areas no deeper than six metres at low tide."* Conservation and restoration of wetlands is regarded as one of the critical factors for establishing climate adaptation as part of the disaster risk reduction. Wetlands provide resilience against water-related hazards such as floods, storm surges and droughts by capturing and holding water and gradually releasing it. Peatlands enhance climate resilience by storing carbon.

The extent of the surface area covered by wetlands can be assessed using the land-use raster data (local or EU-wide, e.g., Corine Land Cover or Urban Atlas) in GIS software that allows to examine the total area. Satellite imagery may be used for visual assessment and manual surface area calculation.

Scale of measurement: City; municipality

Required data: Land-use raster of the area of interest; local records; satellite imagery

Data generation specifications: Quantitative; participatory data collection can be implemented among local people; another opportunity is community involvement in wetland management

Data generation/collection frequency: Annually

Level of expertise required: Moderate – requires knowledge of GIS software; Low – when assessing visually using satellite images

Connection to other indicators: Direct relation to *Water management* and *Biodiversity* challenge categories

Connection to SDGs: SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land

Key References

Kumar, R., Tol, S., McInnes, R.J., Everard, M. and Kulindwa, A.A.. *Wetlands for disaster risk reduction: Effective choices for resilient communities*. Ramsar Policy Brief, (1). Gland, Switzerland: Ramsar Convention Secretariat, 2017.

Ramsar Convention Secretariat. *Managing wetlands: Frameworks for managing Wetlands of International Importance and other wetland sites*. Ramsar handbooks for the wise use of wetlands, 4th edition, vol. 18. Ramsar Convention Secretariat, Gland, Switzerland, 2010.

Ramsar Convention Secretariat. *Participatory skills: Establishing and strengthening local communities' and indigenous people's participation in the management of wetlands*. Ramsar handbooks for the wise use of wetlands, 4th edition, vol. 7. Ramsar Convention Secretariat, Gland, Switzerland, 2010.

Renaud, F.G., Sudmeier-Rieux, K. and Estrella, M. (eds.). *The Role of Ecosystems in Disaster Risk Reduction*. Tokyo: United Nations University Press, 2013.

Renaud, F.G., Sudmeier-Rieux, K., Estrella, M. and Nehren, U. (eds.). *Ecosystem-Based Disaster Risk Reduction and Adaptation in Practice*. In Advances in natural and technological hazards research. Switzerland: Springer International Publishing, 2016, pp.598

12.2.8 Total surface area or restored and/or created wetlands within a defined area

Metric: Surface area of constructed and/or restored wetlands within a defined area (ha)

Strengths: *Straightforward assessment of the surface area occupied by constructed and/or* restored *wetlands*

Weaknesses: *Requires access to local records or international/local spatial datasets*

Wetlands are unique ecosystems that occur in places where the water table is close to the ground level, or where land is covered by water, either seasonally or permanently. Convention on Wetlands (Ramsar, Iran, 1971), or Ramsar Convention, defines wetlands as "… a wide variety of inland habitats such as marshes, peatlands, floodplains, rivers and lakes, and coastal areas such as saltmarshes, mangroves, intertidal mudflats and seagrass beds, and also coral reefs and other marine areas no deeper than six metres at low tide." Conservation and restoration of wetlands is regarded as one of the critical factors for establishing climate adaptation as part of the disaster risk reduction. Wetlands provide resilience against water-related hazards such as floods, storm surges and droughts by capturing and holding water and gradually releasing it. Peatlands enhance climate resilience by storing carbon.

The extent of the surface area covered by constructed and/or restored wetlands can be assessed using the land-use raster data (local or EU-wide, e.g., Corine Land Cover or Urban Atlas) in GIS software that allows to examine the total area. Satellite imagery may be used for visual assessment and manual area calculation.

Scale of measurement: City; municipality

Required data: Land-use raster of the area of interest; local records; satellite imagery

Data generation specifications: Quantitative; participatory data collection can be implemented among local people; another opportunity is community involvement in wetland management

Data generation/collection frequency: Annually

Level of expertise required: Moderate – requires knowledge of GIS software; Low – when assessing visually using satellite images

Connection to other indicators: Direct relation to *Water management* and *Biodiversity* challenge categories

Connection to SDGs: SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land

Key References

Kumar, R., Tol, S., McInnes, R.J., Everard, M. and Kulindwa, A.A.. *Wetlands for disaster risk reduction: Effective choices for resilient communities*. Ramsar Policy Brief, (1). Gland, Switzerland: Ramsar Convention Secretariat, 2017.

Ramsar Convention Secretariat. *Managing wetlands: Frameworks for managing Wetlands of International Importance and other wetland sites*. Ramsar handbooks for the wise use of wetlands, 4th edition, vol. 18. Ramsar Convention Secretariat, Gland, Switzerland, 2010.

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Ramsar Convention Secretariat. *Participatory skills: Establishing and strengthening local communities' and indigenous people's participation in the management of wetlands*. Ramsar handbooks for the wise use of wetlands, 4th edition, vol. 7. Ramsar Convention Secretariat, Gland, Switzerland, 2010.

Renaud, F.G., Sudmeier-Rieux, K. and Estrella, M. (eds.). *The Role of Ecosystems in Disaster Risk Reduction*. Tokyo: United Nations University Press, 2013.

Renaud, F.G., Sudmeier-Rieux, K., Estrella, M. and Nehren, U. (eds.). *Ecosystem-Based Disaster Risk Reduction and Adaptation in Practice*. In Advances in natural and technological hazards research. Switzerland: Springer International Publishing, 2016, pp.598

12.2.9 Human comfort

a) Universal Thermal Climate Index (UTCI)

Metric: *The UTCI is the air temperature that would produce under reference conditions the same thermal strain as the actual thermal environment. In other words, the UTCI is the reference environmental temperature causing strain*

Strengths: *Mathematical expression of a person's thermal comfort in the outdoors. The output is expressed in easily understandable temperature units, e.g., °C*

Weaknesses: *Can be laborious to evaluate*

UTCI index represents air temperature of the reference condition with the same physiological response as the actual condition. The UTCI provides a one-dimensional value that reflects the human physiological reaction to the multi-dimensional outdoor thermal environment (Bröde et al., 2012). It can predict both whole body thermal effects (hypothermia and hyperthermia; heat and cold discomfort), and local effects (facial, hands and feet cooling and frostbite). Applications of the UTCI include weather forecasts, bioclimatological assessments, bioclimatic mapping, urban design, engineering of outdoor spaces, outdoor recreation, epidemiology and climate impact research.

The human body core temperature must be maintained within a narrow range around 37°C to ensure proper function of the body's inner organs and the brain, thus optimising human comfort, performance and health. In contrast, the temperature of the skin and extremities can vary widely, depending upon environmental conditions. This variation in the temperature of extremities is one of the mechanisms to equilibrate heat production and heat loss. The heat exchange between the human body and environment can be described in the form of the energy balance equation:

$$M + W + C + K + E + Q + Res \pm S = 0$$

Where:

M – heat produced by metabolism;
W – heat generated by muscular activity;
C – sensible heat flux (heat transferred by convection);
K – heat transferred through conduction contact with solid bodies);
E – latent heat flux (evaporative heat flux);
Q – radiative heat transfer;
Res – heat transfer through respiration; and,
S – heat content of the body.

The UTCI is derived from this mathematical model of thermoregulation with an integrated adaptive clothing model that also accounts for predicted votes of the dynamic thermal sensation based on core and skin temperature (Fiala et al., 1999, 2001, 2003; Havenith et al., 2011). The deviation of UTCI temperature from measured air temperature depends on measured values of air temperature (T_a) and mean radiant temperature (T_{mrt}), wind speed at a height of 10 m (v_a) and humidity expressed as water vapour pressure (p_a) or relative humidity (rH):

$$\mathbf{UTCI}(T_a, T_{mrt}, v_a, p_a) = Ta + Offset(T_a, T_{mrt}, v_a, p_a)$$

The model reference condition is walking at 4 km/h (135 W/m^2) with T_{mrt}=T_a, v_a=0.5 m/s, rH=50% (T_a >29°C) and p_a=20 hPa (T_a >29°C) (Bröde et al., 2012). The UTCI dynamic model response can be determined using the online calculator available from http://utci.org. The relationship between UTCI temperature (expressed in °C) and physiological stress is shown in the table below (adapted from Błażejczyk et al., 2010)

UTCI (°C) range	Stress category
Above +46	Extreme heat stress
+38 to +46	Very strong heat stress
+32 to +38	Strong heat stress
+26 to +32	Moderate heat stress
+9 to +26	No thermal stress
0 to +9	Slight cold stress
-13 to 0	Moderate cold stress
-27 to -13	Strong cold stress
-40 to -27	Very strong cold stress
Below -40	Extreme cold stress

Scale of measurement: Plot – street – neighbourhood – district

Required data: Air temperature, T_a (°C); Mean radiant temperature, T_{mrt} (degrees Kelvin); Water vapour pressure (hPa); Relative humidity (%); Wind speed at a height of 10 m (m/s)

Data generation specifications: Quantitative; participatory data collection is feasible through direct participation in weather data collection

Data generation/collection frequency: Frequency as desired. UTCI can be calculated frequently with measurement intervals determined by (automated) weather data acquisition

Level of expertise required: Low to Moderate

Connection to other indicators: Direct relation to *Heatwave incidence* and *Number of combined tropical nights and hot days* indicators. Similar to *Physiological equivalent temperature (PET)*

Connection to SDGs: SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action

Key References

Błażejczyk, K., Broede, P., Fiala, D., Havenith, G., Holmér, I., Jendritzky, G., Kampmann, B. & Kunert, A. (2010). Principles of the new Universal Thermal Climate Index (UTCI) and its application to bioclimatic research in European scale. *Miscellanea Geographica, 14*, 91-102.

Bröde, P., Fiala, D., Błażejczyk, K., Holmér, I., Jendritzky, G., Kampmann, B., Tinz, B. & Havenith, G. (2012). *International Journal of Biometeorology, 56*, 481-494.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Fiala, D., Havenith, G., Bröde, P., Kampmann, B & Jendritzky, G. (2011). UTCI-Fiala multi-node model of human temperature regulation and thermal comfort. *International Journal of Biometeorology, 56*, 429-441.

Fiala, D., Lomas, K.J., Stohrer, M. (1999). A computer model of human thermoregulation for a wide range of environmental conditions: the passive system. *Journal of Applied Physiology, 87*, 1957–1972.

Fiala, D., Lomas, K.J., Stohrer, M. (2001). Computer prediction of human thermoregulatory and temperature responses to a wide range of environmental conditions. *International Journal of Biometeorology, 45*, 143–159.

Fiala D, Lomas KJ, Stohrer M (2003). First principles modeling of thermal sensation responses in steady-state and transient conditions. *ASHRAE Transactions, 109*, 179–186.

Havenith, G., Fiala, D., Błażejczyk, K., Richards, M., Bröde, P., Holmér, I., Rintamäki, H., Benshabat, Y., Jendritzky, G. (2011). The UTCI-Clothing Model. *International Journal of Biometeorology, 56*, 461-470.

b) Physiological Equivalent Temperature (PET)

Metric: *Mean or peak daytime local temperature by PET calculation (°C)*

Strengths: *Compared to PMV, PET has the advantage to use °C, which allows the results to be easily interpreted by urban or regional planners*

Weaknesses: *Requires extensive amount of data for evaluation*

Green urban infrastructure can significantly affect climate change adaptation by reducing air and surface temperatures with the help of shading and through increased evapotranspiration. Conversely, green urban infrastructure can also provide insulation from cold and/or shelter from wind, thereby reducing heating requirements (Cheng, Cheung, & Chu, 2010). By moderating the urban microclimate, green infrastructure can support a reduction in energy use and improved thermal comfort (Demuzere et al., 2014). The cooling effect of green space results in lower temperatures in the surrounding built environment (Yu & Hien, 2006).

To calculate PET (Höppe, 1999):

1. Determine the thermal conditions of the body using the Munich energy-balance model for individuals, MEMI, (1) for a given set of climatic parameters. MEMI is based on the energy balance equation of the human body and is related to the Gagge two-node model (Gagge, Stolwijk, & Nishi, 1972). The MEMI equation is as follows:

$$M + W + R + C + E_D + E_{Re} + E_{Sw} + S = 0 \quad (1)$$

where, M is the metabolic rate (internal energy production by oxidation of food); W is the physical work output; R is the net radiation of the body; C is the convective heat flow; E_D is the latent heat flow to evaporate water into water vapour diffusing through the skin; E_{Re} is the sum of heat flows for heating and humidifying the inspired air; E_{Sw} is the heat flow due to evaporation of sweat; and, S is the storage heat flow for heating or cooling the body mass.

As a first step, the mean surface temperature of the clothing (T_{cl}), the mean skin temperature (T_{sk}) and the core temperature (T_c) must be evaluated. These three parameters provide the basis for calculation of E_{Sw}. Two equations are necessary to describe the heat flows from the body core to the skin surface (F_{cs}) as shown in (2), and heat flows from the skin surface through the clothing layer to the clothing surface (F_{sc}) as shown in (3) (Höppe, 1999):

$$F_{CS} = v_b \times \rho_b \times c_b \times (T_c - T_{sk}) \quad (2)$$

where v_b is blood flow from body core to skin (L/s/m^2); ρ_b is blood density (kg/L); and, c_b is the specific heat (W/sK/kg).

$$F_{CS} = (1/I_{cl}) \times (T_{sk} - T_{cl}) \quad (3)$$

where I_{cl} is the heat resistance of the clothing (K/m^2/W).

2. Insert calculated values for mean skin temperature (T_{sk}) and core temperature (T_c) into the MEMI equation (1) and solve the three equations for air temperature, T_a (v□= 0.1 m/s; water vapour pressure = 12 hPa; $T_{mrt} = T_a$). This temperature is equivalent to PET.

Scale of measurement: Building or plot scale

Required data: Energy balance of the human body, heat flows though the body and clothing

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually, and before and after NBS implementation

Level of expertise required: High – requires ability to follow the calculation procedure and units, and to critically evaluate the results

Connection to other indicators: Directly related to Incorporation of environmental design in buildings indicator

Connection to SDGs: SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action

Key References

Gagge, A., Stolwijk, J.A., & Nishi, Y. (1971). An effective temperature scale based on a simple model of human physiological regulatory response. *ASHRAE Transactions, 77*(1), 247-257.

Höppe, P. (1999). The physiological equivalent temperature – a universal index for the biometeorological assessment of the thermal environment. *International Journal of Biometeorology, 2466*, 71-75.

c) Predicted Mean Vote-Predicted Percentage Dissatisfied (PMV-PPD)

Metric: *Mean or peak daytime local temperature by PMV-PPD calculation (unitless value)*

Strengths: *Mathematical expression of a person's thermal comfort under indoor steady-state conditions*

Weaknesses: *Subjective evaluation of thermal sensations. The output is <u>not</u> expressed in any temperature units, e.g., °C*

Green urban infrastructure can significantly affect climate change adaptation by reducing air and surface temperatures with the help of shading and through increased evapotranspiration. Conversely, green urban infrastructure can also provide insulation from cold and/or shelter from wind, thereby reducing heating requirements (Cheng, Cheung, & Chu, 2010). By moderating the urban microclimate, green infrastructure can support a reduction in energy use and improved thermal comfort (Demuzere et al., 2014). The cooling effect of green space results in lower temperatures in the surrounding built environment (Yu & Hien, 2006).

The model aims to estimate the mean thermal sensation of a group of individuals and their respective percentage of dissatisfaction with the thermal environment, expressed in terms of Predicted Mean Vote-Predicted Percentage Dissatisfied (PMV-PPD). The practical application of the PMV equation and associated variables has been described by Ekici (2016). PMV provides a score that relates to the Thermal Sensation Scale (Fanger, 1970). If the score is zero, the occupant satisfaction regarding the environment is at the maximum level (Ekici, 2016).

Thermal Sensation Scale (Fanger, 1970):

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Scale	Description	How it feels
3	Hot	Intolerably warm
2	Warm	Too warm
1	Slightly warm	Tolerably uncomfortable, warm
0	Neutral	Comfortable
-1	Slightly cool	Tolerably uncomfortable, cool
-2	Cool	Too cool
-3	Cold	Intolerably cool

Scale of measurement: Building scale

Required data: Metabolism, clothing, indoor air temperature, indoor mean radiant temperature, indoor air velocity and indoor air humidity (Rupp, Vásquez, & Lamberts, 2015).

Data generation specifications: Semi-quantitative; participatory data collection is feasible through direct participation in the indicator assessment

Data generation/collection frequency: Annually

Level of expertise required: High – requires the ability to apply the mathematical model and evaluate the results

Connection to other indicators: Directly related to *Incorporation of environmental design in buildings* indicator

Connection to SDGs: SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action

Key References

Ekici, C. (2016). Measurement uncertainty budget of the PMV thermal comfort equation. International Journal of Thermophysics, 37, 48

Ekici, C. (2013). Review of Thermal Comfort and Method of Using Fanger's PMV Equation. Proceedings of the 5th International Symposium on Measurement, Analysis and Modelling of Human Functions, 27-29 June 2013, Vancouver, Canada. 4 pp.

Fanger, P. (1970). Thermal comfort. Analysis and applications in environmental engineering. Copenhagen: Danish Technical Press.

Rupp, R. F., Vásquez, N. G., & Lamberts, R. (2015). A review of human thermal comfort in the built environment. Energy and Buildings, 105, 178–205.

12.2.10Urban Heat Island (UHI) effect

Metric: *Urban Heat Island (UHI) effect denotes an urban area that is significantly warmer than its rural or undeveloped surrounding areas. Expressed and evaluated as temperature (°C)*

Strengths*: Fairly easy and straightforward assessment of temperature differences*

Weaknesses: *Requires a rather large amount of temperature measurement stations to holistically identify the effect within the urban area. May require modelling expertise*

The UHI effect is caused by the absorption of sunlight by (stony) materials, reduced evaporation and the emission of heat caused by human activities. The UHI effect is greatest after sunset and reported to reach up to 9°C in some cities, e.g., Rotterdam (Van Hove et al., 2015). Because of the UHI effect, citizens living in urban areas experience more heat stress than those living in the countryside.

To measure UHI effect:

1. Identify or install one or more meteorological (temperature) measurement stations within the built environment, and one measurement station outside the city that functions as a reference station. Alternatively, models can be used.

2. Compare the hourly average air temperature measurements of the urban measurement station(s) with the station outside the city (the reference station).

3. Look for the largest temperature difference (hourly average) between urban and countryside areas during the summer months. This temperature difference is an absolute measure of the UHI effect.

Scale of measurement: City to regional scale

Required data: Hourly temperature measurements

Data generation specifications: Quantitative; participatory data collection is feasible through geographically referenced direct temperature measurements if these are not automated

Data generation/collection frequency: Annually; at minimum before and after NBS implementation

Level of expertise required: Low

Connection to other indicators: Assessed from *Mean or peak daytime temperature* indicator and connected with *Heatwave Risk* indicator

Connection to SDGs: SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action

Key References

Van Hove, L.W.A., Jacobs, C.M.J., Heusinkveld, B.G., Elbers, J.A., van Driel, B.L., & Holtslag, A.A.M. (2015). Temporal and spatial variability of urban heat island and thermal comfort within the Rotterdam agglomeration. Building and Environment, 83, 91-103.

United States Environmental Protection Agency. (2006). Excessive Heat Events Guidebook. Retrieved from https://www.epa.gov/sites/production/files/2016-03/documents/eheguide_final.pdf

12.2.11 Mean or peak daytime temperature

a) Direct measurements

Metric: *Mean or peak daytime local temperature by direct measurement (°C)*

Strengths: *Straightforward assessment of ambient air temperature. Reliable in the long run*

Weaknesses: *Requires a rather large amount of monitoring stations to be installed to monitor various NBS intervention areas*

Green urban infrastructure can significantly affect climate change adaptation by reducing air and surface temperatures with the help of shading and through increased evapotranspiration. Conversely, green urban infrastructure can also provide insulation from cold and/or shelter from wind, thereby reducing heating requirements (Cheng, Cheung, & Chu, 2010). By moderating the urban microclimate, green infrastructure can support a reduction in energy use and improved thermal comfort (Demuzere et al., 2014). The cooling effect of green space results in lower

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

temperatures in the surrounding built environment. A simulation of the surrounding buildings showed the potential for a 10% decrease in the cooling load due to the presence of the green area in the vicinity (Yu & Hien, 2006).

Ambient air temperature can be assessed through continuous monitoring of temperature, near the NBS intervention area, and calculation of mean and peak daytime temperature before and after NBS implementation.

Scale of measurement: Plot to district scale

Required data: Automated continuous monitoring of ambient air temperature

Data generation specifications: Quantitative; participatory data collection is feasible through direct temperature measurements if these are not automated

Data generation/collection frequency: Annually; at minimum, before and after NBS implementation

Level of expertise required: Low

Connection to other indicators: A prerequisite for *Heatwave Risk* and *Urban Heat Island* indicators, and a requirement for *Depth to groundwater* indicator

Connection to SDGs: SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action

Key References

Cheng, C.Y., Cheung, K.K.S., & Chu, L.M. (2010). Thermal performance of a vegetated cladding system on facade walls. Building and Environment, 45(8), 1779-1787.

Demuzere, M., Orru, K., Heidrich, O., Olazabal, E., Geneletti, D., Orru, H., Faehnle, M. (2014). Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure. Journal of Environmental Management, 146, 107-115.

Yu, C., & Hien, W.N. (2006). Thermal benefits of city parks. Energy and Buildings, 38, 105-120.

b) Temperature modelling

Metric: *Mean or peak daytime local temperature by meteorological modelling (°C)*

Strengths: *Allows the calculation with an hourly resolution at the grid, neighbourhood or city scale neighbourhood*

Weaknesses: *Requires high level of expertise and external data*

Green urban infrastructure can significantly affect climate change adaptation by reducing air and surface temperatures with the help of shading and through increased evapotranspiration. Conversely, green urban infrastructure can also provide insulation from cold and/or shelter from wind, thereby reducing heating requirements (Cheng, Cheung, & Chu, 2010). By moderating the urban microclimate, green infrastructure can support a reduction in energy use and improved thermal comfort (Demuzere et al., 2014). The cooling effect of green space results in lower temperatures in the surrounding built environment. A simulation of the surrounding buildings showed the potential for a 10% decrease in the cooling load due to the presence of the green area in the vicinity (Yu & Hien, 2006).

Difference in temperature can be assessed through application of a meteorological model such as the Weather Research and Forecasting model (WRF) (NCAR & UCAR, n.d.; NOAA, n.d.)

Scale of measurement: District to regional scale

Required data: Initial and boundary conditions, topography, land use and urban parameters (building height, width, number of road lanes) (Emmons et al., 2010; Pineda, Jorba, Jorge & Baldasano, 2004). These data can be obtained through national statistics, municipal departments, Corine Land Cover or Urban Atlas, and a mapping application such as OpenStreetMap.

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually; at minimum before and after NBS implementation

Level of expertise required: High – requires ability to use forecasting models and assess the accuracy of results

Connection to other indicators: Contributes to *Natural and climate hazards* indicator group and to *Climate resilience strategy development* indicator

Connection to SDGs: SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action

Key References

Emmons, L.K., Walters, S., Hess, P.G., Lamarque, J.-F-, Pfister, G.G., Fillmore, D. … Kloster, S. (2010). Description and evaluation of the Model for Ozone and Related chemical Tracers, version 4 (MOZART-4). *Geoscientific Model Development*, *3*, 43-67.

National Center for Atmospheric Research (NCAR) & University Corporation for Atmospheric Research (UCAR). (n.d.). Weather Research and Forecasting (WRF) Model Users' Page. Retrieved from http://www2.mmm.ucar.edu/wrf/users/

National Oceanic and Atmospheric Administration (NOAA). (n.d.). Weather Research and Forecasting model coupled to Chemistry (WRF-Chem). Retrieved from https://ruc.noaa.gov/wrf/wrf-chem/

Pineda, N., Jorba, O., Jorge, J. & Baldasano, J.M. (2004). Using NOAA AVHRR and SPOT VGT data to estimate surface parameters: application to a mesoscale meteorological model. *International Journal of Remote Sensing*, *25*(1), 129–143.

Weather Research and Forecasting Model (WRF): https://www.mmm.ucar.edu/weather-research-and-forecasting-model

12.2.12Daily temperature range

Metric: *The range between minimum and maximum mean monthly local temperatures determined by direct measurement (°C)*

Strengths: *Straightforward assessment of ambient air temperature. Reliable in the long run*

Weaknesses: *Requires a rather large amount of monitoring stations to be installed to monitor various NBS intervention areas*

Nature-based solutions can support climate change adaptation by reducing local ambient air temperature. They can also provide insulation from cold and/or shelter from wind. By moderating the urban microclimate, green infrastructure can support reduction in energy use and improved thermal comfort (Demuzere et al., 2014).

Ambient air temperature can be assessed through continuous monitoring of temperature, near the NBS intervention area, and calculation of the average minimum and maximum monthly temperature before and after NBS implementation. The daily temperature range (DTR) allows

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

to assess the temperature changes more precisely than monthly averages. The DTR is calculated as

$$DTR_j = \frac{\sum_{i=1}^{I}(TX_{ij} - TN_{ij})}{I}$$

Where:

TX_{ij} – daily maximum temperature on day i in period j

TN_{ij} – daily minimum temperature on day i in period j

I – the number of days in period j

Scale of measurement: Plot to district scale

Required data: Automated continuous monitoring of ambient air temperature

Data generation specifications: Quantitative; participatory data collection is feasible through direct temperature measurements if these are not automated

Data generation/collection frequency: Annually; at minimum, before and after NBS implementation

Level of expertise required: Low

Connection to other indicators: Connection to *Urban Heat Island effect* and direct relation to *Days with temperature > 90th percentile (TX90p)* and *Warm spell duration index (WSDI)* indicators

Connection to SDGs: SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action

Key References

Demuzere, M., Orru, K., Heidrich, O., Olazabal, E., Geneletti, D., Orru, H., Faehnle, M. (2014). Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure. *Journal of Environmental Management, 146*, 107-115.

ETCCDI. (2009). Climate change indices. Available at: http://etccdi.pacificclimate.org/list_27_indices.shtml

12.2.13 Rate of evapotranspiration

Metric: *Measured or modelled evapotranspiration (typically expressed in mm per unit time)*

Strengths: *The reference evapotranspiration, ET_o, provides a standard to which: (a) evapotranspiration at different periods of the year or in other regions can be compared; (b) evapotranspiration of other crops can be related (Allen, Pereira, Raes, & Smith, 1998). Standard, widely-applied technique*

Weaknesses: *Challenging and expensive to measure directly. Requires high level of expertise to apply*

Evapotranspiration (ET) is a combination of two separate processes whereby water is lost from the soil surface by evaporation and from vegetation by transpiration. Water evaporates from surfaces when sufficient heat is supplied for liquid water to transition to water vapour. During transpiration, plant tissues vaporise water, which is then released to the atmosphere through stomatal openings on the plant leaf. Nearly all water taken up by plants is released to the atmosphere through transpiration. In addition to the non-uniformity of urban vegetation, shading of urban vegetation by landscape trees and structures and edge effects due to the relatively small scale of urban green space in comparison to commercial crop fields can significantly influence ET (Snyder, Pedras, Montazar, Henry, & Ackley, 2015).

Evapotranspiration is measured involving specific devices and accurate measurements of various physical parameters or the soil water balance in lysimeters.

In practice, ET is commonly calculated using meteorological data. Commercially-available ET monitoring stations are generally meteorological stations that calculate potential ET using monitored temperature, relative humidity, wind speed and direction, solar radiation, and precipitation data. The Penman-Monteith equation is the FAO-recommended standard technique for calculation of reference evapotranspiration, ET_o from crops (Allen, Pereira, Raes, & Smith, 1998). The FAO Penman-Monteith method to estimate ET_o is presented in Equation 1:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

Where ET_o is reference evapotranspiration [mm day^{-1}], R_n is net radiation at the crop surface [MJ m^{-2} day^{-1}], G is soil heat flux density [MJ m^{-2} day^{-1}] ,T is mean daily air temperature at 2 m height [°C], u_2 is wind speed at 2 m height [m s^{-1}], e_s is saturation vapour pressure [kPa], e_a is actual vapour pressure [kPa], e_s - e_a is saturation vapour pressure deficit [kPa], D is slope vapour pressure curve [kPa °C^{-1}], and g is psychrometric constant [kPa °C^{-1}].
Using the Penman-Monteith equation, ET from plant surfaces under standard conditions is determined using an experimentally-determined coefficient (k_c) to relate the ET for a specific crop species, ET_c, to ET_o. Thus, for a given crop species:

$$ET_c = k_c \times ET_0 \quad (2)$$

For urban landscapes, the landscape coefficient method (LCM), which uses a different set of coefficients rather than kc to estimate ET, may be more appropriate (Costello, Matheny, Clark, & Jones, 2000):

$$ET = k_L \times ET = k_d \times k_s \times k_{mc} \times ET_0 \quad (3)$$

where k_L is a landscape coefficient defined as a product of k_d, a planting density factor, k_S, a species-specific factor, and k_{mc}, a microclimate factor.

The modifications of the Penman-Monteith equation for plant-specific conditions can be found in the publications by, e.g., Litvak and Pataki (2016) and Litvak, Manago, Hogue, and Pataki (2016).

Scale of measurement: Plot scale, can be extrapolated using land cover data

Required data: Radiation, air temperature, wind speed, vapour pressure, soil heat flux density

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually, and before and after NBS implementation

Level of expertise required: High – requires ability to apply the Penman-Monteith equation and evaluate the results

Connection to other indicators: Related to *Daily temperature range* indicator; a possible consequence of *Green space management* and *Place regeneration* indicator groups

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Connection to SDGs: SDG 11 Sustainable cities and communities

Key References

Allen, R.G., Pereira, L.S., Raes, D., & Smith, M. (1998). Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56. Rome: Food and Agriculture Organization of the United Nations. http://www.fao.org/3/X0490E/x0490e00.htm#Contents

Costello, L.R., Matheny, N.P., Clark, J.R., & Jones, K.S. (2000). A guide to estimating irrigation water needs of landscape plantings in California, the landscape coefficient method and WUCOLS III. Berkeley, CA, USA: University of California Cooperative Extension, California Department of Water Resources. https://ucanr.edu/sites/WUCOLS/

Litvak, E., Manago, K.F., Hogue, T.S., & Pataki, D.E. (2016). Evapotranspiration of urban landscapes in Los Angeles, California at the municipal scale. Water Resources Research, 53(5), 4236-4252.

Litvak, E. & Pataki, D.E. (2016). Evapotranspiration of urban lawns in a semi-arid environment: An in situ evaluation of microclimatic conditions and watering recommendations. Journal of Arid Environments, 134, 87-96.

Snyder, R.L., Pedras, C., Montazar, A., Henry, J.M., & Ackley, D. (2015). Advances in ET-based landscape irrigation management. Agricultural Water Management, 147, 187-197

12.2.14Land surface temperature

Metric: *For earth observation methods: The Earth's radiometric (or skin) temperature derived from the solar radiation, where "surface" denotes any type of surface the satellite captures (snow, vegetation, soil, roofs, etc.) (°C or K)*

For ground-based methods: Radiance over spatially homogeneous sites

Strengths: *Earth observation methods allow for large-scale observations. Direct observation of the changes of the Earth's energy budget*

Weaknesses: *Clear-sky conditions are required for methods observing in the visible and thermal infrared (TIR) spectral ranges. Complicated surfaces obscure the measurements*

Radiation balance at the Earth's surface consists of net short-wave radiation and net long-wave radiation. Long-wave radiation (wavelength 3 to 100 µm) is an energy exchange between the Earth's surface and the atmosphere. Short-wave radiation (wavelength 0.3 to 3 µm) coming from the sun can be reflected back or scattered by air molecules or clouds when they are present, although part of it reaches the ground. Surface energy budget for an area consists of net incoming (solar) radiant energy and the outgoing energy fluxes comprising of latent and sensible heat fluxes (Shuttleworth, 1993). Land surface temperature (LST; different from the air temperature) controlling the long-wave radiation emitted by the Earth's surface is an important variable for evaluating the available energy, i.e., the latent and sensible heat fluxes (Trigo et al., 2008), and capturing the extremes, such as the heat waves, and other important variables, such as the concentration of the atmospheric greenhouse gases.

Earth observation methods

Sensors on-board aircraft or satellites record the land surface emissivity, land surface temperature, or both in the visible, near-infrared and thermal infrared (TIR, 8–13 µm) spectral ranges. Satellite-borne land surface temperature must be validated either against the other sensors on-board of different satellites to ensure quality (e.g., Krishnan *et al.*, 2015).

Ground-based (*in situ*) methods

The *in situ* measurement of land surface temperature (LST) and land surface emissivity (ability to emit infrared energy) can be performed with various instruments. The Surface Radiation

Network (SURFRAD) in the United States (NOAA, n.d.), which follows the standards adopted by the Baseline Surface Radiation Network (Driemel *et al.*, 2018; https://bsrn.awi.de/), mentions the following monitoring equipment:

- Radiometers (narrowband infrared or thermal infrared) for infrared radiation (Martin *et al.*, 2019)
- Pyranometers for global solar radiation, diffuse component of solar irradiance (cloudy days) and solar radiation reflected from the surface
- Pyrheliometer for the direct component of solar irradiance (clear-sky)
- Pyrgeometer for down-welling and up-welling long-wave radiation

The relation between the LST values and surface-emitted radiance can be described with the Planck's law, which relates the radiance emitted by a black body to its temperature. The emissivity (ability to emit infrared energy) of the black bodies is $\varepsilon = 1$. However, the real surfaces do not behave the same way as black bodies, having emissivity values of $0 \leq \varepsilon \leq 1$. Since the LST is evaluated based on the emissivity as temperatures are measured using thermal radiation, it is currently the largest source of error in the LST calculations (Göttsche *et al.*, 2016).

Several considerations must be taken into account when selecting a suitable site for the LST measurements, including (a) selecting an area of homogeneous land cover to ensure the uniform temperature distribution, (b) possibility for the continuous observations, (c) long clear-sky periods, and (d) view angles (Trigo *et al.*, 2008).

Scale of measurement: Global and regional (Earth observations); Site (*in situ*)

Required data: Land surface temperature obtained from remote-sensed or in situ measurements

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Hourly; daily; weekly

Level of expertise required: Very high – for all methods and data retrieval and evaluation

Connection to other indicators: Directly related to *Albedo*, *Rate of evaporation*, and *Occurrence of heat waves* indicators

Connection to SDGs: SDG 13 Climate action, SDG 15 Life on land

Key References

Copernicus Global Land Service. (n.d.). *Land Surface Temperature*. Retrieved on 17.7.2020 from https://land.copernicus.eu/global/products/lst

Driemel, A., Augustine, J., Behrens, K., Colle, S., Cox, C., Cuevas-Agulló, E., ... & König-Langlo, G. (2018). Baseline Surface Radiation Network (BSRN): structure and data description (1992-2017). *Earth System Science Data*, *10*(3), 1491-1501.

Freitas, S. C., Trigo, I. F., Macedo, J., Barroso, C., Silva, R., & Perdigão, R. (2013). Land surface temperature from multiple geostationary satellites. *International Journal of Remote Sensing*, *34*(9-10), 3051-3068.

Göttsche, F.M., Olesen, F.S., Trigo, I.F., Bork-Unkelbach, A., & Martin, M.A. (2016). Long term validation of land surface temperature retrieved from MSG/SEVIRI with continuous in-situ measurements in Africa. *Remote Sensing*, *8*(5), 410.

Krishnan, P., Kochendorfer, J., Dumas, E.J., Guillevic, P.C., Baker, C.B., Meyers, T.P., & Martos, B. (2015). Comparison of in-situ, aircraft, and satellite land surface temperature measurements over a NOAA Climate Reference Network site. *Remote Sensing of Environment*, *165*, 249-264.

Martin, M.A., Ghent, D., Pires, A.C., Göttsche, F.M., Cermak, J., & Remedios, J.J. (2019). Comprehensive in situ validation of five satellite land surface temperature data sets over multiple stations and years. *Remote Sensing*, *11*(5), 479.

NASA Earth Observations. (n.d.). *Land Surface Temperature (TERRA/MODIS).* Retrieved on 17.7.2020 from https://neo.sci.gsfc.nasa.gov/view.php?datasetId=MOD_LSTD_M

National Oceanic & Atmospheric Administration (NOAA). (n.d.). SURFRAD Overview: Surface Radiation Budget Monitoring. Retrieved on 17.7.2020 from https://www.esrl.noaa.gov/gmd/grad/surfrad/overview.html

Shuttleworth, W.J. (1993). *Evaporation*. In: Maidment, D.R. (ed.), Handbook of Hydrology. New York: McGraw-Hill.

Trigo, I.F., Monteiro, I.T., Olesen, F., & Kabsch, E. (2008). An assessment of remotely sensed land surface temperature. *Journal of Geophysical Research: Atmospheres*, *113*, D17108.

Valor, E., Sánchez, J.M., Niclòs, R., Moya, R., Barberà, M.J., Caselles, V., & Coll, C. (2018, July). Comparison of in Situ Land Surface Temperatures Measured with Radiometers and Pyrgeometers: Consequences for Calibration and Validation of Thermal Infrared Sensors. In *IGARSS 2018-2018 IEEE International Geoscience and Remote Sensing Symposium* (pp. 7961-7964). IEEE.

12.2.15Surface reflectance – Albedo

Metric: *Short-wave radiation reflectance coefficient of a surface (0-1, unitless), where 1 denotes full reflection and 0 denotes full absorption. Surface albedo is defined as the instantaneous ratio of surface-reflected radiation flux to incident radiation flux over a given spectral interval (dimensionless) (Wang et al., 2019)*

Strengths: *Surface reflectance can be measured directly. Directly comparable to other variables such as cooling and greenhouse gases emissions. Albedo values for various known surfaces and land-uses already exist*

Weaknesses: *Requires advanced equipment and judgment*

Radiation balance at the Earth's surface consists of net short-wave radiation and net long-wave radiation. Long-wave radiation (wavelength 3 to 100 µm) is an energy exchange between the Earth's surface and the atmosphere. Short-wave radiation (wavelength 0.3 to 3 µm) coming from the sun can be reflected back or scattered by air molecules or clouds when they are present, although part of it reaches the ground. Albedo is a portion of short-wave radiation that is reflected back once it reaches the ground, and it varies with the land cover (Shuttleworth, 1993).

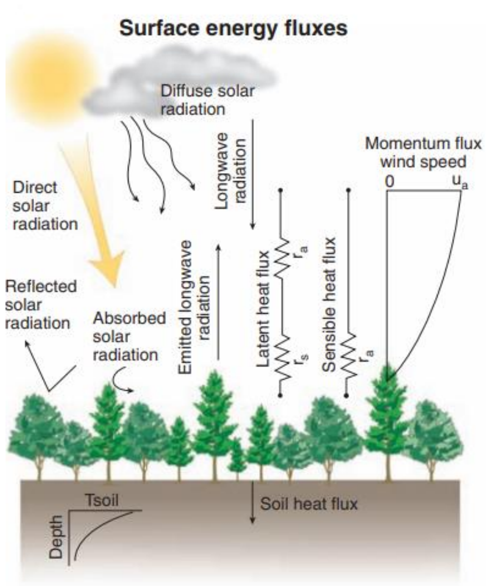


Figure: Surface energy fluxes (reproduced from Bonan, 2008).

Surface reflectance can be measured in the laboratory, in the field, and via remote sensing.

a. In the laboratory, surface reflectance can be measured using spectrophotometers equipped with integrating spheres over wider spectral ranges than the photopic vision (well-lit conditions) response of a human eye, and using light sources other than natural light (ASTM, 2012). Since the beam illuminates only part of a sample, a spatially uniform sample will yield the most fast and accurate results (Levinson, Akbari & Berdahl, 2010).
b. In the field, surface reflectance is typically measures using a pyranometer, a solar radiation meter, which measures the reflected solar irradiance (ASTM, 2016). This method requires a portable and relatively inexpensive equipment and it can be applied to flat and curved surfaces. However, the limitations include the necessity of a clear sky as clouds can lead to erroneous results, and a relatively large size of the surface to prevent the radiation collections from the object's surroundings (Levinson, Akbari & Berdahl, 2010). Ideally, the *in situ* albedo measurements are continuous and have temporal resolution of less than 30 minutes (Wang *et al*., 2019).
c. Remote sensing options utilise the satellite or aerial systems that that record albedo of larger surfaces (Ban-Weiss, Woods & Levinson, 2015), or the Earth such Clouds and the Earth's Radiant Energy System, or CERES (NASA, 2019). While remote sensing is feasible for measuring albedo at larger scales, this method is nor suitable for finer scale applications, and validations in the filed may be necessary (Wang *et al*., 2019; Williamson, Copland & Hik, 2016).

Reference tables exist for certain surfaces and land covers:

Land cover	Albedo
Grass and pasture	0.2 – 0.26†
Snow and ice	0.2 (old) – 0.8 (new)†
Bare soil	0.1 (wet) – 0.35 (dry)†
Asphalt	0.05 – 0.2‡
Red/Brow roof tile	0.1 – 0.35‡
Open water	0.08†

†Shuttleworth (1993)
‡US EPA (1992)

Scale of measurement: Plot scale

Required data: Albedo of various surfaces and land covers

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually

Level of expertise required: High when applying direct measurements; Low when using reference tables

Connection to other indicators: Direct relation to *Rate of evapotranspiration*, *Land surface temperature* and *Urban Heat Island incidence* indicators

Connection to SDGs: SDG 13 Climate action, SDG 15 Life on land

Key References

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

ASTM (2009). ASTM C1549-09, Standard Test Method for Determination of Solar Reflectance Near Ambient Temperature Using a Portable Solar Reflectometer. ASTM International, West Conshohocken, PA.

ASTM (2012). ASTM E903-12, Standard Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres. ASTM International, West Conshohocken, PA.

ASTM (2016). ASTM E1918-16, Standard Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field. ASTM International, West Conshohocken, PA.

Ban-Weiss, G. A., Woods, J., & Levinson, R. (2015). Using remote sensing to quantify albedo of roofs in seven California cities, Part 1: Methods. *Solar Energy*, *115*, 777-790.

Shuttleworth, W.J. (1993). *Evaporation*. In: Maidment, D.R. (ed.), Handbook of Hydrology. New York: McGraw-Hill.

Bonan, G.B. (2008). Forests and climate change: forcings, feedbacks, and the climate benefits of forests. *Science*, *320*(5882), 1444-1449.

Levinson, R., Akbari, H., & Berdahl, P. (2010). Measuring solar reflectance—Part II: Review of practical methods. *Solar Energy*, *84*(9), 1745-1759.

NASA Langley Research Center (2019) CERES. https://ceres.larc.nasa.gov/

Wang, Z., Schaaf, C., Lattanzio, A., Carrer, D., Grant, I., Román, M., Camacho, F., Yu, Y., Sánchez-Zapero, J. & Nickeson, J. (2019). Global Surface Albedo Product Validation Best Practices Protocol. Version 1.0. In Z. Wang, J. Nickeson & M. Román (Eds.), Best Practice for Satellite Derived Land Product Validation (p. 45): Land Product Validation Subgroup (WGCV/CEOS), doi: 10.5067/DOC/CEOSWGCV/LPV/ALBEDO.001

Williamson, S. N., Copland, L., & Hik, D. S. (2016). The accuracy of satellite-derived albedo for northern alpine and glaciated land covers. *Polar Science*, *10*(3), 262-269.

United States Environmental Protection Agency. (1992). *Cooling our communities: A guidebook on tree planting and light-colored surfaces*. Washington, DC: USA

12.2.16Estimated carbon emissions from vehicle traffic

Metric: *CO_2 emissions related to vehicle traffic (t C/y reduction)*

Strengths: *Straightforward assessment of vehicle-related GHG emissions*

Weaknesses: *Requires suitable data source for estimating fuel consumption*

Vehicle traffic emissions are the fraction of greenhouse gas (GHG) emissions that can be affected by nature-based solutions in the urban environment.

Assessment procedure:

1. Suitable available data source measuring the kilometre per person transport in the area should be identified, preferentially giving estimates of consumption of gasoline, diesel, ethanol and natural gas, the most common fuels used in car and rail transport (IPCC, 2006; Toledo & Rovere, 2018).

2. These consumed fuels, as well as potential consumed electricity by electrified rail systems, are converted to emission using emission factors for different fuels. Preferred method is to locate country specific net-calorific-values and CO_2-emission factors, when available, but general default values are presented (IPCC, 2006).

3. CO_2 emissions related to vehicle traffic are calculated as follows:

$$Emissions_{traffic} = Estimated\ use\ of\ fuel\ (t) \times Emission\ factor\ (t\ CO_2/t)$$

$$Decrease\ (\%) = 100\% - \left(\left(\frac{Emission_{traffic\ (after)}}{Emission_{traffic\ (before)}}\right) \times 100\%\right)$$

Emission factors for fuels, adapted from IPCC 2006 Guidelines Vol 2. Tables 1.2 & 1.4. (IPCC, 2006):

	Gasoline	Diesel	Ethanol	Natural gas
t CO_2/t fuel	3.07	3.19	1.91	2.69

Scale of measurement: District scale

Required data: Fuel consumption data or travel distance data. In a community-scale study, only travel distance represented by amount of traffic measurements are seen feasible

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually; at minimum, before and after NBS implementation

Level of expertise required: Low – requires ability to follow the calculation procedure

Connection to other indicators: Possibility to combine with *CO_2 emissions related to building energy consumption* indicator to obtain the total decrease due to NBS implementation

Connection to SDGs: SDG 11 Sustainable cities and communities, SDG 13 Climate action

Key References

Intergovernmental Panel on Climate Change (IPCC). (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme, Eggleston, S., Buendia, L., Miwa, K., Ngara, T., & Tanabe, K. (Eds.). Hayama, Japan: Institute for Global Environmental Strategies (IGES). Retrieved from https://www.ipcc-nggip.iges.or.jp/public/2006gl/.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

12.3 Water Management

Water Management is one of the primary challenges addressed by NBS, owing in part to the multiple water management-focused precursor concepts that fall under the "NBS umbrella", such as stormwater best management practices (BMPs), sustainable urban drainage systems (SUDS), and water-sensitive urban design (WSUD). The range of indicators presented address the quantity and quality of both surface and groundwaters.

Table 18. Indicators of NBS performance and impact related to Water Management

Nr.	Indicator	Units	Class	Applicability to NBS		
				Type 1	Type 2	Type 3
11.3.1a †	Surface runoff in relation to precipitation quantity: direct measurement	m^3/s, L/s or depth-equiv. mm	O	●	●	●
11.3.1b †	Surface runoff in relation to precipitation quantity: curve number method	mm	O	●	●	●
11.3.1c †	Surface runoff in relation to precipitation quantity: rational method	m^3/s or L/s	O	●	●	●
11.3.1d †	Surface runoff in relation to precipitation quantity: IDF curve method	m^3/s or L/s	O	●	●	●
11.3.1e †	Surface runoff in relation to precipitation quantity: process-based hydraulic modelling	mm	O	●	●	●
11.3.2 †	Total Suspended Solids (TSS) content	% or mg/L	O	●	●	●
11.3.3 †	Nitrogen and phosphorus concentration or load	%	O	●	●	●
11.3.4 †	Metal concentration or load	%	O	●	●	●
11.3.5 †	Total faecal coliform bacteria	CFU/100 mL or CFU/100 g ‡	O	●	●	●
11.3.6	Infiltration rate	% change	O	●	●	●
11.3.6	Infiltration capacity	% change	O	●	●	●
11.3.7	Evapotranspiration rate	mm/day	O	●	●	●
11.3.8	Height of flood peak	m^3/s	O	●	●	●
11.3.8	Time to flood peak	h	O	●	●	●
11.3.9	Quantitative status of groundwater	Good or Poor	O	●	●	●
11.3.10	Depth to groundwater	m	O	●	●	●
11.3.11	Water availability for irrigation purposes,	m^3/y	O	●	●	●

	including greywater and captured rainwater					
11.3.12	Water Exploitation Index	%	O	●	●	●
11.3.13	Total surface area of wetlands within a defined area	ha	O	●	●	●
11.3.14	Surface area of restored and/or created wetlands	ha	O		●	●
11.3.15	pH of NBS effluents	unitless	O	●	●	●
11.3.15	Electrical conductivity of NBS effluents	µS/cm	O	●	●	●
11.3.15	Dissolved oxygen content of NBS effluents	mg/L	O	●	●	●
11.3.16	Physico-chemical quality of surface waters	High, Good, Moderate, Poor, Bad	O	●	●	●
11.2.17	Total pollutant discharge to local waterbodies	Nr. 1-5, unitless	O	●	●	●
11.3.18	Groundwater chemical status	High, Good, Moderate, Poor, Bad	O	●	●	●
11.3.19	General ecological status of surface waters	High, Good, Moderate, Poor, Bad	O	●	●	●
11.3.20	Ecological potential for heavily modified or artificial water bodies	Maximum, Good, Moderate, Poor, Bad	O	●	●	●
11.3.21	Biological quality of surface waters	High, Good, Moderate, Poor, Bad	O	●	●	●
11.3.22	Total number of aquatic macroinvertebrates	Total number or % change	O	●	●	●
11.3.22	Species richness of aquatic macroinvertebrates	Total number or % change	O	●	●	●
11.3.23	Hydromorphological quality of surface waters	High, Good, Moderate, Poor, Bad	O	●	●	●

† Indicators designated "recommended" by NBS Impact Evaluation Taskforce (Taskforce 2; Dumitru and Wendling, Eds., *in preparation*)

‡ Faecal coliform bacterial counts can be determined by direct counting as colony forming units (CFU) or using the most probable number method, reported as MPN/100 mL or MPN/100 g

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

12.3.1 Surface runoff in relation to precipitation quantity

a) Direct measurement

Metric: *Runoff coefficient in relation to precipitation quantities (m^3/s, L/s or depth-equivalent mm)*

Strengths: *Traditional, well-studied method for open channel flow measurement. Scalable for different purposes*

Weaknesses: *Requires judgement in case of equipment malfunction*

The extent of impermeable surfaces in urban areas is continually increasing as cities develop and expand, due to the construction of buildings, roads, streets, parking lots, etc. A significant consequence is greater runoff in urban areas, which can also lead to flooding. Many factors are affecting the quantity of surface runoff, including soil characteristics, land use and vegetative cover, hillslope, and storm properties such as rainfall duration, amount, and intensity (Sitterson et al. 2017). In general, surface runoff is generated in two ways (Yang, Li, Sun & Ni, 2014): through saturation excess, where runoff is generated when the soil becomes saturated (for example after a lengthy period of rainfall); or, through infiltration excess, where runoff is generated when the rainfall intensity exceeds the infiltration rate of water into the soil (for example during a heavy precipitation event when rain falls more rapidly than it can infiltrate the soil).

Direct measurement of runoff (and its characteristics) using standard approaches, including weirs, pressure transducers/loggers, tipping-bucket gauges, etc. (e.g., Stovin et al., 2012).

Large scale: Weirs, flumes, orifices. Weirs obstruct the flow making the head behind the weir being a function of flow velocity and flow rate though the weir. Flumes are another traditional method for open channel flow measurement in a channel with converging and diverging sections. The operation principle of the flumes is that the water level is higher in the converging section than in the diverging section, and that there is direct relationship between water depth and flow rate (Adkins, 2006).

Small scale: tipping-bucket gauges, pressure transducers for discharge monitoring. Tipping-bucket gauges record runoff volumes as numbers of bucket tips per 24-h period. The depth of the daily runoff is then calculated by dividing the volume of daily runoff by the area of the test plot (Armson, Stringer, and Ennos, 2013). Pressure transducers allow for automatic continuous monitoring and data collection at certain intervals (e.g., 1-min) (Stovin, Vesuviano, and Kasmin, 2012).

Scale of measurement: Plot or building scale to district scale

Required data: Runoff measurements

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually; at minimum, before and after NBS implementation

Level of expertise required: Moderate – ability to evaluate the accuracy of measurements is required (in case of equipment malfunction)

Connection to other indicators: Direct relation to Height of flood peak and *Time to flood peak* indicators

Connection to SDGs: SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities

Key References

Adkins, G.B. (2006). Flow Measurement Devices. Utah Division of Water Rights, Utah.

Armson, D., Stringer, P. & Ennos, A.R. (2013). The effect of street trees and amenity grass on -urban surface water runoff in Manchester, UK. Urban Forestry & Urban Greening, 12, 282-286.

Stovin, V., Vesuviano, G. & Kasmin, H. (2012). The hydrological performance of a green roof test bed under UK climatic conditions. Journal of Hydrology, 414-415, 148-161

b) Curve number method

Metric: *Runoff in relation to precipitation quantity (mm)*

Strengths: *The most widely used modelling method to estimate runoff from rainfall. Particularly useful for comparing pre- and post-development peak rates, volumes, and hydrographs*

Weaknesses: *Curve number varies due to differences in rainfall intensity and duration, total rainfall, soil moisture conditions, cover density, stage of growth, and temperature*

The extent of impermeable surfaces in urban areas is continually increasing as cities develop and expand, due to the construction of buildings, roads, streets, parking lots, etc. A significant consequence is greater runoff in urban areas, which can also lead to flooding. Many factors are affecting the quantity of surface runoff, including soil characteristics, land use and vegetative cover, hillslope, and storm properties such as rainfall duration, amount, and intensity (Sitterson et al. 2017). In general, surface runoff is generated in two ways (Yang, Li, Sun & Ni, 2014): through saturation excess, where runoff is generated when the soil becomes saturated (for example after a lengthy period of rainfall); or, through infiltration excess, where runoff is generated when the rainfall intensity exceeds the infiltration rate of water into the soil (for example during a heavy precipitation event when rain falls more rapidly than it can infiltrate the soil).

USDA Curve Number – Taking into account losses (interception, infiltration and storage) as well as antecedent moisture conditions – runoff is estimated for storm events. Published Curve Numbers (CN) can be used in the equation. CN values are function of soil, hydrological conditions and landcover (can be weighted). Widely used worldwide. Soil Conservation Service (1972). Used in context of NBS (Gill et al, 2007).

Steps to produce the value for the storm runoff include:

1. Determine the value of *CN* for the specific cover type, hydrologic condition, and hydrologic soil group, using Table 9-1 in the USDA National Engineering Handbook (2004).

2. Determine the value for *S* based on the *CN* value, using Table 10-1 in the USDA National Engineering Handbook (2004) or equation for the *CN*.

3. Determine the runoff (*Q*) either using the graphical solution or tables provided by the USDA National Engineering Handbook (2004). For the determination, values for rainfall and *CN* are needed. Other possibility to determine the runoff is to use the runoff equation where values for rainfall and *S* are needed.

The curve number equation to estimate runoff from rainfall is:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad P > I_a$$

$$Q = 0 \qquad P \leq I_a$$

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Where Q is depth of runoff (in), P is depth of rainfall (in), I_a is initial abstraction (in), and S is maximum potential retention (in).

The initial abstraction (I_a) consists mainly of interception, infiltration during early parts of a storm, and surface depression storage. The initial abstraction can be determined from rainfall-runoff events for small watersheds. However, estimation of the initial abstraction is not easy and I_a has been assumed to be a function of the maximum potential retention (S). An empirical relationship between I_a and S has been expressed as (USDA, 2004):

$$I_a = 0.2S$$

With this relationship, the original runoff equation can be written in a more simplified form:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad P > I_a$$

The runoff based on curve number can be determined based on graphs or tables provided by USDA (2004). The parameter CN is a transformation of potential maximum retention, S (in mm):

$$CN = \frac{1000}{10 + \frac{S}{25.4}}$$

Scale of measurement: District scale to metropolitan area scale

Required data: Hydrologic soil group (HSG), land use/cover, hydrologic surface condition and antecedent moisture condition

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually; at minimum, before and after NBS implementation

Level of expertise required: High – requires ability to execute the calculations, use the graphical solutions and evaluate the results

Connection to other indicators: Direct relation to *Height of flood peak* and *Time to flood peak* indicators

Connection to SDGs: SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities

Key References

United States Department of Agriculture (USDA). (2004). *National Engineering Handbook Part 630 Hydrology*. Washington, D.C.: United States Department of Agriculture, Natural Resources Conservation Service. Retrieved from https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/manage/hydrology/?cid=STELPRDB1043063

c) Rational method

Metric: *Runoff in relation to precipitation quantity (m^3/s or L/s)*

Strengths: *A widely used method, which gives an empirical relation between rainfall intensity and peak flow*

Weaknesses: *Requires significant judgment and understanding from the designer. For the method, several assumptions that are seldom met under natural conditions must be made*

The extent of impermeable surfaces in urban areas is continually increasing as cities develop and expand, due to the construction of buildings, roads, streets, parking lots, etc. A significant consequence is greater runoff in urban areas, which can also lead to flooding. Many factors are affecting the quantity of surface runoff, including soil characteristics, land use and vegetative cover, hillslope, and storm properties such as rainfall duration, amount, and intensity (Sitterson et al. 2017). In general, surface runoff is generated in two ways (Yang, Li, Sun & Ni, 2014): through saturation excess, where runoff is generated when the soil becomes saturated (for example after a lengthy period of rainfall); or, through infiltration excess, where runoff is generated when the rainfall intensity exceeds the infiltration rate of water into the soil (for example during a heavy precipitation event when rain falls more rapidly than it can infiltrate the soil).

Rational Method for estimating 'peak' flow rates for simple urban watersheds/sewers. Often used for design discharges. Requires rainfall intensity, the runoff-coefficient (can be derived from published value) and watershed area (Kuichling, 1889).

A simplified outline of the necessary steps to determine peak runoff using the Rational Method is:

1. Determine the runoff coefficient (C). Typical values are listed in textbooks and manuals (e.g., Viessman & Lewis, 2003; VDOT, 2002). If needed, use a saturation factor (C_f) for storms with a recurrence intervals less than 10 years. These higher intensity storms require modification to estimation of runoff. Saturation factors are given by reference books and design manuals. Note that the saturation factor C_f multiplied by the runoff coefficient C should not exceed 1.0.

Saturation factors (C_f) for rational formula (VDOT, 2002).

Recurrence Interval (Years)	C_f
2, 5 and 10	1.0
25	1.1
50	1.2
100	1.25

2. Determine the time of concentration (T_c) to estimate the average rainfall intensity (i). The methods for determining the time of concentration are described by, e.g., VDOT (2002). One of them is that the time of concentration is the time required for water to flow from the hydraulically most remote point in the drainage area to the point of study.

3. Determine the rainfall intensity (i). It is assumed that the duration is equal to the time of concentration. The rainfall intensity can be selected from the IDF curve.

4. Solve the equation of the Rational Method to obtain the estimated peak runoff:

$$Q = C_f C i A$$

Where Q is maximum rate of runoff (cfs), C_f is saturation factor, C is runoff coefficient representing a ratio of runoff to rainfall (dimensionless), i is average rainfall intensity for a duration equal to the time of concentration for a selected return period (in/hr), and A is drainage area contributing to the point of study (ac).

Scale of measurement: Plot or building scale to district scale. Used mostly for relatively small drainage areas, such as parking lots. The use should be limited to drainage areas <20 acres (ca. 8 ha)

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Required data: Rainfall intensity, drainage area, saturation factor, runoff coefficient

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually; at minimum, before and after NBS implementation

Level of expertise required: High – requires significant judgement on adequacy of calculated values

Connection to other indicators: Direct relation to *Height of flood peak* and *Time to flood peak* indicators

Connection to SDGs: SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities

Key References

Dhakal, N., Fang, X., Asquith, W.H. & Cleveland, T. (2013). Return period adjustment for runoff coefficients based on analysis in undeveloped Texas watersheds. Journal of Irrigation and Drainage Engineering, June 2013

Hayes, D.C., & Young, R.L. 2005. Comparison of Peak Discharge and Runoff Characteristic Estimates from the Rational Method to Field Observations for Small Basins in Central Virginia. Scientific Investigations Report 2005-5254. Reston, VA: United States Geological Survey.

Viessman, W. & Lewis, G.L. (2003). Introduction to Hydrology. 5th edition. Upper Saddle River, NJ: Prentice Hall

Virginia Department of Transportation (VDOT). (2019). Drainage Manual. Location and Design Division. Issued April 2002. Rev. March 2019. Richmond, VA: Virginia Department of Transportation. Retrieved from http://www.virginiadot.org/business/resources/LocDes/DrainageManual/Combined_Drainage_Manual.pdf

d) Intensity-Duration-Frequency (IDF) curve method

Metric: *Runoff in relation to precipitation quantity (L/s or* m^3/s*)*

Strengths: *IDF analysis provides a convenient tool for summarizing regional rainfall information and thus it is useful in municipal stormwater management practices*

Weaknesses: *Requires significant judgment and understanding from the designer. Requires fairly extensive historic rainfall data*

The extent of impermeable surfaces in urban areas is continually increasing as cities develop and expand, due to the construction of buildings, roads, streets, parking lots, etc. A significant consequence is greater runoff in urban areas, which can also lead to flooding. Many factors are affecting the quantity of surface runoff, including soil characteristics, land use and vegetative cover, hillslope, and storm properties such as rainfall duration, amount, and intensity (Sitterson et al. 2017). In general, surface runoff is generated in two ways (Yang, Li, Sun & Ni, 2014): through saturation excess, where runoff is generated when the soil becomes saturated (for example after a lengthy period of rainfall); or, through infiltration excess, where runoff is generated when the rainfall intensity exceeds the infiltration rate of water into the soil (for example during a heavy precipitation event when rain falls more rapidly than it can infiltrate the soil).

Statistical estimation of 'peak' runoff rates for return periods of 5, 10, 100 years based on rainfall and catchment characteristics (area, channel slope, length, soil permeability). E.g. IH124 or FEH methods (UK).

A summary of the steps necessary to create IDF curves is given by Mirrhosseini et al. (2013):

1. Obtain annual maximum series of precipitation depth for a given duration (15 min, 30 min, 45 min, 1 h, 2 h, 3 h, 6 h, 12 h, 24 h, and 48 h)

2. Use a suitable probability distribution (e.g., generalized extreme value per Mirrhosseini et al., 2013) to find precipitation depths for different return periods (2, 5, 10, 25, 50, and 100 y). One of the most common probability distributions used in the IDF analysis is Gumbel's extreme value distribution (Wang & Huang 2004).

3. Repeat the first two steps for different durations

4. Plot rainfall intensity versus duration for different frequencies

In addition, other possible probability distributions can be used.

Another possibility to create IDF curves is to use the equation (MTO 1997):

$$i = A / (t_d + B)^c$$

Where i is average rainfall intensity (mm/h), t_d is rainfall duration (min) and A, B, and c are coefficients. The coefficients can be solved by least squares method described in the Ontario Drainage Management Manual produced by the Ministry of Transportation of Ontario (MTO, 1997). When the coefficients are solved, the above equation can be used to produce plots of rainfall intensity vs. duration for different return periods (Wang & Huang 2004).

Scale of measurement: Different sizes of catchments, district scale to region scale

Required data: Recorded rainfall data (historic) and catchment characteristics (area, channel length, soil permeability)

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually; at minimum, before and after NBS implementation

Level of expertise required: High – requires ability and significant judgement to execute statistical analyses

Connection to other indicators: Direct relation to *Height of flood peak* and *Time to flood peak* indicators

Connection to SDGs: SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities

Key References

Al Mamoon, A., Joergensen, N.E., Rahman, A., & Qasem, H. (2014). Derivation of new design rainfall in Qatar using L-moment based index frequency approach. International Journal of Sustainable Built Environment, 3(1), 111-118.

Fadhel, S., Rico-Ramirez, M.A., & Han, D. (2017). Uncertainty of Intensity-Duration-Frequency (IDF) curves due to varied climate baseline periods. Journal of Hydrology, 547, 600-612.

Ministry of Transportation of Ontario (MTO). (1997). Ministry of Transportation of Ontario Drainage Management Manual. Ontario, Canada: Ministry of Transportation of Ontario. Retrieved from http://www.mto.gov.on.ca/english/publications/drainage-management.shtml

Mirrhosseini, G., Srivastava, P., & Stefanova, L. (2013). The impact of climate change on rainfall Intensity-Duration-Frequency (IDF) curves in Alabama. Regional Environmental Change, 13(S1), 25-33.

Prodanovic, P., & Simonovic, S.P. (2007). Development of Rainfall Intensity Duration Curves for the City of London Under the Changing Climate. Water Resources Research Report No. 058. London, Ontario, Canada: Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Wang, X., & Huang, G. (2014). Technical Report: Developing Future Projected IDF Curves and a Public Climate Change Data Portal for the Province of Ontario. Submitted to Ontario Ministry of the Environment. Saskatchewan, Canada: Institute for Energy, Environment and Sustainable Communities (IEESC) of the University of Regina. Retrieved from http://www.ontarioccdp.ca/final_tech_report.pdf

e) Process-based hydraulic modelling

Metric: *Runoff in relation to precipitation quantity (mm)*

Strengths: *Possibility to extrapolate the measurements spatially and temporally. Allows for future predictions and forecasts given the available measurements*

Weaknesses: *Modelling includes numerous simplifications and approximations (adequacy of process parametrizations, data limitations and uncertainty, and computational constraints on model analysis). Multiple challenges arise when choosing the approach to modelling*

The extent of impermeable surfaces in urban areas is continually increasing as cities develop and expand, due to the construction of buildings, roads, streets, parking lots, etc. A significant consequence is greater runoff in urban areas, which can also lead to flooding. Many factors are affecting the quantity of surface runoff, including soil characteristics, land use and vegetative cover, hillslope, and storm properties such as rainfall duration, amount, and intensity (Sitterson et al. 2017). In general, surface runoff is generated in two ways (Yang, Li, Sun & Ni, 2014): through saturation excess, where runoff is generated when the soil becomes saturated (for example after a lengthy period of rainfall); or, through infiltration excess, where runoff is generated when the rainfall intensity exceeds the infiltration rate of water into the soil (for example during a heavy precipitation event when rain falls more rapidly than it can infiltrate the soil).

One-dimensional and two-dimensional drainage system modelling exist. There are many examples of models applied in an urban context. Existing approaches used to evaluate GI/NBS are the Stormwater Management Model (SWMM [USA]), CityCat (Newcastle), MIKE (DHI) and InfoWorks for Sustainable Drainage Systems (SUDS [UK]). Impact of climate change on runoff can be evaluated using the design storms. The models typically require multiple parameters for accurate results.

Building a model:

1. The modelling process starts with a perceptual model, which is the summary of perceptions of how the catchment responds to rainfall under different conditions. In the conceptual model, mathematical descriptions are formed where hypotheses and assumptions are taken into account.

2. If the equations decided in the conceptual model cannot be solved analytically given some boundary conditions for the real system, an additional stage of approximation is necessary using the techniques of numerical analysis to define a procedural model. This is given in a form of code that will run on the computer.

3. In the next phase, the parameters used in the model needs to be calibrated. The most commonly used method in the model calibration is matching the model predictions and observations from the direct measurements if they are available.

4. After the calibration of parameters, simulations with the model could be made. Results of the simulations should then be reviewed and the model validated. The validation can be done by comparing the results to direct measurements, e.g. observed discharges, if they are available (Beven 2012).

When choosing a conceptual model, the following procedure can be used (Beven, 2012):

- Prepare a list of the models under consideration.
- Prepare a list of the variables predicted by each model. Decide if the model under consideration will give the needed output.
- Prepare a list of the assumptions made by the model. Reject models where the assumptions are estimated to be too inaccurate.
- Make a list of the inputs required by the model, for specification of the flow domain, the boundary and initial conditions and the parameter values.
- Determine whether you have any models left on your list. If not, the criteria should be reviewed again and then review the previous steps.

Comparison of the basic structure for rainfall- runoff models (adapted from Sitterson et al., 2017):

	Empirical	Conceptual	Physical
Method	Non-linear relationship between inputs and outputs, black box concept	Simplified equations that represent water storage in catchment	Physical laws and equations based on real hydrologic responses
Strengths	Small number of parameters needed, can be more accurate, fast run time	Easy to calibrate, simple model structure	Incorporates spatial and temporal variability, very fine scale
Weaknesses	No connection between physical catchment, input data distortion	Does not consider spatial variability within catchment	Large number of parameters and calibration needed, site specific
Best Use	In ungauged watersheds, runoff is the only output needed	When computational time or data are limited	Have great data availability on a small scale
Examples	Curve Number, Artificial Neural Networks[(a)]	HSPF[(b)], TOPMEDEL[(a)], HBV[(a)], Stanford[(a)]	MIKE-SHE[(a)], KINEROS[(c)], VIC[(a)], PRMS[(d)]

[a] Devia, Ganasri, & Dwarakish, 2015
[b] Johnson, Coon, Mehta, Steenhuis, Brooks, & Boll, 2003
[c] Woolhiser, Smith, & Goodrich, 1990
[d] Singh, 1995

Scale of measurement: All scales depending on the type of model used

Required data: Rainfall measurements, spatial drainage area characteristics (e.g., area, slope)

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually; at minimum, before and after NBS implementation

Level of expertise required: High – requires ability to apply hydrologic models and assess the output

Connection to other indicators: Direct relation to *Height of flood peak* and *Time to flood peak* indicators

Connection to SDGs: SDG 11 Sustainable cities and communities

Key References

Beven, K.J. (2012). Rainfall-Runoff Modelling: The Primer. Second Edition. Chichester, West Sussex, U.K.: Wiley-Blackwell.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Clark, M.P., Bierkens, M.F.P., Samaniego, L., Woods, R.A., Uijlenhoet, R., Bennett, … Peters-Lidard, C.D. (2017). The evolution of process-based hydrologic models: historical challenges and the collective quest for physical realism. Hydrology and Earth System Sciences, 21, 3427-3440

Devia, G.K., Ganasri, B.P., & Dwarakish, G.S. (2015). A Review on Hydrological Models. Aquatic Procedia, 4, 1001-1007.

Johnson, M.S., Coon, W. F., Mehta, V.K., Steenhuis, T.S., Brooks, E.S., & Boll, J. (2003). Application of two hydrologic models with different runoff mechanisms to a hillslope dominated watershed in the northeastern US: a comparison of HSPF and SMR. Journal of Hydrology, 284(1-4), 57-76.

Singh, V.P. (Ed.). (1995). Computer Models of Watershed Hydrology. Highlands Ranch, CO: Water Resources Publications, LLC.

Sitterson, J., Knightes, C., Parmar, R., Wolfe, K., Muche, M., & Avant, B. (2017). An Overview of Rainfall-Runoff Model Types. EPA Report Number EPA/600/R-17/482. September 2017. Athens, GA: Office of Research and Development National Exposure Research Laboratory.

Woolhiser, D.A., Smith, R.E., & Goodrich, D.C. (1990). KINEROS, A kinematic runoff and erosion model: Documentation and user manual. ARS-77. Washington, D.C.: United States Department of Agriculture, Agricultural Research Service. Retrieved from https://www.tucson.ars.ag.gov/unit/Publications/PDFfiles/703.pdf

12.3.2 Total suspended solids content

Metric: *Total suspended solids (TSS) or turbidity (%, mg/L and total; units dependent upon measurement technique). A measure of the suspended solids in wastewater, effluent, or water bodies, determined by tests for "total suspended non-filterable solids"*

Strengths: *Simple evaluation. In turbidity measurements, Secchi disk is very commonly used visual method because it is easy to use, inexpensive, and relatively accurate. The turbidity meter method is very accurate*

Weaknesses: *Laboratory measurement of TSS directly quantifies the amount of fine particulate material suspended in water but is relatively time-intensive. Time consuming TSS measurements, non-continuous compared to turbidity*

Total Suspended Solids (TSS) are solids in water that can be trapped by a filter. TSS can include a wide variety of material and can have adsorbed pollutants. High concentrations of suspended solids can affect the health and productivity of the aquatic life. TSS and turbidity are simple indicators of water quality. Sources of TSS include, e.g., sediment runoff from agricultural fields, logging activities, construction sites, roadways, waste discharge, or excessive algal growth. The TSS content often increases sharply during and immediately following a rainfall event. The EU Freshwater Fish Directive (2006/44/EC) recommends ≤25 mg/L TSS for salmonid and cyprinid fish health (European Parliament, 2006), whilst the concentration of TSS in wastewater treatment plant effluents is limited to ≤35 mg/L by Wastewater Directive 91/271/EEC (European Parliament, Council of the European Union, 1991).

Total suspended solids (TSS) are typically quantified in the laboratory using a gravimetric process, yielding TSS measurement in units of mass per volume (e.g., mg/L or ppm). Measurement of TSS involves filtration of a water sample followed by drying and weighing of the particulates removed. Simply, this means anything that is captured by filtering the sample aliquot through a specific pore size filter. A measured volume (no more than 1 L) of sample is passed through a prepared, pre-weighed filter paper. The filter is dried at 104 ± 1°C. After drying, the filter is reweighed and the TSS is calculated.

A semi-quantitative, rapid assessment of TSS can be accomplished by evaluating sample turbidity, a measure of the relative transparency of a water sample. Turbidity measurements rely on comparison of light scattering with standard solutions (turbidity meter) or visual assessment (Secchi disk, transparency tube). Turbidity meters use a light beam with defined characteristics to provide a semi-quantitative measure of the particulates present in the water, providing an integrated measure of light scattering and absorption. The measurement is provided in nephelometric turbidity units (NTU). Turbidity (in NTU) can be directly related to TSS (in mg/L) via creation of a standard curve (TSS versus turbidity) for a given location/type of fine particulate material.

- Measuring turbidity *in-situ*:
  - Secchi disk, which is lowered into the water and the level where the disk disappears is registered
  - Turbidity meter consists of a light source that illuminates a water sample and a photoelectric cell that measures the intensity of light scattered at a 90° angle by the particles in the sample
  - Transparency tube is a clear, narrow plastic tube marked in units with a light and dark pattern painted on the bottom. Water is poured into the tube until the pattern disappears, and the depth is recorded

Scale of measurement: Plot scale to district scale

Required data: TSS or turbidity measurement data

Data generation specifications: Quantitative and semi-quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Daily, weekly, monthly or annually

Level of expertise required: Low to moderate

Connection to other indicators: Synergies with the other indicators in the *Water management* indicator group

Connection to SDGs: SDG 6 Clean water and sanitation, SDG 13 Climate action, SDG 14 Life below water

Key References

ASTM. (2018). *ASTM D5907-18, Standard Test Methods for Filterable Matter (Total Dissolved Solids) and Nonfilterable Matter (Total Suspended Solids) in Water*. ASTM International, West Conshohocken, PA.

Orhel, R.L., & Register, K.M. (2006). *Volunteer Estuary Monitoring. A Methods Manual*. 2nd edition. United States Environmental Protection Agency, Washington, D.C.

International Organization for Standardization (ISO). (2016*). International Standard ISO 7027-1:2016 Water quality — Determination of turbidity — Part 1: Quantitative methods.* International Organization for Standardization, Geneva.

International Organization for Standardization (ISO). (2019). *International Standard ISO 7027-2:2019 Water quality — Determination of turbidity — Part 2: Semi-quantitative methods for the assessment of transparency of waters.* International Organization for Standardization, Geneva.

12.3.3 Nitrogen and phosphorus concentration or load

Metric: *Nitrogen and phosphorus in surface water and/or groundwater (%, expressed as total annual N or P load and/or reduction of maximum annual concentration)*

Strengths: *Laboratory analyses are accurate but can be quite costly. A full suite of analyses can be done for multiple chemical species of N and P. Ion selective electrodes (ISEs) are less expensive and easier to use alternative. Whilst ISEs for various N species (NO_2^-, NO_3^-, NH_3/NH_4^+) are readily available from multiple suppliers, ISEs for phosphate are less common. ISEs have a potential for permanent installation at a given sampling point*

Weaknesses: *Test kits obtain a rapid result, but are in general less accurate than analyses performed in an accredited laboratory. Photometers are generally quite accurate but can be expensive to purchase and maintain. Test kits based on colour comparison, either of test strips or solutions, are relatively less costly but can have limited accuracy at low nutrient concentrations*

Nutrients, including nitrogen (N) and phosphorus (P), can have significant impact on water quality, including effects on plant growth, oxygen concentration, water clarity, and sedimentation rates. Some major anthropogenic sources of nutrients are agricultural and industrial emissions, discharged wastewater and atmospheric deposition. Nitrogen and phosphorus are present in water in many different forms, or as many different chemical species. The forms of N and P that are quantified can include some or all of the following:

- Nitrogen: total N (N_{tot}), total Kjeldahl N (TKN), dissolved organic N (DON), nitrate (NO_3^-), nitrite (NO_2^-) and ammonia/ammonium (NH_3/NH_4^+)
- Phosphorus: total P (P_{tot}), acid-hydrolysable P (AHP), orthophosphate (PO_4^{3-})

Different nitrogen and phosphorus species can be quantified in a water sample either in the field, using a test kit or ion selective electrode (ISE), or via laboratory analyses.

Laboratory analyses can be done for multiple chemical species of N and P.

Ion selective electrodes are analogous to a pH electrode and are used in much the same way as a pH electrode (pH electrodes are essentially ion selective electrodes that are sensitive to the H+ ion) ISEs have a potential for permanent installation at a given sampling point. It is possible to program a data logger connected to an in-situ ISE to measure and record a value at a prescribed frequency.

Test kits are usually used on site (in the field). Test kits typically involve the addition of chemical reagents to a water sample and yield results based on test strip colour comparison, solution colour comparison to a colour wheel or colour chart, or measurement with a photometer. The spectrophotometer measures the quantity of a chemical based on its characteristic absorption spectrum.

Scale of measurement: Plot scale to district scale, depending on location of sampling point

Required data: Measurement data of a water sample

Data generation specifications: Quantitative; participatory data collection possible with test kits and ion selective electrodes under supervision

Data generation/collection frequency: Daily, weekly, monthly or annually

Level of expertise required: Low to moderate

Connection to other indicators: Synergies with the other indicators in the *Water management* indicator group

Connection to SDGs: SDG 13 Climate action, SDG 14 Life below water

Key References

Orhel, R.L., & Register, K.M. (2006). Volunteer Estuary Monitoring. A Methods Manual. Second edition. Washington, D.C: United States Environmental Protection Agency.

Reedyk, S., & Forsyth, A. (2006). *Using field chemistry kits for monitoring nutrients in surface water*. Publication number PRO-121-2006-1. Ottawa, Ontario, Canada: Agriculture and Agri-Food Canada PFRA. Retrieved from http://pfra.ca/doc/Water%20Quality/Water%20Quality%20Protection/using_field_chem_kits_final.pdf

12.3.4 Metal concentration or load

Metric: *Metal pollutants in surface water and/or groundwater (%, expressed as total annual metal pollutant load and/or reduction of maximum annual concentration).*

*(Concentration of heavy metals before NBS treatment - Concentration of heavy metals after NBS treatment)/ Concentration of heavy metals before NBS treatment)*100*

Strengths: *ICP analyses are highly precise and accurate to very low concentrations. Test kits and ion selective electrodes (ISEs) can provide rapid results. ISEs can be installed in-situ to take measurements at regular intervals*

Weaknesses: *ICP analyses can be quite costly and with the high number of metals (Cd, Cr, Pb, Hg, Ni, Zn, Cu…) some of which could be at very low concentration levels, this can add to the expense. There is usually a significant delay between the time of sample collection and receipt of water quality data from the laboratory. A separate kit or ISE is required for each element of interest, and the limit of detection for a given element of interest may be substantially higher than the respective accredited laboratory analysis technique. Analysis of individual metals using field test kits can be time-intensive and/or require trained personnel to conduct the tests*

Metals and metalloids (herein referred to simply as metals) are ubiquitous in the natural environment and can potentially accumulate to toxic levels for the aquatic environment and humans as metals do not degrade with time. As such, metals can have a significant impact on water quality and its fit-for-purpose use. Natural sources of metals include weathering of geologic materials (rocks and soil) and volcanic activity. The primary reservoir of metals is geological substrate. Human activity has greatly accelerated natural biogeochemical cycles, resulting in anthropogenic emissions of metals to the atmosphere one to three orders of magnitude greater than natural fluxes. Anthropogenic sources of metals include point sources such as mining and industrial activities, and non-point sources such as fossil fuel combustion and agricultural activities. Stormwater may transport heavy metals from industries, municipalities and urban areas at different quantities, which are accumulated in soil, sediments and water bodies. Removal can be achieved by appropriately designed NBS.

Some of the more common metal pollutants are: aluminium (Al), arsenic (As), barium (Ba), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), molybdenum (Mo), nickel (Ni), lead (Pb) and mercury (Hg), selenium (Se), vanadium (V) and zinc (Zn).

Metals in water samples are typically quantified in an accredited laboratory using a suite of standardised analyses. Ion-coupled plasma spectrophotometry (ICP) coupled with atomic emission spectrometry (MS), with or without pre-treatment/pre-concentration, is a well-recognised analytical method for the quantification of trace metals in waters. Multiple elements can be analysed from a single sample. Methods may vary depending on the water matrix and metals to be analysed, but generally the method compromised the following steps:

- Sample preparation which may include weighing of the sample, solubilisation of the solids with acids with/without heat (for total recovery analysis), separation of undissolved material

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

- Calibration of the equipment
- Sample analysis

The nature of ICP analyses means that the analysed samples represent a single point in time (the time at which the sample was collected), and metal concentrations may vary substantially in urban waters due to the contribution of run-off from urban surfaces.

Field test kits are available for on-site testing of some metals (e.g., As, Cd, Cu, Pb, Mo, etc.) whilst other metals can be detected using an ion-selected electrode (ISE; e.g., Cd, Pb, Zn, etc.). Field test kits vary greatly and range from semi-quantitative paper test strips for multiple metals, to quantitative colourimetric-type analyses. Some field test kits may involve the use of portable laboratory equipment such as a photometer, fluorometer or similar. With ISEs there is a potential to install a testing unit in-situ to take measurements at regular intervals and save results to a data logger or upload to a central data repository.

Scale of measurement: Plot scale to district scale, depending on location of sampling point for concentrations ranging from ng/L to mg/L

Required data: Water samples. Relatively small sample volume is required (typically 100 mL or less)

Data generation specifications: Quantitative and semi-quantitative; participatory data collection possible with test kits and ion selective electrodes under supervision

Data generation/collection frequency: Daily, weekly, monthly or annually

Level of expertise required: Low to Moderate for sampling; High for analysis

Connection to other indicators: Synergies with the other indicators in the *Water management* indicator group

Connection to SDGs: SDG 6 Clean water and sanitation, SDG 13 Climate action, SDG 14 Life below water

Key References

Chaturvedi, A., Bhattacharjee, S., Mondal, G.C., Kumar, V., Singh, P.K., & Singh, A.K. (2019). Exploring new correlation between hazard index and heavy metal pollution index in groundwater. Ecological Indicators, 97, 239-246.

Chaturvedi, A., Bhattacharjee, S., Singh, A.K., & Kumar, V. (2018). A new approach for indexing groundwater heavy metal pollution. Ecological Indicators, 87, 323-331.

European Parliament, Council of the European Union. (2000). EU Water Framework Directive: Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy. Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02000L0060-20140101

International Organization for Standardization (ISO). 2004. *International Standard ISO 17294-1:2004 Water quality — Application of inductively coupled plasma mass spectrometry (ICP-MS) — Part 1: General guidelines*. International Organization for Standardization, Geneva.

International Organization for Standardization (ISO). 2016. *International Standard ISO 17294-2:2016 Water quality — Application of inductively coupled plasma mass spectrometry (ICP-MS) — Part 2: Determination of selected elements including uranium isotopes*. International Organization for Standardization, Geneva.

Milik, J. & Pasela, R. (2018) Analysis of concentration trends and origins of heavy metal loads in stormwater runoff in selected cities: A review. *E3S Web of Conferences* 44, 00111.

Mohan, S.V., Nithila, P., & Reddy, J. (1996). Estimation of heavy metals in drinking water and development of heavy metal pollution index. *Journal of Environmental Science and Health*. Part A: Environmental Science and Engineering and Toxicology, 31(2), 283-289.

Müller, A., Österlund, H., Marsalek, J., & Viklander, M. (2020). The pollution conveyed by urban runoff: A review of sources. *Science of The Total Environment*, 7097, 136125

12.3.5 Total faecal coliform bacteria

Metric: *Observed number of faecal coliform colony units determined by direct counting (Colony Forming Unit (CFU)/100 mL or CFU/100 g) or most probable number (MPN) methods (MPN/100 mL or MPN/g)*

Strengths: *Almost always implies the faecal contamination of water. Standardized methodology for analyses*

Weaknesses: *Analyses require expert knowledge and judgement*

Faecal coliform bacteria are a subgroup of a larger total coliform group referring to the Gram-negative, rod-shaped bacteria. Faecal coliform bacteria denote a group of thermotolerant coliform organisms, optional aerobic or anaerobic, which grow at 44 ± 0.5 °C and ferment lactose to produce acid and gas (Bartram & Pedley, 1996; Doyle & Erickson, 2006). Although coliform bacteria are easy to detect, their presence does not imply the faecal contamination due to the natural occurrence of some faecal coliform organisms of non-faecal origin. Thus, the pathogenic strains of *Escherichia coli (E. coli)* are usually analysed to determine the sanitary contamination of water (ISO, 2014). Presence of faecal coliform bacteria in the natural waters may indicate the faecal contamination and degradation of the water bodies originating from diffuse sources such as urban runoff and transport from sewer overflows (Davies et al., 1995; Davies & Bavor, 2000).

Colifrom bacteria are measured with:

a. Membrane filtration and direct counting

The traditional way of evaluating the water samples for bacteria is the membrane filtration method. First, the water sample is filtered through a membrane, then the bacteria are cultured on an agar medium in a Petri dish and incubated at a specified temperature for a specified period of time depending on the type of bacteria analysed. Later, the number of the target organisms in the sample is calculated.

The background bacterial growth may inhibit the enumeration of coliform bacteria, so this method is not deemed suitable for shallow and surface waters.

b. Most probable number (MPN) method

MPN is a statistical method used for enumeration of the viable target organisms by sequential inoculation and incubation in a liquid medium in ten-fold dilutions. Several assumptions must be made when using the MPN method, such as assuming the random distribution of the organisms in the sample (implying that no bacterial clustering and repelling is present), and assuming that the tubes will produce detectable growth.

The advantages of the MPN method include the possibility for adjustment of the accuracy of the results when increasing the number of tubes per dilution, and larger sample size than in the plate count method. The MNP method is suitable for all types of water.

Scale of measurement: Plot scale

Required data: Microbiological analyses of water

Data generation specifications: Quantitative; participatory data collection is possible under direct qualified staff supervision

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Data generation/collection frequency: At minimum before and after NBS implementation

Level of expertise required: High – requires familiarity with the laboratory practices and expertise for conducting the microbiological analyses and evaluating the outcomes

Connection to other indicators: Together with other *Water Management* indicators determines the overall status of water quality in an area

Connection to SDGs: SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 14 Life below water

Key References

Bartram, J. & Pedley, S. (1996). *Chapter 10 – Microbiological Analyses*. In: Bartram, J. & Ballance, R. (Eds.). *Water quality monitoring: a practical guide to the design and implementation of freshwater quality studies and monitoring programmes*. CRC Press. Retrieved from: https://www.who.int/water_sanitation_health/resourcesquality/wqmchap10.pdf

Davies, C. M., & Bavor, H. J. (2000). The fate of stormwater-associated bacteria in constructed wetland and water pollution control pond systems. *Journal of Applied Microbiology*, *89*(2), 349-360.

Davies, C. M., Long, J. A., Donald, M., & Ashbolt, N. J. (1995). Survival of fecal microorganisms in marine and freshwater sediments. *Applied and Environmental Microbiology, 61*(5), 1888-1896.

Doyle, M. P., & Erickson, M. C. (2006). Closing the door on the fecal coliform assay. *Microbe*, *1*(4), 162-163.

International Organization for Standardization (ISO). (2014). *International Standard ISO 9308-1:2014: Water quality — Enumeration of Escherichia coli and coliform bacteria — Part 1: Membrane filtration method for waters with low bacterial background flora.* International Organization for Standardization, Geneva.

International Organization for Standardization (ISO). (2012). *International Standard ISO 9308-2: Water quality — Enumeration of Escherichia coli and coliform bacteria — Part 2: Most probable number method.* International Organization for Standardization, Geneva.

International Organization for Standardization (ISO). (2012). *International Standard ISO 9308-3: Water quality — Detection and enumeration of Escherichia coli and coliform bacteria — Part 3: Miniaturized method (Most Probable Number) for the detection and enumeration of E. coli in surface and waste water.* International Organization for Standardization, Geneva.

12.3.6 Infiltration rate and capacity

Metric: *Infiltration capacity (%; change in precipitation infiltration capacity measured using ring infiltrometer & extrapolated/modelled for full unsealed area)*

Strengths: *Straightforward assessment of infiltration capabilities of soil. Fairly easy to run the experiments*

Weaknesses: *Several measurement locations may not represent the situation holistically. Potential sources of errors during the measurement procedure*

Surface imperviousness is characteristic of urban areas and an important environmental indicator (Arnold & Gibbons, 1996; Strohbach et al., 2019). As surface imperviousness increases, the volume and velocity of surface runoff increases and there is a corresponding decrease in water infiltration. A high proportion of surfaces in urban areas are impermeable and the impermeability of surfaces in the cities is increasing as cities become more densely populated. The impermeability of urban surfaces originates from constructing buildings, roads, parking areas, etc., with materials that are not permeable to water.

When measuring water flow parameters in the field (field-saturated parameters), the measurements in the unsaturated or vadose zone (above the water table), are typically conducted using various ring infiltrometer and borehole or well permeameter methods. In the saturated zone (below the water table), water flow parameters (saturated parameters) are usually measured using auger hole methods, and at greater depths using piezometer methods.

Measurements of water flow parameters of the soil in the vadose zone using ring infiltrometers can be conducted with the following steps (Reynolds et al., 2002):

1. The cylinder is inserted 3-10 cm into the soil. The contact between the soil and the inside cylinder should be lightly tamped to prevent flow or leakage around the cylinder walls.

2. A constant depth of water is ponded inside the measuring cylinder and also inside the buffer cylinder if the concentric-ring infiltrometer is used. The ponding depth is usually 5-20 cm depending on the circumstances.

3. The water infiltration rate through the measuring cylinder is measured. The infiltration rate through the buffer cylinder can also be measured if single-ring and concentric-ring infiltration rate results are compared. Quasi-steady flow in the near-surface soil under the measuring cylinder is assumed to occur when the discharge becomes effectively constant. The field-saturated hydraulic conductivity, K_{fs}, can be calculated using the Equation 1.

$$q_s/K_{fs} = Q/(\pi a^2 K_{fs}) = [H/(C_1 d + C_2 a)] + \{1/[\alpha^*(C_1 d + C_2 a]\} + 1 \quad (1)$$

where q_s (L T^{-1}) is quasi-steady infiltration rate, K_{fs} (L T^{-1}) is the field-saturated hydraulic conductivity, Q (L^3 T^{-1}) is the corresponding quasi-steady flow rate, a (L) is the ring radius, H (L) is the steady depth of ponded water in the ring, d (L) is the depth of ring insertion into the soil, C_1=0.316π and C_2=0.184π are dimensionless quasi-empirical constants that apply for $d \geq 3$ cm and $H \geq 5$ cm (Reynolds & Elrick, 1990; Youngs, Leeds-Harrison, & Elrick, 1995). The macroscopic capillary length, α (L^{-1}), can be estimated from soil structure and texture or measured using independent methodology. Some values for α:

Table 1: Soil texture-structure categories for site-estimation of the parameter "α" (Reynolds et al., 2002, adapted from Elrick, Reynolds & Tan, 1989).

Soil texture and structure category	α* (cm^{-1})
Compacted, structureless, clayey or silty materials such as landfill caps and liners, lacustrine or marine sediments	0.01
Soils that are both fine textured (clayey or silty) and unstructured; may also include some fine sands.	0.04
Most structured soils from clays through loams; also includes unstructured medium and fine sands. The category most frequently applicable for agricultural soils.	0.12
Coarse and gravelly sands; may also include highly structured or aggregated soils, as well as soils with large and/or numerous cracks, macropores	0.36

The following instructions for measuring infiltration of a water permeable pavement are based on the ASTM C1701/C1701M-09 (infiltration rate of in situ pervious concrete). More detailed instructions are provided in the standard.

• Install the infiltration ring. The joint between the ring and the pavements should be made watertight using, e.g., plumber's putty.

• Conduct pre-wetting. Pour a total of 3.60 ± 0.05 kg of water inside the ring so that the head maintains between lines marked inside the ring. The timing starts when the water hits the surface and it stops when there is no free water left on the surface.

• Conduct the test. The test shall start within 2 min after the completion of the pre-wetting. Similar procedure for the test is used than in the pre-wetting. However, if the elapsed time in the pre-wetting was less than 30 s, a total of 18.00 ± 0.05 kg of water is used in the test.

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Scale of measurement: Plot scale to street scale

Required data: Soil texture and structure category, infiltration rate of soil

Data generation specifications: Quantitative; participatory data collection is feasible through conducting an infiltration rate experiment under supervision

Data generation/collection frequency: Annually, and before and after NBS implementation

Level of expertise required: Moderate – requires ability to perform the experiment; High – for executing the calculations

Connection to other indicators: Indirect relation to the whole *Water Management* indicator group

Connection to SDGs: SDG 11 Sustainable cities and communities, SDG 13 Climate action

Key References

Arnold, C.L., Jr., & Gibbons, C.J. (1996). Impervious surface coverage: The emergence of a key environmental indicator. Journal of the American Planning Association, 62(2), 243-258.

ASTM C1701/C1701M-09. Standard test method for infiltration rate of in place pervious concrete.

Reynolds, W.D., Elrick, D.E., & Youngs, E.G. (2002). Ring or Cylinder Infiltrometers (Vadose Zone). In J.H. Dane & G.C. Topp (Eds.), Methods of Soil Analysis. Part 4 Physical Methods. Madison, Wisconsin: Soil Science Society of America, Inc.

Strohbach, M.W., Döring, A.O., Möck, M., Sedrez, M., Mumm, O., Schneider, A.-K., … Schröder, B. (2019). The "hidden urbanization": Trends of impervious surface in low-density housing developments and resulting impacts on the water balance. Frontiers in Environmental Science, 7, 29.

Youngs, E.G., Leeds-Harrison, P.B., & Elrick, D.E. (1995). The hydraulic conductivity of low permeability wet soils used as landfill lining and capping material: analysis of pressure infiltrometer measurements. Journal of Soil Technology, 8, 153-160.

12.3.7 Rate of evapotranspiration

Metric: *Measured or modelled evapotranspiration (typically expressed in mm per unit time)*

Strengths: *The reference evapotranspiration,* ET_o*, provides a standard to which: (a) evapotranspiration at different periods of the year or in other regions can be compared; (b) evapotranspiration of other crops can be related (Allen, Pereira, Raes, & Smith, 1998). Standard, widely-applied technique*

Weaknesses: *Challenging and expensive to measure directly. Requires high level of expertise to apply*

Evapotranspiration (ET) is a combination of two separate processes whereby water is lost from the soil surface by evaporation and from vegetation by transpiration. Water evaporates from surfaces when sufficient heat is supplied for liquid water to transition to water vapour. During transpiration, plant tissues vaporise water, which is then released to the atmosphere through stomatal openings on the plant leaf. Nearly all water taken up by plants is released to the atmosphere through transpiration. In addition to the non-uniformity of urban vegetation, shading of urban vegetation by landscape trees and structures and edge effects due to the relatively small scale of urban green space in comparison to commercial crop fields can significantly influence ET (Snyder, Pedras, Montazar, Henry, & Ackley, 2015).

Evapotranspiration is measured involving specific devices and accurate measurements of various physical parameters or the soil water balance in lysimeters.

In practice, ET is commonly calculated using meteorological data. Commercially-available ET monitoring stations are generally meteorological stations that calculate potential ET using monitored temperature, relative humidity, wind speed and direction, solar radiation, and precipitation data. The Penman-Monteith equation is the FAO-recommended standard technique for calculation of reference evapotranspiration, ET_o from crops (Allen, Pereira, Raes, & Smith, 1998). The FAO Penman-Monteith method to estimate ET_o is presented in Equation 1:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

Where ET_o is reference evapotranspiration [mm day^{-1}], R_n is net radiation at the crop surface [MJ m^{-2} day^{-1}], G is soil heat flux density [MJ m^{-2} day^{-1}] ,T is mean daily air temperature at 2 m height [°C], u_2 is wind speed at 2 m height [m s^{-1}], e_s is saturation vapour pressure [kPa], e_a is actual vapour pressure [kPa], e_s - e_a is saturation vapour pressure deficit [kPa], D is slope vapour pressure curve [kPa °C^{-1}], and g is psychrometric constant [kPa °C^{-1}].
Using the Penman-Monteith equation, ET from plant surfaces under standard conditions is determined using an experimentally-determined coefficient (k_c) to relate the ET for a specific crop species, ET_c, to ET_o. Thus, for a given crop species:

$$ET_c = k_c \times ET_0 \quad (2)$$

For urban landscapes, the landscape coefficient method (LCM), which uses a different set of coefficients rather than kc to estimate ET, may be more appropriate (Costello, Matheny, Clark, & Jones, 2000):

$$ET = k_L \times ET = k_d \times k_s \times k_{mc} \times ET_0 \quad (3)$$

where k_L is a landscape coefficient defined as a product of k_d, a planting density factor, k_S, a species-specific factor, and k_{mc}, a microclimate factor.

The modifications of the Penman-Monteith equation for plant-specific conditions can be found in the publications by, e.g., Litvak and Pataki (2016) and Litvak, Manago, Hogue, and Pataki (2016).

Scale of measurement: Plot scale, can be extrapolated using land cover data

Required data: Radiation, air temperature, wind speed, vapour pressure, soil heat flux density

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually, and before and after NBS implementation

Level of expertise required: High – requires ability to apply the Penman-Monteith equation and evaluate the results

Connection to other indicators: Related to *Daily temperature range* indicator; a possible consequence of *Green space management* and *Place regeneration* indicator groups

Connection to SDGs: SDG 11 Sustainable cities and communities

Key References

Allen, R.G., Pereira, L.S., Raes, D., & Smith, M. (1998). Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56. Rome: Food and Agriculture Organization of the United Nations. http://www.fao.org/3/X0490E/x0490e00.htm#Contents

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Costello, L.R., Matheny, N.P., Clark, J.R., & Jones, K.S. (2000). A guide to estimating irrigation water needs of landscape plantings in California, the landscape coefficient method and WUCOLS III. Berkeley, CA, USA: University of California Cooperative Extension, California Department of Water Resources. https://ucanr.edu/sites/WUCOLS/

Litvak, E., Manago, K.F., Hogue, T.S., & Pataki, D.E. (2016). Evapotranspiration of urban landscapes in Los Angeles, California at the municipal scale. Water Resources Research, 53(5), 4236-4252.

Litvak, E. & Pataki, D.E. (2016). Evapotranspiration of urban lawns in a semi-arid environment: An in situ evaluation of microclimatic conditions and watering recommendations. Journal of Arid Environments, 134, 87-96.

Snyder, R.L., Pedras, C., Montazar, A., Henry, J.M., & Ackley, D. (2015). Advances in ET-based landscape irrigation management. Agricultural Water Management, 147, 187-197

12.3.8 Height of flood peak and time to flood peak

Metric: *Flood peak height is the highest point of the rising limb of a flood hydrograph (describing discharge over time) (m^3/s, cfs, L/s or similar units)*

Time to flood peak (h)

Strengths: *Straightforward assessment of degree to which the changes in the local land-use (i.e., change in imperviousness) had an effect on reducing/promoting runoff*

Weaknesses: *Requires in situ measurements*

Rapid urbanisation and industrialisation have led to reduced vegetative cover and decreased water storage in the subsurface, as well as the concentration and accumulation of surface runoff in sewage systems due to reduced infiltration into the soil. As a result, the volume of surface runoff as well as the velocity and time to peak storm runoff and baseflow are all increased. Urbanisation also reduces the land coverage of forests and vegetation that help to dissipate the flow energy (Devi, Ganasri & Dwarakish, 2015; Liu, Gebremeskel, De Smedt, Hoffman & Pfister, 2004). The detrimental effects of urbanisation on hydrologic systems are expected to increase in the future due to both increasing urbanisation as well as changes to the global climate, including rising sea levels, glacial retreat, changing precipitation patterns and an increasing frequency of extreme events (Kiehl, 2011).

Assessment of the effectiveness of flood management methods can be performed by different methods. For example, the assessment of runoff can be performed by *in situ* measurements before and after construction of a flood management structure.

In the studies reviewed by Iacob et al. (2014), the assessment of natural management methods was performed either by hydrologic and hydraulic modelling or by direct monitoring. Parameters used for the assessment of the performance of natural flood management measures were:

(a) Flood peak reduction for different flood event return periods (e.g., 1, 2, 25, 50, or 100 years);

(b) Increase in time to flood peak;

(c) Decrease in annual probability of flood risk for the selected area.

Scale of measurement: Site to catchment scale

Required data: *In situ* runoff measurements

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: At the time of precipitation events and/or daily, monthly and yearly continuous monitoring before and after construction of the area and/or installation of NBS

Level of expertise required: Moderate

Connection to other indicators: Direct relationship to *Surface runoff in relation to precipitation quantity* indicator, and partial relationship to *Measured infiltration rate and capacity* and *Evapotranspiration rate* indicators

Connection to SDGs: SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities

Key References

Iacob, O., Rowan, J.S., Brown, I.M., & Ellis, C. (2014). Evaluating wider benefits of natural flood management strategies: An ecosystem-based adaptation perspective. *Hydrology Research*, *45*(6), 774-787.

12.3.9 Quantitative status of groundwater

Metric: *The degree to which a body of groundwater is affected by direct and indirect abstractions (good, poor)*

Strengths: *A comparable EU-wide applied assessment*

Weaknesses: *Requires arrangements on Member State-level*

Water covers ca. 71 % of the Earth's surface but only 2.5 % of it is fresh, stored as groundwater and in glaciers. Water is vital for living organisms, and it enables a multitude of human activities such as agriculture, manufacturing and transportation of goods. Available water resources are being extensively used for a variety of purposes, and ensuring that the water quality is monitored and the degraded water bodies are enhanced is essential for protecting the water resources. EU Water Framework Directive (2000/60/EC) sets forth the framework for integrated management of surface waters and groundwater resources in the EU Member States, which are presented as River Basin Management Plans.

The following procedure is based off the requirements set by the Water Framework Directive (2000/60/EC):

1. Define groundwater bodies within a river basin area
2. Establish type-specific reference conditions per Annex V
3. Identify significant anthropogenic pressures
4. Identify and estimate significant water abstractions for urban, agricultural, industrial and other uses, including seasonal variations and total annual demand
5. Identify and estimate loss of water in the distribution systems
6. Estimate recharge and artificial recharge of groundwater bodies
7. Estimate the effects caused by water regulation, flood protection and land drainage
8. Establish monitoring of quantitative status for groundwater:
    a. Groundwater level monitoring network
    b. Density of monitoring sites
    c. Frequency of monitoring
    d. Additional monitoring requirements for protected areas as listed under Annex IV
9. Present monitoring results as maps in accordance with Annex V

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

10. Interpret groundwater quantitative status per Annex V

Scale of measurement: River basin; Member State

Required data: Anthropogenic pressures on groundwater reserves; Water abstraction rates; Land-use; Water regulation activities; Water losses

Data generation specifications: Quantitative and qualitative; cannot be collected via participatory processes

Data generation/collection frequency: Frequency of monitoring for drinking water abstraction points:

Community served	Frequency
< 10 000	4 per year
10 000 – 30 000	8 per year
> 30 000	12 per year

Level of expertise required: Moderate to High

Connection to other indicators: Indicators forming parts of the Member States' River Basin Management Plans: *Quantitative status of groundwater, Chemical status of groundwater, Ecological status of surface waters, Biological status of surface waters, Hydromorphological status of surface waters, Physicochemical status of surface waters* and *Ecological potential for heavily modified or artificial water bodies*

Connection to SDGs: SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 12 Responsible consumption and production, SDG 13 Climate action

Key References

European Parliament. (2000). Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. http://data.europa.eu/eli/dir/2000/60/oj

European Parliament. (2006). Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration. http://data.europa.eu/eli/dir/2006/118/2014-07-11

European Commission. (2012). Report from the Commission to the European Parliament and the Council on the Implementation of the Water Framework Directive (2000/60/EC). River Basin Management Plans.

12.3.10Depth to groundwater

Metric: *Depth from land surface reference point to top of groundwater table (m)*

Strengths: *Straightforward and easy assessment of water table change over time*

Weaknesses: *Important to take repeated measurements over a long period of time to accurately evaluate changes in groundwater resource volume*

Measurement of depth to groundwater in a well is frequently performed to examine changes in the level of the water table.

One of the simplest ways to assess the depth from land surface to groundwater is to measure the water level in a shallow well using a chalked steel measuring tape. Blue carpenter's chalk is commonly used to mark the steel tape, which is lowered into the well until the end of the tape is wet. The level of the water will be indicated by the depth to which the chalk is wet and the colour changes from light blue to dark blue.

There are a number of different electronic water level metres marketed by different companies, any of which are suitable for routine monitoring of groundwater level in shallow wells or boreholes. These electronic instruments typically consist of a spool of dual conductor wire with a probe attached to the end and an indicator. As the probe is lowered into the well or borehole, a light or sound will indicate when the indicator comes into contact with water and the circuit is closed.

Regardless of the measurement technique employed, when measuring depth to groundwater the depth measurement should be made relative to an established reference point. This reference point is typically denoted by a permanent mark or notch on the well casing and is associated with a geodetic vertical datum established for surveying, e.g., the European Vertical Reference System or applicable local height datum.

Scale of measurement: Plot scale to street scale or greater, depending on surface topography and extent/connectivity of underlying aquifer(s)

Required data: Depth to the water table

Data generation specifications: Quantitative; participatory data collection is feasible through participation in the measurement procedure

Data generation/collection frequency: Annually

Level of expertise required: Low

Connection to other indicators: Direct relation to *Daily temperature range* indicator

Connection to SDGs: SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities

Key References

Hopkins, J. & Anderson, B. (2016). *A Field manual for Groundwater-level Monitoring at the Texas Water Development Board*. User Manual 52. Retrieved from http://www.twdb.texas.gov/groundwater/docs/UMs/UM-52.pdf

Snyder, D.T. (2008). *Estimated depth to Ground Water and Configuration of the Water Table in the Portland, Oregon Area*. Scientific Investigations Report 2008-5059. Reston, Virginia: United States Geological Survey. Retrieved from https://pubs.usgs.gov/sir/2008/5059/pdf/sir20085059.pdf

12.3.11 Water availability for irrigation purposes, including greywater and captured rainwater

Metric: *Volume of rainwater or greywater used for irrigation purposes (m^3/y or similar unit)*

Strengths: *Secure reserve of water for irrigation at times of drought. Use of automatic meter reading could be a good choice to communicate with stakeholders regarding the benefits of rainwater capture and use for irrigation*

Weaknesses: *Rainwater storage requires a substantial amount of external storage units. There are concerns about the potential for bacterial growth when nutrient-rich waste/greywater remains untreated for a period of time*

Rainwater and greywater have a potential to be reused for irrigation purposes if collected to a storage unit. This is especially prominent for areas exposed to drought.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Domestic wastewater consists of greywater, the wastewater discharged from hand basins, showers and baths, dishwashers, and laundry machines, and blackwater from toilets. Depending on local regulations, water from the kitchen sink be regarded as greywater or blackwater. One person generates 90–120 L greywater each day depending on lifestyle, living standard, age, gender, and other factors. Greywater comprises 50-80% of all domestic wastewater but contains a relatively small fraction of the total pollutant load (Antonopoulou, Kirkou, & Stasinakis, 2013; Donner et al., 2010; Li, Wichmann, & Otterpohl, 2009). Separation of domestic greywater from blackwater and on site re-use for toilet flushing or irrigation of non-edible vegetation provides an alternative water source in areas facing water shortage. On-site greywater re-use can reduce potable water use by as much as 50% (Gross, Shmueli, Ronen, & Raveh, 2007).

Accurate accounting of rainfall capture and use for irrigation requires use of a water level sensor to measure the volume of water contained within a given rainwater storage unit at any time. If the storage unit is completely sealed and the water level can be easily recorded each time it is opened (and again after water is discharged for use), it may be possible to manually record and calculate the volume of water captured and used for irrigation purposes.

An alternate solution is to equip the discharge point of the rainwater storage unit/tank with a water meter, and record the volume of water used over a specific period of time. This is well suited to applications with multiple water storage tanks and/or in situations where it may be challenging to accurately quantify water use manually. The water meter(s) may be connected to an automatic meter reading (AMR) device that enables remote communication of water usage between the water meter and a central point.

It is recommended that domestic greywater is filtered (e.g., sand and/or granular activated carbon filter and/or treatment in vertical subsurface-flow wetland or reed bed, etc.) prior to use for irrigation of non-edible vegetation such as landscaping.

Scale of measurement: Plot scale to street scale

Required data: Volume of rainwater and greywater used for irrigation purposes

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually

Level of expertise required: Low

Connection to other indicators: Related to *Monthly maximum value of daily maximum temperature, Quantitative status of groundwater* and *Depth to groundwater* indicators

Connection to SDGs: SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities

Key References

Antonopoulou, G., Kirkou, A. & Stasinakis, A.S. (2013). Quantitative and qualitative greywater characterization in Greek households and investigation of their treatment using physicochemical methods. *Science of the Total Environment, 454-455*, 426-432.

Donner, E., Eriksson, E., Revitt, D.M., Scholes, L., Holten Lützhøft, H.-C. & Ledin, A. (2010). Presence and fate of priority substances in domestic greywater treatment and reuse systems. *Science of the Total Environment, 408*(12), 2444-2451.

Gross, A., Shmueli, O., Ronen, Z., & Raveh, E. (2007). Recycled vertical flow constructed wetland (RVFCW)-a novel method of recycling greywater for irrigation in small communities and households. *Chemosphere, 66*(5), 916-623.

Li, Y., Wichmann, K., & Otterpohl, R. (2009). Review of the technological approaches for grey water treatment and reuses. *Science of the Total Environment, 407*(11), 3439-3449.

12.3.12Water Exploitation Index

Metric: *Annual total water abstraction as a proportion (%) of available long-term freshwater resources in the geographically relevant area (basin) from which the municipality obtains its water*

Strengths: *European Environment Agency (EEA) uses the WEI to evaluate water scarcity across major river basins in Europe with time*

Weaknesses: *Requires substantial amount of external information and data sources*

The Water Exploitation Index (WEI) compares the volume of water consumed each year to the available freshwater resources. More specifically, the WEI presents total annual freshwater extraction as a proportion (%) of the long-term annual average freshwater available from renewable resources. The WEI warning threshold of 20 % distinguishes a water-stressed area from one not suffering water scarcity. Severe scarcity is defined as WEI > 40%.

The WEI is calculated as follows (European Environment Agency [EEA], 2018):

$$WEI = \left(\frac{Volume\ of\ water\ abstraction}{Volume\ of\ renewable\ freshwater\ resources}\right) \times 100$$

An advanced version of the WEI, called the WEI+, accounts for recharge of available freshwater supplies, or water return (EEA, 2018a):

$$WEI+ = \left(\frac{Volume\ of\ water\ abstraction - Volume\ of\ water\ returns}{Volume\ of\ renewable\ freshwater\ resources}\right) \times 100$$

The volume of long-term renewable freshwater resources in a natural or semi-natural geographically relevant area (e.g., basin or sub-basin) is calculated as (EEA, 2018):

$$Long\ term\ renewable\ freshwater\ resources = E_{xIn} + P - ET_a - \Delta S$$

where E_{xIn} = external inflow, P = precipitation, ET_a = actual evapotranspiration and ΔS = change in storage (lakes and reservoirs).

The equation for renewable freshwater resources can be simplified as follows for highly-modified (i.e., not natural or semi-natural) river basins or sub-basins (EEA, 2018):

$$Long\ term\ renewable\ freshwater\ resources = outflow + (abstraction - return) - \Delta S$$

where outflow = downstream flow or discharge to sea and ΔS = change in storage (lakes and reservoirs).

Scale of measurement: Basin scale

Required data: Necessary information about annual volumes of water abstraction (groundwater, surface water) from a given basin or sub-basin can be obtained from records of water supply companies and city documents relating to water abstraction permits. Wastewater treatment companies, water supply companies and municipal environment/environmental management departments are sources of information related to annual volumes of water returns. Information about long-term renewable water resources can be obtained from local water boards, municipal departments and/or national environment agencies.

Data generation specifications: Quantitative; cannot be collected via participatory processes

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Data generation/collection frequency: Annually

Level of expertise required: Moderate

Connection to other indicators: Not identified

Connection to SDGs: SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 13 Climate action

Key References

European Environment Agency (EEA). (2018). *Use of freshwater resources.* Copenhagen: European Environment Agency. Retrieved from https://www.eea.europa.eu/data-and-maps/indicators/use-of-freshwater-resources-2/assessment-3

12.3.13Total surface area of wetlands within a defined area

Metric: *Total surface area covered with wetlands within a defined area (ha)*

Strengths: *Straightforward assessment of the surface area occupied by wetlands*

Weaknesses: *Requires access to local records or international/local spatial datasets*

Wetlands are unique ecosystems that occur in places where the water table is close to the ground level, or where land is covered by water, either seasonally or permanently. Convention on Wetlands (Ramsar, Iran, 1971), or Ramsar Convention, defines wetlands as *"… a wide variety of inland habitats such as marshes, peatlands, floodplains, rivers and lakes, and coastal areas such as saltmarshes, mangroves, intertidal mudflats and seagrass beds, and also coral reefs and other marine areas no deeper than six metres at low tide."* Conservation and restoration of wetlands is regarded as one of the critical factors for establishing climate adaptation as part of the disaster risk reduction. Wetlands provide resilience against water-related hazards such as floods, storm surges and droughts by capturing and holding water and gradually releasing it. Peatlands enhance climate resilience by storing carbon.

The extent of the surface area covered by wetlands can be assessed using the land-use raster data (local or EU-wide, e.g., Corine Land Cover or Urban Atlas) in GIS software that allows to examine the total area. Satellite imagery may be used for visual assessment and manual surface area calculation.

Scale of measurement: City; municipality

Required data: Land-use raster of the area of interest; local records; satellite imagery

Data generation specifications: Quantitative; participatory data collection can be implemented among local people; another opportunity is community involvement in wetland management

Data generation/collection frequency: Annually

Level of expertise required: Moderate – requires knowledge of GIS software; Low – when assessing visually using satellite images

Connection to other indicators: Direct relation to *Water management* and *Biodiversity* challenge categories

Connection to SDGs: SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land

Key References

Kumar, R., Tol, S., McInnes, R.J., Everard, M. and Kulindwa, A.A.. *Wetlands for disaster risk reduction: Effective choices for resilient communities*. Ramsar Policy Brief, (1). Gland, Switzerland: Ramsar Convention Secretariat, 2017.

Ramsar Convention Secretariat. *Managing wetlands: Frameworks for managing Wetlands of International Importance and other wetland sites*. Ramsar handbooks for the wise use of wetlands, 4th edition, vol. 18. Ramsar Convention Secretariat, Gland, Switzerland, 2010.

Ramsar Convention Secretariat. *Participatory skills: Establishing and strengthening local communities' and indigenous people's participation in the management of wetlands*. Ramsar handbooks for the wise use of wetlands, 4th edition, vol. 7. Ramsar Convention Secretariat, Gland, Switzerland, 2010.

Renaud, F.G., Sudmeier-Rieux, K. and Estrella, M. (eds.). *The Role of Ecosystems in Disaster Risk Reduction*. Tokyo: United Nations University Press, 2013.

Renaud, F.G., Sudmeier-Rieux, K., Estrella, M. and Nehren, U. (eds.). *Ecosystem-Based Disaster Risk Reduction and Adaptation in Practice*. In Advances in natural and technological hazards research. Switzerland: Springer International Publishing, 2016, pp.598

12.3.14Total surface area or restored and/or created wetlands within a defined area

Metric: Surface area of constructed and/or restored wetlands within a defined area (ha)

Strengths: *Straightforward assessment of the surface area occupied by constructed and/or* restored *wetlands*

Weaknesses: *Requires access to local records or international/local spatial datasets*

Wetlands are unique ecosystems that occur in places where the water table is close to the ground level, or where land is covered by water, either seasonally or permanently. Convention on Wetlands (Ramsar, Iran, 1971), or Ramsar Convention, defines wetlands as "… a wide variety of inland habitats such as marshes, peatlands, floodplains, rivers and lakes, and coastal areas such as saltmarshes, mangroves, intertidal mudflats and seagrass beds, and also coral reefs and other marine areas no deeper than six metres at low tide." Conservation and restoration of wetlands is regarded as one of the critical factors for establishing climate adaptation as part of the disaster risk reduction. Wetlands provide resilience against water-related hazards such as floods, storm surges and droughts by capturing and holding water and gradually releasing it. Peatlands enhance climate resilience by storing carbon.

The extent of the surface area covered by constructed and/or restored wetlands can be assessed using the land-use raster data (local or EU-wide, e.g., Corine Land Cover or Urban Atlas) in GIS software that allows to examine the total area. Satellite imagery may be used for visual assessment and manual area calculation.

Scale of measurement: City; municipality

Required data: Land-use raster of the area of interest; local records; satellite imagery

Data generation specifications: Quantitative; participatory data collection can be implemented among local people; another opportunity is community involvement in wetland management

Data generation/collection frequency: Annually

Level of expertise required: Moderate – requires knowledge of GIS software; Low – when assessing visually using satellite images

Connection to other indicators: Direct relation to *Water management* and *Biodiversity* challenge categories

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Connection to SDGs: SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land

Key References

Kumar, R., Tol, S., McInnes, R.J., Everard, M. and Kulindwa, A.A.. *Wetlands for disaster risk reduction: Effective choices for resilient communities*. Ramsar Policy Brief, (1). Gland, Switzerland: Ramsar Convention Secretariat, 2017.

Ramsar Convention Secretariat. *Managing wetlands: Frameworks for managing Wetlands of International Importance and other wetland sites*. Ramsar handbooks for the wise use of wetlands, 4th edition, vol. 18. Ramsar Convention Secretariat, Gland, Switzerland, 2010.

Ramsar Convention Secretariat. *Participatory skills: Establishing and strengthening local communities' and indigenous people's participation in the management of wetlands*. Ramsar handbooks for the wise use of wetlands, 4th edition, vol. 7. Ramsar Convention Secretariat, Gland, Switzerland, 2010.

Renaud, F.G., Sudmeier-Rieux, K. and Estrella, M. (eds.). *The Role of Ecosystems in Disaster Risk Reduction*. Tokyo: United Nations University Press, 2013.

Renaud, F.G., Sudmeier-Rieux, K., Estrella, M. and Nehren, U. (eds*.). Ecosystem-Based Disaster Risk Reduction and Adaptation in Practice*. In Advances in natural and technological hazards research. Switzerland: Springer International Publishing, 2016, pp.598

12.3.15pH, electrical conductivity and dissolved oxygen content of NBS effluents

Metric:

a) *pH: a measure of the relative acidity or alkalinity of a solution (0–14 pH units)*
b) *Electrical Conductivity: is a measure of a solution to conduct electricity (µS/cm or S/m). It reflects a water's dissolved (ionisable) mineral salt content*
c) *Dissolved oxygen (DO) and Temperature: Concentration of oxygen dissolved in water (mg/L or % O_2 saturation). The significance of DO content of natural waters is the requirement for sufficient oxygen to support aquatic life*
d) *Flow rate: Flow of water in a stream or natural channel*

Strengths: *Most of the indicators are easy to measure. Most of the measuring equipment are inexpensive*

Weaknesses: *Some indicators can be measured only with expert users*

Water quality can profoundly impact both aquatic and terrestrial ecosystems. Changes to the quality of water may occur due to many different factors, including human activities. It is therefore important to monitor water quality in environments likely to be affected by anthropogenic activity, or in particularly sensitive aquatic ecosystems. Basic water quality parameters include pH, temperature, electrical conductivity (EC), dissolved oxygen (DO) content and flow rate.

pH

The pH is considered a 'master variable' as the pH, together with oxidative-reductive potential, determines the chemical speciation, behaviour and fate of (bio)chemical compounds in the environment. The pH range of natural waters varies from ca. 4.5 in peat-influenced waters to as high as 10.0 in systems influenced by intense algal photosynthetic activity. The typical pH range of natural waters is 6.5-8.0.

Measuring of the pH is simple and is usually done using either a colorimetric method (visual or electronic) or electronic meters. Steps in the determination of pH include:

- Checking the equipment. Some of the following equipment should be used:

- pH colorimeter field kit
- pH meter with built-in temperature sensor, or
- colorimeter with reagents

- Measuring the pH values
    - In the colorimetric method (both visual and electronic), indicators that change colour according to the pH of the solution are used. With colorimetric kits, chemical or two (reagents) are added to the water sample, and the resulting colour is compared to the colour standards of known pH values
    - With the calibrated pH meter, the electrode is placed in the water and the pH is recorded

The recommended method of pH measurement is electrometry/use of a pH electrode.

Electrical conductivity

Electrical conductivity (EC) is measured using an EC meter. The electric current is applied between the two electrodes, and the probe detects the conductivity.

Conductivity is reported at 25 °C as temperature is proportional to the conductivity levels.

In the aqueous solutions, the electrical conductivity is influenced by the presence of inorganic dissolved solids, each ion carrying an electrical charge. Typically, the distilled water has very low conductivity (ca. 0.05 µS/cm), whereas seawater has considerably higher values (ca. 50 000 µS/cm). Generally, natural waters have stable conductivity levels, and the increase in electrical conductivity usually implies the disturbance associated, for example, with the urban runoff, which can contain elevated concentration of salts and other ions.

The EC (in µS/cm) provides a rough approximation of the total dissolved solids (TDS, in mg/L) content, via the equation:

$$Conductivity \times \frac{2}{3} = Total\ dissolved\ solids$$

Dissolved Oxygen (DO) and Temperature

Dissolved oxygen content (DO) is traditionally measured in the laboratory using a Winkler method. For the Winkler method, water samples are collected overflowing in the sample bottles to minimize the air interference, and then using a set of reagents the oxygen is "fixed". The reagents include:

- 2 ml Manganese sulfate
- 2 ml alkali-iodide-azide
- 2 ml concentrated sulfuric acid
- 2 ml starch solution
- Sodium thiosulfate

After that, the sample is titrated until reaching the endpoint (i.e., colour change). The endpoint determines the concentration of the DO in the water sample, which is equivalent to the number of millilitres of titrant used.

An alternative and less chemical-intensive method is measuring the DO content using a DO meter and a probe that require calibration according to the manufacturer's instructions.

The DO content of water is inversely related to temperature, with decreasing O_2 solubility in water as temperature increases. DO and temperature should always be measured together to ensure accuracy. Many DO meters have an in-built temperature probe and will display DO content in mg/L as well as the per cent (%) O_2 saturation, along with the measured water

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

temperature (in °C). Excessive nutrient (N and P) load to the water bodies results in depleted DO concentrations and degradation of watercourses.

Flow rate

The most common approach to continuous streamflow monitoring involves installation of a stilling well in or near the stream where an intake pipe maintains the water level within the stilling well at the same elevation as the stream.

Discharge can be calculated by multiplying the area of the channel at the selected point in the stream (cross-sectional area) by current velocity. First, the area of the channel is calculated based on manual measurements, typically using cable or steel measuring tape and a wading rod in shallow streams and suspended sounding weights in deeper waters. A current meter is then used to measure stream velocity. Alternately, an acoustic Doppler current profiler can be used to measure water depth and velocity at the same time. When the acoustic Doppler profiler or current meter are not available, floats or volumetric measurements provide an accessible but less accurate method for measuring velocity.

A stage-discharge relationship unique to a given stream can be generated by logarithmic plotting stream stage (in m, y-axis) as a function of stream discharge (in m^3/s, x-axis). This stage-discharge relationship can then be used to calculate the flow rate (discharge, in m3/s) at any measured stream height (stage), or extrapolate the ratings.

Scale of measurement: Plot scale

Required data: pH, electrical conductivity, dissolved oxygen, temperature or flow rate (stream cross-sectional area and velocity) measurement data

Data generation specifications: Quantitative; participatory data collection is possible for pH, electrical conductivity, and dissolved oxygen and temperature measurements under supervision

Data generation/collection frequency: Daily, weekly, monthly or annually

Level of expertise required: Low to moderate

Connection to other indicators: Synergies with the indicator forming the *Water quality* sub-category

Connection to SDGs: SDG 13 Climate action, SDG 14 Life below water

Key References

A number of standard methodologies for water testing are available from, e.g., the International Organization for Standardization (ISO), American Public Health Association (APHA), the European Environment Agency (EEA), and others.

12.3.16Physicochemical quality of surface waters

Metric: *Physicochemical quality of surface waters – rivers, lakes, transitional waters and coastal waters (rated high, good, moderate, poor, bad)*

Strengths: *A comparable EU-wide applied assessment*

Weaknesses: *Requires arrangements on Member State-level*

Water covers ca. 71 % of the Earth's surface but only 2.5 % of it is fresh, stored as groundwater and in glaciers. Water is vital for living organisms, and it enables a multitude of human activities such as agriculture, manufacturing and transportation of goods. Available water resources are being extensively used for a variety of purposes, and ensuring that the water quality is monitored and the degraded water bodies are enhanced is essential for protecting the water resources. EU Water Framework Directive (2000/60/EC) sets forth the framework for integrated management of surface waters and groundwater resources in the EU Member States, which are presented as River Basin Management Plans.

The following procedure is based off the requirements set by the Water Framework Directive (2000/60/EC):

1. Characterise water bodies within a river basin area per Annex II:
    a. Rivers, lakes, transitional waters or coastal waters — or artificial surface water bodies or heavily modified surface water bodies
2. Establish type-specific physicochemical reference conditions per Annex V
3. Identify significant anthropogenic pressures, and estimate point and diffuse source pollution in particular by substances listed under Annex VIII:
    a. Organohalogen compounds and substances which may form such compounds in the aquatic environment
    b. Organophosphorous compounds
    c. Organotin compounds
    d. Substances and preparations, or the breakdown products of such, which have been proved to possess carcinogenic or mutagenic properties or properties which may affect steroidogenic, thyroid, reproduction or other endocrine related functions in or via the aquatic environment
    e. Persistent hydrocarbons and persistent and bioaccumulable organic toxic substances
    f. Cyanides
    g. Metals and their compounds
    h. Arsenic and its compounds
    i. Biocides and plant protection products
    j. Materials in suspension
    k. Substances which contribute to eutrophication (in particular, nitrates and phosphates)
    l. Substances which have an unfavourable influence on the oxygen balance (and can be measured using parameters such as BOD, COD, etc.)
4. Establish monitoring of physicochemical status for surface waters:
    a. Design of surveillance, operational and/or investigative monitoring per Annex V
    b. Frequency of monitoring
    c. Additional monitoring requirements for protected areas as listed under Annex IV
5. Present monitoring results as maps in accordance with Annex V
6. Classify physicochemical status of surface waters per Annex V

Scale of measurement: River basin; Member State

Required data: Reference conditions; Anthropogenic pressures, Point and diffuse pollution sources

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency:

Frequency for surveillance monitoring period:

Quality element	Rivers	Lakes	Transitional	Coastal

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Thermal conditions	3 months	3 months	3 months	3 months
Oxygenation	3 months	3 months	3 months	3 months
Salinity	3 months	3 months	3 months	
Nutrient status	3 months	3 months	3 months	3 months
Acidification status	3 months	3 months		
Other pollutants	3 months	3 months	3 months	3 months
Priority substances	1 month	1 month	1 month	1 month

For operational monitoring, the frequency of monitoring required for any parameter shall be determined by Member States so as to provide sufficient data for a reliable assessment of the status of the relevant quality element. As a guideline, monitoring should take place at intervals not exceeding those indicated for surveillance monitoring.

Level of expertise required: Moderate to High

Connection to other indicators: Indicators forming parts of the Member States' River Basin Management Plans: *Quantitative status of groundwater, Chemical status of groundwater, Ecological status of surface waters, Biological status of surface waters, Hydromorphological status of surface waters, Physicochemical status of surface waters* and *Ecological potential for heavily modified or artificial water bodies*

Connection to SDGs: SDG 3 Good health and well-being, SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 12 Responsible consumption and production, SDG 13 Climate action, SDG 14 Life below water

Key References

European Parliament. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. 2010. http://data.europa.eu/eli/dir/2000/60/oj

European Commission. Report from the Commission to the European Parliament and the Council on the Implementation of the Water Framework Directive (2000/60/EC). River Basin Management Plans. European Commission, 2012.

12.3.17Total pollutant discharge to local waterbodies

Metric: *Water quality status according to Water Framework Directive as determined by pollutant discharge monitoring*

Strengths: *Persistent quality monitoring of the receiving waterbody is a good way of following the environmental impacts of the pollutant discharges of urban communities, but they depend heavily on the condition and size of the receiving waterbody and the whole catchment area*

Weaknesses: *Selecting proper sampling procedures as well as measured variables to capture a representative figure of the pollution discharge loading is challenging*

In the EU, all waterbodies are classified by quality status based on guidelines set in the Water Framework Directive (WFD), Directive 2000/60/EC (European Parliament, Council of the European Union, 2000). The WFD outlines biological, physico-chemical and hydromorphological quality elements. Comparison of measured water quality parameters for a given waterbody with standard values outlined in the WFD allows classification of the status of a waterbody from high to bad. Parameters taken into account include a large number of variables including, e.g., plankton counts, aquatic flora, invertebrates, hydrological continuity and conditions, thermal conditions, oxygen conditions, salinity, nutrient conditions and prevalence of priority pollutants and other specific pollutants. Many of these parameters are waterbody specific and the determination of stress caused by a pollution source depends on the type and size of the waterbody (European Parliament, Council of the European Union, 2000).

Pollutant discharge is estimated by taking samples from urban runoff from the target area and comparing the time series of the selected parameters. First, sampling sites are selected to represent the catchment urban area in question as comprehensively as possible. Ideally, sampling sites can be streams, ditches or runoff sewers collecting from a large catchment area in the urban area of interest, but not yet mixing with a larger waterbody. A sampling schedule is determined and followed. Ideally, continuous automatic aggregate samplers are used with flowmeters, providing the most reliable estimates of parameter yearly aggregates. Alternate sampling method is systematic sampling in which samples are taken with identical time steps (e.g., every 2 months) regardless of conditions, like rainfall, traffic or temperature. All non-continuous sampling procedures inflict bias into results, and will only capture a fraction of the actual runoff quality, which makes results invariably noisy.

On-site measurements, sampling and laboratory analysis are to be performed by personnel and in premises with experience in water sampling and analysis using standardized methods, chemicals and equipment. For technical details, please refer to standard methods or equivalent methods available at the laboratory performing the analysis.

As the details of each urban environment and NBS can differ substantially, and as parameters described here are often only indicative of water quality, potential change in pollution discharge is presented in a Likert-type scale:

1	Several of the parameters indicate significantly worse water quality, or more than half of the parameters indicate somewhat worse water quality
2	One of the parameters indicate significantly worse water quality, or some of the parameters indicate somewhat worse water quality
3	The parameters indicate no change in the water quality
4	One of the parameters indicate significantly better water quality, or some of the parameters indicate somewhat better water quality
5	Several of the parameters indicate significantly better water quality, or more than half of the parameters indicate somewhat better water quality

Scale of measurement: District scale

Required data: Measurement data of the parameters

Data generation specifications: Qualitative and quantitative; participatory data collection possible under supervision

Data generation/collection frequency: Daily, weekly, monthly or annually

Level of expertise required: Low to High

Connection to other indicators: Synergies with the other water quality indicators in the *Water management* indicator group

Connection to SDGs: SDG 13 Climate action, SDG 14 Life below water

Key References

Allen Burton, G., Jr., & Pitt, R.E. (2010). Stormwater Effects Handbook. A Toolbox for watershed Managers, Scientists, and Engineers. Boca Raton, FL: Lewis Publishers, CRC Press.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

European Parliament, Council of the European Union. (2000). EU Water Framework Directive: Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy. Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02000L0060-20140101

United States Environmental Protection Agency (US EPA). (2017). Water Quality Standards Handbook: Chapter 3: Water Quality Criteria. EPA-823-B-17-001. Washington, D.C.: EPA Office of Water, Office of Science and Technology. Retrieved from https://www.epa.gov/sites/production/files/2014-10/documents/handbook-chapter3.pdf

Zumdahl, S.S., & DeCoste, D.J. (2012). Chemical Principles. Seventh Edition. Boston, MA: Cengage Learning.

12.3.18Groundwater chemical status

Metric: *Chemical status of groundwater bodies (high, good, moderate, poor, bad)*

Strengths: *A comparable EU-wide applied assessment*

Weaknesses: *Requires arrangements on Member State-level*

Water covers ca. 71 % of the Earth's surface but only 2.5 % of it is fresh, stored as groundwater and in glaciers. Water is vital for living organisms, and it enables a multitude of human activities such as agriculture, manufacturing and transportation of goods. Available water resources are being extensively used for a variety of purposes, and ensuring that the water quality is monitored and the degraded water bodies are enhanced is essential for protecting the water resources. EU Water Framework Directive (2000/60/EC) sets forth the framework for integrated management of surface waters and groundwater resources in the EU Member States, which are presented as River Basin Management Plans. The Groundwater Directive (2006/118/EC) complements the Water Framework Directive and sets the groundwater quality standards.

The following procedure is based off requirements set by the Water Framework Directive (2000/60/EC) and Groundwater Directive (2006/118/EC):

1. Define groundwater bodies within a river basin area
2. Establish type-specific reference conditions per Annex V (Directive 2000/60/EC)
3. Identify significant anthropogenic pressures, and estimate point and diffuse source pollution in particular by substances listed under Annex VIII (Directive 2000/60/EC):
    a. Organohalogen compounds and substances which may form such compounds in the aquatic environment
    b. Organophosphorous compounds
    c. Organotin compounds
    d. Substances and preparations, or the breakdown products of such, which have been proved to possess carcinogenic or mutagenic properties or properties which may affect steroidogenic, thyroid, reproduction or other endocrine related functions in or via the aquatic environment
    e. Persistent hydrocarbons and persistent and bioaccumulable organic toxic substances
    f. Cyanides
    g. Metals and their compounds
    h. Arsenic and its compounds
    i. Biocides and plant protection products
    j. Materials in suspension
    k. Substances which contribute to eutrophication (in particular, nitrates and phosphates)

    l. Substances which have an unfavourable influence on the oxygen balance (and can be measured using parameters such as BOD, COD, etc.)
4. Establish relevant threshold values in accordance to Article 3 and Annex II (Directive 2006/118/EC) minimum for:
    a. Substances or ions or indicators which may occur both naturally and/or as a result of human activities
        i. Arsenic
        ii. Cadmium
        iii. Lead
        iv. Mercury
        v. Ammonium
        vi. Chloride
        vii. Sulphate
        viii. Nitrites
        ix. Phosphorus (total)/Phosphates
    b. Man-made synthetic substances
        i. Trichloroethylene
        ii. Tetrachloroethylene
    c. Parameters indicative of saline or other intrusions
        i. Conductivity
5. Establish monitoring of chemical status for groundwater:
    a. Groundwater monitoring network
    b. Establish surveillance and operational monitoring per Annex V (Directive 2000/60/EC)
    c. Set of core monitoring parameters:
        i. Oxygen content
        ii. pH value
        iii. Conductivity
        iv. Nitrate
        v. Ammonium
    d. Frequency of monitoring
    e. Additional monitoring requirements for protected areas as listed under Annex IV (Directive 2000/60/EC)
6. Present monitoring results as maps in accordance with Annex V (Directive 2000/60/EC)
7. Interpret chemical status of groundwater per Annex V (Directive 2000/60/EC)

Scale of measurement: River basin; Member State

Required data: Reference conditions; Point and diffuse pollution sources

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Frequency of monitoring for drinking water abstraction points:

Community served	Frequency
< 10 000	4 per year
10 000 – 30 000	8 per year
> 30 000	12 per year

Level of expertise required: Moderate to High

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Connection to other indicators: Indicators forming parts of the Member States' River Basin Management Plans: *Quantitative status of groundwater, Chemical status of groundwater, Ecological status of surface waters, Biological status of surface waters, Hydromorphological status of surface waters, Physicochemical status of surface waters* and *Ecological potential for heavily modified or artificial water bodies*

Connection to SDGs: SDG 3 Good health and well-being, SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 12 Responsible consumption and production, SDG 13 Climate action

Key References

European Parliament. (2000). *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy.* http://data.europa.eu/eli/dir/2000/60/oj

European Parliament. (2006). *Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration*. http://data.europa.eu/eli/dir/2006/118/2014-07-11

European Commission. (2012). *Report from the Commission to the European Parliament and the Council on the Implementation of the Water Framework Directive (2000/60/EC). River Basin Management Plans*. Brussels.

12.3.19 General ecological status of surface waters

Metric: *General ecological status of surface waters applicable to rivers, lakes, transitional waters and coastal waters (rated high, good, moderate, poor, bad)*

Strengths: *A comparable EU-wide applied assessment*

Weaknesses: *Requires arrangements on Member State-level*

Water covers ca. 71 % of the Earth's surface but only 2.5 % of it is fresh, stored as groundwater and in glaciers. Water is vital for living organisms, and it enables a multitude of human activities such as agriculture, manufacturing and transportation of goods. Available water resources are being extensively used for a variety of purposes, and ensuring that the water quality is monitored and the degraded water bodies are enhanced is essential for protecting the water resources. EU Water Framework Directive (2000/60/EC) sets forth the framework for integrated management of surface waters and groundwater resources in the EU Member States, which are presented as River Basin Management Plans.

The following procedure is based off the requirements set by the Water Framework Directive (2000/60/EC):

1. Characterise water bodies within a river basin area per Annex II:
    a. Rivers, lakes, transitional waters or coastal waters — or artificial surface water bodies or heavily modified surface water bodies
2. Establish type-specific ecological reference conditions per Annex V
3. Identify significant anthropogenic pressures, and estimate point and diffuse source pollution in particular by substances listed under Annex VIII:
    a. Organohalogen compounds and substances which may form such compounds in the aquatic environment
    b. Organophosphorous compounds
    c. Organotin compounds
    d. Substances and preparations, or the breakdown products of such, which have been proved to possess carcinogenic or mutagenic properties or properties which

may affect steroidogenic, thyroid, reproduction or other endocrine related functions in or via the aquatic environment
   e. Persistent hydrocarbons and persistent and bioaccumulable organic toxic substances
   f. Cyanides
   g. Metals and their compounds
   h. Arsenic and its compounds
   i. Biocides and plant protection products
   j. Materials in suspension
   k. Substances which contribute to eutrophication (in particular, nitrates and phosphates)
   l. Substances which have an unfavourable influence on the oxygen balance (and can be measured using parameters such as BOD, COD, etc.)
4. Establish monitoring of ecological status for surface waters (The monitoring network shall be designed so as to provide a coherent and comprehensive overview of ecological and chemical status within each river basin and shall permit classification of water bodies into five classes consistent with the normative definitions):
   a. Design of surveillance, operational and/or investigative monitoring per Annex V
   b. Frequency of monitoring
   c. Additional monitoring requirements for protected areas as listed under Annex IV
5. Present monitoring results as maps in accordance with Annex V
6. Consider quality elements for classifying the ecological status per Annex V:
   a. Biological elements
   b. Chemical and physicochemical elements
   c. Hydromorphological elements
   d. Specific pollutants
   e. Classify ecological status of surface waters (separate for rivers, lakes, transitional waters and coastal waters) per Annex V

Scale of measurement: River basin; Member State

Required data: Biological, physicochemical, hydromorphological quality of surface waters

Data generation specifications: Quantitative and qualitative; cannot be collected via participatory processes

Data generation/collection frequency: Different frequencies for biological, physicochemical, hydromorphological and other quality elements determined by Member States so as to provide sufficient data for a reliable assessment of the status of the relevant quality element.

Level of expertise required: Moderate to High

Connection to other indicators: Indicators forming parts of the Member States' River Basin Management Plans: *Quantitative status of groundwater, Chemical status of groundwater, Ecological status of surface waters, Biological status of surface waters, Hydromorphological status of surface waters, Physicochemical status of surface waters* and *Ecological potential for heavily modified or artificial water bodies*

Connection to SDGs: SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 12 Responsible consumption and production, SDG 13 Climate action, SDG 14 Life below water

Key References

European Parliament. (2000). *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy.* http://data.europa.eu/eli/dir/2000/60/oj

European Parliament. (2006). *Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration*. http://data.europa.eu/eli/dir/2006/118/2014-07-11

European Commission. (2012). *Report from the Commission to the European Parliament and the Council on the Implementation of the Water Framework Directive (2000/60/EC). River Basin Management Plans*. Brussels.

12.3.20Ecological potential for heavily modified or artificial water bodies

Metric: *Ecological potential for heavily modified or artificial water bodies (maximum, good, moderate, poor, bad)*

Strengths: *A comparable EU-wide applied assessment*

Weaknesses: *Requires arrangements on Member State-level*

Water covers ca. 71 % of the Earth's surface but only 2.5 % of it is fresh, stored as groundwater and in glaciers. Water is vital for living organisms, and it enables a multitude of human activities such as agriculture, manufacturing and transportation of goods. Available water resources are being extensively used for a variety of purposes, and ensuring that the water quality is monitored and the degraded water bodies are enhanced is essential for protecting the water resources. EU Water Framework Directive (2000/60/EC) sets forth the framework for integrated management of surface waters and groundwater resources in the EU Member States, which are presented as River Basin Management Plans.

The following procedure is based off the requirements set by the Water Framework Directive (2000/60/EC):

1. Characterise water bodies within a river basin area per Annex II:
    a. Rivers, lakes, transitional waters or coastal waters — or artificial surface water bodies or heavily modified surface water bodies
2. Establish type-specific reference conditions per Annex V
3. Identify significant anthropogenic pressures, and estimate point and diffuse source pollution in particular by substances listed under Annex VIII:
    a. Organohalogen compounds and substances which may form such compounds in the aquatic environment
    b. Organophosphorous compounds
    c. Organotin compounds
    d. Substances and preparations, or the breakdown products of such, which have been proved to possess carcinogenic or mutagenic properties or properties which may affect steroidogenic, thyroid, reproduction or other endocrine related functions in or via the aquatic environment
    e. Persistent hydrocarbons and persistent and bioaccumulable organic toxic substances
    f. Cyanides
    g. Metals and their compounds
    h. Arsenic and its compounds
    i. Biocides and plant protection products
    j. Materials in suspension
    k. Substances which contribute to eutrophication (in particular, nitrates and phosphates)

   l. Substances which have an unfavourable influence on the oxygen balance (and can be measured using parameters such as BOD, COD, etc.)
4. Establish monitoring of ecological potential for heavily modified or artificial water bodies:
   a. Design of surveillance, operational and/or investigative monitoring per Annex V
   b. Frequency of monitoring
5. Consider quality elements for classifying the ecological potential for heavily modified or artificial water bodies per Annex V:
   a. General conditions
   b. Biological quality elements
   c. Chemical and physicochemical elements
   d. Hydromorphological elements
   e. Specific synthetic pollutants
   f. Specific non-synthetic pollutants
6. The quality elements applicable to artificial and heavily modified surface water bodies shall be those applicable to whichever of the four natural surface water categories (rivers, lakes, transitional waters or coastal waters) most closely resembles the heavily modified or artificial water body concerned.
7. Present monitoring results as maps in accordance with Annex V
8. Classify ecological potential for heavily modified or artificial water bodies per Annex V

Scale of measurement: River basin; Member State

Required data: Reference conditions; Anthropogenic pressures; General, biological, physicochemical, hydromorphological quality of heavily modified or artificial water bodies

Data generation specifications: Quantitative and qualitative; cannot be collected via participatory processes

Data generation/collection frequency: Different frequencies for biological, physicochemical, hydromorphological and other quality elements determined by Member States so as to provide sufficient data for a reliable assessment of the status of the relevant quality element.

Level of expertise required: Moderate to High

Connection to other indicators: Indicators forming parts of the Member States' River Basin Management Plans: *Quantitative status of groundwater, Chemical status of groundwater, Ecological status of surface waters, Biological status of surface waters, Hydromorphological status of surface waters, Physicochemical status of surface waters* and *Ecological potential for heavily modified or artificial water bodies*

Connection to SDGs: SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 12 Responsible consumption and production, SDG 13 Climate action, SDG 14 Life below water

Key References

European Parliament. (2000). *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy.* http://data.europa.eu/eli/dir/2000/60/oj

European Commission. (2012). *Report from the Commission to the European Parliament and the Council on the Implementation of the Water Framework Directive (2000/60/EC). River Basin Management Plans*. Brussels.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

12.3.21 Biological quality of surface waters

Metric: *Biological quality of surface waters - rivers, lakes, transitional waters and coastal waters (rated high, good, moderate, poor, bad)*

Strengths: *A comparable EU-wide applied assessment*

Weaknesses: *Requires arrangements on Member State-level*

Water covers ca. 71 % of the Earth's surface but only 2.5 % of it is fresh, stored as groundwater and in glaciers. Water is vital for living organisms, and it enables a multitude of human activities such as agriculture, manufacturing and transportation of goods. Available water resources are being extensively used for a variety of purposes, and ensuring that the water quality is monitored and the degraded water bodies are enhanced is essential for protecting the water resources. EU Water Framework Directive (2000/60/EC) sets forth the framework for integrated management of surface waters and groundwater resources in the EU Member States, which are presented as River Basin Management Plans.

The following procedure is based off the requirements set by the Water Framework Directive (2000/60/EC):

1. Characterise water bodies within a river basin area per Annex II:
    a. Rivers, lakes, transitional waters or coastal waters — or artificial surface water bodies or heavily modified surface water bodies
2. Establish type-specific biological reference conditions per Annex V
3. Identify significant anthropogenic pressures, and estimate point and diffuse source pollution in particular by substances listed under Annex VIII:
    a. Organohalogen compounds and substances which may form such compounds in the aquatic environment
    b. Organophosphorous compounds
    c. Organotin compounds
    d. Substances and preparations, or the breakdown products of such, which have been proved to possess carcinogenic or mutagenic properties or properties which may affect steroidogenic, thyroid, reproduction or other endocrine related functions in or via the aquatic environment
    e. Persistent hydrocarbons and persistent and bioaccumulable organic toxic substances
    f. Cyanides
    g. Metals and their compounds
    h. Arsenic and its compounds
    i. Biocides and plant protection products
    j. Materials in suspension
    k. Substances which contribute to eutrophication (in particular, nitrates and phosphates)
    l. Substances which have an unfavourable influence on the oxygen balance (and can be measured using parameters such as BOD, COD, etc.)
4. Establish monitoring of biological status for surface waters:
    a. Design of surveillance, operational and/or investigative monitoring per Annex V
    b. Frequency of monitoring
    c. Additional monitoring requirements for protected areas as listed under Annex IV
5. Present monitoring results as maps in accordance with Annex V

6. Classify biological status of surface waters per Annex V

Scale of measurement: River basin; Member State

Required data: Biological reference conditions; Anthropogenic pressures

Data generation specifications: Quantitative and qualitative; cannot be collected via participatory processes

Data generation/collection frequency:

For surveillance monitoring period:

Quality element	Rivers	Lakes	Transitional	Coastal
Phytoplankton	6 months	6 months	6 months	6 months
Other aquatic flora	3 years	3 years	3 years	3 years
Macroinvertebrates	3 years	3 years	3 years	3 years
Fish	3 years	3 years	3 years	

For operational monitoring, the frequency of monitoring required for any parameter shall be determined by Member States so as to provide sufficient data for a reliable assessment of the status of the relevant quality element. As a guideline, monitoring should take place at intervals not exceeding those indicated for surveillance monitoring.

Level of expertise required: Moderate to High

Connection to other indicators: Indicators forming parts of the Member States' River Basin Management Plans: *Quantitative status of groundwater, Chemical status of groundwater, Ecological status of surface waters, Biological status of surface waters, Hydromorphological status of surface waters, Physicochemical status of surface waters* and *Ecological potential for heavily modified or artificial water bodies*

Connection to SDGs: SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 12 Responsible consumption and production, SDG 13 Climate action, SDG 14 Life below water

Key References

European Parliament. (2000). *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy.* http://data.europa.eu/eli/dir/2000/60/oj

European Commission. (2012). *Report from the Commission to the European Parliament and the Council on the Implementation of the Water Framework Directive (2000/60/EC). River Basin Management Plans*. Brussels.

12.3.22 Total number and species richness of aquatic macroinvertebrates

Metric: *Total number and species richness of aquatic macroinvertebrates (express as total number or as % change)*

Strengths: *Macroinvertebrate monitoring can not only provide information about how changes to the landscape or stream characteristics affect the health of the biological community. Yields an opportunity for community members to engage in environmental monitoring*

Weaknesses: *May not yield accurate results*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Aquatic macroinvertebrates are animals that do not have a backbone, can be observed without magnification and spend at least part of their life in water. Most macroinvertebrates spend part of all of their life attached to submerged rocks, logs and vegetation. They are good indicators of the health of aquatic ecosystems because:

- Macroinvertebrates are affected by physical, chemical and biological conditions of the stream
- Macroinvertebrates are relatively long-lived and cannot escape pollution, so can therefore reflect changes to stream conditions across space and time
- Macroinvertebrates are ubiquitous in perennial aquatic systems
- Macroinvertebrates are a critical part of the food web in streams
- Macroinvertebrates have a range of different life history strategies (e.g., mode of respiration, feeding strategy, reproduction) that can be used to evaluate causes of aquatic ecosystem impairment
- Macroinvertebrates can easily be sampled and identified in a cost-effective manner

It is recommended that an aquatic biologist assist in the design of a biosurvey programme and provide a locally-adapted macroinvertebrate identification key. Monitoring approaches typically involve the establishment of a transect-type study area or sampling 'reach' and macroinvertebrate sample collection along with habitat assessment. The relative intensity of the biosurvey and level of supervision by professional aquatic biologists depends upon the programme objective. It is generally recommended that macroinvertebrate sampling programmes start with the simplest, least resource-intensive approach and work towards increasing complexity depending on the available resources, expertise and volunteer interest. An example of a macroinvertebrate sampling programme is:

- Establish sample location (sample station)
- Estimate habitat proportions
- Collect macroinvertebrate samples
- Clean and preserve the sample
- Habitat assessment and estimation of flow
- Generate a site sketch

Scale of measurement: Plot to neighbourhood/district scale

Required data: Sampling distances from the stream, types of habitats, relative proportion of each habitat, stream bed composition, stream flow

Data generation specifications: Qualitative and quantitative; opportunities for community members to engage in the data collection with assistance

Data generation/collection frequency: Daily, weekly, monthly or annually

Level of expertise required: Low to Moderate

Connection to other indicators: Synergies with the group of *Water quality* indicators

Connection to SDGs: SDG 13 Climate action, SDG 14 Life below water

Key References

European Parliament, Council of the European Union. (2000). *EU Water Framework Directive: Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy*. Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02000L0060-20140101

12.3.23Hydromorphological quality of surface waters

Metric: *Hydromorphological quality of surface waters - rivers, lakes, transitional waters and coastal waters (rated high, good, moderate, poor, bad)*

Strengths: *A comparable EU-wide applied assessment*

Weaknesses: *Requires arrangements on Member State-level*

Water covers ca. 71 % of the Earth's surface but only 2.5 % of it is fresh, stored as groundwater and in glaciers. Water is vital for living organisms, and it enables a multitude of human activities such as agriculture, manufacturing and transportation of goods. Available water resources are being extensively used for a variety of purposes, and ensuring that the water quality is monitored and the degraded water bodies are enhanced is essential for protecting the water resources. EU Water Framework Directive (2000/60/EC) sets forth the framework for integrated management of surface waters and groundwater resources in the EU Member States, which are presented as River Basin Management Plans.

The following procedure is based off the requirements set by the Water Framework Directive (2000/60/EC):

1. Characterise water bodies within a river basin area per Annex II:
   a. Rivers, lakes, transitional waters or coastal waters — or artificial surface water bodies or heavily modified surface water bodies
2. Establish type-specific hydromorphological reference conditions per Annex V
3. Identify and estimate the impacts of significant water flow regulation
4. Identify and estimate significant morphological alterations to water bodies
5. Establish monitoring of hydromorphological status for surface waters:
   a. Design of surveillance, operational and/or investigative monitoring per Annex V
   b. Frequency of monitoring
   c. Additional monitoring requirements for protected areas as listed under Annex IV
6. Present monitoring results as maps in accordance with Annex V
7. Classify hydromorphological status of surface waters per Annex V

Scale of measurement: River basin; Member State

Required data: Biological reference conditions; Anthropogenic pressures; Water regulation activities

Data generation specifications: Quantitative and qualitative; cannot be collected via participatory processes

Data generation/collection frequency:

Frequency for surveillance monitoring period:

Quality element	Rivers	Lakes	Transitional	Coastal
Continuity	6 years			
Hydrology	Continuous	1 month		
Morphology	6 years	6 years	6 years	6 years

For operational monitoring, the frequency of monitoring required for any parameter shall be determined by Member States so as to provide sufficient data for a reliable assessment of the

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

status of the relevant quality element. As a guideline, monitoring should take place at intervals not exceeding those indicated for surveillance monitoring.

Level of expertise required: Moderate to High

Connection to other indicators: Indicators forming parts of the Member States' River Basin Management Plans: *Quantitative status of groundwater, Chemical status of groundwater, Ecological status of surface waters, Biological status of surface waters, Hydromorphological status of surface waters, Physicochemical status of surface waters* and *Ecological potential for heavily modified or artificial water bodies*

Connection to SDGs: SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 12 Responsible consumption and production, SDG 13 Climate action, SDG 14 Life below water

Key References

European Parliament. (2000). *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy.* http://data.europa.eu/eli/dir/2000/60/oj

European Commission. (2012). *Report from the Commission to the European Parliament and the Council on the Implementation of the Water Framework Directive (2000/60/EC). River Basin Management Plans*. Brussels.

12.4 Natural and Climate Hazards

Nature-based solutions are a core element of ecosystem-based disaster risk reduction (Eco-DRR) and climate change adaptation, including water security. As a result of global climate change, natural disasters are becoming increasingly frequent and more extreme with a concomitant increase in the severity of impacts. Flooding and its impacts on society are of particular concern; however, periodic flooding frequently coincides with over-exploitation of available freshwater resources and water scarcity due to temporal misalignment between water supply and demand. Flood and drought events are expected to increase both in frequency and in severity in the future. Parts of Eastern Europe and Scandinavia are among those considered subject to the greatest flood risk, whereas meteorological and hydrological droughts across Europe are expected to increase in frequency, duration, and severity across most of Europe, with the greatest effect anticipated in southern Europe (EEA, 2017).

The services provided by well-managed ecosystems can reduce exposure to hazards whilst providing essential natural resources such as water, food, and building materials. The indicators presented in this section both address preparedness and planning measures, as well as provide a means to evaluate the outcomes of NBS implementation.

Table 19. Indicators of NBS performance and impact related to Natural and Climate Hazards

Nr.	Indicator	Units	Class	Applicability to NBS		
				Type 1	Type 2	Type 3
11.4.1 †	Disaster resilience	unitless	S	●	●	●
11.4.2 †	Disaster-risk informed development	Nr. 0-2, unitless	S	●		
11.4.3 †	Multi-hazard early warning	Nr. 0-2, unitless	S	●		
11.4.4	Insurance against catastrophic events	%	P	●		
11.4.5	Height of flood peak	m^3/s	O	●	●	●
11.4.5	Time to flood peak	h	O	●	●	●
11.4.6a	Heatwave: days with temperature >90th percentile	%	O	●	●	●
11.4.6b	Heatwave: Warm Spell Duration Index (WSDI)	Nr. of days	O	●	●	●
11.4.6c	Heatwave: number of combined tropical nights and hot days	Nr./y	O	●	●	●
11.4.7a	Human comfort: Universal Thermal Climate Index (UTCI)	°C	O	●	●	●
11.4.7b	Human comfort: Physiological Equivalent Temperature (PET)	°C	O	●	●	●

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

11.4.7c	Human comfort: Predicted Mean Vote-Predicted Percentage Dissatisfied (PMV-PPD)	unitless	O	•	•	•
11.4.8	Urban Heat Island effect	°C	O	•	•	•
11.4.9	Quantitative status of groundwater	Good or Poor	O	•	•	•
11.4.10	Water Exploitation Index (WEI)	%	O	•	•	•
11.4.11	Water availability for irrigation purposes, including greywater	m^3/y	O	•	•	•

† Indicators designated "recommended" by NBS Impact Evaluation Taskforce (Taskforce 2; Dumitru and Wendling, Eds., *in preparation*)

12.4.1 Disaster resilience

Metric: *The Scorecard prompts to identify "most probable" and "most severe" risk scenarios for each of the identified city hazards, or for a potential multi-hazard event*

Strengths: *Promote resilience awareness. Establishing a baseline status of disaster resilience. Enabling planning towards DRR*

Weaknesses: *Need for a facilitator to interpret the results. The assessment is not immediate and requires time (e.g., month(s))*

The Disaster resilience scorecard provides a set of assessment criteria for the local governments that allow assessing their disaster resilience, structuring around UNDRR's Ten Essentials for Making Cities Resilient. It also helps to monitor and review progress and challenges in the implementation of the Sendai Framework for Disaster Risk Reduction: 2015-2030 and supports the baseline analysis for preparation of the disaster risk reduction and resilience strategies.

First, the actors are identified, which should include local authorities, private businesses, research centres, academia, community groups, etc. Via interviews and workshops, external and internal parties provide their scores and comments to the ten categories (i.e., Essentials) and their sub-categories that are evaluated in the MS Excel spreadsheet. The overall score of the assessment provides information on the city's overall relative disaster resilience whilst individual sub-categories support identification of specific vulnerabilities to different hazards and risks.

Two options and their respective Excel spreadsheets exist for the DRR evaluation:

- Preliminary level: responding to key Sendai Framework targets and indicators, and with some critical sub-questions. In total there are 47 questions indicators, each with a 0 – 3 score
- Detailed assessment: a multi-stakeholder exercise that can be a basis for a detailed city resilience action plan. The detailed assessment includes 117 indicator criteria, each with a score of 0 – 5

Scale of measurement: City scale

Required data: Information on the city pressures and hazards

Data generation specifications: Quantitative and qualitative; participatory data collection is feasible, with data available to Cities' departments

Data generation/collection frequency: Additional data collection is needed only if the assessment is repeated to monitor progress in DRR

- Short-term: within 1 year since the compilation
- Mid-term: from 1 to 5 years since the compilation
- Long-term: 5 years since the compilation

Level of expertise required: High – requires the ability to use the scorecard template and the ability to interpret the outcomes

Connection to other indicators: The evaluation of each Essential may rely on multiple indicators for the respective topic

Connection to SDGs: SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land

Key References

United Nations Office for Disaster Risk Reduction, *Disaster Resilience Scorecard for Cities – Preliminary Level Assessment,* May 2017. https://www.unisdr.org/campaign/resilientcities/toolkit/article/disaster-resilience-scorecard-for-cities

12.4.2 Disaster-risk informed development

Metric: *The extent to which disaster risk has been taken into account when planning national-level or municipal-level economic or urban development (0-2)*

Strengths: *Ensures robust action planning for urban disaster resilience*

Weaknesses: *Requires prior risk assessment on national/municipal level*

Natural and climate hazards such as floods or earthquakes cannot be prevented. However, it is possible to anticipate the consequences and take preventive measures. Including disaster risk planning into national and/or municipal urban development plans enhances the resilience against natural hazards that reduces the economic losses and damages to property.

The inclusion of disaster-risk informed urban development to local development plans can be assessed using the scale:

0 – No inclusion: Disaster risk has not been accounted in either national economic development plans, or in city-level urban planning;

1 – Partial inclusion: Present only in the active national development plan/strategy;

2 – Full inclusion: Accounted for in both the active national development plan/strategy and in city-level urban planning (e.g., through policies, directives, urban development plans or strategies).

Scale of measurement: Municipality; country

Required data: Local risk assessment for natural and climate hazards; local development plans

Data generation specifications: Semi-quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Level of expertise required: Moderate

Connection to other indicators: The indicator can be assessed in conjunction with *Disaster resilience* indicator. It is directly related to all indicators the *Natural and Climate Hazards* indicator group and encompasses them and their impacts for a holistic urban development.

Connection to SDGs: SDG 9 Industry, innovation and infrastructure, SDG 11 Sustainable cities and communities, SDG 13 Climate action

Key References

Tyszka, T. and Zielonka, P. *Large risks with low probabilities: Perceptions and willingness to take preventive measures against flooding*. IWA Publishing, 2017, pp. 105-118.

12.4.3 Multi-hazard early warning

Metric: *The degree of implementation of multi-hazard early warning system (0-2)*

Strengths: *Straightforward assessment of local disaster risk reduction*

Weaknesses: *Requires municipal- or national-level measures*

Natural and climate hazards occur worldwide, and they bring casualties, property damages and substantial economic losses. Disaster risk reduction is the backbone to mitigation the destructive consequences. Several parts comprise multi-hazard early warning system: (i) Disaster risk knowledge, (ii) Detection, monitoring, analysis and forecasting of the hazards and possible consequences, (iii) Warning dissemination and communication, and (iv) Preparedness and response capabilities (World Meteorological Organisation, 2018).

Implementation of multi-hazard early warning system can be assessed using the scale:

0 – No monitoring implemented;

1 – Only a weather monitoring system is present;

2 – Both weather monitoring system and multi-hazard early warning system are present.

Scale of measurement: Municipality

Required data: Disaster risk knowledge, hazard monitoring and forecasting, warning communication and preparedness capabilities on the municipal or national level

Data generation specifications: Semi-quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually

Level of expertise required: Moderate

Connection to other indicators: Directly related to *Disaster-risk informed development* indicator

Connection to SDGs: SDG 9 Industry, innovation and infrastructure, SDG 11 Sustainable cities and communities, SDG 13 Climate action

Key References

World Meteorological Organisation. *Detection, Monitoring, Analysis & Forecasting of Hazards and Possible Consequences*. Retrieved from: https://public.wmo.int/en/resources/world-meteorological-day/wmd-2018/multi-hazard/detection-monitoring

World Meteorological Organisation. (2018). *Multi-hazard Early Warning Systems: A Checklist: Outcome of the first Multi-hazard Early Warning Conference*. 1st Multi-hazard Early Warning Conference (Cancún, Mexico).

12.4.4 Insurance against catastrophic events

Metric: *Share of population holding insurance against catastrophic consequences of natural and climate hazards (%)*

Strengths: *Simple assessment that indicates the disaster preparedness*

Weaknesses: *Requires access to policy holder databases*

Catastrophes originating from natural and/or climate hazards are low-probability high-impact and high-cost events, and they are usually not included in the general insurance policies. Catastrophe insurances are widely used to enhance the resilience of businesses, individuals and public amenities from external pressures and aid them in restoring any financial losses.

The indicator is assessed as:

$$\frac{Population\ holding\ catastrophe\ insurance\ policies}{Total\ popultation} \times 100\%$$

Scale of measurement: Municipality; country

Required data: National records on proportion of population holding insurance policies against catastrophic events

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually

Level of expertise required: Low to Moderate

Connection to other indicators: Directly related to all indicators the *Natural and Climate Hazards* indicator group

Connection to SDGs: SDG 9 Industry, innovation and infrastructure, SDG 11 Sustainable cities and communities, SDG 13 Climate action

Key References

–

12.4.5 Height of flood peak and time to flood peak

Metric: *Flood peak height is the highest point of the rising limb of a flood hydrograph (describing discharge over time) (m^3/s, cfs, L/s or similar units)*

Time to flood peak (h)

Strengths: *Straightforward assessment of degree to which the changes in the local land-use (i.e., change in imperviousness) had an effect on reducing/promoting runoff*

Weaknesses: *Requires in situ measurements*

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Rapid urbanisation and industrialisation have led to reduced vegetative cover and decreased water storage in the subsurface, as well as the concentration and accumulation of surface runoff in sewage systems due to reduced infiltration into the soil. As a result, the volume of surface runoff as well as the velocity and time to peak storm runoff and baseflow are all increased. Urbanisation also reduces the land coverage of forests and vegetation that help to dissipate the flow energy (Devi, Ganasri & Dwarakish, 2015; Liu, Gebremeskel, De Smedt, Hoffman & Pfister, 2004). The detrimental effects of urbanisation on hydrologic systems are expected to increase in the future due to both increasing urbanisation as well as changes to the global climate, including rising sea levels, glacial retreat, changing precipitation patterns and an increasing frequency of extreme events (Kiehl, 2011).

Assessment of the effectiveness of flood management methods can be performed by different methods. For example, the assessment of runoff can be performed by *in situ* measurements before and after construction of a flood management structure.

In the studies reviewed by Iacob et al. (2014), the assessment of natural management methods was performed either by hydrologic and hydraulic modelling or by direct monitoring. Parameters used for the assessment of the performance of natural flood management measures were:

(a) Flood peak reduction for different flood event return periods (e.g., 1, 2, 25, 50, or 100 years);

(b) Increase in time to flood peak;

(c) Decrease in annual probability of flood risk for the selected area.

Scale of measurement: Site to catchment scale

Required data: *In situ* runoff measurements

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: At the time of precipitation events and/or daily, monthly and yearly continuous monitoring before and after construction of the area and/or installation of NBS

Level of expertise required: Moderate

Connection to other indicators: Direct relationship to *Runoff coefficient* indicator, and partial relationship to *Infiltration* and *Evapotranspiration*

Connection to SDGs: SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities

Key References

Iacob, O., Rowan, J.S., Brown, I.M., & Ellis, C. (2014). Evaluating wider benefits of natural flood management strategies: An ecosystem-based adaptation perspective. *Hydrology Research*, *45*(6), 774-787.

12.4.6 Heatwave

a) Days with temperature > 90th percentile (TX90p)

Metric: *Percentage of days during which the maximum daily temperature (TX) exceeds the 90th percentile (TX90p) threshold of the daily maximum temperature (%)*

Strengths: *Straightforward assessment of heatwaves occurrence*

Weaknesses: *Requires statistical tools and judgement*

Nature-based solutions can support climate change adaptation by reducing local ambient air temperature. They can also provide insulation from cold and/or shelter from wind. By moderating the urban microclimate, green infrastructure can support reduction in energy use and improved thermal comfort (Demuzere et al., 2014).

Ambient air temperature can be assessed through continuous monitoring of temperature, near the NBS intervention area, and evaluation of the maximum daily temperature before and after NBS implementation. Evaluating the effect on the heatwave reduction by assessing the daily temperatures produces more accurate results that monthly averages, which tend to "lose" the small changes that are crucial for several domains, such as health and agriculture (Alexander *et al.*, 2006). The TX90p defines the occurrence of the extremely hot days falling above the 90th percentile (1/10th of the sample) allowing the evaluation of the *extent* of the extreme temperatures changes (Alexander *et al.*, 2006). The TX90p is evaluated as

$$TX_{ij} > TX_{in}90$$

Where:

TX_{ij} – daily maximum temperature on day i in period j

$TX_{in}90$ – calendar day 90th percentile centred on a five-day window for the base period 1961-1990

Scale of measurement: Plot to district scale

Required data: Automated continuous monitoring of ambient air temperature

Data generation specifications: Quantitative; participatory data collection is feasible through direct temperature measurements if these are not automated

Data generation/collection frequency: Annually; at minimum, before and after NBS implementation

Level of expertise required: Low – for continuous temperature monitoring; Moderate – when using the statistical tools

Connection to other indicators: Directly contributes to evaluation of the *Warm spell duration index* indicator and is indirectly related to *Daily temperature range* indicator

Connection to SDGs: SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action

Key References

Alexander, L. V., Zhang, X., Peterson, T. C., Caesar, J., Gleason, B., Klein Tank, A. M. G., ... & Tagipour, A. (2006). Global observed changes in daily climate extremes of temperature and precipitation. *Journal of Geophysical Research: Atmospheres*, *111*, D05109.

Demuzere, M., Orru, K., Heidrich, O., Olazabal, E., Geneletti, D., Orru, H., Faehnle, M. (2014). Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure. *Journal of Environmental Management, 146*, 107-115.

ETCCDI. (2009). *Climate change indices*. Available at: http://etccdi.pacificclimate.org/list_27_indices.shtml

b) Warm spell duration index (WSDI)

Metric: *Number of days per annum when the maximum daily temperature TX > 90th percentile threshold (see indicator TX90p) for at least six consecutive days*

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Strengths: *Straightforward assessment of heatwaves occurrence*

Weaknesses: *Requires statistical tools and judgement*

Nature-based solutions can support climate change adaptation by reducing local ambient air temperature. They can also provide insulation from cold and/or shelter from wind. By moderating the urban microclimate, green infrastructure can support reduction in energy use and improved thermal comfort (Demuzere et al., 2014).

Evaluating the effect on the heatwave reduction by assessing the daily temperatures produces more accurate results that monthly averages, which tend to "lose" the small changes that are crucial for several domains, such as health and agriculture. The WSDI defines the periods of excessive heat during the daytime, and it is evaluated using a percentile-based threshold (Alexander *et al.*, 2006):

$$TX_{ij} > TX_{in}90$$

Where:

TX_{ij} – daily maximum temperature on day *i* in period *j*

$TX_{in}90$ – calendar day 90th percentile centred on a five-day window for the base period 1961-1990

Scale of measurement: Plot to district scale

Required data: Automated continuous monitoring of ambient air temperature

Data generation specifications: Quantitative; participatory data collection is feasible through direct temperature measurements if these are not automated

Data generation/collection frequency: Annually; at minimum, before and after NBS implementation

Level of expertise required: Low – for continuous temperature monitoring; Moderate – when using the statistical tools

Connection to other indicators: Directly evaluated from *Days with temperature > 90th percentile (TX90p)* indicator and closely related to *Daily temperature range* indicator

Connection to SDGs: SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action

Key References

Alexander, L. V., Zhang, X., Peterson, T. C., Caesar, J., Gleason, B., Klein Tank, A. M. G., ... & Tagipour, A. (2006). Global observed changes in daily climate extremes of temperature and precipitation. *Journal of Geophysical Research: Atmospheres*, *111*, D05109.

Demuzere, M., Orru, K., Heidrich, O., Olazabal, E., Geneletti, D., Orru, H., Faehnle, M. (2014). Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure. *Journal of Environmental Management, 146*, 107-115.

ETCCDI. (2009). *Climate change indices*. Available at: http://etccdi.pacificclimate.org/list_27_indices.shtml

c) Combined tropical nights and hot days

Metric: *Number of combined tropical nights (>20°C) and hot days (>35°C)*

Strengths: *Easy and straightforward assessment*

Weaknesses: *Requires substantial amount of external data for modelling*

Heatwave is a period of prolonged abnormally high surface temperatures relative to those normally expected. Heatwaves can be characterized by low humidity, which may exacerbate drought, or high humidity, which may exacerbate the health effects of heat-related stress such as heat exhaustion, dehydration and heatstroke. Heatwaves in Europe are associated with significant morbidity and mortality. Furthermore, climate change is expected to increase average summer temperatures and the frequency and intensity of hot days (Russo et al., 2014). In cities and urban areas, the UHI tends to exacerbate heatwave episodes.

This indicator is assessed through continuous monitoring of temperature, and/or estimated by applying meteorological models such as the Weather Research and Forecasting WRF model (NCAR & UCAR, n.d.; NOAA, n.d.)

"Tropical nights" are defined as days when the daily minimum temperature is > 20°C. The number of tropical nights is equal to the number of days annually when the daily minimum temperature is > 20°C (ETCCDI; http://etccdi.pacificclimate.org/list_27_indices.shtml). For the purposes of this indicator, "hot days" are defined as days when the daily maximum temperature is > 35°C.

Scale of measurement: Building/plot to regional scale

Required data: Initial and boundary conditions, topography, land use and urban parameters (building height, width, number of road lanes) (Emmons et al., 2010; Pineda, Jorba, Jorge & Baldasano, 2004). These data can be obtained through national statistics, municipal departments, Corine Land Cover, and a mapping application such as OpenStreetMap.

Data generation specifications: Quantitative; participatory data collection is feasible through sample collection, e.g., air temperature measurements if these are not automated

Data generation/collection frequency: Annually, and before and after NBS implementation

Level of expertise required: Low – for continuous temperature monitoring; High – for applying meteorological models

Connection to other indicators: Assessed from *Mean or peak daytime temperature* indicator and connected with *Urban Heat Island* indicator

Connection to SDGs: SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action

Key References

Emmons, L.K., Walters, S., Hess, P.G., Lamarque, J.-F-, Pfister, G.G., Fillmore, D. … Kloster, S. (2010). Description and evaluation of the Model for Ozone and Related chemical Tracers, version 4 (MOZART-4). *Geoscientific Model Development*, *3*, 43-67.

National Center for Atmospheric Research (NCAR) & University Corporation for Atmospheric Research (UCAR). (n.d.). Weather Research and Forecasting (WRF) Model Users' Page. Retrieved from http://www2.mmm.ucar.edu/wrf/users/

National Oceanic and Atmospheric Administration (NOAA). (n.d.). Weather Research and Forecasting model coupled to Chemistry (WRF-Chem). Retrieved from https://ruc.noaa.gov/wrf/wrf-chem/

Pineda, N., Jorba, O., Jorge, J. & Baldasano, J.M. (2004). Using NOAA AVHRR and SPOT VGT data to estimate surface parameters: application to a mesoscale meteorological model. *International Journal of Remote Sensing*, *25*(1), 129–143.

Russo, S., Dosio, A., Graversen, R., Sillmann, J., Carrao, H., Dunbar, M.B. …Vogt, J.V. (2014). Magnitude of extreme heat waves in present climate and their projection in a warming world. Journal of Geophysical Research: Atmospheres, 119(22), 12500–12512.

Weather Research and Forecasting Model (WRF): https://www.mmm.ucar.edu/weather-research-and-forecasting-model

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

12.4.7 Human comfort

a) Universal Thermal Climate Index (UTCI)

Metric: *The UTCI is the air temperature that would produce under reference conditions the same thermal strain as the actual thermal environment. In other words, the UTCI is the reference environmental temperature causing strain*

Strengths: *Mathematical expression of a person's thermal comfort in the outdoors. The output is expressed in easily understandable temperature units, e.g., °C*

Weaknesses: *Can be laborious to evaluate*

UTCI index represents air temperature of the reference condition with the same physiological response as the actual condition. The UTCI provides a one-dimensional value that reflects the human physiological reaction to the multi-dimensional outdoor thermal environment (Bröde et al., 2012). It can predict both whole body thermal effects (hypothermia and hyperthermia; heat and cold discomfort), and local effects (facial, hands and feet cooling and frostbite). Applications of the UTCI include weather forecasts, bioclimatological assessments, bioclimatic mapping, urban design, engineering of outdoor spaces, outdoor recreation, epidemiology and climate impact research.

The human body core temperature must be maintained within a narrow range around 37°C to ensure proper function of the body's inner organs and the brain, thus optimising human comfort, performance and health. In contrast, the temperature of the skin and extremities can vary widely, depending upon environmental conditions. This variation in the temperature of extremities is one of the mechanisms to equilibrate heat production and heat loss. The heat exchange between the human body and environment can be described in the form of the energy balance equation:

$$M + W + C + K + E + Q + Res \pm S = 0$$

Where:

M – heat produced by metabolism;
W – heat generated by muscular activity;
C – sensible heat flux (heat transferred by convection);
K – heat transferred through conduction contact with solid bodies);
E – latent heat flux (evaporative heat flux);
Q – radiative heat transfer;
Res – heat transfer through respiration; and,
S – heat content of the body.

The UTCI is derived from this mathematical model of thermoregulation with an integrated adaptive clothing model that also accounts for predicted votes of the dynamic thermal sensation based on core and skin temperature (Fiala et al., 1999, 2001, 2003; Havenith et al., 2011). The deviation of UTCI temperature from measured air temperature depends on measured values of air temperature (T_a) and mean radiant temperature (T_{mrt}), wind speed at a height of 10 m (v_a) and humidity expressed as water vapour pressure (p_a) or relative humidity (rH):

$$\mathbf{UTCI}(T_a, T_{mrt}, v_a, p_a) = Ta + Offset(T_a, T_{mrt}, v_a, p_a)$$

The model reference condition is walking at 4 km/h (135 W/m^2) with T_{mrt}=T_a, v_a=0.5 m/s, rH=50% (T_a >29°C) and p_a=20 hPa (T_a >29°C) (Bröde et al., 2012). The UTCI dynamic model response can be determined using the online calculator available from http://utci.org. The relationship between UTCI temperature (expressed in °C) and physiological stress is shown in the table below (adapted from Błażejczyk et al., 2010).

UTCI (°C) range	Stress category
Above +46	Extreme heat stress
+38 to +46	Very strong heat stress
+32 to +38	Strong heat stress
+26 to +32	Moderate heat stress
+9 to +26	No thermal stress
0 to +9	Slight cold stress
-13 to 0	Moderate cold stress
-27 to -13	Strong cold stress
-40 to -27	Very strong cold stress
Below -40	Extreme cold stress

Scale of measurement: Plot – street – neighbourhood – district

Required data: Air temperature, T_a (°C); Mean radiant temperature, T_{mrt} (degrees Kelvin); Water vapour pressure (hPa); Relative humidity (%); Wind speed at a height of 10 m (m/s)

Data generation specifications: Quantitative; participatory data collection is feasible through direct participation in weather data collection

Data generation/collection frequency: Frequency as desired. UTCI can be calculated frequently with measurement intervals determined by (automated) weather data acquisition

Level of expertise required: Low-Moderate

Connection to other indicators: Direct relation to *Heatwave incidence* and *Number of combined tropical nights and hot days* indicators. Similar to *Physiological equivalent temperature (PET)*

Connection to SDGs: SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action

Key References

Błażejczyk, K., Broede, P., Fiala, D., Havenith, G., Holmér, I., Jendritzky, G., Kampmann, B. & Kunert, A. (2010). Principles of the new Universal Thermal Climate Index (UTCI) and its application to bioclimatic research in European scale. *Miscellanea Geographica, 14*, 91-102.

Bröde, P., Fiala, D., Błażejczyk, K., Holmér, I., Jendritzky, G., Kampmann, B., Tinz, B. & Havenith, G. (2012). *International Journal of Biometeorology, 56*, 481-494.

Fiala, D., Havenith, G., Bröde, P., Kampmann, B & Jendritzky, G. (2011). UTCI-Fiala multi-node model of human temperature regulation and thermal comfort. *International Journal of Biometeorology, 56*, 429-441.

Fiala, D., Lomas, K.J., Stohrer, M. (1999). A computer model of human thermoregulation for a wide range of environmental conditions: the passive system. *Journal of Applied Physiology, 87*, 1957–1972.

Fiala, D., Lomas, K.J., Stohrer, M. (2001). Computer prediction of human thermoregulatory and temperature responses to a wide range of environmental conditions. *International Journal of Biometeorology, 45*, 143–159.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Fiala D, Lomas KJ, Stohrer M (2003). First principles modeling of thermal sensation responses in steady-state and transient conditions. *ASHRAE Transactions, 109*, 179–186.

Havenith, G., Fiala, D., Błażejczyk, K., Richards, M., Bröde, P., Holmér, I., Rintamäki, H., Benshabat, Y., Jendritzky, G. (2011). The UTCI-Clothing Model. *International Journal of Biometeorology, 56*, 461-470.

b) Physiological Equivalent Temperature (PET)

Metric: *Mean or peak daytime local temperature by PET calculation (°C)*

Strengths: *Compared to PMV, PET has the advantage to use °C, which allows the results to be easily interpreted by urban or regional planners*

Weaknesses: *Requires extensive amount of data for evaluation*

Green urban infrastructure can significantly affect climate change adaptation by reducing air and surface temperatures with the help of shading and through increased evapotranspiration. Conversely, green urban infrastructure can also provide insulation from cold and/or shelter from wind, thereby reducing heating requirements (Cheng, Cheung, & Chu, 2010). By moderating the urban microclimate, green infrastructure can support a reduction in energy use and improved thermal comfort (Demuzere et al., 2014). The cooling effect of green space results in lower temperatures in the surrounding built environment (Yu & Hien, 2006).

To calculate PET (Höppe, 1999):

1. Determine the thermal conditions of the body using the Munich energy-balance model for individuals, MEMI, (1) for a given set of climatic parameters. MEMI is based on the energy balance equation of the human body and is related to the Gagge two-node model (Gagge, Stolwijk, & Nishi, 1972). The MEMI equation is as follows:

$$M + W + R + C + E_D + E_{Re} + E_{Sw} + S = 0 \quad (1)$$

where, M is the metabolic rate (internal energy production by oxidation of food); W is the physical work output; R is the net radiation of the body; C is the convective heat flow; E_D is the latent heat flow to evaporate water into water vapour diffusing through the skin; E_{Re} is the sum of heat flows for heating and humidifying the inspired air; E_{Sw} is the heat flow due to evaporation of sweat; and, S is the storage heat flow for heating or cooling the body mass.

As a first step, the mean surface temperature of the clothing (T_{cl}), the mean skin temperature (T_{sk}) and the core temperature (T_c) must be evaluated. These three parameters provide the basis for calculation of E_{Sw}. Two equations are necessary to describe the heat flows from the body core to the skin surface (F_{cs}) as shown in (2), and heat flows from the skin surface through the clothing layer to the clothing surface (F_{sc}) as shown in (3) (Höppe, 1999):

$$F_{CS} = v_b \times \rho_b \times c_b \times (T_c - T_{sk}) \quad (2)$$

where, v_b is blood flow from body core to skin (L/s/m^2); ρ_b is blood density (kg/L); and, c_b is the specific heat (W/sK/kg).

$$F_{CS} = (1/I_{cl}) \times (T_{sk} - T_{cl}) \quad (3)$$

where, I_{cl} is the heat resistance of the clothing (K/m^2/W).

2. Insert calculated values for mean skin temperature (T_{sk}) and core temperature (T_c) into the MEMI equation (1) and solve the three equations for air temperature, T_a (v_b= 0.1 m/s; water vapour pressure = 12 hPa; $T_{mrt} = T_a$). This temperature is equivalent to PET.

Scale of measurement: Building or plot scale

Required data: Energy balance of the human body, heat flows though the body and clothing

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually, and before and after NBS implementation

Level of expertise required: High – requires ability to follow the calculation procedure and units, and to critically evaluate the results

Connection to other indicators: Directly related to Incorporation of environmental design in buildings indicator

Connection to SDGs: SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action

Key References

Gagge, A., Stolwijk, J.A., & Nishi, Y. (1971). An effective temperature scale based on a simple model of human physiological regulatory response. *ASHRAE Transactions, 77*(1), 247-257.

Höppe, P. (1999). The physiological equivalent temperature – a universal index for the biometeorological assessment of the thermal environment. *International Journal of Biometeorology, 2466*, 71-75.

c) Predicted Mean Vote-Predicted Percentage Dissatisfied (PMV-PPD)

Metric: *Mean or peak daytime local temperature by PMV-PPD calculation (unitless value)*

Strengths: *Mathematical expression of a person's thermal comfort under indoor steady-state conditions*

Weaknesses: *Subjective evaluation of thermal sensations. The output is not expressed in any temperature units, e.g., °C*

Green urban infrastructure can significantly affect climate change adaptation by reducing air and surface temperatures with the help of shading and through increased evapotranspiration. Conversely, green urban infrastructure can also provide insulation from cold and/or shelter from wind, thereby reducing heating requirements (Cheng, Cheung, & Chu, 2010). By moderating the urban microclimate, green infrastructure can support a reduction in energy use and improved thermal comfort (Demuzere et al., 2014). The cooling effect of green space results in lower temperatures in the surrounding built environment (Yu & Hien, 2006).

The model aims to estimate the mean thermal sensation of a group of individuals and their respective percentage of dissatisfaction with the thermal environment, expressed in terms of Predicted Mean Vote-Predicted Percentage Dissatisfied (PMV-PPD). The practical application of the PMV equation and associated variables has been described by Ekici (2016). PMV provides a score that relates to the Thermal Sensation Scale (Fanger, 1970). If the score is zero, the occupant satisfaction regarding the environment is at the maximum level (Ekici, 2016).

Thermal Sensation Scale (Fanger, 1970):

Scale	Description	How it feels
3	Hot	Intolerably warm
2	Warm	Too warm
1	Slightly warm	Tolerably uncomfortable, warm
0	Neutral	Comfortable
-1	Slightly cool	Tolerably uncomfortable, cool

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

-2	Cool	Too cool
-3	Cold	Intolerably cool

Scale of measurement: Building scale

Required data: Metabolism, clothing, indoor air temperature, indoor mean radiant temperature, indoor air velocity and indoor air humidity (Rupp, Vásquez, & Lamberts, 2015).

Data generation specifications: Semi-quantitative; participatory data collection is feasible through direct participation in the indicator assessment

Data generation/collection frequency: Annually

Level of expertise required: High – requires the ability to apply the mathematical model and evaluate the results

Connection to other indicators: Directly related to *Incorporation of environmental design in buildings* indicator

Connection to SDGs: SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action

Key References

Ekici, C. (2016). Measurement uncertainty budget of the PMV thermal comfort equation. International Journal of Thermophysics, 37, 48

Ekici, C. (2013). Review of Thermal Comfort and Method of Using Fanger's PMV Equation. Proceedings of the 5th International Symposium on Measurement, Analysis and Modelling of Human Functions, 27-29 June 2013, Vancouver, Canada. 4 pp.

Fanger, P. (1970). Thermal comfort. Analysis and applications in environmental engineering. Copenhagen: Danish Technical Press.

Rupp, R. F., Vásquez, N. G., & Lamberts, R. (2015). A review of human thermal comfort in the built environment. Energy and Buildings, 105, 178–205.

12.4.8 Urban Heat Island (UHI) effect

Metric: *Urban Heat Island (UHI) effect denotes an urban area that is significantly warmer than its rural or undeveloped surrounding areas. Expressed and evaluated as temperature (°C)*

Strengths*: Fairly easy and straightforward assessment of temperature differences*

Weaknesses: *Requires a rather large amount of temperature measurement stations to holistically identify the effect within the urban area. May require modelling expertise*

The UHI effect is caused by the absorption of sunlight by (stony) materials, reduced evaporation and the emission of heat caused by human activities. The UHI effect is greatest after sunset and reported to reach up to 9°C in some cities, e.g., Rotterdam (Van Hove et al., 2015). Because of the UHI effect, citizens living in urban areas experience more heat stress than those living in the countryside.

To measure UHI effect:

1. Identify or install one or more meteorological (temperature) measurement stations within the built environment, and one measurement station outside the city that functions as a reference station. Alternatively, models can be used.

2. Compare the hourly average air temperature measurements of the urban measurement station(s) with the station outside the city (the reference station).

3. Look for the largest temperature difference (hourly average) between urban and countryside areas during the summer months. This temperature difference is an absolute measure of the UHI effect.

Scale of measurement: City to regional scale

Required data: Hourly temperature measurements

Data generation specifications: Quantitative; participatory data collection is feasible through geographically referenced direct temperature measurements if these are not automated

Data generation/collection frequency: Annually; at minimum before and after NBS implementation

Level of expertise required: Low

Connection to other indicators: Assessed from *Mean or peak daytime temperature* indicator and connected with *Heatwave Risk* indicator

Connection to SDGs: SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action

Key References

Van Hove, L.W.A., Jacobs, C.M.J., Heusinkveld, B.G., Elbers, J.A., van Driel, B.L., & Holtslag, A.A.M. (2015). Temporal and spatial variability of urban heat island and thermal comfort within the Rotterdam agglomeration. Building and Environment, 83, 91-103.

United States Environmental Protection Agency. (2006). Excessive Heat Events Guidebook. Retrieved from https://www.epa.gov/sites/production/files/2016-03/documents/eheguide_final.pdf

12.4.9 Quantitative status of groundwater

Metric: *The degree to which a body of groundwater is affected by direct and indirect abstractions (good, poor)*

Strengths: *A comparable EU-wide applied assessment*

Weaknesses: *Requires arrangements on Member State-level*

Water covers ca. 71 % of the Earth's surface but only 2.5 % of it is fresh, stored as groundwater and in glaciers. Water is vital for living organisms, and it enables a multitude of human activities such as agriculture, manufacturing and transportation of goods. Available water resources are being extensively used for a variety of purposes, and ensuring that the water quality is monitored and the degraded water bodies are enhanced is essential for protecting the water resources. EU Water Framework Directive (2000/60/EC) sets forth the framework for integrated management of surface waters and groundwater resources in the EU Member States, which are presented as River Basin Management Plans.

The following procedure is based off the requirements set by the Water Framework Directive (2000/60/EC):

1. Define groundwater bodies within a river basin area
2. Establish type-specific reference conditions per Annex V
3. Identify significant anthropogenic pressures

4. Identify and estimate significant water abstractions for urban, agricultural, industrial and other uses, including seasonal variations and total annual demand
5. Identify and estimate loss of water in the distribution systems
6. Estimate recharge and artificial recharge of groundwater bodies
7. Estimate the effects caused by water regulation, flood protection and land drainage
8. Establish monitoring of quantitative status for groundwater:
    a. Groundwater level monitoring network
    b. Density of monitoring sites
    c. Frequency of monitoring
    d. Additional monitoring requirements for protected areas as listed under Annex IV
9. Present monitoring results as maps in accordance with Annex V
10. Interpret groundwater quantitative status per Annex V

Scale of measurement: River basin; Member State

Required data: Anthropogenic pressures on groundwater reserves; Water abstraction rates; Land-use; Water regulation activities; Water losses

Data generation specifications: Quantitative and qualitative; cannot be collected via participatory processes

Data generation/collection frequency: Frequency of monitoring for drinking water abstraction points:

Community served	Frequency
< 10 000	4 per year
10 000 – 30 000	8 per year
> 30 000	12 per year

Level of expertise required: Moderate to High

Connection to other indicators: Indicators forming parts of the Member States' River Basin Management Plans: *Quantitative status of groundwater, Chemical status of groundwater, Ecological status of surface waters, Biological status of surface waters, Hydromorphological status of surface waters, Physicochemical status of surface waters* and *Ecological potential for heavily modified or artificial water bodies*

Connection to SDGs: SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 12 Responsible consumption and production, SDG 13 Climate action

Key References

European Parliament. (2000). Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. http://data.europa.eu/eli/dir/2000/60/oj

European Parliament. (2006). Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration. http://data.europa.eu/eli/dir/2006/118/2014-07-11

European Commission. (2012). Report from the Commission to the European Parliament and the Council on the Implementation of the Water Framework Directive (2000/60/EC). River Basin Management Plans.

12.4.10 Water Exploitation Index

Metric: *Annual total water abstraction as a proportion (%) of available long-term freshwater resources in the geographically relevant area (basin) from which the municipality obtains its water*

Strengths: *European Environment Agency (EEA) uses the WEI to evaluate water scarcity across major river basins in Europe with time*

Weaknesses: *Requires substantial amount of external information and data sources*

The Water Exploitation Index (WEI) compares the volume of water consumed each year to the available freshwater resources. More specifically, the WEI presents total annual freshwater extraction as a proportion (%) of the long-term annual average freshwater available from renewable resources. The WEI warning threshold of 20 % distinguishes a water-stressed area from one not suffering water scarcity. Severe scarcity is defined as WEI > 40%.

The WEI is calculated as follows (European Environment Agency [EEA], 2018):

$$WEI = \left(\frac{Volume\ of\ water\ abstraction}{Volume\ of\ renewable\ freshwater\ resources}\right) \times 100$$

An advanced version of the WEI, called the WEI+, accounts for recharge of available freshwater supplies, or water return (EEA, 2018a):

$$WEI + = \left(\frac{Volume\ of\ water\ abstraction - Volume\ of\ water\ returns}{Volume\ of\ renewable\ freshwater\ resources}\right) \times 100$$

The volume of long-term renewable freshwater resources in a natural or semi-natural geographically relevant area (e.g., basin or sub-basin) is calculated as (EEA, 2018):

$$Long\ term\ renewable\ freshwater\ resources = E_{xIn} + P - ET_a - \Delta S$$

where E_{xIn} = external inflow, P = precipitation, ET_a = actual evapotranspiration and ΔS = change in storage (lakes and reservoirs).

The equation for renewable freshwater resources can be simplified as follows for highly-modified (i.e., not natural or semi-natural) river basins or sub-basins (EEA, 2018):

$$Long\ term\ renewable\ freshwater\ resources = outflow + (abstraction - return) - \Delta S$$

where outflow = downstream flow or discharge to sea and ΔS = change in storage (lakes and reservoirs).

Scale of measurement: Basin scale

Required data: Necessary information about annual volumes of water abstraction (groundwater, surface water) from a given basin or sub-basin can be obtained from records of water supply companies and city documents relating to water abstraction permits. Wastewater treatment companies, water supply companies and municipal environment/environmental management departments are sources of information related to annual volumes of water returns. Information about long-term renewable water resources can be obtained from local water boards, municipal departments and/or national environment agencies.

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Level of expertise required: Moderate

Connection to other indicators: Not identified

Connection to SDGs: SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 13 Climate action

Key References

European Environment Agency (EEA). (2018). *Use of freshwater resources.* Copenhagen: European Environment Agency. Retrieved from https://www.eea.europa.eu/data-and-maps/indicators/use-of-freshwater-resources-2/assessment-3

12.4.11 Water availability for irrigation purposes, including greywater and captured rainwater

Metric: *Volume of rainwater or greywater used for irrigation purposes (m^3/y or similar unit)*

Strengths: *Secure reserve of water for irrigation at times of drought. Use of automatic meter reading could be a good choice to communicate with stakeholders regarding the benefits of rainwater capture and use for irrigation*

Weaknesses: *Rainwater storage requires a substantial amount of external storage units. There are concerns about the potential for bacterial growth when nutrient-rich waste/greywater remains untreated for a period of time*

Rainwater and greywater have a potential to be reused for irrigation purposes if collected to a storage unit. This is especially prominent for areas exposed to drought.

Domestic wastewater consists of greywater, the wastewater discharged from hand basins, showers and baths, dishwashers, and laundry machines, and blackwater from toilets. Depending on local regulations, water from the kitchen sink be regarded as greywater or blackwater. One person generates 90–120 L greywater each day depending on lifestyle, living standard, age, gender, and other factors. Greywater comprises 50-80% of all domestic wastewater but contains a relatively small fraction of the total pollutant load (Antonopoulou, Kirkou, & Stasinakis, 2013; Donner et al., 2010; Li, Wichmann, & Otterpohl, 2009). Separation of domestic greywater from blackwater and on site re-use for toilet flushing or irrigation of non-edible vegetation provides an alternative water source in areas facing water shortage. On-site greywater re-use can reduce potable water use by as much as 50% (Gross, Shmueli, Ronen, & Raveh, 2007).

Accurate accounting of rainfall capture and use for irrigation requires use of a water level sensor to measure the volume of water contained within a given rainwater storage unit at any time. If the storage unit is completely sealed and the water level can be easily recorded each time it is opened (and again after water is discharged for use), it may be possible to manually record and calculate the volume of water captured and used for irrigation purposes.

An alternate solution is to equip the discharge point of the rainwater storage unit/tank with a water meter, and record the volume of water used over a specific period of time. This is well suited to applications with multiple water storage tanks and/or in situations where it may be challenging to accurately quantify water use manually. The water meter(s) may be connected to an automatic meter reading (AMR) device that enables remote communication of water usage between the water meter and a central point.

It is recommended that domestic greywater is filtered (e.g., sand and/or granular activated carbon filter and/or treatment in vertical subsurface-flow wetland or reed bed, etc.) prior to use for irrigation of non-edible vegetation such as landscaping.

Scale of measurement: Plot scale to street scale

Required data: Volume of rainwater and greywater used for irrigation purposes

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually

Level of expertise required: Low

Connection to other indicators: Related to *Runoff in relation to precipitation quantities* indicators

Connection to SDGs: SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities

Key References

Antonopoulou, G., Kirkou, A. & Stasinakis, A.S. (2013). Quantitative and qualitative greywater characterization in Greek households and investigation of their treatment using physicochemical methods. *Science of the Total Environment, 454-455*, 426-432.

Donner, E., Eriksson, E., Revitt, D.M., Scholes, L., Holten Lützhøft, H.-C. & Ledin, A. (2010). Presence and fate of priority substances in domestic greywater treatment and reuse systems. *Science of the Total Environment, 408*(12), 2444-2451.

Gross, A., Shmueli, O., Ronen, Z., & Raveh, E. (2007). Recycled vertical flow constructed wetland (RVFCW)-a novel method of recycling greywater for irrigation in small communities and households. *Chemosphere, 66*(5), 916-623.

Li, Y., Wichmann, K., & Otterpohl, R. (2009). Review of the technological approaches for grey water treatment and reuses. *Science of the Total Environment, 407*(11), 3439-3449.

12.5 Green Space Management

Management of green space refers to the planning, establishment and maintenance of green and blue infrastructure. Properly managed green and blue space provides a wide range of social and ecological benefits, providing solutions to challenges such as air and noise pollution, urban heating, flooding, and human wellbeing.

Many of the co-benefits obtained from effective green space management are addressed under other challenge categories. For example:

- The microclimate impacts of green and blue space are addressed in detail under Climate Resilience;
- Impacts of green and blue space on water management are comprehensively addressed under Water Management;
- The role of green and blue spaces in moderating Climate and Natural Hazards is addressed in the corresponding section;
- The impacts of green and blue space on human wellbeing are addressed under Health and Wellbeing;
- Social impacts of green and blue space are addressed under both Place Regeneration and Social Justice and Social Cohesion; and,
- Economic impacts of green and blue space are addressed under New Economic Opportunities and Green Jobs.

We have sought to avoid excessive overlap by not repeating all indicators potentially applicable to green space management here, choosing to focus primarily on indicators specific to green space management in the context of urban planning (e.g., the accessibility and distribution of public green space, the extent of pedestrian and bicycle paths) and the outcomes of maintenance actions in public green and blue spaces (e.g., soil condition, ambient pollen concentration).

Table 20. Indicators of NBS performance and impact related to Green Space Management

Nr.	Indicator	Units	Class	Applicability to NBS		
				Type 1	Type 2	Type 3
11.5.1	Accessibility of green space, measured as travel time	%	O	●		●
11.5.2†	Accessibility of green spaces, measured as distance	%	O	●		●
11.5.3	Distribution of public green space	% or m²/100 000	O	●		●
11.5.4†	Soil organic carbon content	t/ha	O	●	●	●
11.5.5	Soil carbon to nitrogen ratio (C/N ratio)	Unitless number	O	●	●	●
11.5.6	Ambient pollen concentration	pollen grains/m³	O	●	●	●
11.5.7	Proportion of road network dedicated to pedestrians and/or bicyclists	% of network	S	●		

† Indicators designated "recommended" by NBS Impact Evaluation Taskforce (Taskforce 2; Dumitru and Wendling, Eds., *in preparation*)

12.5.1 Accessibility of green space, measured as travel time

Metric: *Proportion of population with access to a green space of at least 0.5 ha in size within a 15-minute walk from an individual's place of residence (WHO, 2016)*

Strengths: *Rapid and simple method*

Weaknesses: *Occasional lack of accurate data*

Multiple studies have documented the positive impact on quality of life that is derived from accessible urban green spaces, including parks, street trees, school green areas, public institutions' gardens, residential gardens, cemeteries, sportsgrounds, squares, urban forests, green spaces of the industrial and commercial production, green roofs, vertical gardens, arable lands, vacant lands, and greenhouses (e.g., Badiu et al., 2016). Some of the benefits of urban green spaces include improvements in air quality and local climate regulation (e.g., Rafael, Vicente, Rodrigues, Miranda, Borrego & Lopes, 2018); opportunities for nature experience, recreation and sports activities (e.g., Langemeyer, Baró, Roebeling & Gómez-Baggethun, 2015); real-estate value (e.g., Roebeling et al., 2017); and stormwater runoff control. One way to estimate the impacts of urban green space is to evaluate green space accessibility.

Using ArcGIS or similar spatial land cover datasets for the area in question (e.g., in the case of cities, usually can be obtained from the municipality), identify and map public green, blue and blue/green spaces equal to or greater than 0.5 ha in size. Assuming an average walking pace of 5 km/h, define circles with radii 1.25 km from each identified public green space. Note that these values can be adjusted to accommodate differences in walking pace. Using census area or similar data, determine the total number of residents within all the mapped 15-minute walking distance circles.

Scale of measurement: District scale to city scale

Required data: Area and categorisation of green spaces (land use maps, green space maps, green space qualification etc.), total urban area, census data (municipal departments, statistical services etc.)

Data generation specifications: Qualitative and quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Before and after the NBS implementation

Level of expertise required: Moderate

Connection to other indicators: Synergies with *Distribution of public green space, Proportion of natural area,* and *Availability and equitable distribution of blue-green space* indicators

Connection to SDGs: SDG 3 Good health and well-being, SDG 15 Life on land

Key References

Badiu, D.L., Ioja, C.I., Patroescu, M., Breuste, J., Artmann, M., Nita, M.R., Gradinaru, S.R., Hossu, C.A., & Onose, D.A. (2016). Is urban green space per capita a valuable target to achieve cities' sustainability goals? Romania as a case study. *Ecological Indicators*, *70*, 53-66.

Langemeyer, J., Baró, F., Roebeling, P., & Gómez-Baggethun, E. (2015). Contrasting values of cultural ecosystem

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

services in urban areas: the case of park Montjuïc in Barcelona. *Ecosystem Services*, 12, 178-186.

Rafael, S., Vicente, B., Rodrigues, V., Miranda, A.I., Borrego, C., & Lopes, M. (2018). Impacts of green infrastructures on aerodynamic flow and air quality in Porto's urban area. *Atmospheric Environment*, *190*, 317-330.

Roebeling, P., Saraiva, M., Palla, A., Gnecco, I., Teotónio, C., Fidélis, T., … Rocha, J. (2017). Assessing the socio-economic impacts of green/blue space, urban residential and road infrastructure projects in the Confluence (Lyon): a hedonic pricing simulation approach. *Journal of Environmental Planning and Management*, 60(3), 482-499.

World Health Organization (WHO). (2016). *Urban green spaces and health: A review of evidence*. Copenhagen: World Health Organization.

12.5.2 Accessibility of green spaces, measured as distance

Metric: *Proportion of population with access to urban green spaces of minimum size 0.5 ha within 300 m walk from an individual's place of residence (WHO, 2016)*

Strengths: *Rapid and simple method*

Weaknesses: *Occasionally lack of accurate data*

Multiple studies have documented the positive impact on quality of life that is derived from accessible urban green spaces, including parks, street trees, school green areas, public institutions' gardens, residential gardens, cemeteries, sportsgrounds, squares, urban forests, green spaces of the industrial and commercial production, green roofs, vertical gardens, arable lands, vacant lands, and greenhouses (e.g., Badiu et al., 2016). Some of the benefits of urban green spaces include improvements in air quality and local climate regulation (e.g., Rafael, Vicente, Rodrigues, Miranda, Borrego & Lopes, 2018); opportunities for nature experience, recreation and sports activities (e.g., Langemeyer, Baró, Roebeling & Gómez-Baggethun, 2015); real-estate value (e.g., Roebeling et al., 2017); and stormwater runoff control.

One way to estimate the impacts of urban green space is to evaluate green space accessibility. As one of the indicators in EEA's Interactive map for Green infrastructure indicators, effective green infrastructure is presented. EEA defines effective green infrastructure as a potential distribution of green infrastructure element in the territory or in the neighbouring area.

Accessibility of urban green spaces can be determined as a distance to green spaces or time to reach the green spaces. As an example, in a study by Tamosiunas et al. (2014), spatial land cover sets for the city were obtained from the municipality, and they were processed using an ArcGIS software for green space exposure. City parks larger than 1 ha were included. Distances to the nearest city park were estimated by geocoding home addresses of the survey responders and using SAS and GIS software.

Another possibility to define accessibility of urban green spaces is to determine the percentage of the green space in the living environment. In studies by de Vries et al. (2003), Maas et al. (2006), and Maas et al. (2009), a National Land Cover Classification database (LGN3 and LGN4 in The Netherlands) was used as a data source for green space exposure evaluation. In the study by de Vries et al. (2003), additional sources were used including, for example, infrastructure and noise levels. All the environmental data used were combined in a single geographical information system (GIS). Living environments were defined as circles with radius of 1 km or 3 km. In studies by Ward Thompson et al. (2012) and Roe et al. (2013) the study participants' living environment was defined as the area in the Census Area Statistics (CAS), which is a geographical unit used in the administration of the United Kingdom's decennial census. Green space locations were obtained from the website of the Centre for

Research on Environment Society and Health (CRESH). The green spaces included parks, woodlands, scrub and other natural environments, but not private gardens.

Scale of measurement: District scale to city scale

Required data: Area and categorisation of green spaces (land use maps, green space maps, green space qualification etc.), total urban area, census data (municipal departments, statistical services etc.)

Data generation specifications: Qualitative and quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Before and after the NBS implementation

Level of expertise required: Moderate

Connection to other indicators: Synergies with *Distribution of public green space, Proportion of natural area,* and *Availability and equitable distribution of blue-green space* indicators

Connection to SDGs: SDG 3 Good health and well-being, SDG 15 Life on land

Key References

de Vries, S., Verheij, R.A., Groenewegen, P.P., & Spreeuwenberg, P. (2003). Natural Environments – healthy environments? An exploratory analysis of the relationship between greenspace and health. *Environment and Planning, 35*, 1717-1731.

Maas, J., Verheij, R.A., de Vries, S., Spreeuwenberg, P., Schellevis, F.G., & Groenewegen, P.P. (2009). Morbidity is related to a green living environment. *Journal of Epidemiology and Community Health, 63*(12), 967-973.

Maas, J., Verheij, R.A., Groenewegen, P.P., de Vries, S., & Spreeuwenberg, P. (2006). Green space, urbanity, and health: how strong is the relation? *Journal of Epidemiology and Community Health, 60*, 587-592.

Roe, J.J., Ward Thompson, C., Aspinall, P.A., Brewer, M.J., Duff, E.I., Miller, D., … Clow, A. (2013). Green space and stress: Evidence from cortisol measures in deprived urban communities. *International Journal of Environmental Research and Public Health, 10*, 4086-4103.

Tamosiunas, A., Grazuleviciene, R., Luksiene, D., Dedele, A., Reklaitiene, R., Baceviciene, M., … Niewenhuijsen, M.J. (2014). Accessibility and use of urban green spaces, and cardiovascular health: findings from a Kaunas cohort study. *Environmental Health, 13*(1), 20.

Ward Thompson, C.W., Roe, J., Aspinall, P., Mitchell, R., Clow, A., & Miller, D. (2012). More green space is linked to less stress in deprived communities: Evidence from salivary cortisol patterns. *Landscape and Urban Planning, 105*, 221 – 229.

World Health Organization (WHO). (2016). *Urban green spaces and health: A review of evidence*. Copenhagen: World Health Organization.

12.5.3 Distribution of public green space

Metric: *Distribution of public green space expressed as a proportion of total urban surface area (%) or per capita (m^2/100 000)*

Strengths: *Rapid and simple method*

Weaknesses: *Occasionally lack of accurate data*

Multiple studies have documented the positive impact on quality of life that is derived from accessible urban green spaces, including parks, street trees, school green areas, public institutions' gardens, residential gardens, cemeteries, sportsgrounds, squares, urban forests,

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

green spaces of the industrial and commercial production, green roofs, vertical gardens, arable lands, vacant lands, and greenhouses (e.g., Badiu et al., 2016). Some of the benefits of urban green spaces include improvements in air quality and local climate regulation (e.g., Rafael, Vicente, Rodrigues, Miranda, Borrego & Lopes, 2018); opportunities for nature experience, recreation and sports activities (e.g., Langemeyer, Baró, Roebeling & Gómez-Baggethun, 2015); real-estate value (e.g., Roebeling et al., 2017); and stormwater runoff control.

It is important that within cities, the urban green spaces are equally distributed. The European Environment Agency defines the distribution of green urban areas as the relationship between green area boundaries (edges) and all the other elements in the city. With unequal distribution of urban green areas, benefits are focused on fewer city elements (neighbourhoods, streets, buildings or houses) and it also prevents connectivity of all the available green spaces in the ecological network. (EEA network.)

There are two fundamental ways by which the distribution of green space within a city can be evaluated, namely the total surface area and the per capita area of green space:

Total surface

- The categories of green spaces considered from the Urban Atlas (which have a minimum extent of 0.5 ha and a minimum width of 10 m) were urban green spaces and sports and leisure facilities (Badiu et al., 2016)
- Percentage of green space (urban green, agricultural green, forests and nature areas) (de Vries, Verheij, Groenewegen & Spreeuwenberg, 2003)

Per capita

- Green space per capita: distance to the road (Badiu et al., 2016)
- Surface of green public spaces expressed as area per inhabitant or per every 1000 inhabitants (Chiesura, 2004)
- Assessing health factors (smoking, obesity, etc.) as a function of distance between green space and home in metres (Tamosiunas et al., 2014)

The EEA's interactive map for green infrastructure indicators (https://www.eea.europa.eu/themes/sustainability-transitions/urban-environment/urban-green-infrastructure/urban-green-infrastructure-1) presents indicators, including the share of green urban areas and distribution of green urban areas for multiple European cities. Share of green urban areas defines a proportion of green urban areas inside the core cities (proportion of all vegetated areas within the city boundaries in relation to the total area). Distribution of green urban areas presents the ratio of the length of the urban area perimeter (in m) to the urban area (in ha).

Scale of measurement: District scale to city scale

Required data: Area and categorisation of green spaces (land use maps, green space maps, green space qualification etc.), total urban area, census data (municipal departments, statistical services etc.)

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Before and after NBS implementation

Level of expertise required: Moderate – for using the GIS software

Connection to other indicators: Synergies with *Accessibility of urban green spaces, Proportion of natural area*, and *Availability and equitable distribution of blue-green space* indicators

Connection to SDGs: SDG 3 Good health and well-being, SDG 15 Life on land

Key References

Badiu, D.L., Ioja, C.I., Patroescu, M., Breuste, J., Artmann, M., Nita, M.R., Gradinaru, S.R., Hossu, C.A., & Onose, D.A. (2016). Is urban green space per capita a valuable target to achieve cities' sustainability goals? Romania as a case study. *Ecological Indicators, 70*, 53-66.

Chiesura, A. (2004). The role of urban parks for the sustainable city. *Landscape and Urban Planning, 68*(1), 129-138.

Langemeyer, J., Baró, F., Roebeling, P., & Gómez-Baggethun, E. (2015). Contrasting values of cultural ecosystem services in urban areas: the case of park Montjuïc in Barcelona. *Ecosystem Services, 12*, 178-186.

Madureira, H., Nunes, F., Oliveira, J. V, Cormier, L., & Madureira, T. (2015). Urban residents' beliefs concerning green space benefits in four cities in France and Portugal. *Urban Forestry & Urban Greening, 14*(1), 56-64.

Rafael, S., Vicente, B., Rodrigues, V., Miranda, A.I., Borrego, C., & Lopes, M. (2018). Impacts of green infrastructures on aerodynamic flow and air quality in Porto's urban area. *Atmospheric Environment, 190*, 317-330.

Roebeling, P., Saraiva, M., Palla, A., Gnecco, I., Teotónio, C., Fidélis, T., … Rocha, J. (2017). Assessing the socio-economic impacts of green/blue space, urban residential and road infrastructure projects in the Confluence (Lyon): a hedonic pricing simulation approach. *Journal of Environmental Planning and Management, 60*(3), 482-499.

Tamosiunas, A., Grazuleviciene, R., Luksiene, D., Dedele, A., Reklaitiene, R., Baceviciene, … Niewenhuijsen, M.J. (2014). Accessibility and use of urban green spaces, and cardiovascular health: findings from a Kaunas cohort study. *Environmental Health, 13*(1), 20.

12.5.4 Soil organic carbon content

Metric: *Total amount of carbon (tonnes) stored in soil per unit area and unit time*

Strengths: *Physical sampling and laboratory analysis of soil C yields accurate information, with improved accuracy of estimated C storage in soil with increasing sampling intensity. Combustion-based analytical methods are relatively simple and widely applicable*

Weaknesses: *Small changes in soil C may be difficult to quantify in carbonate-rich soils, in which case multiple analytical steps may be required to obtain reliable measurements. Soil sample collection is relatively labour-intensive; analyses typically require an external laboratory (rather than analysed in-house)*

Accounting for C stored in soil and vegetation in an urban area can provide an indication of the condition of natural green spaces, total free surface area and total quantity of vegetation in the area examined. Measures of C storage and sequestration also provide a tangible connection to climate change mitigation, and the impacts of local land use, planning and management decision-making. It is important to note the substantial variation in C sequestration and storage capacity of different types of NBS.

The most reliable and accurate method of determining soil C content is field sampling followed by laboratory analysis. Combustion is an accurate, commonly used analytical technique to quantify total C in soil – including both organic and inorganic soil C. Combustion analysis involves converting all forms of C in the soil to CO_2 by wet or dry combustion, then measuring evolved CO_2. Change in soil C content occurs most readily in the SOC fraction, so observed changes in total soil C content with time are most likely to represent changes to SOC content.

Sampling is performed using a measuring tape (for establishment of sampling transect or grid), soil corer, and plastic bags.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

It may be challenging to detect small changes in soil C content in soils that contain substantial inorganic (mineral) C. A rapid field test of the soil's reactivity to acid can indicate whether it may be necessary to undertake more intensive analyses of soil samples to quantify both the organic and inorganic C fractions, rather than total (inorganic + organic) C by combustion. Rapid assessment of soil carbonate content involves reacting a small sample (ca. 1 g) of soil with 1-2 drops of 1 M hydrochloric acid (HCl) in a glass or porcelain container and observing the reaction for ~5 min. The reaction between soil carbonate minerals and HCl is visible as bubbles/effervescence as bubbles of CO_2 are produced.

If the HCl 'field test' indicates the presence of inorganic C then the soil sample should be pre-treated to remove inorganic C prior to determination of organic C content by wet digestion. A sample of the carbonate-containing soil should be treated at room with a mixture of dilute sulphuric acid (H_2SO_4) and ferrous sulphate ($FeSO_4$) for at least 20 min or until effervescence appears to cease. The flask containing the soil and $H_2SO4/FeSO_4$ mixture should then be heated over a flame and boiled slowly for 1.5 min to destroy any remaining carbonate. Finally, pulverised potassium dichromate ($K_2Cr_2O_7$) should be added to the mixture and organic C determined by chromic acid digestion (wet combustion) (Nelson & Sommers, 1996).

Scale of measurement: Plot scale; it is possible to extrapolate results from small number of field samples based on soil maps to approximate soil C storage at landscape (regional) scale

Required data: Site characteristics, including maps of soil type, topography, and vegetative cover. Average soil bulk density (in kg/m^3; can be measured or estimated based on soil type). Obtainable from local municipality, department of environment, geological survey.

Data generation specifications: Quantitative; participatory data collection is feasible through soil sample collection

Data generation/collection frequency: Annually, including at a minimum measurement before and after NBS implementation

Level of expertise required: Low to Moderate – field sampling; Moderate – combustion analysis in laboratory conditions; High – soil sample pre-treatment for determination of organic C content

Connection to other indicators: Used for evaluating C storage necessary for *Carbon removed or stored per unit area per unit time* indicator

Connection to SDGs: SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land

Key References

Nelson, D.W., & Sommers, L.E. (1996). Total Carbon, Organic Carbon, and Organic Matter. In D.L. Sparks (Ed.), *Methods of Soil Analysis Part 3, Chemical Methods* (pp. 961-1010). Madison, WI: Soil Science Society of America, Inc.

Rowell, D.L. (2014). *Soil Science: Methods & Applications*. New York: Routledge.

Soil Survey Staff. (2009). *Soil Survey Field and Laboratory Methods Manual. Soil Survey Investigations Report No. 51, Version 2.0. R. Burt (Ed.).* Lincoln, NE: United States Department of Agriculture, Natural Resources Conservation Service.

12.5.5 Soil carbon to nitrogen ratio (C/N ratio)

Metric: *The ratio between the total mass of carbon and the total mass of nitrogen in soil*

Strengths: *Physical sampling and laboratory analysis of soil C and N yields accurate information, with improved accuracy of estimated C and N content of soil with increasing* *sampling intensity. Combustion-based analytical methods are relatively simple and widely applicable*

Weaknesses: *Small changes in soil C may be difficult to quantify in carbonate-rich soils, in which case multiple analytical steps may be required to obtain reliable measurements. Soil sample collection is relatively labour-intensive; analyses typically require an external laboratory (rather than analysed in-house)*

The respective quantities of carbon and nitrogen in soil is critical to soil microbial activity and a fundamental indicator of biogeochemical cycling in ecosystems. Changes to soil C/N ratio impacts nutrient cycling in soils and the structure and function of plant communities, thereby affecting ecosystem service functions. Soils with higher C/N ratio are better able to buffer soil and water N pollution, because soils with greater C/N ratio generally exhibit slower rates of N mineralisation and nitrification, and greater capacity for N immobilisation (Groffman et al., 2006). The accumulation of C and N in urban green space soils is determined both by the length of time following urbanisation that an area is managed as a green space and the structural composition of green space vegetation. Factors such as the presence of trees, an understory, and surface litter are key to soil C and N accumulation. Urban green space soils under tree canopies have been shown to have significantly greater soil C and N content and higher C/N ratios compared with grassed areas (Livesley et al., 2015). Planting and placement of trees within urban green spaces should facilitate accumulation of understory vegetation and litter to promote high C/N ratios and C and N storage in soils.

Soil microorganisms require C and N in a ratio of about 24:1 to support metabolic processes (USDA-NRCS, 2011). The majority of N in soil is present in organic form. Organic N is mineralised to ammonium (NH_4^+) via organic matter breakdown, then, under oxygenated conditions, oxidised to nitrate (NO_3^-). Plants are able to take up both NH_4^+ and NO_3^-, with some evidence for direct plant uptake of organic N, particularly in N-limited environments. Microbiological uptake of all forms of N is called immobilisation because the N is taken up or 'immobilised' in microbial biomass. Nitrogen mineralisation/ immobilisation reactions in soil are dependent upon the total N content and the C/N ratio. If decomposing organic material contains more N than microorganisms need for cell growth (i.e., where C/N < 24:1), surplus nitrogen is excreted as NH_4^+. Conversely, if decomposing organic materials contain less N than required by soil microorganisms for cell growth (i.e., C/N >24:1), the soil microorganisms must acquire additional N from the soil. In the longer term, this can lead to reduced soil fertility due to a deficit of N.

Management of urban landscapes can disrupt C and nutrient cycling through irrigation, litter removal, fertiliser or mulch addition, or other practices. Studies have shown that soil C/N ratios of urban green spaces increase with time since green space establishment, or with the duration of altered management intensity (Golubiewski, 2006; Livesley et al., 2015). Understanding the C/N ratio can promote C storage whilst maintaining adequate soil fertility, as well as management of soil N to minimise leaching of nitrate (NO_3^-) to local waterbodies and/or gaseous losses (i.e., as N_2, N_2O, NO, NH_3).

Nitrogen accumulates in soil through fixation of atmospheric N to organic forms. Soil organic matter is typically 5-6% N, so N levels in soil closely follow soil organic matter content. The N content of soil parent materials is low because N does not form stable minerals. Soil N pools:

- Gaseous: N_2, N_2O, NO, NH_3
- Mineral N: NH_4^+, NO_2^-, NO_3^- (<2% of total N but very important)
- Fixed N: NH_4^+ trapped in vermiculite-like clays (4-8% of total N)

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

- Organic N: 80-95% of total soil N, needs to be mineralised prior to biological uptake

Soil N moves between pools via a series of reactions. Soil organic matter is mineralised to form ammonium (NH_4^+). In the presence of oxygen, the NH_4^+ undergoes nitrification to form nitrate (NO_3^-). Both NH_4^+ and NO_3^- are forms of N available for plant and microbial uptake. Excess NH_4^+ in soil may be bound to soil clay minerals. If not taken up by plants or microorganisms, soil nitrate (NO_3^-) may be lost from the system by leaching to local waterways or through volatilisation as N2, N_2O, NO or NH_3 gas.

The most reliable and accurate method of determining soil C and N content is field sampling followed by laboratory analysis. Sampling is performed using a measuring tape (for establishment of sampling transect or grid), soil corer, and plastic bags. Soil cores should be taken to a depth of at least 0.3 m, and up to 1.0 m depth depending on the rooting depth of local vegetation.

Combustion is an accurate, commonly used analytical technique to quantify C and N in soil. A carbon-nitrogen combustion analyser can provide measures of total carbon, total organic carbon and total inorganic carbon (after sample acidification), total nitrogen, and C/N ratio.

Scale of measurement: Plot scale

Required data: Site characteristics, including maps of soil type, topography, and vegetative cover. Average soil bulk density (in kg/m^3; can be measured or estimated based on soil type). Obtainable from local municipality, department of environment, geological survey.

Data generation specifications: Quantitative; participatory data collection is feasible through soil sample collection

Data generation/collection frequency: Annually, including at a minimum measurement before and after NBS implementation

Level of expertise required: Low to Moderate – field sampling; Moderate – combustion analysis in laboratory conditions; High – soil sample pre-treatment for determination of organic C content

Connection to other indicators: Similar method used to determine *Carbon removed or stored per unit area per unit time* indicator

Connection to SDGs: SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land

Key References

Bremner, J.M. (1996). Nitrogen – total. In D.L. Sparks (Ed.), *Methods of Soil Analysis Part 3, Chemical Methods* (pp. 961-1010). Madison, WI: Soil Science Society of America, Inc.

Golubiewski, N.E. (2006). Urbanization increases grassland carbon pools: Effects of landscaping in Colorado's Front Range. *Ecological Applications*, 16(2), 555-571.

Groffman, P.M., Pouyat, R.V., Cadenasso, M.L., Zipperer, W.C., Szlavecz, K., Yesilonis, I.D., Band, L.E. & Brush, G.S. (2006). Land use context and natural soil controls on plant community composition and soil nitrogen and carbon dynamics in urban and rural forests. *Forest Ecology and Management*, 236(2-3), 177-192.

Livesley, S.J., Ossala, A., Threlfall, C.G., Hahs, A.K. & Williams, N.S.G. (2015). Soil carbon and carbon/nitrogen ratio change under tree canopy, tall grass, and turf grass areas of urban green space. *Journal of Environmental Quality*, 45, 215-223.

Nelson, D.W., & Sommers, L.E. (1996). Total Carbon, Organic Carbon, and Organic Matter. In D.L. Sparks (Ed.), *Methods of Soil Analysis Part 3, Chemical Methods* (pp. 961-1010). Madison, WI: Soil Science Society of America, Inc.

Rowell, D.L. (2014). *Soil Science: Methods & Applications*. New York: Routledge.

Soil Survey Staff. (2009). *Soil Survey Field and Laboratory Methods Manual. Soil Survey Investigations Report No. 51, Version 2.0. R. Burt (Ed.).* Lincoln, NE: United States Department of Agriculture, Natural Resources Conservation Service.

USDA-NRCS. (2011.) Carbon to Nitrogen Ratios in Cropping Systems. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd331820.pdf

12.5.6 Ambient pollen concentration

Metric: *Number of grains of pollen per cubic metre of air (pollen grains/m^3)*

Strengths: *The results are widely accepted and known to be consistent*

Weaknesses: *The method of identifying and characterising trapped pollen and spores is time-consuming and requires considerable expertise*

Urban green spaces frequently have a limited number of plant species, including a higher proportion of non-native species in comparison with rural areas (McKinney, 2002). The low species diversity in many urban areas is directly linked to the formation of concentrated pollen emission sources. In particular, large-scale use of a small number of roadside tree species results in production of large quantities of a single species of pollen. Areas of concentrated pollen may not be readily dispersed by air currents. Some studies indicate that urban citizens are 20% more likely to suffer airborne pollen allergies than people living in rural areas, largely due to the uniformity of green spaces, where a small number of species that have proved highly suited to urban environmental conditions are overwhelmingly used, and the interaction of pollen with air pollutants (Cariñanos & Casares-Porcel, 2011).

The volumetric Hirst-type pollen and spore trap designed in 1952 remains one of the devices most commonly used for pollen and spore monitoring (Buters et al., 2018). The Hirst-type trap is standard in pollen monitoring networks in Europe. The Hirst-type pollen and spore trap uses a vacuum pump to continuously draw air at a known rate (e.g., 10 L/min). A wind vane attached to the sampler head ensures that the trap inlet is always facing the prevailing wind. Depending on the configuration of the trap, pollen and spores are captured on adhesive coated transparent plastic tape (Melinex) or on a microscope slide coated with an adhesive. Adhesive tapes are attached to a metal drum that rotates with time.

Pollen traps can be fitted with a drum specific to a 24-h or a 7-day sampling period. At the conclusion of the sampling period, the tape with adhered pollen and spores is cut into pieces representing 24-h periods of time and mounted on a microscope slide. Where the pollen and spores are captured directly on a microscope slide, the slide must be changed every 24 h. These slides are examined by microscopy for counting and identification of pollen and spores.

Scale of measurement: Plot to neighbourhood scale

Required data: Pollen measurement data

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Continuous collection with a 24 h or a 7-day sampling period

Level of expertise required: Moderate

Connection to other indicators: Synergies with *Distribution of public green space*, *Accessibility of urban green spaces,* and *Proportion of natural area,* and *Availability and equitable distribution of blue-green space* indicators

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Connection to SDGs: SDG 3 Good health and well-being, SDG 15 Life on land

Key References

Buters, J.T.M., Antunes, C., Galveias, A., Bergmann, K.C., Thibaudon, M., Galán, C. … & Oteros, J. (2018). Pollen and spore monitoring in the world. *Clinical and Translational Allergy, 8*, 9.

Cariñanos, P., & Casares-Porcel, M. (2011). Urban green zones and related pollen allergy: A review. Some guidelines for designing spaces with low allergy impact. *Landscape and Urban Planning, 101*(3), 205-214.

McKinney, M. (2002). Urbanization, Biodiversity, and Conservation: The impacts of urbanization on native species are poorly studied, but educating a highly urbanized human population about these impacts can greatly improve species conservation in all ecosystems. *BioScience, 52*(10), 883-890.

12.5.7 Proportion of road network dedicated to pedestrians and/or bicyclists

Metric: *Proportion of road network dedicated to pedestrians and/or bicyclists (% of network)*

Strengths: *The numeric indicator is easy to obtain and can be compared to different areas of interest*

Weaknesses: *Path length as a variable does not yield information regarding their use, utility, or perceived value by the community, which depend for instance on their coverage, consistency, terrain, safety and connectivity*

Increase in pedestrian and bicycle traffic is regarded beneficial for its economic, environmental, health and life quality effects. Availability of pedestrian paths and bicycle lanes can decrease the dependency on automobile ownership and use and related costs, free space from automobile traffic and congestion, reduce air pollution, increase physical activity and related health benefits and improve social activity and interaction within communities.

Increase in pedestrian/bicycle path length is measured as percentage increase of the length of pedestrian/cycling paths in the whole urban community in question. The pedestrian/bicycle paths are roads or lanes designated and marked for use by pedestrians and/or bicycles. The calculation can be performed from a map with adequate markings of path types and lengths, from which pedestrian/bicycle paths are summed before and after NBS implementation. Pedestrian paths and bicycle routes can be considered together or separately, depending on the specific metric desired.

$$Increase\ (\%) = \left(\frac{Length\ of\ cycling\ paths_{after}}{Length\ of\ cycling\ paths_{before}} \cdot 100\%\right) - 100\%$$

Scale of measurement: Street to metropolitan scale

Required data: Length of cycling paths (e.g., from a map)

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Before and after the path implementation

Level of expertise required: Moderate

Connection to other indicators: Synergies with *Area devoted to roads*, and *Encouraging a healthy lifestyle* indicators

Connection to SDGs: SDG 3 Good health and well-being, SDG 15 Life on land

Key References

–

12.6 Biodiveristy Enhancement

A critical impact of urbanisation is the reduction in total extent of natural habitat, along with the fragmentation of remaining natural habitat. Both the absolute reduction in habitat as well as the reduction in inter- and intra-species connectivity due to fragmentation lead to biodiversity loss. The indicators presented under the Biodiversity Enhancement challenge area address habitat connectivity as a significant factor underlying biodiversity loss, and provide widely-used indices for biodiversity assessment (e.g., Shannon Diversity Index, Shannon Evenness Index).

Other indicators provided herein support evaluation of the relative proportion of green and blue space within a defined urban zone, and benchmarking of biodiversity conservation efforts via the City Biodiversity Index. Avian biodiversity in cities has been linked to the total area of green space (e.g., Callaghan *et al.*, 2018), and is a particularly interesting biodiversity metric because it is well-suited to citizen science initiatives.

Table 21. Indicators of NBS performance and impact related to Green Space Management

Nr.	Indicator	Units	Class	Applicability to NBS		
				Type 1	Type 2	Type 3
11.6.1 †	Structural connectivity of urban green and blue spaces	ha	O	●		●
11.6.2 †	Species diversity within defined area per Shannon Diversity Index	Unitless number	O	●	●	●
11.6.3 †	Number of species within defined area per Shannon Evenness Index	Unitless number, 0-1	O	●	●	●
11.6.4	Proportion of natural areas within a defined urban zone	%	O	●		●
11.6.5	Number of native bird species within a defied urban area	Nr./ha	O	●	●	●
11.6.6	City Biodiversity Index (CBI)	%	O	●	●	●

† Indicators designated "recommended" by NBS Impact Evaluation Taskforce (Taskforce 2; Dumitru and Wendling, Eds., *in preparation*)

12.6.1 Structural connectivity of urban green and blue spaces

Metric: *Degree of physical ("structural") connectivity between natural environments within a defined urban area*

Strengths: *Relatively easy to evaluate*

Weaknesses: *Estimation about connections*

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Biodiversity is the measure of biological variety in the environment and it has an important role in functioning ecosystems services and health of environment and society. Biodiversity is an aspect of natural environment that is most directly affected by anthropogenic influence. City biodiversity is seen as an important aspect of sustainable and resilient urban development. The fragmentation of natural environments is a major threat to biodiversity as scattered and non-connected natural areas are much less efficient in preserving biodiversity than large and connected areas.

To estimate fragmentation, natural areas are defined and then an estimation is made about their connections. A mesh indicator value is calculated. Natural areas are categorized into separate interconnected patches. The area of each patch is summed, squared and these squares are summed and divided by the total area of natural areas.

$$Mesh\ indicator = \left(\frac{A_1^2 + A_2^2 + \cdots + A_n^2}{A_1 + A_2 + \cdots A_n}\right)$$

This index (in hectares) is a metric - mesh indicator - used in the indicator value.

Scale of measurement: District to region scale

Required data: Data on zones in natural or naturalized condition in the urban area of interest from, e.g., government agencies, municipalities, nature groups, universities, etc.

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually

Level of expertise required: Moderate

Connection to other indicators: Related to *Reclamation of contaminated land* and *Ratio of open spaces to built form* indicators

Connection to SDGs: SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land

Key References

Chan, L., Hillel, O., Elmqvist, T., Werner, P., Holman, N., Mader, A., & Calcaterra, E. (2014). User's Manual on the Singapore Index on Cities' Biodiversity (also known as the City Biodiversity Index). Singapore: National Parks Board, Singapore.

12.6.2 Species diversity within defined area per Shannon Diversity Index

Metric: *The diversity of species within a defined area (unitless)*

Strengths: *Quantitative evaluation of the biodiversity in the area. Widely used method*

Weaknesses: *The results largely depend on the quality and homogeneity of the collected data. Uncertainties related to the method*

Shannon Diversity Index is one of the biodiversity indices that quantitatively evaluates the species richness in a defined area.

$$p_i = \frac{n_i}{N}$$

$$H' = -\sum p_i \ln p_i$$

Where:

H' is the Shannon Diversity Index

p_i is the proportion of individuals found in the *i*-th species

n_i is the abundance of the *i*-th species

N is the total number of species

The resulting product (*H'*) is summed for all species and then multiplied by –1.

The expertise to identify various taxa via periodic field surveys is crucial for the accurate representation of species abundance. An expert to evaluate the sampling bias and training of the volunteers are required if the data collection is performed with citizen science.

Scale of measurement: Plot to district scale

Required data: Number of all taxonomic groups within a defined area (collected via field surveys)

Data generation specifications: Quantitative and semi-quantitative; participatory data collection is feasible via citizen science

Data generation/collection frequency: Annually or at smaller intervals; at minimum, before and after NBS implementation

Level of expertise required: Moderate to High – for the expert species identification and evaluating the bias in the collected data if citizen science is involved

Connection to other indicators: Directly contributes to evaluation of *Shannon Evenness Index*

Connection to SDGs: SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land

Key References

Magurran, A. E. (2004). *Measuring biological diversity*. Blackwell Publishing.

Daly, A. J., Baetens, J. M., & De Baets, B. (2018). Ecological diversity: measuring the unmeasurable. *Mathematics*, *6*(7), 119.

12.6.3 Number of species within defined area per Shannon Evenness Index

Metric: *Proportional abundance of species within a defined area (0–1; unitless)*

Strengths: *Quantitative evaluation of the species richness in the area. Widely used method*

Weaknesses: *The results largely depend on the quality and homogeneity of the collected data. Uncertainties related to the method*

Shannon Evenness Index describes the proportional abundance of species:

$$SEI = \frac{H'}{H_{max}} = \frac{-\sum p_i \ln p_i}{\ln S}$$

Where:

H' is the Shannon Diversity Index (see *Shannon Diversity Index* indicator)

p_i is the proportion of individuals found in the *i*-th species

S is the maximum diversity of species

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

The expertise to identify various taxa via periodic field surveys is crucial for the accurate representation of species abundance. An expert to evaluate the sampling bias and training of the volunteers are required if the data collection is performed with citizen science.

Scale of measurement: Plot to district scale

Required data: Number of all taxonomic groups within a defined area (collected via field surveys)

Data generation specifications: Quantitative and semi-quantitative; participatory data collection is feasible via citizen science

Data generation/collection frequency: Annually or at smaller intervals; at minimum, before and after NBS implementation

Level of expertise required: Moderate to High – for the expert species identification and evaluating the bias in the collected data if citizen science is involved

Connection to other indicators: Directly evaluated from the *Shannon Diversity Index* indicator

Connection to SDGs: SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land

Key References

Magurran, A. E. (2004). *Measuring biological diversity*. Blackwell Publishing.

Daly, A. J., Baetens, J. M., & De Baets, B. (2018). Ecological diversity: measuring the unmeasurable. *Mathematics*, *6*(7), 119.

Statistical Office of the European Union. (2018). *Shannon evenness index.* Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Shannon_evenness_index_(SEI)

12.6.4 Proportion of natural areas within a defined urban zone

Metric: *Proportion of natural areas within a defined urban zone (fraction or %)*

Strengths: *Simple and easy to assess*

Weaknesses: *Does not imply the intactness of biodiversity but provides a measure for habitat evaluation*

Biodiversity is the measure of biological variety in the environment and it has an important role in functioning ecosystems services and health of environment and society. Biodiversity is an aspect of natural environment that is most directly affected by anthropogenic influence. City biodiversity is seen as an important aspect of sustainable and resilient urban development. Natural areas are defined as ecosystems, which are not significantly influenced by human actions and comprise mainly of native species in natural environments. Such environments are important in preserving biodiversity as natural areas typically harbour much larger biodiversity than urban or constructed green spaces.

The area can be calculated using mapping tools, including satellite images from Google Maps. Calculate the share of the sum of natural and naturalized areas to the total area to get the indicator value. Natural areas include forests, swamps, streams, lakes, etc., but exclude parks and green infrastructure. Re-naturalized areas can be included.

Scale of measurement: District to region scale

Required data: Data on zones in natural or naturalized condition in the urban area of interest from, e.g., government agencies, municipalities, nature groups, universities, etc.

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually

Level of expertise required: Low

Connection to other indicators: Partly related to *Reclamation of contaminated land* indicator

Connection to SDGs: SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land

Key References

Chan, L., Hillel, O., Elmqvist, T., Werner, P., Holman, N., Mader, A., & Calcaterra, E. (2014). User's Manual on the Singapore Index on Cities' Biodiversity (also known as the City Biodiversity Index). Singapore: National Parks Board, Singapore.

12.6.5 Number of native bird species within a defined urban area

Metric: *Number of different native species of birds within a defined urban area*

Strengths: *Birds are relatively easy to detect and monitor*

Weaknesses: *While considered a universally good indicator of biodiversity change, the data can be difficult to obtain, it has high variability and requires long timescales to show significant trends*

Biodiversity is the measure of biological variety in the environment and it has an important role in functioning ecosystems services and health of environment and society. Biodiversity is an aspect of natural environment that is most directly affected by anthropogenic influence. City biodiversity is seen as an important aspect of sustainable and resilient urban development. Bird species numbers act as an indicator about changes in the diversity of the urban environment.

Total native bird species detected in built areas are counted. The number of species acts as the indicator value.

Scale of measurement: District to region scale

Required data: Total native bird species detected in built areas. The count census numbers can be obtained from city council archives or bird watch organizations.

Data generation specifications: Quantitative or semi-quantitative; participatory data collection is feasible over prolonged time scales using a citizen science approach

Data generation/collection frequency: Annually

Level of expertise required: Low to Moderate – for the identification of the taxonomic groups

Connection to other indicators: Related to *Reclamation of contaminated land* and *Ratio of open spaces to built form* indicators

Connection to SDGs: SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land

Key References

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Chan, L., Hillel, O., Elmqvist, T., Werner, P., Holman, N., Mader, A., & Calcaterra, E. (2014). User's Manual on the Singapore Index on Cities' Biodiversity (also known as the City Biodiversity Index). Singapore: National Parks Board, Singapore.

12.6.6 City Biodiversity Index

Metric: *The number of native species detected in the urban area, compared to a baseline number of species*

Strengths: *Encourage reintroduction of lost native species to urban areas through active development or protection*

Weaknesses: *The data can be difficult to obtain, it has high variability and requires long timescales to show significant trends*

The definition of biodiversity is the presence of different species of different taxonomic groups. The net change in the number of species in a municipality is an indication of biological diversity loss or gain. A more comprehensive sample of the biodiversity in an area can be obtained through a census of species in different groups. Vascular plants, birds, and butterflies have been defined in the City Biodiversity Index as core taxonomic groups to be followed in all cities. On top of these, cities are encouraged to select two supplementary taxonomical groups chosen to best reflect local biodiversity. The supplementary taxonomical groups can include, e.g., bryophytes, fungi, amphibians, reptiles, fish, beetles, spiders, seagrasses or others.

Counts of animal and plant species found on the whole urban area of interest are used. As focus in this metric is increasing biodiversity and reintroducing broader array of natural species, it can be sufficient to select a certain biotypes or areas and a selection of species for monitoring. The indicator value is the number of new native species detected in the urban area, compared to a baseline species number.

Scale of measurement: District to region scale

Required data: Data on counts of animal and plant species found on the whole urban area of interest. These can be available through municipalities, government agencies, environmental organizations, bird watch organizations or universities.

Data generation specifications: Quantitative or semi-quantitative; participatory processes are possible via citizen science but the relevance of such approach in terms of implementation at certain temporal and spatial scales must be considered prior to implementation

Data generation/collection frequency: Annually

Level of expertise required: Low

Connection to other indicators: Related to *Reclamation of contaminated land* and *Ratio of open spaces to built form* indicators

Connection to SDGs: SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land

Key References

Chan, L., Hillel, O., Elmqvist, T., Werner, P., Holman, N., Mader, A., & Calcaterra, E. (2014). User's Manual on the Singapore Index on Cities' Biodiversity (also known as the City Biodiversity Index). Singapore: National Parks Board, Singapore.

12.7 Air Quality

Air pollution is considered the world's single greatest environmental health risk. In 2017, 44%, 77% and 96% of the EU-28 urban population was exposed to levels of PM_{10}, $PM_{2.5}$ and O_3, respectively, exceeding the WHO air quality guideline values (EEA, 2019). Air pollution has considerable environmental and socio-economic impacts. Particulate matter (PM), NO_2 and ground level O_3 currently pose the greatest threat to human health in Europe, particularly in urban areas, whilst O_3 and nitrogen oxides (NO_x) are the air pollutants most harmful to natural ecosystems.

Improvements in ambient air quality can reduce the burden of disease attributable to air pollution whilst contributing to the near- and long-term mitigation of climate change. Urban vegetation can play an important role in the attenuation of air pollutants in cities and mitigation of the associated impacts of air pollution on morbidity, mortality and life expectancy. The air quality indicators presented herein are aligned with European air quality policy instruments.

Table 22. Indicators of NBS performance and impact related to Air Quality

Nr.	Indicator	Units	Class	Applicability to NBS		
				Type 1	Type 2	Type 3
11.7.1 †	Number of days during which atmospheric $PM_{2.5}$ exceeds threshold values	Nr. of days	O	●	●	●
11.7.1 †	Number of days during which atmospheric PM_{10} exceeds threshold values	Nr. of days	O	●	●	●
11.7.1 †	Number of days during which atmospheric NO_2 exceeds threshold values	Nr. of days	O	●	●	●
11.7.1 †	Number of days during which atmospheric SO_2 exceeds threshold values	Nr. of days	O	●	●	●
11.7.1 †	Number of days during which atmospheric CO exceeds threshold values	Nr. of days	O	●	●	●
11.7.1 †	Number of days during which ground-level O_3 exceeds threshold values	Nr. of days	O	●	●	●
11.7.1 †	Number of days during which PAHs (as indicated by benzo[a]pyrene) exceed threshold values	Nr. of days	O	●	●	●
11.7.2 †	Proportion of population exposed to ambient air pollution	%	O	●	●	●

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

11.7.3	Modelled O_3, SO_2, NO_2 and CO capture/removal by vegetation	kg/ha/y	O	●	●	●
11.7.4	Ambient pollen concentration	Pollen grains/m^3	O	●	●	●
11.7.5	Concentration of fine particulate matter ($PM_{2.5}$)in ambient air	µg/m^3	O	●	●	●
11.7.5	Concentration of coarse particulate matter (PM_{10}) in ambient air	µg/m^3	O	●	●	●
11.7.5	Concentration of NO_2 in ambient air	µg/m^3	O	●	●	●
11.7.5	Concentration of O_3 in ambient air	µg/m^3	O	●	●	●
11.7.6	Morbidity due to poor air quality	Nr./y	O	●	●	●
11.7.6	Mortality due to poor air quality	Nr./y	O	●	●	●
11.7.6	Years of Life Lost due to poor air quality	y	O	●	●	●

† Indicators designated "recommended" by NBS Impact Evaluation Taskforce (Taskforce 2; Dumitru and Wendling, Eds., *in preparation*)

12.7.1 Number of days during which air quality parameters exceed threshold values

Metric: *Number of documented exceedances to the limit value established in the Air Quality Framework Directive (*Directive 2008/50/EC*) for $PM_{2.5}$, PM_{10}, NO_2, SO_2, CO, ground-level O_3 and PAHs (as indicated by benzo[a]pyrene)*

Strengths: *Accurate results with automated measurements*

Weaknesses: *Some of the measurement systems can be expensive and require continual management and upkeep*

Air pollution is considered the single largest environmental health risk in the world, causing an estimated 2-6 million or more yearly deaths globally (Health Effects Institute [HEI], 2018; World Health Organisation [WHO], 2016). An important focus of research has been on the role of urban vegetation in the formation and removal of air pollutants in cities (e.g., Miranda et al., 2017) and the associated impacts of air pollution on morbidity, mortality and life-expectancy (e.g., Costa et al., 2014). The most relevant air pollutants are particulate matter of different sizes (PM2.5, PM10), ozone (O3), nitrogen dioxide (NO2), sulphur dioxide (SO2), polycyclic aromatic hydrocarbons (PAHs), carbon monoxide (CO), benzene (C6H6) and toxic metals (As, Cd, Ni, Pb and Hg) (EEA, 2018b).

Air pollution concentrations for regulatory compliance are based on measured pollutant concentrations (PM_{10} and $PM_{2.5}$, O_3, NO_2, SO_2, CO and PAHs) in ambient air. To assess differences in air quality as a result of NBS implementation, air quality monitoring should be conducted in close proximity to the NBS of interest and at an analogous reference site.

Particulate matter (PM_{10} and $PM_{2.5}$) concentration

The reference method for the sampling and measurement of $PM_{2.5}$ and PM_{10} is described in EN12341:2014 "*Ambient Air — standard gravimetric measurement method for the determination of the PM_{10} or $PM_{2,5}$ mass concentration of suspended particulate matter*". Briefly, particulate matter is measured using an air sampler that draws ambient air at a constant flow rate through a specially shaped inlet onto a filter that is weighed periodically to measure the accumulated particle load. The inlet defines the particle size cut-off (2.5 or 10 µm). A stationary measuring station is placed in a representative traffic, urban, industrial or rural location and continuous measurement of particulate matter using standardized air sampler equipment is undertaken. The limit concentration for $PM_{2.5}$ is 25 $\mu g/m^3$ averaged over one calendar year. Similarly, the limit concentration for PM_{10} is 40 $\mu g/m^3$ averaged over one year. To obtain these values, daily $PM_{2.5}$ and PM_{10} averages are averaged over a year to reach a yearly average, which acts as the indicator (ISO, 2018). There is an additional daily average limit value for PM_{10} of 50 $\mu g/m^3$, which cannot be exceeded more than 35 times in a calendar year.

Nitrogen dioxide (NO_2) concentration

The reference method for the measurement of nitrogen dioxide and oxides of nitrogen is that described in EN 14211:2012 "*Ambient air — Standard method for the measurement of the concentration of nitrogen dioxide and nitrogen monoxide by chemiluminescence*". To quantify nitrogen dioxide, a stationary measuring station is placed in a representative traffic, urban, industrial or rural location and continuous measurement of nitrogen dioxide is undertaken using standardized chemiluminescence detection equipment. An average of hourly averages is used to calculate a daily average. Daily averages are then used to calculate a yearly average (ISO, 2018). The limit concentration for NO_2 is 200 $\mu g/m^3$ in any one-hour time period, and 40 $\mu g/m^3$ averaged over one year.

Sulfur dioxide (SO_2) concentration

The reference method for the measurement of sulphur dioxide is described in EN 14212:2012 "*Ambient air — Standard method for the measurement of the concentration of sulphur dioxide by ultraviolet fluorescence*". To quantify sulfur dioxide, a stationary measuring station is placed in a representative traffic, urban, industrial or rural location and continuous measurement of nitrogen dioxide is undertaken using ultraviolet fluorescence detection equipment. An average of hourly averages is used to calculate a daily average. Daily averages are used to calculate a yearly average (ISO, 2018). The limit concentration for SO_2 is 350 $\mu g/m^3$ in any one-hour time period and 125 $\mu g/m^3$ averaged over one day.

Ground-level ozone (O_3) concentration

The reference method for the measurement of ozone is described in EN 14625:2012 "*Ambient air — Standard method for the measurement of the concentration of ozone by ultraviolet photometry*". A stationary measuring station is placed in a representative traffic, urban, industrial or rural location and continuous measurement of ozone by ultraviolet photometry using standardized equipment is undertaken. The convention for ozone measurement is to calculate a daily maximum 8-hour mean (ISO, 2018). The limit concentration for maximum daily 8-hour mean ground-level O_3 is 120 $\mu g/m^3$.

Carbon monoxide (CO) concentration

The reference method for the measurement of carbon monoxide is described in EN 14626:2012 "*Ambient air — Standard method for the measurement of the concentration of carbon monoxide by non-dispersive infrared spectroscopy*". A stationary measuring station is placed in a representative traffic, urban, industrial or rural location and continuous measurement of CO

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

using non-dispersive infrared spectroscopy equipment is undertaken. Like O_3, the convention for CO measurement is to calculate a daily maximum 8-hour mean (ISO, 2018). The limit concentration for maximum daily 8-hour mean CO is 10 µg/m^3.

Polycyclic aromatic hydrocarbon (PAH) concentration

The reference method for the sampling of polycyclic aromatic hydrocarbons in ambient air is described in EN 12341:2014. The PAH benzo(a)pyrene (BaP) serves as an analogue for all PAHs in the European air quality regulations. To assess the contribution of BaP in ambient air, the Ambient Air Quality Directive (2004/107/EC) outlines an obligation for Member States to monitor other relevant PAHs at a limited number of measurement sites including at least: benzo(a)anthracene, benzo(b)fluoranthene, benzo(j)fluoranthene, benzo(k)fluoranthene, indeno(1,2,3-cd)pyrene, and dibenz(a,h)anthracene. The reference method for the measurement of benzo(a)pyrene in ambient air is described in EN 15549:2008 "*Air quality — Standard method for the measurement of concentration of benzo[a]pyrene in ambient air*". Briefly, benzo(a)pyrene (BaP) is analysed as part of the captured PM_{10} matter. BaP samples are extracted from captured PM_{10} then analysed by high performance liquid chromatography (HPLC) with fluorescence detection (FLD) or by gas chromatography with mass spectrometric detection (GC/MS). The target value for BaP is 1 ng/m^3 averaged over one calendar year

Summary list of ambient air quality pollutants and limit concentrations.

Pollutant	Units	Limit concentration	Averaging period
$PM_{2.5}$	µg/m^3	25 µg/m^3	1 year
PM_{10}	µg/m^3	50 µg/m^3	24 hours
PM_{10}	µg/m^3	40 µg/m^3	1 year
NO_2	µg/m^3	200 µg/m^3	1 hour
NO_2	µg/m^3	40 µg/m^3	1 year
SO_2	µg/m^3	350 µg/m^3	1 hour
SO_2	µg/m^3	125 µg/m^3	24 hours
CO	mg/m^3	10 mg/m^3	Maximum daily 8-hour mean
O_3	µg/m^3	120 µg/m^3	Maximum daily 8-hour mean
PAHs	ng BaP/m^3	1 ng/m^3	1 year

Scale of measurement: District to regional scale

Required data: Pollutant measurement data from municipalities and regional, national and European authorities

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Continuous measurements with hourly, daily, monthly, and yearly averages

Level of expertise required: Moderate

Connection to other indicators: Indicators of the *Air Quality* group

Connection to SDGs: SDG 3 Good health and well-being; SDG 11 Sustainable cities and communities; SDG 15 Life on land

Key References

Directive 2015/1480 of 28 August 2015 amending several annexes to Directives 2004/107/EC and 2008/50/EC of the European Parliament and of the Council laying down the rules concerning reference methods, data validation and location of sampling points for the assessment of ambient air quality

Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe

Directive 2004/107/EC of the European Parliament and of the Council of 15 December 2004 relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air

Costa, S., Ferreira, J., Silveira, C., Costa, C., Lopes, D., Relvas, H., … Teixeira, J.P. (2014). Integrating Health on Air Quality Assessment - Review Report on Health Risks of Two Major European Outdoor Air Pollutants: PM and NO_2. Journal of Toxicology and Environmental Health - Part B Critical Reviews, 17(6), 307-340.

European Environment Agency. (2018b). Air quality in Europe – 2018 report. EEA Report No. 12/2018. Luxembourg: Publications Office of the European Union. Retrieved from https://www.eea.europa.eu/publications/air-quality-in-europe-2018

Health Effects Institute (HEI). (2018). State of Global Air 2018. Special Report. Boston, MA: Health Effects Institute.

International Organization for Standardization (ISO). (2018). Sustainable cities and communities — Indicators for city services and quality of life (ISO 37120:2018). Available from https://www.iso.org/standard/68498.html

Miranda, A.I., Martins, H., Valente, J., Amorim, J.H., Borrego, C., Tavares, R., … Alonso, R. (2017). Case Studies: modeling the atmospheric benefits of urban greening, In D. Pearlmutter, C. Calfapietra, R. Samson, L. O'Brien,S. Ostoic, G. Sanesi, R. Alonso (Eds.), The Urban Forest. Cultivating Green Infrastructures for People and the Environment (pp. 89-99). New York: Springer International Publishing.

National Oceanic and Atmospheric Administration (NOAA). (n.d.). Weather Research and Forecasting model coupled to Chemistry (WRF-Chem). Retrieved from https://ruc.noaa.gov/wrf/wrf-chem/

World Health Organization (WHO). (2016). Ambient air pollution: A global assessment of exposure and burden of disease. Geneva: World Health Organization. Retrieved from https://www.who.int/phe/publications/air-pollution-global-assessment/en/

12.7.2 Proportion of population exposed to ambient air pollution

Metric: *Urban population exposed to air pollutant concentrations above EU standards and WHO air quality guidelines. The following units are used in this indicator:*

Concentration:

micrograms (µg) of pollutant per cubic metre for $PM_{2.5}$, PM_{10}, O_3, NO_2 and SO_2

Nanograms (ng) of pollutant per cubic metre for BaP

Urban population (POP): number of inhabitants in the 'core city' and, from 2016 on, 'greater city' of the Urban Audit cities represented by the urban stations taken into account in the calculations

Percentage of the urban population

Strengths: *Accurate results with automated measurements. Based on the reported monitoring data by Member States*

Weaknesses: *Some of the measurement systems can be expensive and require continual management and upkeep. Methodological uncertainty, data uncertainty and rationale uncertainty*

High population densities in urban areas and related economic activities result in increased emissions of air pollutants, which in turn lead to higher ambient concentrations of these

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

pollutants and higher rates of human exposure. Urban areas across the European Union (EU) arehome to more than 70% of the population of the EU-28 (Eurostat, 2014b).

The latest World Health Organization (WHO) review of the health effects of air pollution (WHO, 2013) concluded that particulate matter (PM), ozone (O_3) and nitrogen dioxide (NO_2) observed at levels commonly present in Europe have adverse health effects of. A 2013 assessment by the WHO's International Agency for Research on Cancer (IARC) (D. Loomiset al., 2013) concluded that outdoor air pollution is carcinogenic to humans, with the particulate matter component of air pollution most closely associated with an increased incidence of cancer, especially lung cancer. This is in addition to the role air pollution plays in the development of heart and respiratory diseases, including acute respiratory infections and chronic obstructive pulmonary diseases.

This indicator focuses on the air pollutants that are more relevant in terms of their health effects and urban concentrations: PM — both PM_{10} (particles with a diameter of 10 micrometres or less) and fine PM, or $PM_{2.5}$ (particles with a diameter of 2.5 micrometres or less); O_3; NO_2; sulphur dioxide (SO_2); and benzo[a]pyrene (BaP).

According to several WHO studies (WHO, 2000, 2006, 2013, 2014), exposure to PM can cause or aggravate cardiovascular and lung diseases, heart attacks and arrhythmias. It can also affect the central nervous system, the reproductive system and cause cancer. Exposure to high O_3 concentrations can cause breathing problems, trigger asthma, reduce lung function and cause lung diseases. Exposure to NO_2 increases symptoms of bronchitis in asthmatic children and reduces lung function growth. SO_2 can affect the respiratory system and the functioning of the lungs, and causes irritation of the eyes. Finally, BaP is carcinogenic and is used as an indicator of the carcinogenic effect of the total polycyclic aromatic hydrocarbons (PAHs).

This indicator can be used to assess the impact of the NBS implantation using data before and after the implementation or to compare data in cities with different level of NBS or GI implantation.

Urban population exposure

Information on cities is obtained from the Urban Audit (UA) data (Eurostat, 2014c). The urban population considered is the total number of people represented by any of the urban monitoring stations in the 'core city' and, from 2016, the 'greater city' of the UA cities taking part in the calculations. Initially, stations in the EEA air-quality database are spatially joined with UA core and, from 2016, greater cities in a geographical information system in order to select those stations that fall within the boundaries of the cities included in the UA collection. The selected stations include station types classified as 'urban traffic', 'suburban traffic', 'urban background' and 'suburban background'.

According to a study for the European Commission by Entec UK Limited (EC, 2006), in Europe, on average, 5% of the city population lives closer than 100 m from major routes and is therefore potentially exposed to concentrations measured at traffic stations. The remaining 95% of the city population is assumed to be exposed to urban and suburban background concentrations. These percentages vary among jurisdictions. To calculate the percentages of persons living closer than 100 m to major traffic routes, national data on the population living closer than 100 m from major roads can been taken from Appendix D (EC, 2006).

For PM_{10}, $PM_{2.5}$, O_3, NO_2 and SO_2, only stations with at least 75% of valid data per calendar year are used. For BaP, the minimum data time coverage accepted is 14% (51 days), according to the data quality objectives related to indicative measurements in the Directive 2004/107/EU (EU, 2004).

For each year, each city (i) in country (j), and every pollutant, the total number of urban or suburban traffic stations (nit) and the total number of urban or suburban background stations (nib) are obtained. A percentage (Ptj %) of the total population of the city (Popi) is proportionally assigned to each of the traffic stations and Pbj % of Popi is proportionally assigned to each of the background stations. Thus, every traffic station has an allocated population equal to ((Ptj / 100) * Popi / nit) and every background station has an allocated population equal to ((Pbj /100) *Popi / nib).

EU limit and target values

Fine particulate matter ($PM_{2.5}$)

The annual mean concentration is calculated for each of the selected stations fulfilling the valid data criteria. Depending on the mean concentration, each station (and its allocated population) is then classified uniquely in one of the two concentration classes (less than or equal to the target value (25 $\mu g/m^3$), or greater than the target value).

The percentage of the urban population allocated to these two concentration classes is calculated by dividing the population represented by the stations assigned to each concentration class by the sum of the population assigned to each station.

Coarse particulate matter (PM_{10})

For each selected station that fulfils the valid data criteria, the 90.4 percentile (P90.4) of the daily mean concentration series is calculated. P90.4 represents, in a complete series of 365 elements, the 36th highest value. When P90.4 is less than or equal to 50 $\mu g/m^3$, it indicates that the daily limit value (DLV) was not exceeded on more than 35 days.

Depending on the value of P90.4, each station (and its allocated population) is then classified uniquely in one of the two concentration classes (P90.4 > 50 $\mu g/m^3$, i.e., greater than the DLV and P90.4 ≤ 50 $\mu g/m^3$, i.e., less than the DLV).

The percentage of the urban population allocated to these two concentration classes is calculated by dividing the population represented by the stations assigned to each individual concentration class by the sum of the population assigned to each station.

Ozone (O_3)

For each selected station fulfilling the valid data criteria, the 93.2 percentile (P93.2) of the daily maximum 8-hourly mean concentration series is calculated. P93.2 represents, in a complete series of 365 elements, the 26th highest value. When P93.2 is less than or equal to 120 $\mu g/m^3$, it indicates that the long term objective was not exceeded on more than 25 days.

Depending on the value of P93.2, each station (and its allocated population) is then classified uniquely in one of the two concentration classes (P93.2 >120 $\mu g/m^3$, i.e., exceedance of the long term objective on more than 25 days, and P93.2 ≤120 $\mu g/m^3$, i.e., exceedance of the long term objective on fewer than or equal to 25 days).

The percentage of the urban population allocated to these two concentration classes is calculated by dividing the population represented by the stations assigned to each individual concentration class by the sum of the population assigned to each station.

Nitrogen dioxide (NO_2)

The annual mean concentration is calculated for each of the selected stations that fulfills the valid data criteria.

Depending on the annual mean concentration, each station (and its allocated population) is then classified uniquely in one of the two concentration classes (less than or equal to the limit value (40 $\mu g/m^3$), or greater than the limit value).

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

The percentage of the urban population allocated to these two concentration classes is calculated by dividing the population represented by the stations assigned to each concentration class by the sum of the population assigned to each station.

Benzo[a]pyrene (BaP)

The annual mean concentration is calculated for each of the selected stations fulfilling the valid data criteria.

Depending on the mean concentration, each station (and its allocated population) is then classified uniquely in one of the two concentration classes (less than or equal to the target value (1.0 ng/m^3), or greater than the target value).

The percentage of the urban population allocated to these two concentration classes is calculated by dividing the population represented by the stations assigned to each concentration class by the sum of the population assigned to each station.

Sulfur dioxide (SO_2)

For each selected station that fulfills the valid data criteria, the 99.2 percentile (P99.2) of the daily mean concentration series is calculated. P99.2 represents, in a complete series of 365 elements, the 4th highest value. When P99.2 is less than or equal to 125 µg/m^3, it indicates that the daily limit value would was not exceeded on more than three days.

Depending on the value of P99.2, each station (and its allocated population) is then classified uniquely in one of these two concentration classes (P99.2 >125 µg/m^3, i.e., greater than the daily limit value and P99.2 ≤125 µg/m^3, i.e., less than the daily limit value).

The percentage of the urban population allocated to these two concentration classes is calculated by dividing the population represented by the stations assigned to each individual concentration class by the sum of the population assigned to each station.

For a more detailed description of the indicator, please follow the link in the first reference listed below.

Scale of measurement: At sampling points as indicated by the data resolution needed to quantify NBS impacts. EEA data are provided at district to region scale. Data regarding microclimatic impacts of NBS can be obtained by installation of specific sensors in close proximity to implemented NBS.

Required data: Air quality measurements or records, for example

- Gisco - Urban Audit 2012 provided by Statistical Office of the European Union (Eurostat)
- AirBase provided by European Environment Agency (EEA)
- Air Quality e-Reporting (AQ e-Reporting) provided by European Environment Agency (EEA)

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually

Level of expertise required: Moderate

Connection to other indicators: Related to *Number of days during which air quality parameters exceed threshold values* and the other indicators of the *Air Quality* group.

Connection to SDGs: SDG 3 Good health and well-being; SDG 11 Sustainable cities and communities; SDG 15 Life on land

Key References

EC, 2006 - Development of a methodology to assess the population exposed to high levels of noise and air pollution close to major transport infrastructure, prepared by Entec UK Limited (Appendix D).

ETC/ACC, 2009 - Indicators on urban air quality. A review of current methodologies. ETC/ACC Technical paper 2009/8 (http://acm.eionet.europa.eu/reports/ETCACC_TP_2009_8_UrbanAQindicators)

EU, 2004 - Directive 2004/107/EC of the European Parliament and of the Council of 15 December 2004 relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32004L0107

Eurostat, 2014c - Urban Audit. (http://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units/urban-audit).https://www.eea.europa.eu/data-and-maps/indicators/exceedance-of-air-quality-limit-3/assessment-5

https://www.eea.europa.eu/data-and-maps/indicators/exceedance-of-air-quality-limit-3/assessment-5

12.7.3 Modelled O_3, SO_2, NO_2 and CO capture/removal by vegetation

Metric: *Annual capture of O_3, SO_2, NO_2, CO and $PM_{2.5}$ by trees and shrubs and grass (all expressed in units of mass)*

Strengths: *Effective method for extensive analyses*

Weaknesses: *Needs expert users and a lot of input data*

Vegetation can remove air pollutants (particles and gases) by the process of dry deposition. Deposition is the transport from a point in the air to a plant surface, which is mainly related to near-surface pollutant concentration, weather conditions and vegetation properties. Most plants have a large surface area per unit volume, increasing the probability of deposition compared with the smooth, manufactured surfaces present in urban areas. For example, 10-30 times faster deposition has been reported for sub-micrometre (<1 µm) particles on synthetic grass compared with glass and cement surfaces (Air Quality Expert Group [AQEG], 2013; Roupsard, Amielh, Maro, Coppalle, & Branger, 2013). To estimate the magnitude of this contribution models are commonly used.

The chemical transport model WRF-Chem (National Oceanic and Atmospheric Administration [NOAA], n.d.) has a dry deposition model that can estimate the amount of pollutants removed by vegetation (O_3, NOX, VOC, PM_{10} and $PM_{2.5}$) with an hourly resolution per grid cell. As input data WRF-Chem requires:

i. high resolution inventory of anthropogenic emissions
ii. biogenic emissions (MEGAN model; Guenther et al., 2006)
iii. initial and boundary conditions (MOZART model; Emmons et al., 2010), and
iv. topography and land use (United States Geological Survey [USGS] 33 classes database; Pineda et al., 2004)

These results can be used to calculate the annual amount of pollutants removed by vegetation at the grid, neighbourhood or city scale.

The i-Tree Eco model (USDA Forest Service, 2019) can also be applied to estimate the air pollutants removed by vegetation. Although it does not provide spatial variability, it can calculate hourly amounts of pollutants removed by urban forests, as well as the associated percentage of air quality improvement throughout a year. Pollution removal is calculated for ozone (O_3), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO) and particulate matter ($PM_{2.5}$). To apply the i-Tree Eco model, the following data is required:

i. extent of vegetation cover and characteristics (e.g., type, age and height)

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

ii. land use
iii. air quality
iv. meteorology

Results can be used to calculate the annual amount of pollutants removed by vegetation at the local scale.

Scale of measurement: Street to metropolitan scale

Required data: Various requirements based on the model type

Data generation specifications: Qualitative and quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Before and after the NBS implementation

Level of expertise required: Moderate to High – to apply models and evaluate the outcomes

Connection to other indicators: Other indicator group *Air quality* indicators

Connection to SDGs: SDG 3 Good health and well-being, SDG 15 Life on land

Key References

Air Quality Expert Group [AQEG]. (2018). *Impacts of Vegetation on Urban Air Pollution*. Prepared for Department for Environment, Food and Rural Affairs, Scottish Government, Welsh Government, and Department of the Environment in Northern Ireland. Carlisle, UK: Department for Environment, Food and Rural Affairs. Retrieved from https://uk-air.defra.gov.uk/assets/documents/reports/cat09/1807251306_180509_Effects_of_vegetation_on_urban_air_pollution_v12_final.pdf.

Emmons, L.K., Walters, S., Hess, P.G., Lamarque, J.-F-, Pfister, G.G., Fillmore, D. … Kloster, S. (2010). Description and evaluation of the Model for Ozone and Related chemical Tracers, version 4 (MOZART-4). *Geoscientific Model Development, 3*, 43-67.

Guenther, A., Karl, T., Harley, P., Wiedinmyer, C., Palmer, P.I., & Geron, C. (2006). Estimates of global terrestrial isoprene emissions using MEGAN (Model of Emissions of Gases and Aerosols from Nature). *Atmospheric Chemistry and Physics, 6*(11), 3181–3210.

United States Department of Agriculture (USDA) Forest Service. (2019). *i-Tree Eco Manual*. Northern Research Station, USDA Forest Service. Retrieved from https://www.itreetools.org/resources/manuals/Ecov6_ManualsGuides/Ecov6_UsersManual.pdf

National Oceanic and Atmospheric Administration (NOAA). (n.d.). *Weather Research and Forecasting model coupled to Chemistry (WRF-Chem)*. Retrieved from https://ruc.noaa.gov/wrf/wrf-chem/

Pineda, N., Jorba, O., Jorge, J., & Baldasano, J.M. (2004). Using NOAA AVHRR and SPOT VGT data to estimate surface parameters: application to a mesoscale meteorological model. *International Journal of Remote Sensing, 25*(1), 129–143.

Roupsard, P., Amielh, M., Maro, D., Coppalle, A., & Branger, H. (2013). Measurement in a wind tunnel of dry deposition velocities of submicron aerosol with associated turbulence onto rough and smooth urban surfaces. *Journal of Aerosol Science, 55*, 12-24.

12.7.4 Ambient pollen concentration

Metric: *Number of grains of pollen per cubic metre of air (pollen grains/m^3)*

Strengths: *The results are widely accepted and known to be consistent*

Weaknesses: *The method of identifying and characterising trapped pollen and spores is time-consuming and requires considerable expertise*

Urban green spaces frequently have a limited number of plant species, including a higher proportion of non-native species in comparison with rural areas (McKinney, 2002). The low species diversity in many urban areas is directly linked to the formation of concentrated pollen emission sources. In particular, large-scale use of a small number of roadside tree species results in production of large quantities of a single species of pollen. Areas of concentrated pollen may not be readily dispersed by air currents. Some studies indicate that urban citizens are 20% more likely to suffer airborne pollen allergies than people living in rural areas, largely due to the uniformity of green spaces, where a small number of species that have proved highly suited to urban environmental conditions are overwhelmingly used, and the interaction of pollen with air pollutants (Cariñanos & Casares-Porcel, 2011).

The volumetric Hirst-type pollen and spore trap designed in 1952 remains one of the devices most commonly used for pollen and spore monitoring (Buters et al., 2018). The Hirst-type trap is standard in pollen monitoring networks in Europe. The Hirst-type pollen and spore trap uses a vacuum pump to continuously draw air at a known rate (e.g., 10 L/min). A wind vane attached to the sampler head ensures that the trap inlet is always facing the prevailing wind. Depending on the configuration of the trap, pollen and spores are captured on adhesive coated transparent plastic tape (Melinex) or on a microscope slide coated with an adhesive. Adhesive tapes are attached to a metal drum that rotates with time.

Pollen traps can be fitted with a drum specific to a 24-h or a 7-day sampling period. At the conclusion of the sampling period, the tape with adhered pollen and spores is cut into pieces representing 24-h periods of time and mounted on a microscope slide. Where the pollen and spores are captured directly on a microscope slide, the slide must be changed every 24 h. These slides are examined by microscopy for counting and identification of pollen and spores.

Scale of measurement: Plot to neighbourhood scale

Required data: Pollen measurement data

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Continuous collection with a 24 h or a 7-day sampling period

Level of expertise required: Moderate

Connection to other indicators: Synergies with *Distribution of public green space*, *Accessibility of urban green spaces,* and *Proportion of natural area,* and *Availability and equitable distribution of blue-green space* indicators

Connection to SDGs: SDG 3 Good health and well-being, SDG 15 Life on land

Key References

Buters, J.T.M., Antunes, C., Galveias, A., Bergmann, K.C., Thibaudon, M., Galán, C. … & Oteros, J. (2018). Pollen and spore monitoring in the world. *Clinical and Translational Allergy, 8*, 9.

Cariñanos, P., & Casares-Porcel, M. (2011). Urban green zones and related pollen allergy: A review. Some guidelines for designing spaces with low allergy impact. *Landscape and Urban Planning, 101*(3), 205-214.

McKinney, M. (2002). Urbanization, Biodiversity, and Conservation: The impacts of urbanization on native species are poorly studied, but educating a highly urbanized human population about these impacts can greatly improve species conservation in all ecosystems. *BioScience, 52*(10), 883-890.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

12.7.5 Concentration of particulate matter (PM_{10} and $PM_{2.5}$), NO_2, and O_3 in ambient air

Metric: *Concentration of $PM_{2.5}$, PM_{10}, NO_2 and ground-level O_3 ($\mu g/m^3$) in ambient air*

Strengths: *Accurate results with automated measurements*

Weaknesses: *Some of the measurement systems can be expensive and they need constant management and upkeep*

Air pollution is considered the single largest environmental health risk in the world, causing an estimated 2-6 million or more yearly deaths globally (Health Effects Institute [HEI], 2018; World Health Organisation [WHO], 2016). An important focus of research has been on the role of urban vegetation in the formation and removal of air pollutants in cities (e.g., Miranda et al., 2017) and the associated impacts of air pollution on morbidity, mortality and life-expectancy (e.g., Costa et al., 2014). The most relevant pollutants in air are particulate matter of different sizes (PM2.5, PM10), ozone (O_3), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), polycyclic aromatic hydrocarbons (PAHs), carbon monoxide (CO), benzene (C_6H_6) and toxic metals (As, Cd, Ni, Pb and Hg) (EEA, 2018b). Whilst different pollutants can have large local effects, the most prevalent pollutants with most serious health effects are particulate matter, ozone and nitrogen dioxide, which are selected for metrics here.

Air pollution concentrations can be estimated based on measured and/or modelled concentrations in ambient air (O_3, NOx, VOC, PM_{10} and $PM_{2.5}$) near the NBS intervention area. Data can be retrieved from air quality monitoring stations or from measured values during experimental campaigns. Data can also be estimated by applying air quality models, such as the WRF-Chem model (National Oceanic and Atmospheric Administration [NOAA], n.d.), which estimates 3D concentration fields with an hourly resolution at the grid, neighbourhood or city scale.

Particulate matter (PM_{10} and $PM_{2.5}$) concentration

Particulate matter is measured using an air sampler that draws ambient air at a constant flow rate through a specially shaped inlet onto a filter that is weighed periodically to measure the accumulated particle load. The inlet defines the particle size cut-off (2.5 or 10 µm). A stationary measuring station is placed in a representative traffic, urban, industrial or rural location and continuous measurement of particulate matter using standardized air sampler equipment is undertaken. Daily averages are averaged over a year to reach a yearly average, which acts as the indicator (ISO, 2018).

Nitrogen dioxide (NO2) concentration

To quantify nitrogen dioxide, a stationary measuring station is placed in a representative traffic, urban, industrial or rural location and continuous measurement of nitrogen dioxide using standardized equipment is undertaken. An average of hourly averages is used to calculate a daily average and daily averages to calculate a yearly average, which acts as the indicator (ISO, 2018).

Ground-level ozone (O_3) concentration

A stationary measuring station is placed in a representative traffic, urban, industrial or rural location and continuous measurement of ozone using standardized equipment is undertaken. The convention for ozone measurement is to calculate a daily maximum 8-hour mean, which acts as the indicator (ISO, 2018).

Scale of measurement: District to region scale

Required data: Pollutant measurement data

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Continuous measurements with hourly, daily, monthly, and yearly averages

Level of expertise required: Low – for continuous measurements; Moderate – for evaluating data artefacts

Connection to other indicators: Other indicators in the *Air quality* indicator group

Connection to SDGs: SDG 3 Good health and well-being, SDG 15 Life on land

Key References

Costa, S., Ferreira, J., Silveira, C., Costa, C., Lopes, D., Relvas, H., … Teixeira, J.P. (2014). Integrating Health on Air Quality Assessment - Review Report on Health Risks of Two Major European Outdoor Air Pollutants: PM and NO2. *Journal of Toxicology and Environmental Health - Part B Critical Reviews, 17*(6), 307-340.

European Environment Agency. (2018b). *Air quality in Europe – 2018 report*. EEA Report No. 12/2018. Luxembourg: Publications Office of the European Union. Retrieved from https://www.eea.europa.eu/publications/air-quality-in-europe-2018

Health Effects Institute (HEI). (2018). *State of Global Air 2018*. Special Report. Boston, MA: Health Effects Institute.

International Organization for Standardization (ISO). (2018). *Sustainable cities and communities — Indicators for city services and quality of life (ISO 37120:2018).* Available from https://www.iso.org/standard/68498.html

Miranda, A.I., Martins, H., Valente, J., Amorim, J.H., Borrego, C., Tavares, R., … Alonso, R. (2017). *Case Studies: modeling the atmospheric benefits of urban greening*, In D. Pearlmutter, C. Calfapietra, R. Samson, L. O'Brien,S. Ostoic, G. Sanesi, R. Alonso (Eds.), The Urban Forest. Cultivating Green Infrastructures for People and the Environment (pp. 89-99). New York: Springer International Publishing.

National Oceanic and Atmospheric Administration (NOAA). (n.d.). *Weather Research and Forecasting model coupled to Chemistry (WRF-Chem).* Retrieved from https://ruc.noaa.gov/wrf/wrf-chem/

World Health Organization (WHO). (2016). *Ambient air pollution: A global assessment of exposure and burden of disease.* Geneva: World Health Organization. Retrieved from https://www.who.int/phe/publications/air-pollution-global-assessment/en/

12.7.6 Morbidity, Mortality and Years of Life Lost due to poor air quality

Metric: *(Years of life lost) Reduction in years of life (y) due to premature mortality in comparison with standard life expectancy*

(Morbidity): Long-term (annual) incidence of chronic bronchitis due to poor air quality calculated using atmospheric NO_2 and PM_{10} data

(Mortality): Long-term (annual) incidence of mortality due to poor air quality calculated using atmospheric $PM_{2.5}$, PM_{10}, O_3 and NO_2 data

Strengths: *The indicator is easy to define*

Weaknesses: *The method needs corresponding air pollutant concentration, demographic and epidemiological input data*

Air pollution has been related to numerous adverse health effects, typically expressed in several morbidity and mortality endpoints (see Costa et al., 2014). In particular, an increasing amount of epidemiological and clinical studies observes that exposure to air pollution is associated with increased risk of heart disease, myocardial infarction and stroke as well as lung cancer (e.g., Costa et al., 2014). While the impact of these health effects may appear low at the individual level, the overall public-health burden is sizable as the entire population is exposed (Pascal et al., 2011).

The general approach in health impact assessment is to use exposure-response functions, linking the concentration of pollutants to which the population is exposed to the number of health events occurring in that population (Costa et al., 2014; Silveira et al., 2016). Therefore, the following aspects are usually considered: i) involved pollutants and their air concentration levels, ii) health indicators analysed in terms of morbidity and mortality, iii) affected age groups, and iv) exposure time. The health response is usually calculated by:

$$\Delta R = IR \times CRF \times \Delta C \times Pop$$

Where,

- *ΔR* is the response as a result of the number of the unfavourable implications (cases, days or episodes) over all health indicators;
- *IR* is the baseline morbidity/mortality annual rate (%); this information is available in the national statistical institute of each country;
- *CRF* is the correlation coefficient between the pollutant concentration variation and the probability of experiencing a specific health indicator (%; i.e., Relative Risk (RR) associated with a concentration change of 1 μg m^{-3});
- *ΔC* indicates the change in the pollutant concentration (μg ·m^{-3}) after adoption of the adaptation/mitigation measure;
- *Pop* is the population units per age group exposed to pollution.

Morbidity (chronic bronchitis) due to poor air quality is calculated using NO_2 and PM_{10} to determine CRF and ΔC in the preceding equation.

Mortality, assessed as total mortality, is calculated using PM_{10}, $PM_{2.5}$, O_3 and NO_2 to determine CRF and ΔC in the preceding equation.

Both morbidity and mortality are based on long-term (annual) effects (Table). Where air quality data are derived from WRF-Chem results can be calculated on a daily/weekly/monthly/annual basis at the grid, neighbourhood or city scale.

Table. Air pollutant health indicators (WHO, 2013)

Pollutant	Health outcome	Age group
PM_{10}	Chronic bronchitis (incidence)	>18 y
	Chronic bronchitis (prevalence)	6-18 y
	Total mortality	<1 y
		>30 y
$PM_{2.5}$	Total mortality	>30 y
NO_2	Total mortality	>30 y
	Prevalence of bronchitic symptoms in asthmatic children	5–14 y
O_3 (April-September)	Total mortality (respiratory diseases)	>30 y

Years of life lost (YoLL) is an often-used health indicator, and refers to the total number of years of reduced life due to premature mortality. Using the mortality indicator, the YoLL can be calculated as the number of deaths multiplied by a standard life expectancy at the age at which death occurs (see Gardner & Sanborn, 1990).

Scale of measurement: Street to metropolitan scale

Required data: i) involved pollutants and their air concentration levels, ii) health indicators analysed in terms of morbidity and mortality, iii) affected age groups, and iv) exposure time

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Daily, weekly, monthly or annually

Level of expertise required: Moderate

Connection to other indicators: Other indicators in the *Air quality* indicator group

Connection to SDGs: SDG 3 Good health and well-being, SDG 15 Life on land

Key References

Costa, S., Ferreira, J., Silveira, C., Costa, C., Lopes, D., Relvas, H., … Teixeira, J.P. (2014). Integrating Health on Air Quality Assessment-Review Report on Health Risks of Two Major European Outdoor Air Pollutants: PM and NO2. *Journal of Toxicology and Environmental Health - Part B Critical Reviews, 17*(6), 307-340.

Gardner, J.W., & Sanborn, J.S. (1990). Years of potential life lost (YPLL) – what does it measure? *Epidemiology (Cambridge, Mass.), 1*(4), 322–329.

Pascal, M., Corso, M., Ung, A., Declercq, C., Medina, S. & Aphekom. (2011). *APHEKON-Improving knowledge and communication for decision making on air pollution and health in Europe, Guidelines for assessing the health impacts of air pollution in European cities*, Work Package 5, Deliverable D5. Saint-Maurice, France: French Institute for Public Health Surveillance.

Silveira C., Roebeling P., Lopes M., Ferreira J., Costa S., Teixeira J.P., ... Miranda A.I. (2016). Assessment of health benefits related to air quality improvement strategies in urban areas: An Impact Pathway Approach. *Journal of Environmental Management, 183*, 694-702.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

12.8 Place Regeneration

The goal of urban regeneration is to create enduring improvements in the physical, economic, social and environmental conditions of an urban area. Nature-based solutions are well-suited to achievement of improved conditions across multiple spheres per the capacity for NBS to simultaneously address multiple different environmental, social and economic challenges. Nature-based solutions have significant potential to contribute to sustainable urban (re)development, for example by ensuring access of all citizens to high-quality green and blue spaces, increasing the resilience of local areas to natural disasters through implementation of appropriate NBS, fostering a sense of community through collaborative design, implementation and management of NBS, etc. The indicators presented herein under Place Regeneration address both the quality of the regeneration process as well as its outcomes.

Table 23. Indicators of NBS performance and impact related to Urban Regeneration

Nr.	Indicator	Units	Class	Applicability to NBS		
				Type 1	Type 2	Type 3
11.8.1 †	Derelict land reclaimed for NBS	ha	O			●
11.8.2 †	Quantity of blue-green space as ratio to built form	Nr. (0-1), unitless	O	●		●
11.8.3	Area devoted to roads	Nr. (0-1), unitless	O	●		●
11.8.4 †	Preservation of cultural heritage	Nr. (1-5), unitless	P	●	●	
11.8.5	Economic activity: Retail and commercial activity in proximity to green space	%	O	●		●
11.8.6 †	Incorporation of environmental design in buildings	Nr. (0-5), unitless	P			●
11.8.7	Design for sense of place	Nr, (1-5), unitless	P	●		●

† Indicators designated "recommended" by NBS Impact Evaluation Taskforce (Taskforce 2; Dumitru and Wendling, Eds., *in preparation*)

12.8.1 Derelict land reclaimed for NBS

Metric: *Reclamation of idle/derelict and/or contaminated land (brownfields), expressed as total area, area per capita or % of contaminated area reclaimed*

Strengths: *Simple and easy to calculate. Provides a measure that can be easily followed*

Weaknesses: *Definition and classification of areas as brownfield is not rigorously defined, and thus comparison between areas and countries can be misleading without closer case studies*

Brownfield land refers to urban developed areas that are currently idle. Typically, they are sites of previous commercial or industrial activities, which might have detected or suspected pollution and soil contamination problems, hindering their future development. Redeveloping brownfields can save pristine green spaces from development as well as reclaim unused spaces into meaningful application (University of the West of England [UWE] Science Communication Unit, 2013).

Idle, developed areas within the community are identified and their combined surface area is calculated using maps. This is done yearly and the percentage change in the area is reported, as well as the actual area remaining.

Scale of measurement: Street to metropolitan scale

Required data: Proportion of idle/derelict and/or contaminated land (brownfields) redeveloped each year for productive use via implementation of NBS, and the absolute area of identified brownfield remaining

Data generation specifications: Quantitative; participatory data collection is feasible through citizens' reports on brownfield areas in their communities

Data generation/collection frequency: Annually

Level of expertise required: Low

Connection to other indicators: Not identified

Connection to SDGs: SDG 9 Industry, infrastructure and innovation, SDG 11 Sustainable cities and communities, SDG 13 Climate action

Key References

University of the West of England (UWE) Science Communication Unit. (2013). *Science for Environment Policy (issue 39): Brownfield Regeneration*. Bristol, United Kingdom: University of the West of England Science Communication Unit.

12.8.2 Quantity of blue-green space as ratio to built form

Metric: *Ratio of open spaces to built form within a defined urban area (ratio)*

Strengths: *Simple and easy to use*

Weaknesses: *Large uncertainties of inclusion of all relevant urban features*

Urban space and environment can have an effect in resident health, resilience to weather events and even crime rate, and access to green urban space is seen as positive. Several terms and definitions have been used including green space, open space, public space, urban greenery and public park. Benefits of open spaces relate to both their materials and functions: the increased biodiversity and ecosystem services that increased vegetation and soil permeability and water retention can offer, as well as the potential increased social benefits of open meeting spaces, areas for recreation, sports and relaxation (WHO, 2016).

The simplest method is to measure the proportional area physically occupied by buildings. This method however does not take into account any other form of non-building space that not considered beneficial open space, such as roads and parking lots.

Another simple method would be to calculate the green space of urban area, based on surface type counting hard impermeable surfaces as grey areas and soft permeable surfaces as green areas. This method misses all covered parks and terraces, which can form a large portion of open areas in urban environments, even if they are not green areas (Jim, 2004).

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

For the purpose of this indicator, a suitable parameter is the selection of all urban green areas, added with selected open 'grey' open areas, such as public squares or pedestrian precincts. The total area covered by buildings is calculated from maps or appropriate sources. The green area is calculated and selected grey open areas are added. The ratio of the open area to the building area is calculated.

Scale of measurement: Street to metropolitan scale

Required data: Amount of green spaces, buildings and other infrastructure assets in the urban area

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually

Level of expertise required: Low

Connection to other indicators: Relation to *Derelict land reclaimed for NBS* indicator and to the whole *Green Space Management* indicator group

Connection to SDGs: SDG 9 Industry, infrastructure and innovation, SDG 11 Sustainable cities and communities, SDG 13 Climate action

Key References

Jim, C. (2004). Green-space preservation and allocation for sustainable greening of compact cities. *Cities, 21*(4), 311-320.

University of the West of England (UWE) *Science Communication Unit. (2013). Science for Environment Policy (issue 39): Brownfield Regeneration*. Bristol, United Kingdom: University of the West of England Science Communication Unit.

World Health Organization. (2016). *Urban green spaces and health: A review of evidence*. Copenhagen: WHO Regional Office for Europe. Retrieved from http://www.euro.who.int/__data/assets/pdf_file/0005/321971/Urban-green-spaces-and-health-review-evidence.pdf?ua=1

12.8.3 Area devoted to roads

Metric: *Total proportion of a defined urban area devoted to roadways for motorised vehicle use only (ratio or fraction)*

Strengths: *Simple and easy to use*

Weaknesses: *Undefined threshold values for the total area/roads area ratio*

Roads are open areas, but depending on the road type, typically do not yield the same positive effects associated with the open urban areas/urban public spaces. Roadways are generally non-permeable, and depending on the road type, are inaccessible and potentially dangerous, produce air, light and noise pollution, and form barriers to movement and ecological compartmentalization.

The total area covered by grey roads for cars is calculated from maps or estimated from appropriate sources, and the ratio to the total area is calculated

Scale of measurement: Street to metropolitan scale

Required data: Road type, speed, congestion, traffic type and structure

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually

Level of expertise required: Low

Connection to other indicators: Relation to *CO_2 emissions related to vehicle traffic, Annual air pollutant capture/removal by vegetation, Particulate matter (PM_{10} and $PM_{2.5}$) concentration, Nitrogen dioxide (NO_2) concentration, Ground-level ozone (O_3) concentration* indicators and *Water management* indicator group

Connection to SDGs: SDG 9 Industry, infrastructure and innovation, SDG 11 Sustainable cities and communities

Key References

–

12.8.4 Preservation of cultural heritage

Metric: *The extent to which preservation of local cultural heritage is considered during urban planning (unitless value)*

Strengths: *Simple and straightforward assessment*

Weaknesses: *Subjective evaluation of heritage preservation*

Unlike ecological, economic and social sustainability, culture is not institutionalised as an aspect of sustainable development at present. Hawkes (2001) introduced cultural sustainability as a "fourth pillar" of sustainable development and emphasised the role of cultural heritage in urban planning. Extensive discourse (e.g., UNESCO, 2001; UNESCO, 2005) on the relationship between culture and sustainable development together with numerous scientific studies exploring social and cultural dimensions of sustainability indicate that cultural sustainability is linked to issues such as social equity and social justice, participation and engaged governance, social cohesion, and social capital (Soini & Birkeland, 2014).

The extent to which urban design and heritage conservation are integrated within urban development so that it enhances or connects to the existing character of the place, e.g., preservation, restoration and/or adaptive re-use of historic buildings and cultural landscapes, can be assessed using a five-point Likert scale:

(Not at all) 1 — 2 — 3 — 4 — 5 (Very much)

1. **Not at all**: no attention has been paid to existing cultural heritage in urban planning.

2. **Fair**: heritage places have received some attention in urban planning, but not as an important element.

3. **Moderate**: some attention has been given to the conservation of heritage places.

4. **Much**: heritage places are reflected in urban planning

5. **Very much**: preservation of cultural heritage and connections to existing heritage places are a key element of urban planning.

Scale of measurement: District to regional scale

Required data: Information on preservation of cultural heritage, including built heritage as well as the cultural landscapes within an urban area

Data generation specifications: Qualitative; cannot be collected via participatory processes

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Data generation/collection frequency: Annually

Level of expertise required: Low

Connection to other indicators: Not identified

Connection to SDGs: SDG 11 Sustainable cities and communities

Key References

Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). *CITYkeys indicators for smart city projects and smart cities*. CITYkeys D1.4. Retrieved from http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf

Hawkes, J. (2001). *The Fourth Pillar of Sustainability: Culture's essential role in public planning*. Melbourne, VIC: Common Ground Publishing Pty Ltd in association with the Cultural Development Network (Vic.).

Soini, K., & Birkeland, I. (2014). Exploring the scientific discourse on cultural sustainability. *Geoforum, 51*, 213-223.

Tweed, C., & Sutherland, M. (2007). Built cultural heritage and sustainable urban development. *Landscape and Urban Planning, 83*(1), 62-69.

United Nations Educational, Scientific and Cultural Organization (UNESCO). (2001). *UNESCO Universal Declaration on Cultural Diversity*. Retrieved from https://unesdoc.unesco.org/ark:/48223/pf0000124687.page=67

United Nations Educational, Scientific and Cultural Organization (UNESCO). (2005). *Convention on the Protection and Promotion of the Diversity of Cultural Expressions*. Retrieved from https://unesdoc.unesco.org/ark:/48223/pf0000142919

12.8.5 Economic activity: Retail and commercial activity in proximity to green space

Metric: *Proportion of ground floor surface of buildings within 300 m from the implemented NBS that is used for commercial or public purposes, expressed as percentage of total ground floor surface (%)*

Strengths: *The indicator is easy to define*

Weaknesses: *A lot of input data needs to be collected and processed*

The atmosphere of a neighbourhood and its overall liveability are influenced by the use of ground floor spaces for commercial and public purposes. The availability of amenities not only enhances the consumer experience, but also contributes to successful retail and commerce by supporting small businesses and retailers (Arlington Economic Development, 2014). Residential and office buildings generally have the most potential for increased use of ground floor space.

This metric is calculated as:

$$\left(\frac{Ground\ floor\ space\ for\ commerical\ or\ public\ use\ (m^2)}{Total\ ground\ floor\ space\ (m^2)}\right) \times 100$$

This indicator may be limited to a defined urban area within 300 m from NBS (e.g., an area with a given distance or walking time from implemented NBS).

Scale of measurement: Neighbourhood or district scale

Required data: Data about ground floor space usage can be obtained from administrative documents and/or from interviews with the department for urban planning within the local municipality

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Before and after NBS implementation

Level of expertise required: Low to Moderate

Connection to other indicators: Synergies with the indicators in the *New economic opportunities and Green Jobs* indicator group

Connection to SDGs: SDG 8 Decent work and economic growth, and SDG 9 Industry, innovation and infrastructure

Key References

Arlington Economic Development. (2014). *Ground Floor Retail and Commerce: Policies, Guidelines and Action Plan.* Draft – September 2014. Arlington, VA: Arlington Economic Development Department, Real Estate Development Group. Retrieved from https://www.arlingtoneconomicdevelopment.com/index.cfm?LinkServID=6E1B9F23-AA29-D1AC-1DFE1072C67F5C64&showMeta=0

Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., and Huovila, A. (2017). *CITYkeys indicators for smart city projects and smart cities*. CITYkeys project D1.4. http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf

World Health Organization. (2016). *Urban green spaces and health: A review of evidence*. Copenhagen: World Health Organization.

12.8.6 Incorporation of environmental design in buildings

Metric: *Degree to which buildings are designed to be environmentally friendly with respect to energy efficiency, water consumption, waste production, indoor environmental quality, and implementation of NBS (unitless number, 0-5)*

Strengths: *Simple and easy to use*

Weaknesses: *Crude assessment of environmental design of buildings*

Environmental design is a broad concept concerning the structural, design and systemic features of buildings defining their impact on their environment. It is related to the concept of green buildings, which refers to environmentally sustainable design, construction, operation, maintenance and end of life of buildings.

The area is divided into buildings, groups of buildings or blocks that represent similar building stock, as seen suitable. Each component is assessed on its environmental design considering incorporated environmental design considering parameters listed in Table 1. The building(s) being assessed are scored from 0 to 1 with respect to each parameter. The average point score (0 to 5) of a building provides the indicator value, i.e., the degree to which buildings are designed to be environmentally friendly with respect to these parameters.

Table 1: Parameters for environmental design in buildings (or groups of buildings).

	Parameter	Methods to consider (examples)	Scoring
1	Energy efficiency	Improved insulation Reflecting windows Improved ventilation Heat exchangers in ventilation	0 points: No design incorporated 0.5 points: Some measures taken 1 point: Good measures taken

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

		Smart lighting, smart electronics Renewable electricity (solar/wind) Heat pumps	
2	Water consumption	Low water toilets Separate greywater collection Rainwater collection and use	As no. 1
3	Waste production	Waste separation On-site composting Building material demolition design	As no. 1
4	Environmental quality	Indoor air quality measure/control Indoor/outdoor noise level control Indoor/outdoor lighting level control	As no. 1
5	Nature-based solutions	Incorporation of NBS A green roof Rain garden	As no. 1
	Environmental design		Sum of points

Scale of measurement: District to metropolitan scale

Required data: Energy efficiency, water consumption, waste production, indoor environmental quality, and implementation of NBS of buildings

Data generation specifications: Semi-quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually

Level of expertise required: Low

Connection to other indicators: Some relation to *Rainwater or greywater use for irrigation purposes* indicator; relation to *CO_2 emissions related to building energy consumption* and *Mean or peak daytime temperature – Predicted Mean Vote-Predicted Percentage Dissatisfied* indicators

Connection to SDGs: SDG 6 Clean water and sanitation, SDG 7 Clean and affordable energy, SDG 9 Industry, infrastructure and innovation, SDG 11 Sustainable cities and communities, SDG 13 Climate action

Key References

Doan, D. T., Ghaffarianhoseini, A., Naismith, N., Zhang, T., Ghaffarianhoseini, A., & Tookey, J. (2017). A critical comparison of green building rating systems. *Building and Environment, 123*, 243–260.

Sharifi, A., & Murayama, A. (2013). A critical review of seven selected neighborhood sustainability assessment tools. *Environmental Impact Assessment Review, 38*, 73–87.

Sharifi, A., & Murayama, A. (2014). Neighborhood sustainability assessment in action: Cross-evaluation of three assessment systems and their cases from the US, the UK, and Japan. *Building and Environment, 72*, 243–258.

12.8.7 Design for sense of place

Metric: *The extent to which 'sense of place' is considered during urban planning or during the planning and implementation of a specific project (unitless value)*

Strengths: *Simple and straightforward assessment*

Weaknesses: *Subjective evaluation of people's connectedness and identity with the built environment, and people's perceptions and experiences of the built environment through design*

The phrase "design for a sense of place" relates to a complex concept involving the embodiment of tangible and intangible qualities in the design that make a place distinctive (create an identity). The unique place identity or sense of place in turn fosters authentic human attachment and a feeling of belonging. The sense of place concept arises from the examination of people's connectedness and identity with the built environment, in parallel with evaluation of people's perceptions and experiences of the built environment through design (Hu & Chen, 2018).

Design principles to foster a sense of place include preserving existing elements, ensuring safety and focusing on the creation of places that (Bosch et al., 2017):

- Are welcoming and respond to, or express the values of groups within the community for whom the place is designed;
- Are comprised of several physical and social settings for events and activities that make places pleasant and culturally relevant;
- Are scaled and proportioned to facilitate easy navigation, interaction and overview by the users; and,
- Have identifiable features, landmarks or historical places to enhance visual appeal and orientation.

The extent to which a given NBS project has considered design for a sense of place can be qualitatively rated on a five-point Likert scale:

(Not at all) 1 — 2 — 3 — 4 — 5 (Very much)

1. **Poor**: no attention has been paid to the idea of creating a sense of place in the design of the NBS project; residents are not able identify any distinctive elements.

2. **Fair**: the idea of creating a sense of place has received some attention in the NBS project, but not as an important element.

3. **Average**: some attention has been given in the NBS project design to the idea of creating a sense of place.

4. **Good**: Much attention has been given to the idea of creating a sense of place in the NBS project design.

5. **Very good**: The focus on creating a sense of place in the design is clearly and recognizably present in the NBS project, even for outsiders.

Scale of measurement: Building to municipality scale

Required data: Design, implementation and features of an NBS project

Data generation specifications: Qualitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually, and before and after NBS implementation

Level of expertise required: Low

Connection to other indicators: Some relation to *Cultural heritage*-related indicators

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Connection to SDGs: SDG 11 Sustainable cities and communities, SDG 13 Climate action

Key References

Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). *CITYkeys indicators for smart city projects and smart cities*. CITYkeys D1.4. Retrieved from http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf

Hu, M., & Chen, R. (2018). A framework for understanding sense of place in an urban design context. *Urban Science, 2*(2), 34.

12.9 Knowledge and Social Capacity Building for Sustainable Urban Transformation

Social capacity refers to the relationships between individuals, groups and/or organisations that create an ability to act together to achieve positive outcomes. Knowledge and social capacity building, for example through educational initiatives, can contribute to amassing resources for sustainable urban transitions. Knowledge and Social Capacity Building for Sustainable Urban Transformation was defined as a unique societal challenge area by experts on the NBS Impact evaluation Taskforce (Taskforce 2) between 2017 and 2020. At present, we have a limited number of indicators within this challenge area but expect that new indicators and methods of determination will be developed with time. For additional indicators of Knowledge and Social Capacity Building for Sustainable Urban Transformation, please see Dumitru and Wendling (Eds.) (*in preparation*).

Table 24. Indicators of NBS performance and impact related to Knowledge and Social Capacity Building for Sustainable Urban Transformation

Nr.	Indicator	Units	Class	Applicability to NBS		
				Type 1	Type 2	Type 3
11.9.1	Environmental awareness	Nr. (0-5)	P	●	●	●

12.9.1 Environmental awareness

Metric: *The extent to which a project has used opportunities to increase citizen's awareness of urban nature and ecosystem services, and educate urban citizens about sustainability and the environment (unitless)*

Strengths: *Nature-based solution projects are uniquely placed to contribute to citizens' awareness regarding the multiple co-benefits of urban nature, and the connection between re-naturing cities and the provision of ecosystem services*

Weaknesses: *May not provide the holistic evaluation*

The conservation, rehabilitation or restoration of ecosystems and ecological processes is a key strategy to maintain, enhance or recover the natural capital, or ecosystem services, provided by intact natural systems. Awareness of environmental issues is a critical first step in creating support for environmental projects and programs.

The extent to which a project exploits opportunities to increase citizens' awareness of NBS and ecosystem services, or to more generally educate citizens about sustainability and the environment, can be evaluated using a five-point Likert scale (Bosch et al., 2017):

(Not at all) 1 – 2 – 3 – 4 – 5 (Very much)

1. **Not at all**: opportunities to increase environmental awareness were not taken into account in the project communication

2. **Poor**: opportunities to increase environmental awareness were slightly taken into account in the project communication.

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

3. **Somewhat**: opportunities to increase environmental awareness were somewhat taken into account in the project communication, at key moments in the project there was attention for this issue.

4. **Good**: opportunities to increase environmental awareness were sufficiently taken into account in the project communication; the project utilized many possibilities to address this issue in their communications.

5. **Excellent**: opportunities to increase environmental awareness were taken into account in the project communication; the project utilized every possibility to address this issue in both online and offline communications.

Scale of measurement: Metropolitan scale (project based)

Required data: Information on opportunities to increase citizens' awareness of NBS and ecosystem services or to more generally educate them about sustainability and the environment

Data generation specifications: Qualitative; participatory data collection is the core of this metric; Questionnaires

Data generation/collection frequency: Annually; at minimum, before and after NBS implementation

Level of expertise required: Low

Connection to other indicators: Relation to *Design for sense of place* indicator and *Green Space Management* indicator group

Connection to SDGs: SDG 11 Sustainable cities and communities

Key References

Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). *CITYkeys indicators for smart city projects and smart cities*. CITYkeys D1.4. Retrieved from http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf

12.10 Participatory Planning and Governance

Inclusive planning and management processes are essential to NBS. The indicators presented under the societal challenge Participatory Planning and Governance address the openness and inclusiveness of the processes through which NBS are co-created, co-implemented and co-managed. Institutional practices that support inclusive co-creation, social innovation and collaboration are necessary to fully realise the broad range of co-benefits offered by NBS. Open collaborative governance and participatory planning of NBS strategies promote opportunities for social transformation and increased social inclusiveness in cities (Wendling *et al.,* 2018).

The indicators presented herein under the Participatory Planning and Governance challenge area enable assessment of both the processes and outcomes involved in NBS co-creation, co-implementation and co-management.

Table 25. Indicators of NBS performance and impact related to Participatory Planning and Governance

Nr.	Indicator	Units	Class	Applicability to NBS		
				Type 1	Type 2	Type 3
11.10.1 †	Openness of participatory processes: proportion of citizens involved	%	P	●	●	●
11.10.2	Involvement of citizens from traditionally under-represented groups	Nr. (1-5), unitless	P	●	●	●
11.10.3	Community involvement in planning	Nr. (1-5), unitless	P	●	●	●
11.10.4	Community involvement in implementation	Nr. (1-5), unitless	P		●	●
11.10.5	Active engagement of citizens in decision-making	%	P	●	●	●
11.10.6	Consciousness of citizenship	Nr. (1-5), unitless	O	●	●	●
11.10.7	Adoption of new forms of NBS (co-)financing	Nr. (1-5), unitless	O	●	●	●
11.10.8	Development of a climate resilience strategy (extent)	Nr. (1-7), unitless	O	●	●	●
11.10.9	Alignment of climate resilience strategy with UNISDR-defined elements	Nr. (0-5) across 117 categories	O	●	●	●
11.10.10	Adaptation of local plans and regulations to include NBS	Nr. (1-5), unitless	O	●	●	●
11.10.11	Perceived ease of governance of NBS	Nr. (1-5), unitless	O	●	●	●

† Indicators designated "recommended" by NBS Impact Evaluation Taskforce (Taskforce 2; Dumitru and Wendling, Eds., *in preparation*)

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

12.10.1 Openness of participatory processes: proportion of citizens involved

Metric: *The proportion of public participation processes in a given municipality per 100 000 residents per year (expressed as %)*

Strengths: *Provides an indication of the alignment between citizens' need and desires and the decision-making processes in a municipality*

Weaknesses: *Does not imply the quality of participation processes*

Public participation in NBS projects encompasses a wide range of different opportunities for citizens, nongovernmental organizations, businesses, and other stakeholders co-create, co-implement and co-manage NBS, concomitantly creating a sense of ownership. The integral role of citizens and other stakeholders in NBS projects can influence the openness of other processes managed by the municipality. Increasing the openness of processes such as policy planning and implementation strengthens the connections between government agencies and the public they serve.

Openness of participatory processes (%) is calculated as (Bosch et al., 2017):

$$\left(\frac{Total\ number\ of\ open\ public\ participation\ processes}{Population\ of\ city/100000}\right) \times 100$$

Scale of measurement: District to municipality scale (project-based)

Required data: Total number of open public participation processes, city population

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually; at minimum, before and after NBS implementation

Level of expertise required: Low

Connection to other indicators: Relation to *Design for sense of place* and *Community involvement in planning* and *Community involvement in implementation* indicators

Connection to SDGs: SDG 10 Reduced inequalities, SDG 11 Sustainable cities and communities, SDG 16 Peace, justice and strong institutions, SDG 17 Partnerships for the goals

Key References

–

12.10.2 Involvement of citizens from traditionally under-represented groups

Metric: *The extent to which the NBS project has led to the increased participation by groups of people who are typically not well represented in the society (unitless)*

Strengths: *The indicator gives useful data for reducing inequalities. Easy to use*

Weaknesses: *May not provide a holistic assessment*

Definitions of "vulnerable" and "under-represented" groups in society vary somewhat, but in general the following groups can be considered vulnerable to discrimination and/or under-represented:

- Women and girls
- Children
- Refugees
- Internally displaced persons
- Stateless persons
- National minorities
- Indigenous peoples
- Migrant workers
- Disabled persons
- Elderly persons
- HIV positive persons and those suffering from AIDS
- Roma/Gypsies/Sinti
- Lesbian, gay, bisexual, transgender, queer, and differently gendered people (LGBTQ+)

Particular effort is necessary to ensure that these groups receive equal representation and opportunity to become involved in NBS projects. Specifically engaging vulnerable and/or under-represented groups in NBs projects enhances social cohesion and diversity whilst tapping into underdeveloped social capital.

The participation of vulnerable or traditionally under-represented groups in NBS projects or specific NBS project activities can be qualitatively assessed using a five-point Likert scale:

(Not at all) 1 – 2 – 3 – 4 – 5 (Excellent)

1. **Not at all**: the project has not increased participation of groups not well represented in society.
2. **Poor**: the project has achieved little when it comes to participation of groups not well represented in society.
3. **Fair**: the project has somewhat increased the participation of groups not well represented in society.
4. **Good**: the project has significantly increased the participation of groups not well represented in society.
5. **Excellent**: Participation of groups not well represented in society has clearly been hugely improved due to the project.

Information used to evaluate the performance of a particular NBS project with regard to the participation of vulnerable or traditionally under-represented groups can be obtained from project documentation and/or interviews with the project leaders and stakeholders (including representatives of the groups targeted).

Scale of measurement: District to metropolitan scale

Required data: Information used to evaluate the performance of a particular NBS project with regard to the participation of vulnerable or traditionally under-represented groups can be obtained from project documentation and/or interviews with the project leaders and stakeholders (including representatives of the groups targeted).

Data generation specifications: Qualitative; cannot be collected via participatory processes

Data generation/collection frequency: Before and after implementation of the NBS project

Level of expertise required: Moderate

Connection to other indicators: Synergies with other indicators in the *Participatory Planning and Governance* indicator group

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Connection to SDGs: SDG 10 Reduced inequalities

Key References

Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). *CITYkeys indicators for smart city projects and smart cities*. CITYkeys D1.4. Retrieved from http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf

12.10.3Community involvement in planning

Metric: *The extent to which citizens and other stakeholders have been involved in the planning phase of a given project (unitless)*

Strengths: *Few data necessary*

Weaknesses: *Difficult to understand the level of all citizens' involvement*

Public participation in NBS projects encompasses a wide range of different opportunities for citizens, nongovernmental organizations, businesses, and other stakeholders co-create, co-implement and co-manage NBS, concomitantly creating a sense of ownership. The integral role of citizens and other stakeholders in NBS projects can influence the openness of other processes managed by the municipality. Stakeholder involvement has been shown to positively influence agreement on solutions and acceptance of policy interventions, largely through raising citizens' awareness (Driessen, Glasbergen and Verdaas 2001).

A five-point Likert scale based on the ladder of citizen participation (Arnstein, 1969) can be used to qualitatively assess the success of community involvement in NBS planning. The Likert scale follows Arnstein's ladder from non-participation (1) through degrees of tokenism (2-3) to citizen empowerment via partnership (4) or citizen control (5):

(No involvement) 1 – 2 – 3 – 4 – 5 (High involvement)

1. **Not at all**: No community involvement.

2. **Inform and consult**: A relatively complete project plan is announced to the community for information only, or for the purpose of receiving community feedback. The consultation process primarily seeks community acceptance of the plan.

3. **Advise**: A project plan is drafted by a project team then presented to community actors, who are invited to ask questions, provide feedback and give advice. Based on this input the planners may alter the project plan.

4. **Partnership**: Community actors are invited by project planners to participate in the planning process by prioritising issues and planning actions. The local community is able to influence the planning process.

5. **Community self-development**: Project planners empower community actors to outline their needs and to make actionable plans.

Scale of measurement: District to municipality scale (project-based)

Required data: Information on public participation processes during the planning phase of NBS project

Data generation specifications: Qualitative; participatory data collection is the core of this metric

Data generation/collection frequency: Annually; at minimum, before and after NBS implementation

Level of expertise required: Low

Connection to other indicators: Relation to *Design for sense of place, Openness of participatory processes* indicators and *Green Space Management* indicator group

Connection to SDGs: SDG 10 Reduced inequalities, SDG 11 Sustainable cities and communities, SDG 16 Peace, justice and strong institutions, SDG 17 Partnerships for the goals

Key References

Arnstein, S.R. (1969). A ladder of citizen participation. *Journal of the American Planning Association, 35*(4), 216-224.

Driessen, P.P.J., Glasbergen, P., & Verdaas, C. (2001.) Interactive policy-making: A model of management for public works. *European Journal of Operational Research, 128*, 322-337.

12.10.4Community involvement in implementation

Metric: *The extent to which citizens and other stakeholders have been involved in the implementation phase of a given project (unitless)*

Strengths: *Few data necessary*

Weaknesses: *Difficult to understand the level of all citizens' involvement*

Public participation in NBS projects encompasses a wide range of different opportunities for citizens, nongovernmental organizations, businesses, and other stakeholders co-create, co-implement and co-manage NBS, concomitantly creating a sense of ownership. The integral role of citizens and other stakeholders in NBS projects can influence the openness of other processes managed by the municipality. Involvement of citizens and other stakeholders during project implementation ensures establishment of a common understanding of the project's longer-term maintenance or management needs, and provides NBS managers and developers with critical input regarding the NBS project's performance relative to stakeholder expectations.

A five-point Likert scale based on Arnstein's (1969) ladder of citizen participation can be used to evaluate the extent of citizen's power in determining the implementation program:

(No involvement) 1 – 2 – 3 – 4 – 5 (High involvement)

1. **Not at all**: No community involvement.

2. **Inform and consult**: An essentially complete project is presented to the community for information only, or in order to receive community feedback. The consultation process primarily seeks community acceptance of the project at the implementation stage.

3. **Advise**: The project implementation is done by a project team. Community actors are invited to ask questions, provide feedback and give advice. Based on this input the planners may alter how the project is implemented.

4. **Partnership**: Community actors are invited by project managers and developers to participate in the implementation process. The local community is able to influence the implementation process.

European Commission | This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

5. **Community self-development**: The project planners empower community actors to manage the project implementation and evaluate the results.

Scale of measurement: District to municipality scale (project-based)

Required data: Information on public participation processes during the implementation phase of NBS project

Data generation specifications: Qualitative; participatory data collection is the core of this metric

Data generation/collection frequency: Annually; at minimum, before and after NBS implementation

Level of expertise required: Low

Connection to other indicators: Relation to *Design for sense of place, Openness of participatory processes* indicators and *Green Space Management* indicator group

Connection to SDGs: SDG 10 Reduced inequalities, SDG 11 Sustainable cities and communities, SDG 16 Peace, justice and strong institutions, SDG 17 Partnerships for the goals

Key References

Arnstein, S.R. (1969). A ladder of citizen participation. *Journal of the American Planning Association, 35*(4), 216-224.

12.10.5Active engagement of citizens in decision-making

Metric: *The extent to which the NBS project has contributed to the active engagement of citizens in public decision-making (unitless)*

Strengths: *Straightforward assessment*

Weaknesses: *Records may not reflect the true situation*

Participatory or inclusive governance, wherein municipalities partner with citizens to develop and manage solutions to contemporary challenges, focuses on enhancing citizen engagement in municipal governance by providing opportunity for citizens to play a direct role in public decision-making. The increased engagement of citizens in urban governance and decision-making is a primary objective of the European Innovation Partnership on Smart Cities and Communities (EIP-SCC).

The proportion (%) of citizens involved in participatory governance is calculated on an annual basis, as:

$$\left(\frac{No. of\ citizens\ enaged\ in\ relevant\ projects\ in\ a\ given\ year}{Total\ population\ of\ the\ city}\right) \times 100$$

Scale of measurement: Municipality scale

Required data: Municipalities maintain records of the number of citizens involved in face-to-face meetings or other activities. Evaluation of citizen engagement should take into account online (internet- or app/smartphone-based) engagement. Software providers and/or platform hosts can provide metrics related to the number of unique visitors for use in calculating digital citizen engagement.

Data generation specifications: Qualitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually

Level of expertise required: Low

Connection to other indicators: Relation to *Openness of participatory processes, Design for sense of place* indicators and *Green Space Management* indicator group

Connection to SDGs: SDG 10 Reduced inequalities, SDG 11 Sustainable cities and communities, SDG 16 Peace, justice and strong institutions, SDG 17 Partnerships for the goals

Key References

European Innovation Partnership on Smart Cities and Communities (EIP SCC). (2013.) Strategic Implementation Plan. Issues 14.10.2013. Brussels: EIP SCC. https://smartcities.at/assets/Uploads/sip-final-en2.pdf

12.10.6 Consciousness of citizenship

Metric: *The extent to which the NBS project has contributed in increasing consciousness of citizenship (qualitative, unitless)*

Strengths: *The indicator gives useful data for urban planning but the data collecting and evaluation might be challenging*

Weaknesses: *May not provide the holistic picture*

Consciousness of citizenship can be described as an individual's awareness of their community, civic rights and responsibilities and their relationship with the community, state or nation. An individual with consciousness of citizenship is aware of how the community functions and their respective role in the community. As such, consciousness of citizenship contributes to a sense of community. According to Ng (2015), civic consciousness includes the following elements:

- Personal identity and citizenship: characteristics such as personal awareness, pride, obedience to the law, and a sense of equality
- National identity: respect for national authorities, belief in the legitimacy of the current political system, sense of the nation as a cohesive whole
- Moral consciousness: upholding family and social normative values in public and in private, willingness to promote public welfare
- Ecological consciousness: awareness of the finite nature of natural resources, consideration of the environmental consequences of personal actions
- Global citizenship: actively concerned with others at home and abroad

The extent to which an NBS project seeks to contribute to the local consciousness of citizenship can be qualitatively rated on a five-point Likert scale, from no effort to substantial effort:

(No increase) 1 – 2 – 3 – 4 – 5 (High increase)

1. **None**: The NBS project has made no effort to increase civic consciousness.
2. **Little**: The NBS project has made a small effort to increase civic consciousness.
3. **Somewhat**: The NBS project has developed some initiatives to increase civic consciousness.
4. **Significant**: The NBS project has executed several activities to increase civic consciousness
5. **High**: increasing civic consciousness was (one of) the main goals of the NBS project and substantial effort has been made to enhance civic consciousness.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Scale of measurement: District to metropolitan scale

Required data: Project documentation and/or interviews during the NBS project

Data generation specifications: Qualitative; cannot be collected via participatory processes

Data generation/collection frequency: Before and after implementation of the NBS project

Level of expertise required: Moderate

Connection to other indicators: Related to *Environmental awareness* and *Design for sense of place* indicators

Connection to SDGs: SDG 11 Sustainable cities and communities, SDG 12 Responsible consumption and production, and SDG 16 Peace, justice and strong institutions

Key References

Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). *CITYkeys indicators for smart city projects and smart cities*. CITYkeys D1.4. http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf

Ng, J.A.I. (2015). Scale on Civic Consciousness (SCC) for the National Service Training Program. *International Journal of Humanities and Management Sciences, 3*(3), 161-165.

12.10.7Adoption of new forms of NBS (co-)financing

Metric: *The extent to which the NBS project has contributed to, or inspired, the development of new forms of financing (unitless)*

Strengths: *Easy and straightforward assessment*

Weaknesses: *The results may not be holistic*

Despite widespread recognition of the multiple co-benefits offered by NBS, financing for urban green spaces remains a common barrier to NBS implementation. Close partnerships between municipal governments, businesses and citizens (public-private-people partnerships, PPPPs) are one example of a new business and financing model that yields resource and governance synergies that can support NBS implementation. Other examples include new financial products such as 'green mortgages' or revolving funds for sustainable investments.

This metric uses a five-point Likert scale to evaluate the extent to which a given NBS project has contributed to the development of innovative forms of financing (Bosch et al., 2017):

(No impact on new forms of financing) 1 – 2 – 3 – 4 – 5 (High impact)

1. **No impact**: the project used a new form of financing but this is not known to the outside world.

2. **Little impact**: the project used a new form of financing but is hardly known for this

3. **Some impact**: the project used a new form of financing and received some professional attention because of this.

4. **Notable impact**: the project is (one of the first) to develop and use a new form of financing and has attracted a lot of professional attention because of this, which has led to a few further experiments with the new way of financing.

5. **High impact**: the project developed and used a new form of financing and has attracted a lot of public and professional attention because of this, which has led to several further experiments with the new way of financing.

Scale of measurement: Municipality scale

Required data: Information on the development of innovative forms of financing related to a NBS project

Data generation specifications: Qualitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually; at minimum, before and after NBS implementation

Level of expertise required: Low

Connection to other indicators: Relation to *Openness of participatory processes, Design for sense of place* indicators and *Green Space Management* indicator group

Connection to SDGs: SDG 10 Reduced inequalities, SDG 11 Sustainable cities and communities, SDG 16 Peace, justice and strong institutions, SDG 17 Partnerships for the goals

Key References

Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). *CITYkeys indicators for smart city projects and smart cities*. CITYkeys D1.4. Retrieved from http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf

Kabisch, N., Frantzeskaki, N., Pauleit, S., Naumann, S., Davis, M., Artmann, M., … Bonn, A. (2016). Nature-based solutions to climate change adaptation and mitigation in urban areas: perspectives on indicators, knowledge gaps, barriers, and opportunities for action. *Ecology and Society, 21*(2), 39.

12.10.8 Development of a climate resilience strategy (extent)

Metric: *The extent to which the city has developed and implemented a climate resilience strategy (unitless)*

Strengths: *Projects involving NBS can increase awareness of ecosystem based adaptation to climate change and encourage the development of municipal climate resilience strategies that incorporate natural solutions to climate change impacts. Increased awareness of NBS benefits. Easy to evaluate*

Weaknesses: *An overly simple assessment*

Many climate resilience strategies are linked with disaster and risk reduction as the impacts of climate change are commonly experienced in urban areas as flooding and/or drought, and over-heating (urban heat island effect). Nature-based solutions are a key tool for use in urban climate change mitigation and adaptation efforts.

The metric is evaluated using a seven-point Likert scale based on the steps suggested by the "Mayors adapt" initiative for climate change adaptation in urban areas (Bosch et al., 2017; Climate Adapt, n.d.):

(No action) 1 – 2 – 3 – 4 – 5 – 6 – 7 (Implementation, monitoring and evaluation)

1. No action has been taken yet

2. The ground for adaptation has been prepared (the basis for a successful adaptation process)

3. Risks and vulnerabilities have been assessed

4. Adaptation options have been identified

5. Adaptation options have been selected

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

6. Adaptation options are being implemented

7. Monitoring and evaluation is being carried out.

Scale of measurement: Municipal scale

Required data: Information on the development and implementation of climate resilience strategy in the city

Data generation specifications: Qualitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually

Level of expertise required: Low

Connection to other indicators: Relation to *Openness of participatory processes, Policy learning concerning adapting policies and strategic plans, New forms of financing* indicators

Connection to SDGs: SDG 6 Clean water and sanitation, SDG 10 Reduced inequalities, SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land

Key References

Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). *CITYkeys indicators for smart city projects and smart cities*. CITYkeys D1.4. Retrieved from http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf

Climate Adapt. (n.d.). *About the Urban Adaptation Support Tool*. https://climate-adapt.eea.europa.eu/knowledge/tools/urban-ast/step-0-1

12.10.9 Alignment of climate resilience strategy with UNISDR-defined elements

Metric: *The extent to which the city has implemented the "Ten Essentials for Making Cities Resilient" included in the Sendai Framework for Disaster Risk Reduction*

Strengths: *Essentials are able to cover many of the issues that cities need to address to become more disaster resilient and they are able to address multiple perspectives, such as governance and financial capacity, planning and disaster preparation and disaster response and post-event recovery (United Nations Office for Disaster Risk Reduction [UNISDR], 2017)*

Weaknesses: *Requires a substantial amount of external information*

Many climate resilience strategies are linked with disaster and risk reduction as the impacts of climate change are commonly experienced in urban areas as flooding and/or drought, and over-heating (urban heat island effect). Nature-based solutions are a key tool for use in urban climate change mitigation and adaptation efforts. The evaluation of Climate Resilience Strategy Development can rely on the assessment proposed by the United Nations Office for Disaster Risk Reduction (UNISDR) that allows local governments and to assess their disaster resilience and to enable the development of a local disaster risk reduction strategy (resilience action plans).

The metric is evaluated using UNISDR Disaster Resilience Scorecard for Cities, which is a tool that allows local governments to monitor and review progress and challenges in the Implementation of the Sendai Framework for Disaster Risk Reduction and to enable the development of a local disaster risk reduction strategy. The assessment is performed with respect to a selected climate hazard (e.g., the most severe, the most probable) and can be made at two levels: preliminary and detailed.

In detail, for each of the Essentials, a number of issues is identified within the tool, and for each of the issue a score must be assigned. Final results include an overall score, a representation of results focused on the score obtained for each essential in graphical form and also a representation of results focused on the score obtained for each sub-issue of each essential in graphical form.

Scale of measurement: Municipal scale

Required data: Information on the progress and challenges in the Implementation of the Sendai Framework for Disaster Risk Reduction and the development of a local disaster risk reduction strategy

Data generation specifications: Qualitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually

Level of expertise required: Low

Connection to other indicators: Relation to *Openness of participatory processes, Policy learning concerning adapting policies and strategic plans, New forms of financing* indicators. Direct consequence of *Disaster resilience* indicator

Connection to SDGs: SDG 6 Clean water and sanitation, SDG 10 Reduced inequalities, SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land

Key References

United Nations Office for Disaster Risk Reduction (UNISDR). (2017). *Disaster Resilience Scorecard for Cities – Preliminary level assessment.* Retrieved from https://www.unisdr.org/campaign/resilientcities/toolkit/article/disaster-resilience-scorecard-for-cities

12.10.10 Adaptation of local plans and regulations to include NBS

Metric: *The extent to which the NBS project has contributed to, or inspired, changes in municipal rules, regulations and behavioural change instruments to support implementation and "mainstreaming" of NBS (unitless)*

Strengths: *Policy learning can create windows of opportunity for other, similar urban innovations. Diffusion of good policies to increase NBS implementation and maintenance and, hence, urban resilience*

Weaknesses: *Implementation of NBS in the absence of policy and planning support may be challenging, as bottom-up and decentralised processes are inherent within the concept*

Policy learning to systemically incorporate ecosystem-based adaptation into climate change strategies and ecosystem services into municipal planning is a critical step in shifting the prevailing paradigm of dealing with risk and disaster (Wamsler, Luederitz & Brink, 2014).

The extent of policy learning during or as a result of an NBS project can be evaluated using a five-point Likert scale (Bosch et al., 2017):

(No impact) 1 – 2 – 3 – 4 – 5 (High impact)

1. **No impact**: the NBS project has not, at any level, inspired changes in municipal rules and regulations.

2. **Little impact**: the NBS project has led to localised discussion about the suitability of the current municipal rules and regulations.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

3. **Some impact**: the NBS project has led to public discussion, leading to a change in municipal rules and regulations.

4. **Notable impact**: the NBS project has led to public discussion, leading to a change in municipal rules and regulations. This, in turn, has sparked discussion amongst other administrations about the suitability of current rules and regulations.

5. **High impact**: the NBS project has led to public discussion, leading to a change in municipal rules and regulations. This, in turn, has inspired other administrations to reconsider their respective rules and regulations

Scale of measurement: Municipal scale

Required data: Information on changes in municipal rules and regulations to support implementation and "mainstreaming" of NBS as a result of a NBS project

Data generation specifications: Qualitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually; at minimum, before and after NBS implementation

Level of expertise required: Low

Connection to other indicators: Relation to *Openness of participatory processes, Design for sense of place* indicators and *Green Space Management* indicator group

Connection to SDGs: SDG 6 Clean water and sanitation, SDG 7 Clean and affordable energy, SDG 10 Reduced inequalities, SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land

Key References

Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). *CITYkeys indicators for smart city projects and smart cities*. CITYkeys D1.4. Retrieved from http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf

Wamsler, C., Luederitz, C., & Brink, E. (2014). Local levers for change: Mainstreaming ecosystem-based adaptation into municipal planning to foster sustainability transitions. *Global Environmental Change, 29*, 189-201.

12.10.11 Perceived ease of governance of NBS

Metric: *The extent to which the NBS project has contributed to, or inspired, the development of new forms of NBS governance in the form of changes to rules or regulations (unitless)*

Strengths: *Easy and straightforward assessment*

Weaknesses: *The results may not be holistic*

Existing municipal rules and regulations based upon centralised or top-down systems of management, traditional construction processes, etc., may serve as a barrier to innovations like NBS. Projects may be able to forge a new path, or shift the paradigm within which municipalities operate in order to better support innovative actions that challenge the status quo. There is growing recognition of the critical importance of citizen engagement in sustainable urban development. Long-term climate change mitigation and adaptation planning has been identified as a key area for participatory or inclusive governance, wherein municipalities partner with citizens to develop and manage solutions (Brink & Wamsler, 2018).

The extent to which an NBS project has contributed to, or inspired, the development of new forms of NBS governance in the form of changes to rules or regulations can be evaluated using a five-point Likert scale (Bosch et al., 2017):

(No impact) 1 – 2 – 3 – 4 – 5 (High impact)

1. **No impact**: the project has not, at any level, inspired changes in rules and regulations.

2. **Little impact**: the project has led to a localised discussion about the suitability of the current rules and regulations.

3. **Some impact**: the project has led to a public discussion, leading to a change in rules and regulations.

4. **Notable impact**: the project has led to a public discussion, leading to a change in rules and regulations. This in its turn has sparked a discussion amongst other administrations about the suitability of the current rules and regulations.

5. **High impact**: the project has led to a public discussion, leading to a change in rules and regulations. This in turn has inspired other administrations to reconsider their rules and regulations

Scale of measurement: Municipality scale

Required data: Information on changes to rules or regulations based on contribution or inspiration from an NBS project

Data generation specifications: Qualitative; cannot be collected via participatory processes

Data generation/collection frequency: Annually; at minimum, before and after NBS implementation

Level of expertise required: Low

Connection to other indicators: Relation to *Openness of participatory processes, Design for sense of place* indicators and *Green Space Management* indicator group

Connection to SDGs: SDG 10 Reduced inequalities, SDG 11 Sustainable cities and communities, SDG 16 Peace, justice and strong institutions, SDG 17 Partnerships for the goals

Key References

Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). *CITYkeys indicators for smart city projects and smart cities*. CITYkeys D1.4. Retrieved from http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf

Brink, E., & Wamsler, C. (2018). Collaborative governance for climate change adaptation: Mapping citizen-municipality interactions. *Environmental Policy & Governance, 28*, 82-97.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

12.11 Social Justice and Social Cohesion

Social justice is a key element of the European Green Deal, with a Just Transition Platform established to ensure that citizens' rights and livelihoods are secured as Europe shifts to a climate-neutral economy by 2050. Green gentrification is the term frequently used to refer to negative social consequences of urban greening from the perspective of environmental justice and sustainable development. Numerous studies have shown that low-income communities, members of minority groups, and migrant communities have relatively less access to green space, greater exposure to climate hazards and impacts, and the fewest resources available to respond to climate change. These socially vulnerable groups also bear relatively greater risk of dispossession and displacement arising from urban greening projects (e.g., Gould & Lewis, 2016; Rigolon & Németh, 2020). The indicators presented under Social Justice and Social Cohesion facilitate evaluation of both the processes and outcomes associated with NBS. In particular, the involvement of vulnerable or traditionally under-represented groups in NBS processes and the availability and distribution of urban blue-green space with respect to specific individual or household socioeconomic profiles and landscape design facilitate analysis of the fairness of NBS processes and outcomes.

Social cohesion refers broadly to the sense of belonging within a community, and the relationships among community members. Processes aimed at increasing social cohesion typically seek to reduce inequalities and socioeconomic disparities. Consciousness of citizenship is one way to evaluate social cohesion by assessing an individual's relationship with their community. The per capita number of violent incidents, nuisances and crimes, in contrast, provides an indication of fractures in the society.

Table 26. Indicators of NBS performance and impact related to Social Justice and Social Cohesion

Nr.	Indicator	Units	Class	Applicability to NBS		
				Type 1	Type 2	Type 3
11.11.1	Consciousness of citizenship	Nr. (1-5), unitless	O	●	●	●
11.11.2	Citizen engagement by NBS projects	%	P	●	●	●
11.11.3 †	Participation of vulnerable or traditionally under-represented groups	Nr. (1-5)	P	●	●	●
11.11.4	Number of violent incidents, nuisances and crimes per 100 000 population	Nr. per 100 000	O	●	●	●
11.11.5 †	Availability and equitable distribution of blue-green space	map	O	●	●	●

† Indicators designated "recommended" by NBS Impact Evaluation Taskforce (Taskforce 2; Dumitru and Wendling, Eds., *in preparation*)

12.11.1Consciousness of citizenship

Metric: *The extent to which the NBS project has contributed in increasing consciousness of citizenship (qualitative, unitless)*

Strengths: *The indicator gives useful data for urban planning but the data collecting and evaluation might be challenging*

Weaknesses: *May not provide the holistic picture*

Consciousness of citizenship can be described as an individual's awareness of their community, civic rights and responsibilities and their relationship with the community, state or nation. An individual with consciousness of citizenship is aware of how the community functions and their respective role in the community. As such, consciousness of citizenship contributes to a sense of community. According to Ng (2015), civic consciousness includes the following elements:

- Personal identity and citizenship: characteristics such as personal awareness, pride, obedience to the law, and a sense of equality
- National identity: respect for national authorities, belief in the legitimacy of the current political system, sense of the nation as a cohesive whole
- Moral consciousness: upholding family and social normative values in public and in private, willingness to promote public welfare
- Ecological consciousness: awareness of the finite nature of natural resources, consideration of the environmental consequences of personal actions
- Global citizenship: actively concerned with others at home and abroad

The extent to which an NBS project seeks to contribute to the local consciousness of citizenship can be qualitatively rated on a five-point Likert scale, from no effort to substantial effort:

(No increase) 1 – 2 – 3 – 4 – 5 (High increase)

1. **None**: The NBS project has made no effort to increase civic consciousness.
2. **Little**: The NBS project has made a small effort to increase civic consciousness.
3. **Somewhat**: The NBS project has developed some initiatives to increase civic consciousness.
4. **Significant**: The NBS project has executed several activities to increase civic consciousness
5. **High**: increasing civic consciousness was (one of) the main goals of the NBS project and substantial effort has been made to enhance civic consciousness

Scale of measurement: Neighbourhood – district - metropolitan scale

Required data: Project documentation and/or interviews during the NBS project

Data generation specifications: Qualitative; cannot be collected via participatory processes

Data generation/collection frequency: Before and after implementation of the NBS project

Level of expertise required: Moderate

Connection to other indicators: Synergies with indicator group *Participatory Planning and Governance* indicators

Connection to SDGs: SDG 11 Sustainable cities and communities, SDG 12 Responsible consumption and production, and SDG 16 Peace, justice and strong institutions

Key References

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). *CITYkeys indicators for smart city projects and smart cities*. CITYkeys D1.4. Retrieved from http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf

Herranz-Pascual et al. (2020). *CLEVER Social Survey Questionnaire (CLEVER-SSQn).* In: Zorita et al., D4.3 Monitoring strategy in the FR interventions. Deliverable 4.3, CLEVER Cities Project, 6th July 2020.

Ng, J.A.I. (2015). Scale on Civic Consciousness (SCC) for the National Service Training Program. *International Journal of Humanities and Management Sciences, 3*(3), 161-165.

12.11.2Citizen engagement by NBS projects

Metric: *Percentage of people in the target group that have been reached and/or are activated by the NBS project (%)*

Strengths: *Provides a quantitative measure of the project's engagement of people within the target group, enabling rapid assessment of how successful the project has been in this regard*

Weaknesses: *The target group must be clearly defined in order to quantify the size of the target audience. This could be particularly challenging in NBS projects as the co-creation process is driven equally by project planners and stakeholders, meaning that the target audience can change with time as the NBS is co-defined. Evaluation of the target audience, identification of critical stakeholders and quantification of the total target audience should, therefore, be an on-going process in an NBS project. This metric does not consider how people are reached, or identify limitations to citizen engagement*

Much of a project's success depends on reaching the "right" people. In many instances the reach of a project is assessed by the total number of people reached, or the total number of people from vulnerable or under-represented groups who become involved.

People reached by an NBS project can be calculated as:

$$\left(\frac{Number\ of\ citizens\ reached}{Total\ no.citizens\ in\ target\ group}\right) \times 100$$

Scale of measurement: District to metropolitan scale

Required data: Number of citizens reached or activated in the target group by the NBS project total number of citizens in the target group

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: On-going process during the NBS project

Level of expertise required: Moderate

Connection to other indicators: Synergies with indicator group *Participatory Planning and Governance* indicators

Connection to SDGs: SDG 10 Reduced inequalities

Key References

Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). *CITYkeys indicators for smart city projects and smart cities*. CITYkeys D1.4. Retrieved from http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf

12.11.3Participation of vulnerable or traditionally under-represented groups

Metric: *The extent to which the NBS project has led to the increased participation by groups of people who are typically not well represented in the society (unitless)*

Strengths: *The indicator gives useful data for reducing inequalities. Easy to use*

Weaknesses: *May not provide a holistic assessment*

Definitions of "vulnerable" and "under-represented" groups in society vary somewhat, but in general the following groups can be considered vulnerable to discrimination and/or under-represented:

- Women and girls
- Children
- Refugees
- Internally displaced persons
- Stateless persons
- National minorities
- Indigenous peoples
- Migrant workers
- Disabled persons
- Elderly persons
- HIV positive persons and those suffering from AIDS
- Roma/Gypsies/Sinti
- Lesbian, gay, bisexual, transgender, queer, and differently gendered people (LGBTQ+)

Particular effort is necessary to ensure that these groups receive equal representation and opportunity to become involved in NBS projects. Specifically engaging vulnerable and/or under-represented groups in NBs projects enhances social cohesion and diversity whilst tapping into underdeveloped social capital.

The participation of vulnerable or traditionally under-represented groups in NBS projects or specific NBS project activities can be qualitatively assessed using a five-point Likert scale:

(Not at all) 1 – 2 – 3 – 4 – 5 (Excellent)

6. **Not at all**: the project has not increased participation of groups not well represented in society.
7. **Poor**: the project has achieved little when it comes to participation of groups not well represented in society.
8. **Fair**: the project has somewhat increased the participation of groups not well represented in society.
9. **Good**: the project has significantly increased the participation of groups not well represented in society.
10. **Excellent**: Participation of groups not well represented in society has clearly been hugely improved due to the project.

Information used to evaluate the performance of a particular NBS project with regard to the participation of vulnerable or traditionally under-represented groups can be obtained from project documentation and/or interviews with the project leaders and stakeholders (including representatives of the groups targeted).

Scale of measurement: District to metropolitan scale

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Required data: Information used to evaluate the performance of a particular NBS project with regard to the participation of vulnerable or traditionally under-represented groups can be obtained from project documentation and/or interviews with the project leaders and stakeholders (including representatives of the groups targeted).

Data generation specifications: Qualitative; cannot be collected via participatory processes

Data generation/collection frequency: Before and after implementation of the NBS project

Level of expertise required: Moderate

Connection to other indicators: Synergies with other indicators in the *Participatory Planning and Governance* indicator group

Connection to SDGs: SDG 10 Reduced inequalities

Key References

Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). *CITYkeys indicators for smart city projects and smart cities*. CITYkeys D1.4. Retrieved from http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf

12.11.4 Number of violent incidents, nuisances and crimes per 100 000 population

Metric: *Number of violent incidents, nuisances and crimes per 100 000 population*

Strengths: *Simple and easy to use indicator*

Weaknesses: *All the crimes might not be reported*

The number of violent incidents, reportable nuisances and other crimes is a primary indicator of feelings of personal safety (ISO, 2018). For simplicity, the crime rate of a given metropolitan area can be assessed before and after NBS implementation to determine the impact of NBS actions on local crime. Individual surveys are necessary to directly assess citizens' feelings of personal safety, but the crime rate can provide an easily quantifiable metric of actual crime in a given area.

The crime rate is defined as the number of violent incidents, annoyances and crimes per 100 000 population. It is calculated as:

$$Number\ of\ crimes\ per\ 100\,000\ population = \frac{Total\ number\ of\ crimes\ reported}{(City's\ total\ population/100\,000)}$$

The result is expressed as the number of crimes per 100 000 population.

Scale of measurement: District to metropolitan scale

Required data: Number of crimes reported and city's population

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Before and after NBS implementation

Level of expertise required: Moderate

Connection to other indicators: No synergies identified

Connection to SDGs: SDG 11 Sustainable cities and communities, SDG 15 Life on land, and SDG 16 Peace, justice and strong institutions

Key References

Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). *CITYkeys indicators for smart city projects and smart cities*. CITYkeys D1.4. Retrieved from http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf

International Organization for Standardization (ISO). (2018). *Sustainable cities and communities — Indicators for city services and quality of life (ISO 37120:2018).* Retrieved from https://www.iso.org/standard/68498.html

12.11.5 Availability and equitable distribution of blue-green space

Metric: *The availability and distribution of blue-green space with respect to specific individual or household socioeconomic profiles and landscape design*

Strengths: *Provides useful data for urban city planning*

Weaknesses: *Needs expert users and a lot of input data*

It is widely accepted that access to urban green space improves the quality of life for urban residents, facilitating social cohesion, democracy, and equity whilst enhancing physical and psychological health and well-being. Urban green spaces also contribute to the economic vitality of urban neighbourhoods by increasing property values and encouraging tourism (Ibes, 2015). A number of recent studies have highlighted inequitable access to green space in cities around the world. Spatial analysis of metropolitan areas can reveal the relationship between green space access and socio-economic status.

The overall methodology involves selecting relevant characteristics and datasets, then overlaying these dataset using a geographic information system (GIS). Statistical analyses of spatially-explicit variables are then used to explore the relationship between urban green space availability and selected socio-economic characteristics. Additional factors, such as size or type of green space, biodiversity value, etc. can also be evaluated. Steps of the process are given below:

Step 1: Separate the metropolitan area of interest into its respective spatial/administrative units which provide clearly defined areas with readily available data regarding population density, demographics, median household income, level of home ownership, etc. Additional information regarding dominant building type (single family and multi-family residences, buildings for retail or commercial/industrial use, mean or maximum building height etc.) can be obtained from municipality records for each spatial/administrative unit.

Step 2: Using GIS, overlay the spatial units with available urban landscape data. For example, Cohen *et al.* (2012) obtained high resolution urban landscape data (1 m) from the Paris Urban Planning Agency that described the spatial distribution of: vegetation patches per strata (i.e., < 1 m, 1–10 m, > 10 m); (2) water bodies, bare soil and asphalt; and, built up areas based on the median height of buildings and the period of construction. This layer was intersected with the census block group data to view distribution patterns of urban landscapes.

Step 3: Statistically analyse spatially-explicit data to evaluate green space availability (and green space type and size and/or biodiversity value, if desired) as a function of socio-economic factors in order to determine equity of green space distribution). A number of different statistical methods may be employed to evaluate the equity of public green space distribution. For example, Cohen *et al.* (2012) used available botanical information for each of the census block groups, calculating the mean household income per botanical and landscape class cluster. They also assessed the correlation between mean revenue, floral richness, the ecological diversity index and building density.

Scale of measurement: Metropolitan scale

Required data: Spatial/administrative data regarding population density, demographics, median household income, level of ownership, etc. Also urban landscape data with green spaces and green space characteristics

Data generation specifications: Qualitative and quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Before and after NBS implementation

Level of expertise required: Moderate to High – for applying and combining various data sources in the GIS software

Connection to other indicators: Connection to *Distribution of public green space* and *Accessibility of urban green spaces*

Connection to SDGs: SDG 15 Life on land

Key References

Cohen, M., Baudoin, R., Palibrk, M., Persyn, N., & Rhein, C. (2012). Urban biodiversity and social inequalities in built-up cities: New evidences, next questions. The example of Paris, France. *Landscape and Urban Planning, 106*, 277–287.

Ibes, D.C. (2015). A multi-dimensional classification and equity analysis of an urban park system: A novel methodology and case study application. *Landscape and Urban Planning, 137*, 122–137.

Kabisch, N. & Haase, D. (2014). Green justice or just green? Provision of urban green spaces in Berlin, Germany. *Landscape and Urban Planning, 122*, 129–139.

12.12 Health and Wellbeing

Documented impacts of urbanisation on human health and well-being include increases in non-communicable and infectious diseases, mental health problems, substance abuse, crime, exposure to increasing climate risks, immune dysregulation and high levels of health inequity[i]. A growing body of empirical evidence indicates a causal relationship between time spent in urban green spaces and the health and well-being of city dwellers. Urban green spaces are believed to affect health and well-being by mediating exposure to potentially harmful factors, enabling psychophysiological stress recovery and attention restoration, and through effects on social connectivity and chronic disease. Communities equipped with the knowledge and tools to co-create liveable public spaces can contribute to development of both individual and community-level sense of coherence and build resilience to stressors, thereby improving community health and well-being.

Recently, the COVID-19 pandemic has highlighted the importance of urban green spaces to human wellbeing. The pandemic has caused countries across the world to implement social distancing and lockdown measures in order to curb the spread of COVID-19. Although these measures have proven successful, feelings of loneliness, anxiety and depression have reportedly increased among the world's populations, particularly among people living in dense urban settings with limited public space. Ensuring access to nature for all citizens should thus be a fundamental strategy of cities, both when coping with the current health crisis as well as when planning future urban development.

Table 27. Indicators of NBS performance and impact related to Health and Wellbeing

Nr.	Indicator	Units	Class	Applicability to NBS		
				Type 1	Type 2	Type 3
11.12.1	Encouraging a healthy lifestyle	Nr. (1-5), unitless	O	●		●
11.12.2	Heat related discomfort: Universal Thermal Climate Index (UTCI)	°C	O	●		●
11.12.3	Hospital admissions due to high temperature during extreme heat events	Nr. per 100 000	O	●		●
11.12.4	Exposure to noise pollution	%	O	●		●
11.12.5	Morbidity due to poor air quality	No./y	O	●	●	●
11.12.5	Mortality due to poor air quality	No./y	O	●	●	●
11.12.5	Years of Life Lost due to poor air quality	No. of years	O	●	●	●

12.12.1Encouraging a healthy lifestyle

Metric: *Extent to which the NBS project and associated activities serve to promote a healthy lifestyle among local residents (qualitative, unitless)*

Strengths: *The indicator gives useful data for assessing impacts of the NBS on healthy lifestyle*

Weaknesses: *Data collection and processing might be challenging*

A core co-benefit of NBS is the encouragement of healthy lifestyles for urban residents. Many different measures can be employed to encouraging a healthy lifestyle, such as:

- Increasing bicycling opportunities in the neighbourhood - network of bicycle paths covering an area between residences and businesses/services
- Increasing walking opportunities in the neighbourhood - network of pedestrian walkways covering an area between residences and businesses/services
- Increasing the number, diversity or accessibility public sports facilities
- Increasing the extent or accessibility of community gardening facilities
- Designating public areas as non-smoking zones

The overall process of NBS co-creation, co-implementation and co-management with stakeholders provides ample opportunity to specifically target NBS interventions that provide opportunities for local citizens to adopt healthier lifestyles. The extent to which this is considered during NBS planning and implementation is assessed qualitatively using a five-point Likert scale from not at all (1, no encouragement of healthy lifestyles) to excellent (extensive online and offline encouragement):

(Not at all) 1 – 2 – 3 – 4 – 5 (Excellent)

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

1. **Not at all**: no measures were taken to encourage a healthy lifestyle.
2. **Poor**: there was little encouragement of a healthy lifestyle.
3. **Somewhat**: there was some encouragement of a healthy lifestyle with the implementation of some measures.
4. **Good**: a sufficient encouragement of a healthy lifestyle was translated into several offline (biking facilities, public sports facilities) and online (i.e., reminder app) initiatives.
5. **Excellent**: a healthy lifestyle was extensively encouraged offline (biking facilities, public sports facilities, pedestrian networks) and online (i.e., exercise apps).

Scale of measurement: District to metropolitan scale

Required data: NBS project documentation, urban land use data

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Before and after implementation of the NBS project

Level of expertise required: Moderate

Connection to other indicators: Synergies with indicators *Distribution of public green space*, *Accessibility of urban green spaces*, *Proportion of road network dedicated to pedestrians and/or bicyclists*, and *Availability and equitable distribution of blue-green space*

Connection to SDGs: SDG 3 Good health and well-being, and SDG 15 Life on land

Key References

Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). *CITYkeys indicators for smart city projects and smart cities*. CITYkeys D1.4. http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf

12.12.2 Heat related discomfort: Universal Thermal Climate Index (UTCI)

Metric: *The UTCI is the air temperature that would produce under reference conditions the same thermal strain as the actual thermal environment. In other words, the UTCI is the reference environmental temperature causing strain*

Strengths: *Mathematical expression of a person's thermal comfort in the outdoors. The output is expressed in easily understandable temperature units, e.g., °C*

Weaknesses: *Can be laborious to evaluate*

UTCI index represents air temperature of the reference condition with the same physiological response as the actual condition. The UTCI provides a one-dimensional value that reflects the human physiological reaction to the multi-dimensional outdoor thermal environment (Bröde et al., 2012). It can predict both whole body thermal effects (hypothermia and hyperthermia; heat and cold discomfort), and local effects (facial, hands and feet cooling and frostbite). Applications of the UTCI include weather forecasts, bioclimatological assessments, bioclimatic mapping, urban design, engineering of outdoor spaces, outdoor recreation, epidemiology and climate impact research.

The human body core temperature must be maintained within a narrow range around 37°C to ensure proper function of the body's inner organs and the brain, thus optimising human comfort, performance and health. In contrast, the temperature of the skin and extremities can vary widely, depending upon environmental conditions. This variation in the temperature of extremities is one of the mechanisms to equilibrate heat production and heat loss. The heat exchange between the human body and environment can be described in the form of the energy balance equation:

$$M + W + C + K + E + Q + Res \pm S = 0$$

Where:

M – heat produced by metabolism;
W – heat generated by muscular activity;
C – sensible heat flux (heat transferred by convection);
K – heat transferred through conduction contact with solid bodies);
E – latent heat flux (evaporative heat flux);
Q – radiative heat transfer;
Res – heat transfer through respiration; and,
S – heat content of the body.

The UTCI is derived from this mathematical model of thermoregulation with an integrated adaptive clothing model that also accounts for predicted votes of the dynamic thermal sensation based on core and skin temperature (Fiala et al., 1999, 2001, 2003; Havenith et al., 2011). The deviation of UTCI temperature from measured air temperature depends on measured values of air temperature (T_a) and mean radiant temperature (T_{mrt}), wind speed at a height of 10 m (v_a) and humidity expressed as water vapour pressure (p_a) or relative humidity (rH):

$$\mathbf{UTCI}(T_a, T_{mrt}, v_a, p_a) = Ta + Offset(T_a, T_{mrt}, v_a, p_a)$$

The model reference condition is walking at 4 km/h (135 W/m^2) with T_{mrt}=T_a, v_a=0.5 m/s, rH=50% (T_a >29°C) and p_a=20 hPa (T_a >29°C) (Bröde et al., 2012). The UTCI dynamic model response can be determined using the online calculator available from http://utci.org. The relationship between UTCI temperature (expressed in °C) and physiological stress is shown in the table below (adapted from Błażejczyk et al., 2010).

UTCI (°C) range	Stress category
Above +46	Extreme heat stress
+38 to +46	Very strong heat stress
+32 to +38	Strong heat stress
+26 to +32	Moderate heat stress
+9 to +26	No thermal stress
0 to +9	Slight cold stress
-13 to 0	Moderate cold stress
-27 to -13	Strong cold stress
-40 to -27	Very strong cold stress
Below -40	Extreme cold stress

Scale of measurement: Plot – street – neighbourhood – district

Required data: Air temperature, T_a (°C); Mean radiant temperature, T_{mrt} (degrees Kelvin); Water vapour pressure (hPa); Relative humidity (%); Wind speed at a height of 10 m (m/s)

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Data generation specifications: Quantitative; participatory data collection is feasible through direct participation in weather data collection

Data generation/collection frequency: Frequency as desired. UTCI can be calculated frequently with measurement intervals determined by (automated) weather data acquisition

Level of expertise required: Low-Moderate

Connection to other indicators: Direct relation to *Heatwave incidence* and *Number of combined tropical nights and hot days* indicators. Similar to *Physiological equivalent temperature (PET)*

Connection to SDGs: SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action

Key References

Błażejczyk, K., Broede, P., Fiala, D., Havenith, G., Holmér, I., Jendritzky, G., Kampmann, B. & Kunert, A. (2010). Principles of the new Universal Thermal Climate Index (UTCI) and its application to bioclimatic research in European scale. *Miscellanea Geographica, 14*, 91-102.

Bröde, P., Fiala, D., Błażejczyk, K., Holmér, I., Jendritzky, G., Kampmann, B., Tinz, B. & Havenith, G. (2012). *International Journal of Biometeorology, 56*, 481-494.

Fiala, D., Havenith, G., Bröde, P., Kampmann, B & Jendritzky, G. (2011). UTCI-Fiala multi-node model of human temperature regulation and thermal comfort. *International Journal of Biometeorology, 56*, 429-441.

Fiala, D., Lomas, K.J., Stohrer, M. (1999). A computer model of human thermoregulation for a wide range of environmental conditions: the passive system. *Journal of Applied Physiology, 87*, 1957–1972.

Fiala, D., Lomas, K.J., Stohrer, M. (2001). Computer prediction of human thermoregulatory and temperature responses to a wide range of environmental conditions. *International Journal of Biometeorology, 45*, 143–159.

Fiala D, Lomas KJ, Stohrer M (2003). First principles modeling of thermal sensation responses in steady-state and transient conditions. *ASHRAE Transactions, 109*, 179–186.

Havenith, G., Fiala, D., Błażejczyk, K., Richards, M., Bröde, P., Holmér, I., Rintamäki, H., Benshabat, Y., Jendritzky, G. (2011). The UTCI-Clothing Model. *International Journal of Biometeorology, 56*, 461-470.

12.12.3 Hospital admissions due to high temperature during extreme heat events

Metric: *Change in the number of hospital admissions due to high temperature during extreme heat events from baseline values*

Strengths: *Easy to measure*

Weaknesses: *Difficulties in ruling out other causes for hospital admissions*

Heat waves are the most significant weather-related cause of human mortality worldwide (Agarwal, Dwivedi & Ghanshyam, 2018). This metric can easily be evaluated using public health data regarding daily emergency room admissions. These data can be used either to evaluate total emergency room admissions, or to assess hospital admissions for specific disease categories such as heat stroke, dehydration and cardiac arrest (e.g., Davis & Novicoff, 2018). Further disaggregation of data may include separation by population demographic (e.g., Gronlund, Zanobetti, Schwartz, Wellenius & O'Neill, 2014).

Scale of measurement: District to metropolitan scale

Required data: Public health data regarding either total emergency room admissions or hospital admissions for specific disease categories

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Before and after NBS implementation

Level of expertise required: Low to Moderate

Connection to other indicators: Synergies with the *Natural and climate hazards* indicator group

Connection to SDGs: SDG 3 Good health and well-being, and SDG 13 Climate action

Key References

Agarwal, A.K., Dwivedi, S. & Ghanshyam, A. (2018). Summer heat: Making a consistent health impact. *Indian Journal of Occupational and Environmental Medicine, 22*(1), 57-58.

Davis, R.E., & Novicoff, W.M. (2018). The impact of heat waves on emergency department admissions in Charlottesville, Virginia, U.S.A. *International Journal of Environmental Research and Public Health, 15*(7) 1436.

Gronlund, C.J., Zanobetti, A., Schwartz, J.D., Wellenius, G.A., & O'Neill, M.S. (2014). Heat, heat waves, and hospital admissions among the elderly in the United States, 1992-2006. *Environmental Health Perspectives, 122*(11), 1187-1192.

12.12.4Exposure to noise pollution

Metric: *Proportion of population exposed to noise levels of L_{den} > 55 dB(A)*

Strengths: *Easy to measure*

Weaknesses: *Accurate data require extensive measurements*

Prolonged exposure to noise, such as the environmental noise pollution caused by road, rail and airport traffic, industry, construction, and other outdoor activities, can lead to significant physical and mental health effects (ISO, 2018). Environmental noise pollution is any disturbing noise that interferes with or harms humans or wildlife.

L_{den} (day-evening-night level) is the indicator adopted by the Environmental Noise Directive, and it is evaluated as (European Parliament, Council of the European Union, 2002):

$$L_{den} = 10\log_{10}\frac{1}{24}\left(12\times 10^{\frac{L_{day}}{10}} + 4\times 10^{\frac{L_{evening}+5}{10}} + 8\times 10^{\frac{L_{night}+10}{10}}\right)$$

In which L_{day}, L_{night} and $L_{evening}$ are the A-weighted long-term averages as defined in ISO 1996-2:1987, and they are determined over all the day, night and evening periods of a year, respectively. The day is defined at 12 hours, the evening four hours and the night eight hours. The Member States may change the duration of the periods only if the choice is the same for all sources (European Parliament, Council of the European Union, 2002).

Environmental noise pollution is commonly measured in level of A-weighted decibels (dB(A)), which accounts for the hearing threshold of a human ear being less sensitive to very high and very low frequencies. The noise reduction can be calculated as:

$$\left(\frac{dB(A)\ level\ after\ NBS\ implementation}{dB(A)\ level\ before\ NBS\ implementation}\right)\times 100 = \%\ change\ in\ noise\ level$$

The proportion of the population exposed to elevated noise levels is then assessed with:

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

$$\left(\frac{No. inhabitatants\ exposed\ to\ L_{den} > 55\ dB(A)}{Total\ number\ of\ inhabitants}\right) \times 100\ \% = \%\ population\ affected\ by\ noise$$

Regardless of the calculation used, the noise level should be measured (or modelled) at the object receiving the noise. In urban areas, "night" hours are defined differently depending on jurisdiction but typically involve a specific time range, e.g., 22:00-07:00, rather than the meteorological definition of night as the period between dusk and dawn.

Scale of measurement: Street to district scale

Required data: *In situ* noise level data, number of inhabitants exposed to noise, and total number of inhabitants

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: At minimum before and after NBS implementation

Level of expertise required: Low to Moderate

Connection to other indicators: Related to *Area devoted to roads* indicator

Connection to SDGs: SDG 3 Good health and well-being, and SDG 15 Life on land

Key References

European Environment Agency. (2020). *Environmental noise in Europe — 2020.* Luxembourg: Publications Office of the European Union.

European Parliament, Council of the European Union. (2002). Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise - Declaration by the Commission in the Conciliation Committee on the Directive relating to the assessment and management of environmental noise. *Official Journal of the European Union L 189.* Retrieved from http://data.europa.eu/eli/dir/2002/49/oj

International Organization for Standardization (ISO). (2018). *Sustainable cities and communities — Indicators for city services and quality of life (ISO 37120:2018).* Retrieved from https://www.iso.org/standard/68498.html

12.12.5Morbidity, Mortality and Years of Life Lost due to poor air quality

Metric: *Reduction in years of life (y) due to premature mortality in comparison with standard life expectancy*

(Morbidity): Long-term (annual) incidence of chronic bronchitis due to poor air quality calculated using atmospheric NO_2 and PM_{10} data

(Mortality): Long-term (annual) incidence of mortality due to poor air quality calculated using atmospheric $PM_{2.5}$, PM_{10}, O_3 and NO_2 data

Strengths: *The indicator is easy to define*

Weaknesses: *The method needs corresponding air pollutant concentration, demographic and epidemiological input data*

Air pollution has been related to numerous adverse health effects, typically expressed in several morbidity and mortality endpoints (see Costa et al., 2014). In particular, an increasing amount of epidemiological and clinical studies observes that exposure to air pollution is associated with increased risk of heart disease, myocardial infarction and stroke as well as lung cancer (e.g., Costa et al., 2014). While the impact of these health effects may appear low at the individual level, the overall public-health burden is sizable as the entire population is exposed (Pascal et al., 2011).

The general approach in health impact assessment is to use exposure-response functions, linking the concentration of pollutants to which the population is exposed to the number of health events occurring in that population (Costa et al., 2014; Silveira et al., 2016). Therefore, the following aspects are usually considered: i) involved pollutants and their air concentration levels, ii) health indicators analysed in terms of morbidity and mortality, iii) affected age groups, and iv) exposure time. The health response is usually calculated by:

$$\Delta R = IR \times CRF \times \Delta C \times Pop$$

Where,

- *ΔR* is the response as a result of the number of the unfavourable implications (cases, days or episodes) over all health indicators;
- *IR* is the baseline morbidity/mortality annual rate (%); this information is available in the national statistical institute of each country;
- *CRF* is the correlation coefficient between the pollutant concentration variation and the probability of experiencing a specific health indicator (%; i.e., Relative Risk (RR) associated with a concentration change of 1 $\mu g\ m^{-3}$);
- *ΔC* indicates the change in the pollutant concentration ($\mu g \cdot m^{-3}$) after adoption of the adaptation/mitigation measure;
- *Pop* is the population units per age group exposed to pollution.

Morbidity (chronic bronchitis) due to poor air quality is calculated using NO_2 and PM_{10} to determine CRF and ΔC in the preceding equation.

Mortality, assessed as total mortality, is calculated using PM_{10}, $PM_{2.5}$, O_3 and NO_2 to determine CRF and ΔC in the preceding equation.

Both morbidity and mortality are based on long-term (annual) effects (Table). Where air quality data are derived from WRF-Chem results can be calculated on a daily/weekly/monthly/annual basis at the grid, neighbourhood or city scale.

Table. Air pollutant health indicators (WHO, 2013)

Pollutant	Health outcome	Age group
PM_{10}	Chronic bronchitis (incidence)	>18 y
	Chronic bronchitis (prevalence)	6-18 y
	Total mortality	<1 y
		>30 y
$PM_{2.5}$	Total mortality	>30 y
NO_2	Total mortality	>30 y
	Prevalence of bronchitic symptoms in asthmatic children	5–14 y
O_3 (April-September)	Total mortality (respiratory diseases)	>30 y

Years of life lost (YoLL) is an often-used health indicator, and refers to the total number of years of reduced life due to premature mortality. Using the mortality indicator, the YoLL can

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

be calculated as the number of deaths multiplied by a standard life expectancy at the age at which death occurs (see Gardner & Sanborn, 1990).

Scale of measurement: Street to metropolitan scale

Required data: i) involved pollutants and their air concentration levels, ii) health indicators analysed in terms of morbidity and mortality, iii) affected age groups, and iv) exposure time

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Daily, weekly, monthly or annually

Level of expertise required: Moderate

Connection to other indicators: Other indicators in the *Air quality* indicator group

Connection to SDGs: SDG 3 Good health and well-being, SDG 15 Life on land

Key References

Costa, S., Ferreira, J., Silveira, C., Costa, C., Lopes, D., Relvas, H., … Teixeira, J.P. (2014). Integrating Health on Air Quality Assessment-Review Report on Health Risks of Two Major European Outdoor Air Pollutants: PM and NO2. *Journal of Toxicology and Environmental Health - Part B Critical Reviews, 17*(6), 307-340.

Gardner, J.W., & Sanborn, J.S. (1990). Years of potential life lost (YPLL) – what does it measure? *Epidemiology (Cambridge, Mass.), 1*(4), 322–329.

Pascal, M., Corso, M., Ung, A., Declercq, C., Medina, S. & Aphekom. (2011). *APHEKON-Improving knowledge and communication for decision making on air pollution and health in Europe, Guidelines for assessing the health impacts of air pollution in European cities*, Work Package 5, Deliverable D5. Saint-Maurice, France: French Institute for Public Health Surveillance.

Silveira C., Roebeling P., Lopes M., Ferreira J., Costa S., Teixeira J.P., ... Miranda A.I. (2016). Assessment of health benefits related to air quality improvement strategies in urban areas: An Impact Pathway Approach. *Journal of Environmental Management, 183*, 694-702.

12.13 New Economic Opportunities and Green Jobs

The adoption and implementation of NBS has the potential to create new economic opportunities and jobs, particularly in the green sector, by promoting low-carbon, resource-efficient and socially inclusive economic growth. Nature-based solutions can contribute substantially to the greening of the economy, wherein economic growth is driven by public and private investment in activities, infrastructure and assets that support reduced emissions of carbon and pollutants, and increased energy and resource efficiency whilst enhancing biodiversity and the provision of ecosystem services.

Table 28. Indicators of NBS performance and impact related to New Economic Opportunities and Green Jobs

Nr.	Indicator	Units	Class	Applicability to NBS		
				Type 1	Type 2	Type 3
11.13.1 †	Mean land and/or property value in proximity to NBS	€	O	●		●
11.13.2 †	Retail and commercial activity in proximity to green space	%	O	●		●
11.13.3	Number of new businesses established in proximity to NBS	Nr./year	O	●		●
11.13.4	Value of rates paid by businesses in proximity to NBS	€/year	O	●		●
11.13.5	Subsidies applied for private NBS measures	€/year	O	●	●	●
11.13.6	Number of new jobs in green sector	%	O	●	●	●

† Indicators designated "recommended" by NBS Impact Evaluation Taskforce (Taskforce 2; Dumitru and Wendling, Eds., *in preparation*)

12.13.1 Mean land and/or property value in proximity to NBS

Metric: *Mean or median value of land and property within 300 m distance from the NBS*

Strengths: *The indicator is easy to define*

Weaknesses: *A lot of input data needs to be collected and processed*

The change in attractiveness of an area due to the presence of public green space or other NBS can be determined by an individual's willingness to pay for, and thus the sale price or value of, land or property located in proximity to the NBS (Gore et al., 2013).

Similar effects are likely to occur when implementation of NBS encourages development of new housing areas. A survey of real estate developers and consultants from across Europe

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

revealed that 95% of respondents believe that open space readily adds value to commercial. On average, property developers would be willing to pay ≥3% more for the opportunity to be near public open space, with some putting the premium as high as 15-20% (Gensler, the Urban Land Institute [ULI], & the Urban Investment Network [UIN], 2011; Roebeling et al., 2017). This premium depends on the type, quality, size and distance to the public green space as well as on the proximity to other environmental amenities and urban centres (Roebeling et al., 2017).

Hedonic analysis can be used to understand the effect of NBS on property value. This method enables analysis of property sale data, yielding the difference in sale prices as a function of various attributes that are thought to affect the price. As a result, hedonic analysis can identify the price premium associated with the presence of and access to NBS (Crompton, 2005; Troy & Grove, 2008).

Change in mean and median land and property prices following implementation of NBS can also be assessed (Forest Research, 2005). The change in mean or median land and property prices can be measured as a percentage or monetary value; however, information may need to be gathered over a period of years to gain a full understanding of the change in value. Data required include real estate values in the area defined as "surrounding the NBS". These data can be extracted annually from municipalities, cadastre and real estate agencies before and after the NBS implementation (see e.g. Bockarjova et al., 2020) or be simulated based only on pre-existing data and information (see e.g. Roebeling et al., 2017; Mendonça et al., 2020).

Understanding and identifying the buffer zone surrounding NBS and assessing the change in property value in parallel is a critical component. Proximity of land or property to NBS could be defined similarly to urban green space accessibility as in the indicator *Accessibility of urban green spaces*, i.e., land or properties within a 300 m distance from NBS. The type, quality and size of a given NBS, including the different recreational opportunities and aesthetic values, associated with the NBS, will largely determine the extent (in distance or time) and magnitude of its impact on local land and property values.

Scale of measurement: Local, neighbourhood or district scale

Required data: Property sale data from municipalities, cadastre and real estate agencies as well as area and categorisation of green spaces

Data generation specifications: Qualitative and quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Before and after NBS implementation

Level of expertise required: Low to Moderate

Connection to other indicators: Synergies with the *Green space accessibility* indicator, and the other indicators in the *New Economic Opportunities and Green Jobs* indicator group

Connection to SDGs: SDG 8 Decent work and economic growth, and SDG 9 Industry, innovation and infrastructure

Key References

Crompton, J.L. (2005). The impact of parks on property values: empirical evidence from the past two decades in the United States. *Managing Leisure, 10*(4), 203-218.

Gore, T., Ozdemiroglu, E., Eadson, W., Gianferrara, E., & Phang, Z. (2013). *Green Infrastructure's contribution to economic growth: A review*. A Final Report for Department for Defra and Natural England. July 2013. London: eftec. Retrieved from http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=19056

Forest Research. (2005). *Regeneration of previously developed land: Bold Colliery Community Woodland: district valuer's report on property values*. Cockermouth, Cumbria: North West England Conservancy. Retrieved from https://www.forestresearch.gov.uk/tools-and-resources/urban-regeneration-and-greenspace-partnership/greenspace-in-practice/planning-integrated-landscapes/brownfield-regeneration/

Gensler, the Urban Land Institute (ULI), & the Urban Investment Network (UIN). (2011). *Open Space: An asset without a champion?* San Francisco, CA: Gensler. Retrieved from https://www.gensler.com/uploads/document/220/file/Open_Space_03_08_2011.pdf

Madureira, H., Nunes, F., Oliveira, J. V, Cormier, L., & Madureira, T. (2015). Urban residents' beliefs concerning green space benefits in four cities in France and Portugal. *Urban Forestry & Urban Greening, 14*(1), 56-64.

Mendonça, R., Roebeling, P., Martins, F., Fidélis, T., Teotónio, C., Rocha, J., and Alves, H., 2020. Assessing economic instruments to steer urban residential sprawl, using a hedonic pricing simulation modelling approach. *Land Use Policy*, *92*, 104458.

Roebeling, P., Saraiva, M., Palla, A., Gnecco, I., Teotónio, C., Fidélis, T., … Rocha, J. (2017). Assessing the socio-economic impacts of green/blue space, urban residential and road infrastructure projects in the Confluence (Lyon): a hedonic pricing simulation approach. *Journal of Environmental Planning and Management, 60*(3), 482-499.

Tamosiunas, A., Grazuleviciene, R., Luksiene, D., Dedele, A., Reklaitiene, R., Baceviciene, M., … Niewenhuijsen, M.J. (2014). Accessibility and use of urban green spaces, and cardiovascular health: findings from a Kaunas cohort study. *Environmental Health, 13*(1), 20.

Troy, A., & Grove, J.M. (2008). Property values, parks, and crime: A hedonic analysis in Baltimore, MD. *Landscape and Urban Planning, 87*(3), 233-245.

World Health Organization (WHO). (2016). *Urban green spaces and health: A review of evidence*. Copenhagen: World Health Organization.

12.13.2Retail and commercial activity in proximity to green space

Metric: *Proportion of ground floor surface of buildings within 300 m from the NBS that is used for commercial or public purposes, expressed as percentage of total ground floor surface*

Strengths: *The indicator is easy to define*

Weaknesses: *A large quantity of input data need to be collected and processed*

The atmosphere of a neighbourhood and its overall liveability are influenced by the use of ground floor spaces for commercial and public purposes. The availability of amenities not only enhances the consumer experience, but also contributes to successful retail and commerce by supporting small businesses and retailers (Arlington Economic Development, 2014). Residential and office buildings generally have the most potential for increased use of ground floor space.

This metric is calculated as:

$$\left(\frac{Ground\ floor\ space\ for\ commerical\ or\ public\ use\ (m^2)}{Total\ ground\ floor\ space\ (m^2)}\right) \times 100$$

This indicator may be limited to a defined urban area within a specific distance of 300 m from NBS (e.g., an area with a given distance or walking time from implemented NBS).

Scale of measurement: Neighbourhood or district scale

Required data: Data about ground floor space usage can be obtained from administrative documents and/or from interviews with the department for urban planning within the local municipality

Data generation specifications: Quantitative; cannot be collected via participatory processes

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Data generation/collection frequency: Before and after NBS implementation

Level of expertise required: Low to Moderate

Connection to other indicators: Synergies with the indicator group *Economic activity & Green Jobs* indicators

Connection to SDGs: SDG 8 Decent work and economic growth, and SDG 9 Industry, innovation and infrastructure

Key References

Arlington Economic Development. (2014). *Ground Floor Retail and Commerce: Policies, Guidelines and Action Plan.* Draft – September 2014. Arlington, VA: Arlington Economic Development Department, Real Estate Development Group. Retrieved from https://www.arlingtoneconomicdevelopment.com/index.cfm?LinkServID=6E1B9F23-AA29-D1AC-1DFE1072C67F5C64&showMeta=0

Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., and Huovila, A. (2017). *CITYkeys indicators for smart city projects and smart cities*. CITYkeys project D1.4. http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf

World Health Organization. (2016). *Urban green spaces and health: A review of evidence*. Copenhagen: World Health Organization.

12.13.3Number of new businesses established in proximity to NBS

Metric: *Number of new businesses established in the area within 300 m from the implemented NBS*

Strengths: *The indicator is easy to define*

Weaknesses: *A lot of input data needs to be collected*

Urban regeneration can lead to improvement in the economic, physical, and social conditions of an area that has witnessed negative changes (Tallon, 2013). As such, it can include aspects such as development of business, housing, and a positive change on the community level (Tyler, Warnock, Provins, & Lanz, 2013). Nature-based solutions also provide a ground for 'Green businesses' to flourish (Organisation for Economic Co-operation and Development [OECD], 2013).

A report by Gore, Ozdemiroglu, Eadson, Gianferrara, and Phang (2013) states that gross domestic product (GDP) and gross value added (GVA) metrics alone cannot accurately estimate the contribution of green infrastructure/NBS to economic growth. Some methods to measure success can include occupation of premises in local areas or taking up of vacated spaces, changes in taxation, increase in start-ups, increase in visitors, new and expanding producer and retail firms, direct employment in development, maintenance and services, indirect employment in supporting firms, attracting and retaining the workforce.

The major indicator is the number of established businesses located around the implemented NBS and also the rates paid for occupying that particular space (Gore et al., 2013). However, this will require gathering data over a period of years to understand the trend and business activities, both before and after the NBS implementation. Data can be derived annually from municipalities, planning departments and interviews with local businesses.

Understanding and identifying the buffer zone surrounding NBS and assessing the number of new businesses in parallel is a critical component. It may be useful to define the proximity of land or property to NBS similarly to urban green space accessibility as in the indicator *Accessibility of urban green spaces*, i.e., land or properties within a 300 m distance from NBS.

The type, quality and size of a given NBS, and the different recreational opportunities, attractiveness and aesthetic values associated with the NBS, will largely determine the extent (in distance or time) and magnitude of its impact on local business development.

Scale of measurement: District to regional scale

Required data: Lot of possibilities exist, including GDP, GVA, number of start-ups, etc.

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Before and after NBS implementation

Level of expertise required: Low to Moderate

Connection to other indicators: Synergies with the indicator group *Economic activity & Green Jobs,* and the *Distribution of public green space* and *Accessibility of urban green spaces* indicators

Connection to SDGs: SDG 8 Decent work and economic growth, and SDG 9 Industry, innovation and infrastructure

Key References

Gore, T., Ozdemiroglu, E., Eadson, W., Gianferrara, E., & Phang, Z. (2013). *Green Infrastructure's contribution to economic growth: A review*. A Final Report for Department for Defra and Natural England. July 2013. London: eftec. http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=19056

Madureira, H., Nunes, F., Oliveira, J. V, Cormier, L., & Madureira, T. (2015). Urban residents' beliefs concerning green space benefits in four cities in France and Portugal. *Urban Forestry & Urban Greening, 14*(1), 56-64.

Organisation for Economic Co-operation and Development (OECD). (2013). *Green Growth in Cities.* Paris, France: OECD Environment Directorate. Retrieved from https://doi.org/10.1787/9789264195325-en

Tallon, A. (2013). *Urban Regeneration in the UK*. Abingdon, Oxon: Routledge.

Tamosiunas, A., Grazuleviciene, R., Luksiene, D., Dedele, A., Reklaitiene, R., Baceviciene, M., … Niewenhuijsen, M.J. (2014). Accessibility and use of urban green spaces, and cardiovascular health: findings from a Kaunas cohort study. *Environmental Health, 13*(1), 20.

Tyler, P., Warnock, C., Provins, A., & Lanz, B. (2013). Valuing the benefits of urban regeneration. *Urban Studies, 50*, 169-190.

World Health Organization. (2016). *Urban green spaces and health: A review of evidence*. Copenhagen: World Health Organization.

12.13.4Value of rates paid by businesses in proximity to NBS

Metric: *Value of rates paid by businesses established in the area within 300 m from the implemented NBS*

Strengths: *The indicator is easy to define*

Weaknesses: *A substantial amount of input data needs to be collected*

To accurately determine the impact of NBS implementation on the value of rates paid by nearby businesses, it is necessary to gather data over a period of years to understand trends and business activities before and after NBS implementation. Data can be derived annually from municipalities, planning departments and interviews with local businesses.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Understanding and identifying the buffer zone surrounding NBS and assessing the number of new businesses in parallel is a critical component. It may be useful to define the proximity of land or property to NBS similarly to urban green space accessibility as in the indicator *Accessibility of urban green spaces*, i.e., land or properties within a 300 m distance from NBS. The type and size of a given NBS, and the different recreational opportunities and aesthetic values associated with the NBS, will largely determine the extent (in distance or time) and magnitude of its impact on local business development.

Scale of measurement: District to regional scale

Required data: Input data from municipalities, planning departments, and interviews with local businesses as well as area and categorisation of green spaces

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Before and after NBS implementation

Level of expertise required: Low to Moderate

Connection to other indicators: Synergies with the indicator group *Economic activity & Green Jobs,* and the *Distribution of public green space* and *Accessibility of urban green spaces* indicators

Connection to SDGs: SDG 8 Decent work and economic growth, and SDG 9 Industry, innovation and infrastructure

Key References

Gore, T., Ozdemiroglu, E., Eadson, W., Gianferrara, E., & Phang, Z. (2013). *Green Infrastructure's contribution to economic growth: A review*. A Final Report for Department for Defra and Natural England. July 2013. London: eftec. http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=19056

Madureira, H., Nunes, F., Oliveira, J. V, Cormier, L., & Madureira, T. (2015). Urban residents' beliefs concerning green space benefits in four cities in France and Portugal. *Urban Forestry & Urban Greening, 14*(1), 56-64.

Tamosiunas, A., Grazuleviciene, R., Luksiene, D., Dedele, A., Reklaitiene, R., Baceviciene, M., … Niewenhuijsen, M.J. (2014). Accessibility and use of urban green spaces, and cardiovascular health: findings from a Kaunas cohort study. *Environmental Health, 13*(1), 20.

World Health Organization. (2016). *Urban green spaces and health: A review of evidence*. Copenhagen: World Health Organization.

12.13.5Subsidies applied for private NBS measures

Metric: *Number or total value (in EUR) of direct (cash) subsidies or tax concessions applied to private NBS measures*

Strengths: *The indicator is easy to define*

Weaknesses: *Medium or long term assessment. Data are required from multiple different municipal departments. May require input from citizens*

This KPI, related to economic aspects measurements, evaluates how NBS interventions can influence the private sector.

When a positive externality on consumption is present in a market, the government can actually increase the value that the market creates for society by providing a subsidy equal to the benefit of the externality (such subsidies are referred to as Pigouvian subsidies or corrective subsidies). This subsidy moves the market to the socially optimal outcome because it makes the benefit that the market confers on society explicit to producers and consumers, giving producers and consumers the incentive to factor the benefit of the externality into their decisions. In addition to dealing with externalities, subsidies (market-based instruments) are capable of steering land use decisions and are considered and more advantageous as compared to other (command and control) instruments (see e.g. Mendonça et al., 2020).

For the purposes of this indicator, "subsidies applied for private NBS measures" are narrowly defined as direct (cash) subsidies or tax concessions (exemptions or credits) awarded to an individual or organisation to implement, or following implementation of, an NBS on privately-owned property. The subsidies applied for private NBS measures can be expressed either the number of subsidies, or as a monetary value (in EUR).

Together with the total number or value of subsidies awarded, tracking the availability of subsidies for private NBS measures along with the number of applications for available subsidies can provide a qualitative measure of changing demand for NBS in the private sector.

To determine the number of subsides implemented (by zone affected), collect data from the municipality's economic department and other relevant departments.

Direct value on subsides (by zone), before and after implementation, during the established period are calculated as:

$$\textit{Number of subsides implemented} = n * Z\ [(n^{o}\ \textit{subsides})\ (€/m^{2})]$$

Where *n* refers to the subsides total number multiplied by its value by zone Z (directly related to the each NBS)

Scale of measurement: Neighbourhood to city scale

Required data: Local and national governments, as well as the individuals or organisations receiving the aforementioned subsidies, serve as sources of information for this metric. This may include City official data, city platforms, questionnaires, and/or small-medium enterprise accounts (related to de NBS investment zone)

Data generation specifications: Qualitative and quantitative; cannot be collected via participatory processes

- (number of subsidies) (number /year) (€/m^2)
- (number of subsidies or number of tax concessions) (number /year) (€/year);

Data generation/collection frequency: Annually, both before and after NBS implementation

Level of expertise required: Low to Moderate

Connection to other indicators: Synergies with the indicator group *Economic activity & Green Jobs*

Connection to SDGs: SDG 8 Decent work and economic growth, and SDG 9 Industry, innovation and infrastructure

Key References

Raymond, C.M., Berry, P., Breil, M., Nita, M.R., Kabisch, N., de Bel, M., Enzi, V., Frantzeskaki, N., Geneletti, D., Cardinaletti, M., Lovinger, L., Basnou, C., Monteiro, A., Robrecht, H., Sgrigna, G., Munari, L. and Calfapietra, C. (2017). *An Impact Evaluation Framework to Support Planning and Evaluation of Nature-based Solutions Projects*. Report prepared by the EKLIPSE Expert Working Group on Nature-based Solutions to Promote Climate Resilience in Urban Areas. Centre for Ecology & Hydrology, Wallingford, United Kingdom.

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Mendonça, R., Roebeling, P., Martins, F., Fidélis, T., Teotónio, C., Rocha, J., and Alves, H., 2020. Assessing economic instruments to steer urban residential sprawl, using a hedonic pricing simulation modelling approach. Land Use Policy, 92, 104458

12.13.6Number of new jobs in green sector

Metric: *Total number or per cent increase in the (new) jobs related to environmental service activities that contribute substantially to preserving or restoring environmental quality*

Strengths: *Easy to measure*

Weaknesses: *Requires extensive processing of input data if not already available*

'Green jobs' in areas directly connected to the environment such as resource conservation, waste management, water and green space management, and air quality can support economic growth and development. Some NBS projects may generate new jobs and new economic opportunities (Raymond et al., 2017; Byrd et al., 2017; European Commission, 2013). Large-scale and/or long-term NBS projects are likely to create new jobs through the development of activities related to enjoyment of the natural environment (e.g., outdoor activity instruction and guiding, bike and other outdoor equipment rental and/or repair, nature education, etc.).

The United Nations Environment Programme (UNEP), International Labour Organization (ILO), International Organisation of Employers (IOE), and International Trade Union Confederation (ITUC) (2008, pp. 3) define green jobs as "work in agricultural, manufacturing, research and development (R&D), administrative and service activities that contribute substantially to preserving or restoring environmental quality. Specifically, but not exclusively, this includes jobs that help to protect ecosystems and biodiversity; reduce energy, materials, and water consumption through high efficiency strategies; de-carbonize the economy; and minimize or altogether avoid generation of all forms of waste and pollution." The employing company or organisation can either be in a 'green' sector (e.g., green infrastructure design), or in a conventional sector (e.g., engineering services) but be making genuine and substantial efforts to green its operations.

This Indicator will be equal to 0 in the baseline scenario (i.e., prior to NBS actions) and will be assessed in a Long Term Scenario, using data made available after NBS have been implemented to determine the number of new jobs created in the green sector. The number of jobs, or number of new jobs, in the green sector can be counted or estimated for a given municipality based on business registrations and/or administrative documents as follows.

- The total number of new jobs in the green sector is a simple count and is expressed as a number.
- The per cent increase in green jobs is calculated as:

$$\left(\frac{Number\ of\ (new)\ green\ jobs}{Total\ number\ of\ (new) jobs}\right) \times 100$$

Alternatively, this indicator may be qualitatively estimated in the Design Scenario, using a probabilistic (e.g., Likert) scale prior to NBS implementation, e.g., during the NBS co-creation phase. In the Design Scenario, a five-point Likert scale with categories "Very Poor", "Poor", "Average", "Good", and "Very Good", can be used to assess the potential realisation of new jobs in the green sector within the study area.

Scale of measurement: District to regional scale

Required data: Data about the number of green jobs and total number of jobs from business registrations and/or administrative documents; National Statistical Institute; Chamber of Commerce.

Data generation specifications: Quantitative; cannot be collected via participatory processes

Data generation/collection frequency: Before and after NBS implementation. Recommended annual assessment

Level of expertise required: Low to Moderate

Connection to other indicators: Synergies with the indicator group *Economic activity & Green Jobs* indicators

Connection to SDGs: SDG 8 Decent work and economic growth, and SDG 9 Industry, innovation and infrastructure

Key References

Byrd C., Andersson E., Kronenberg J., Hansen R., Buijs A. (2017). *Understanding and Promoting the Values of Urban Green Infrastructure: a learning module*. GREEN SURGE project Deliverable 4.5, University of Copenhagen, Copenhagen, Denmark

European Commission (2013). *Rural Development in the European Union - Statistical and economic information – 2013*. European Union, 2013. https://ec.europa.eu/agriculture/statistics/rural-development/2013_en

Madureira, H., Nunes, F., Oliveira, J. V, Cormier, L., & Madureira, T. (2015). Urban residents' beliefs concerning green space benefits in four cities in France and Portugal. *Urban Forestry & Urban Greening, 14*(1), 56-64.

Raymond C.M., Berry P., Breil M., Nita M.R., Kabisch N., de Bel M., Enzi V., Frantzeskak N., Geneletti D., Cardinaletti M., Lovinger L., Basnou C., Monteiro A., Robrecht H., Sgrigna G., Munari L., Calfapietra C. (2017). *An Impact Evaluation Framework to Support Planning and Evaluation of Nature-based Solutions Projects*. Report prepared by the EKLIPSE Expert Working Group on Nature-based Solutions to Promote Climate Resilience in Urban Areas. Centre for Ecology & Hydrology, Wallingford, United Kingdom

Tamosiunas, A., Grazuleviciene, R., Luksiene, D., Dedele, A., Reklaitiene, R., Baceviciene, M., … Niewenhuijsen, M.J. (2014). Accessibility and use of urban green spaces, and cardiovascular health: findings from a Kaunas cohort study. *Environmental Health, 13*(1), 20.

Tyler, P., Warnock, C., Provins, A., & Lanz, B. (2013). Valuing the benefits of urban regeneration. *Urban Studies, 50*, 169-190.

United Nations Environment Programme (UNEP), International Labour Organization (ILO), International Organisation of Employers (IOE), & International Trade Union Confederation (ITUC). (2008). *Green Jobs: Towards Decent Work in a Sustainable, Low-Carbon World*. Nairobi, Kenya: United Nations Publishing Services Section. Retrieved from https://www.ilo.org/global/topics/green-jobs/publications/WCMS_158727/lang--en/index.htm

12.14 Conclusions

This document reports updates to UNaLab Deliverable 3.1 D3.1 *Performance and Impact Monitoring of Nature-Based Solutions* (Wendling *et al.*, 2019). The list of indicators and the associated methods of determination presented herein are non-exhaustive. The development of new indicators of NBS performance and impact is a continuous process alongside the evolution of NBS as a mainstream concept. Updates to the present document, including changes resulting from field-testing and validation of these guidelines, will be reported in M60 of the UNaLab project (May 2022) in Deliverable 5.5 *Final NBS Implementation Handbook*.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

References

Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). CITYkeys indicators for smart city projects and smart cities. CITYkeys D1.4. Retrieved from http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf

Calliari, E., Staccione, A., & Mysiak. J. (2019). An assessment framework for climate-proof nature-based solutions. *Science of the Total Environment*, *656*, 691-700.

Callaghan, C.T., Major, R.E., Lyons, M.B., Martin, J.M., & Kingsford, R.T. (2018). The effects of local and landscape habitat attributes on bird diversity in urban greenspaces. *Ecosphere*, 9(7), e02347.

Cohen-Shacham, E., Walters, G., Janzen, C., & Maginnis, S. (Eds.). (2016). *Nature-based Solutions to address global societal challenges*. Gland, Switzerland: International Union for the Conservation of Nature.

Dumitru, A.M. & Wendling, L.A., Eds. (I*n preparation). Evaluating the Impact of Nature-based Solutions: A Handbook for Practitioners.* Brussels: European Commisson Directorate General for Research and Innovation.

Eggermont, H., Balian, E., Azevedo, J.M.N., Beumer, V., Brodin, T., Claudet, J., …Le Roux, X. (2015). Nature-based solutions: New influence for environmental management and research in Europe. *GAIA*, *24*(4), 243-248.

European Commission. (2015). *Towards an EU Research and Innovation policy agenda for Nature-Based Solutions & Re-Naturing Cities. Final Report of the Horizon 2020 Expert Group on 'Nature-Based Solutions and Re-Naturing Cities'*. Luxembourg: Publications Office of the European Union. Retrieved from https://publications.europa.eu/en/publication-detail/-/publication/fb117980-d5aa-46df-8edc-af367cddc202

EEA 2017. Climate change, impacts and vulnerability in Europe 2016. Report No 1/2017. http://www.eea.europa.eu/media/publications/

EEA, 2019. *Air quality in Europe - 1029 Report*. EEA Report No. 10/2019. Luxembourg: Publications Office of the European Union.

Faivre, N., Sgobbi, A., Happaerts, S., Raynal, J., & Schmidt, L. (2017). Translating the Sendai Framework into action: the EU approach to ecosystem-based disaster risk reduction. *International Journal of Disaster Risk Reduction*, *32*, 4-10.

Gould, K.A. & Lewis, T.L. (2017). *Green Gentrification. Urban sustainability and the struggle for environmental justice.* London: Routledge.

Huovila, A., Airaksinen, M., Pinto-Seppä, I., Piira, K., Bosch, P., Penttinen, T., … Kontinakis, N. (2017). CITYkeys Smart City Performance Measurement System. *International Journal for Housing Science*, *41*(2), 113–125.

Kabisch, N., Frantzeskaki, N., Pauleit, S., Naumann, S., Davis, M., Artmann, M., … Bonn, A. (2016). Nature-based solutions to climate change adaptation and mitigation in urban areas: perspectives on indicators, knowledge gaps, barriers, and opportunities for action. *Ecology and Society*, *21*(2), 39.

Maes, J., Zulian, G., Günther, S., Thijssen, M., & Raynal, J. (2019). *Enhancing Resilience of Urban Ecosystems through Green Infrastructure. Final Report, EUR 29630 EN.* Luxembourg: Publications Office of the European Union.

Maes, J., Zulian, G., Thijssen, M., Castell, C., Baró, F., Ferreira, A.M., ... Teller, A. (2016). *Mapping and Assessment of Ecosystems and their Services. Urban Ecosystems.* Luxembourg: Publications Office of the European Union.

Nel, S., du Plessis, C., & Landman, K. (2018). Planning for dynamic cities: introducing a framework to understand urban change from a complex adaptive systems approach. *International Planning Studies*, *33*(3), 250-263.

Organisation for Economic Co-operation and Development (OECD). (2008). *Key Environmental Indicators*. Paris, France: OECD Environment Directorate. Retrieved from https://www.oecd.org/env/indicators-modelling-outlooks/37551205.pdf

Raymond, C.M., Berry, P., Breil, M., Nita, M.R., Kabisch, N., de Bel, M., ... Calfapietra, C. (2017). *An Impact Evaluation Framework to Support Planning and Evaluation of Nature-based Solutions Projects. Report prepared by the EKLIPSE Expert Working Group on Nature-based Solutions to Promote Climate Resilience in Urban Areas*. Wallingford, United Kingdom: Centre for Ecology and Hydrology.

Rigolon, A., Németh, J. (2020). Green gentrification or 'just green enough': Do park location, size and f unction affect whether a place gentrifies or not? *Urban Studies*, 57(2), 402-420.

Somarakis, G., Stavros, S. & Chrysoulakis, N. (Eds.). 2019. ThinkNature Nature-Based Solutions Handbook. ThinkNature project funded by the EU Horizon 2020 Research and Innovation programme. https://platform.think-nature.eu/system/files/thinknature_handbook_final_print_0.pdf

United Nations Environment Programme (UNEP), United Nations Educational, Scientific and Cultural Organization (UNESCO), World Health Organisation (WHO), United Nations (UN) Women, United Nations Office on Drugs and Crime (UNODC), World Bank Group … United Nations Statistics Division. (2016). *A Guide to Assist National and Local Governments to Monitor and Report on SDG Goal 11+ Indicators: Monitoring Framework, Definitions, Metadata, UN-Habitat Technical Support.* Nairobi, Kenya: UN-Habitat. Retrieved from http://unhabitat.org/sdg-goal-11-monitoring-framework/

United Nations (UN) General Assembly. (2015). *Transforming Our World: The 2030 Agenda for sustainable development. A/RES/70/1.* New York: United Nations. Retrieved from http://www.unfpa.org/sites/default/files/resource-pdf/Resolution_A_RES_70_1_EN.pdf

United Nations (UN) General Assembly (2017). Resolution adopted by the General Assembly on 6 July 2017. 71/313 Work of the Statistical Commission pertaining to the 2030 Agenda for Sustainable Development. 10 July 2017, A/RES/71/313. Retrieved from https://undocs.org/A/RES/71/313

Wendling, L., Huovila, A., zu Castell-Rüdenhausen, M., Hukkalainen, M., & Airaksinen, M. (2018). Benchmarking Nature-Based Solution and Smart City assessment schemes against the Sustainable Development Goal indicator framework. *Frontiers in Environmental Science, 6*, 69.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

13 APPENDIX II: UPDATE TO D5.1 NATURE-BASED SOLUTIONS TECHNICAL HANDBOOK

Table of Contents

The following Nature Based Solutions (NBS) Factsheets were originally developed for the *Nature-Based Solutions Technical Handbook* (D5.1; Eisenberg & Polcher, 2018). For more information about the NBS Technical Handbook and the following Factsheets, please refer to the Section 4.5 of this Deliverable.

13.1 Green space

13.1.1 Residential park

Residential park

Fig. 1: Innocentia Park, Hamburg (source: Bildarchiv der Behörde für Umwelt und Energie Hamburg, Abteilung Stadtgrün)

Fig. 2: Innocentia Park 2, Hamburg (source: BSU, Hamburg.de)

i. Basic information

Synonyms	Urban park, Pocket park						
Type	1	2	3	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation			
Addressed challenges	Climate resilience	Water management	Natural and climate hazards	Biodiversity	Air quality	Public health and well-being	Social justice and cohesion
	X	X	X	X	X	X	X
Examples in UNaLab FRC	*Green zones in Clausplein Square, Eindhoven NL; Green zones in former Nutsbedrijven, Eindhoven NL; Gavoglio Barracks, GenovaIT*						
Reference to other key studies	*Stiemerbeek Park, Genk BE; Pocket Parks, Budapest HU*						

ii. General description

Residential Parks are part of the Green Infrastructure (GI) of cities and serve the residential areas as the nearest main entry point for nature-based recreation. Larger spatial elements of GI are district parks that often deliver more functions and combine various uses (e.g. sport fields). Smaller spatial elements of GI that also act as residential parks may be composed as playgrounds, connecting green strips of land, or pocket parks.

iii. Role of nature

The residential park acts like an oasis in an urban environment, with positive effects for urban climate, recreation, and biodiversity into the neighbouring residential areas.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

iv.	**Technical and design parameters**
	Residential parks should be well connected and accessible for pedestrians. The park should be at least 1.5 ha size and have a compact form (120 m x 20 m) with high proportion of trees or small forest (> 50 %), and few sealed surfaces. The layout of the typical *London Residential Park* with tree and shrub plantations next to the streets and a central open area can be seen as a model. Pocket parks are a good alternative where space is limited. These urban parks are typically around 1200 m^2 (no greater than 5000 m^2) and can offer some similar, although smaller-scale, benefits as larger urban parks.
v.	**Conditions for implementation**
	New urban development areas provide the opportunity to establish residential parks at the most suitable location, thereby maximising the effects on urban climate. However, the establishment of new parks in urban regeneration projects is also possible and may be very beneficial. In order to have a maximised impact on urban climate, spatially equal distribution of parks is important.
vi.	**Benefits and limitations**
	Potential benefits: - Residential parks are multifunctional and deliver all benefits of green infrastructure. *Potential limitations/limitations:* - Accessibility is a key factor for the success of residential parks.
vii.	**Performance**

P1	Transpiration	2
	Shading	2
	Evaporation	2
	Building (Insulation)	-
	Reflection (Albedo)	2
P2	Water conveyance	2
	Water infiltration	2
	Water retention	2
	Water storage	2
	Water reuse	-
P3	Water filtering	2
	Water bio-remediation	-
P4	Deposition	2
	Air biofiltration	2
	Noise reduction	-
P5	Habitat provision	2
	Connectivity	2
P6	Beauty / Appearance	2
	Usability / Functionality	2
	Social interaction	2
	Education	-
P7	Food / Energy / Material	1
P8	CO2 Sequestration	1

viii. Literature and further reading

Algretawee, H., Rayburg, S., & Neave, M. (2019). Estimating the effect of park proximity to the central of Melbourne city on Urban Heat Island (UHI) relative to Land Surface Temperature (LST). Ecological Engineering, 138, 374-390. https://doi.org/10.1016/j.ecoleng.2019.07.034.

Blake, A. (2014). Urban parks: pocket parks. [PDF]. Retrieved from https://depts.washington.edu/open2100/pdf.

	Connecting Nature. (2020). Schansbroek, Genk-brownfield regeneration. Retrieved from https://connectingnature.eu/oppla-case-study/19379. Naturvation. (2017). Urban nature atlas: pocket parks in Budapest. Retrieved from https://www.naturvation.eu/nbs/budapest/pocket-parks-budapest. Oppla (2020). Schansbroek, Genk-brownfield regeneration. Retrieved March 20, 2021, from https://connectingnature.eu/oppla-casestudy/19379. Pearlmutter, D., Calfapietra, C., Samson, R., O'Brien, L., Ostoić, S. K., Sanesi, G., & del Amo, R. A. (Eds.). (2017). The urban forest: cultivating green infrastructure for people and the environment (Vol. 7). Springer. Peschardt, K. K. (2014). Health Promoting Pocket Parks in a Landscape Architectural Perspective. Department of Geosciences and Natural Resource Management, University of Copenhagen. Peschardt, K. K., Schipperijn, J., & Stigsdotter, U. K. (2012). Use of small public urban green spaces s (SPUGS). Urban forestry & urban greening, 11(3), 235-244. Ravnikar, Ž., & Marušić, B. G. (2019). Nature-based solutions (NBS). Urbani Izziv, 30(1), 144-146. Urban Nature Atlas. (2021). Pocket parks in Budapest. Retrieved from https://web.archive.org/web/20220823092609/https:/una.city/nbs/budapest/pocket-parks-budapest.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

13.1.2 Green corridors

Green Corridors	
 *Fig. 3: Green Corridor along a cycle path (source: LAND; https://www.landsrl.com/)*	 *Fig. 4: Green Corridor over a bridge (source: LAND; https://www.landsrl.com/)*

i. Basic information

Synonyms							
Type	1	2	3	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation			
Addressed challenges	Climate resilience	Water management	Natural and climate hazards	Biodiversity	Air quality	Public health and well-being	Social justice and cohesion
	X	X		X	X	X	X
Examples in UNaLab FRC							
Reference to other key studies	*High Line Park, New York US; Green Corridor, Singapore SG; Project 20 Green Walks Berlin, Berlin DE*						

ii. General description

Areas of derelict infrastructure, e.g. railway lines, that are transformed into linear parks play an important role in urban green infrastructure networks and help to re-nature cities. Also regeneration along waterways and rivers often results in linear interconnecting parks. Green corridors can increase accessibility to green spaces while promoting environmentally sustainable transportation like walking and cycling. Additionally, they may support biodiversity via improved ecological networks and habitat connectivity.

iii. Role of nature

Transition areas between biomes are called ecotones, green corridors with their linear natural elements can be seen as ecotones that connect neighbouring and distant areas. Ecotones are often rich in biodiversity because they are connected to two (or more) different biotopes.

iv. Technical and design parameters

When green corridors are based on derelict infrastructure the location and the network properties are more or less fixed. For new developments green corridors can be designed as connecting elements.

v. Conditions for implementation

Abandoned traffic infrastructure may be the most convenient way to establish linear parks and green corridors. The lack of care and sustained neglect of the area leads to an automatic development of the natural features in the space. For new urban developments linear elements can also be designed and built.

vi. Benefits and limitations

	Potential benefits: - Linear elements are very important for GI connectivity. - The re-use of old grey infrastructure opens up a great potential for creating an interconnected system. *Potential limitations/disservices:* - Depending on the previous use, the green corridor may need a high level of maintenance (e.g. bridges).	
ii.	**Benefits and limitations**	
P1	Transpiration	1
	Shading	1
	Evaporation	1
	Building (Insulation)	1
	Reflection (Albedo)	-
P2	Water conveyance	1
	Water infiltration	1
	Water retention	1
	Water storage	1
	Water reuse	-
P3	Water filtering	1
	Water bio-remediation	-
P4	Deposition	2
	Air Biofiltration	1
	Noise Reduction	-
P5	Habitat provision	2
	Connectivity	2
P6	Beauty / Appearance	2
	Usability / Functionality	1
	Social interaction	2
	Education	-
P7	Food / Energy / Material	1
P8	CO2 Sequestration	-
ii.	**Literature and Further Reading**	

High Line. (2020). High Line: overview. Retrieved from thehighline.org.

Senate Department for the Environment, Transport and Climate Protection (n.d.). 20 green walks in Berlin. Retrieved from https://www.berlin.de/sen/uvk/en/nature-and-green/landscape-planning/20-green-walks-in-berlin/.

Strand, D. (2018). Singapore's Green Corridor park as a homegrown import. International Communication of Chinese Culture, 5(1-2), 61-81.

Zhang, Z., Meerow, S., Newell, J. P., & Lindquist, M. (2019). Enhancing landscape connectivity through multifunctional green infrastructure corridor modeling and design. Urban Forestry & Urban Greening, 38, 305-317.

Žlender, V., & Thompson, C. W. (2017). Accessibility and use of peri-urban green space for inner-city dwellers: A comparative study. Landscape and urban planning, 165, 193-205.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

13.1.3 Urban gardens

Urban gardens

Fig. 5: Left:Urban garden on Züblin Parkhaus, Stuttgart DE (source:Jakstis), right: Allotment garden in Berlin DE (source: Fischer)

i. Basic information

Synonyms	Community gardens, intercultural gardens, allotment gardens, urban farming, urban agriculture						
Type	1	2	3	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation			
Addressed challenges	Climate resilience	Water management	Natural and climate hazards	Biodiversity	Air quality	Public health and well-being	Social justice and cohesion
	X	X		X	X	X	X
Examples in UNaLab FRC	*Urban gardens in Vuores, Tampere FI*						
Reference to other key studies	*Allmendekontor Berlin, DE*						

ii. General description

Urban gardening is a common way to establish garden space for citizens. There are many different concepts of urban gardening, but mostly they are semi-private with a possibility to rent individual beds (community gardens, urban garden projects) to individual garden plots (allotment gardens). Especially when smaller in size and directed towards community work, urban gardens are established in many diverse locations such as courtyards or public spaces. Depending on the size and intent of the garden, they offer a variety of benefits. For example, they can be sources for locally produced food and promote social interaction.

iii. Role of nature

Urban gardens act as small oases in an urban environment, with positive effects for urban climate, recreation, and biodiversity into the neighbouring residential areas.

iv. Technical and design parameters

There are many possible designs for urban gardens. They are often constructed according to the space available, and needs/intentions of the organizing community. Care must be taken with regard to previous or neighbouring land uses that may have caused soil contamination (e.g. transformed parking lots, industrial sites).

v. Conditions for implementation

In order to implement urban gardens, an organized, caring community with initiative and an appropriate space are necessary.

vi. Benefits and limitations

Potential benefits:

- Urban gardens are multifunctional and deliver many benefits of green infrastructure

	- Provide locally sourced food - Encourage social interaction *Potential limitations/limitations:* - Accessibility is a key factor for the success of urban gardens	
vii.	**Performance**	
P1	Transpiration	2
	Shading	-
	Evaporation	2
	Building (Insulation)	-
	Reflection (Albedo)	-
P2	Water conveyance	-
	Water infiltration	1
	Water retention	1
	Water storage	1
	Water reuse	-
P3	Water filtering	1
	Water bio-remediation	-
P4	Deposition	-
	Air biofiltration	2
	Noise reduction	-
P5	Habitat provision	1
	Connectivity	-
P6	Beauty / Appearance	2
	Usability / Functionality	2
	Social interaction	2
	Education	-
P7	Food / Energy / Material	2
P8	CO2 Sequestration	-
viii.	**Literature and further reading**	

Allmende-Kontor. (2020). Allmende-Kontor. Retrieved from https://www.allmende-kontor.de.

van der Jagt, A.P.N., Szaraz, L.R., Delshammar, T., Cvejić, R., Santos, R., Goodness, J., Buijs, A. (2017) Cultivating nature-based solutions: The governance of communal urban gardens in the European Union. Environmental Research 159, 264–275

Lin, B.B., Egerer, M.H., Ossola, A., 2018. Urban gardens as a space to engender biophilia: evidence and ways forward. Front. Built Environ. 4, 79.

Park, H., Kramer, M., Rhemtulla, J.M., Konijnendijk, C.C., 2019. Urban food systems that involve trees in Northern America and Europe: a scoping review. Urban For. Urban Greening 45, 126360.

Petrovic, N., Simpson, T., Orlove, B., et al., 2019. Environmental and social dimensions of community gardens in East Harlem. Landscape Urban Plann. 183, 36–49.

Russo, A., Escobedo, F.J., Cirella, G.T., et al., 2017. Edible green infrastructure: an approach and review of provisioning ecosystem services and disservices in urban environments. Agric. Ecosyst. Environ. 242, 53–66.

Sowińska-Świerkosz, B., Michalik-Śnieżek, M., & Bieske-Matejak, A. (2021). Can allotment gardens (AGs) be considered an example of nature-based solutions (NBS) based on the use of historical green infrastructure? Sustainability, 13(2), 835. https://doi.org/10.3390/su13020835.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

13.2 Trees and shrubs

13.2.1 Single line street trees

Single line street trees

Fig. 6: Townhall Square Eindhoven (source: Eisenberg)

Fig. 7: Tree lined street (source: LAND; https://www.landsrl.com/)

i. Basic information

Synonyms	Street trees						
Type	1	2	3	<u>action type:</u> 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation			
Addressed challenges	Climate resilience	Water management	Natural and climate hazards	Biodiversity	Air quality	Public health and well-being	Social justice and cohesion
	X	X		X	X	X	X
Examples in UNaLab FRC	*Street trees on Vestdijk Street, Eindhoven NL;* *Street trees on Bilderdijklaan Street, Eindhoven NL*						
Reference to other key studies	Street trees and tree pits, Glasgow UK; Melbourne Urban Forest strategy, Melbourne AUS; Million trees project New York City US						

ii. General description

Single line trees represent one possibility to establish several trees in urban areas. As the name implies, single line trees are arranged along e.g. streets, bicycle paths and sidewalks and the trees are situated on one side.

Trees in general have multiple effects on the local micro-climate conditions, absorb particulate matter and provide shade for people and buildings. One of the main positive effects for human well-being in periods with high temperatures is the air cooling effect. The mentioned effect of street trees in general depends on different factors such as tree size, canopy coverage, planting density, tree species, tree health, location, availability of root water and leaf area index.

Additionally, tree lines are often combined with low landscaping measures such as raingardens.

iii. Role of nature

Single line trees simulate those trees growing at the edge of the woods and their effects on the surrounding environment outside the tree-covered area. The trees shade adjoining land uses. As a result, the shaded surface is cooler than surfaces without a protecting tree cover.

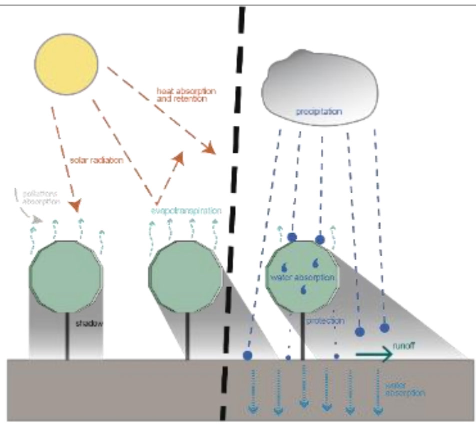


Fig. 8: Role of single trees (source: ILPOE, 2018)

The shading effect is determined by the characteristics of the trees (tree and canopy density, season). Other effects are a reduced wind velocity; transpiration/air cooling, and air purification/absorption of particular matter.

iv.	**Technical and design parameters**
	The most important aspect is the selection of suitable trees that serve the intended purpose and are fit for the geo-environmental conditions (see Annex 1). Additionally, selected trees should have low biogenic volatile organic compound (BVOC) production potential to reduce the possible negative effect of ozone production in warmer months. The area of the root space for neighbouring trees can be connected in suitable conditions and if separated root space should be 12 m³ with a minimum depth of 1.5 m (FLL 2015). Depending on local climatic conditions, permanent or temporary irrigation facilities need to be considered. The distance between the trees depend on the maximum size of the adult tree but also on the size of the planted tree and design ideas. Protection measures (e.g. poles against car parking, wire mesh against animals) may also be necessary. Because it takes decades until newly planted trees fulfil the services of adult trees, individually as well as in combination, initiatives to protect existing trees are also important.
v.	**Conditions for implementation**
	Local circumstances (e.g. topography, street characteristics, surrounding land use, and underground uses) need to be considered when planning and establishing new single line trees. Suitable location for the establishment of trees should offer enough space for trees to grow, both below and above ground. Depending on the site conditions and available space, suitable tree species have to be selected. The consideration of the maximum height of the trees is important to avoid space problems in the future. Trees that are not sufficiently rooted may cause accidents and constitute a danger for people on or beside the road. The soil and subsurface should generally be suitable for the establishment of street trees and may need to be replaced by standard soils if necessary. The selection of suitable tree species should also consider local conditions like topography. For example, when used for the stabilization of banks or small hills steadfast trees are necessary. Species and sub species that are suitable for urban conditions should be planted, and are often suggested by local authorities.
vi.	**Benefits and limitations**
	Potential benefits: - Single trees are associated with diverse benefits for urban ecosystems: • Microclimate regulation • Habitat provision • Aesthetics/recreation • Rainwater regulation (delayed runoff)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

	Potential limitations/disservices: - Allergic potential of pollen - BVOC emissions, resulting in increased ozone emissions in warmer months	
vii.	**Performance**	
P1	Transpiration	1
	Shading	1
	Evaporation	-
	Building (Insulation)	-
	Reflection (Albedo)	1
P2	Water conveyance	-
	Water infiltration	1
	Water retention	1
	Water storage	-
	Water reuse	-
P3	Water filtering	-
	Water bio-remediation	-
P4	Deposition	1
	Air Biofiltration	1
	Noise Reduction	-
P5	Habitat provision	1
	Connectivity	1
P6	Beauty / Appearance	2
	Usability / Functionality	1
	Social interaction	1
	Education	-
P7	Food / Energy / Material	-
P8	CO2 Sequestration	-
viii.	**Literature and further reading**	

Abd Kadir, M. A., & Othman, N. (2012). Towards a better tomorrow: street trees and their values in urban areas. Procedia-Social and Behavioral Sciences, 35, 267-274.

Armson, D., Stringer, P., & Ennos, A. R. (2013). The effect of street trees and amenity grass on urban surface water runoff in Manchester, UK. Urban Forestry & Urban Greening, 12(3), 282-286.

Burden, D. (2006). Urban Street Trees: 22 Benefits Specific Applications. Glatting Jackson and Walkable Communities Inc.

City of Melbourne. (n.d.). Urban forest visual: explore Melbourne's urban forest. Retrieved from http://melbourneurbanforestvisual.com.au/.

Fitzky, A. C., Sandén, H., Karl, T., Fares, S., Calfapietra, C., Grote, R., ... & Rewald, B. (2019). The interplay between ozone and urban vegetation–BVOC emissions, ozone deposition and tree ecophysiology. Frontiers in Forests and Global Change, 2, 50.

Green Blue Urban. (n.d.) Sauchiehall Street Glasgow. Retrieved from https://greenblue.com/gb/case-studies/sauchiehall-street-glasgow/.

Grote, R., Samson, R., Alonso, R., Amorim, J. H., Cariñanos, P., Churkina, G., ... & Paoletti, E. (2016). Functional traits of urban trees: air pollution mitigation potential. Frontiers in Ecology and the Environment, 14(10), 543-550.

McDonald, R., Kroeger, T., Boucher, T., Wang, L., & Salem, R. (2016). Planting healthy air: a global analysis of the role of urban trees in addressing particulate matter pollution and extreme heat. Planting healthy air: a global analysis of the role of urban trees in addressing particulate matter pollution and extreme heat.

NYC parks. (n.d.). MillionTreesNYC. Retrieved from https://www.nycgovparks.org/trees/milliontreesnyc.

Patterson, Gordon (n.d.). Trees in urban areas.

Pearlmutter, D., Calfapietra, C., Samson, R., O'Brien, L., Ostoić, S. K., Sanesi, G., & del Amo, R. A. (Eds.). (2017). The urban forest: cultivating green infrastructure for people and the environment (Vol. 7). Springer.

Vogt, J., Gillner, S., Hofmann, M., Tharang, A., Dettmann, S., Gerstenberg, T., Schmidt, C., Gebauer, H., van de Riet, K., Berger, U., & Roloff, A. (2017). Citree: A database supporting tree selection for urban areas in temperate climate. Landscape and Urban Planning, 157, 14-25. https://doi.org/10.1016/j.landurbplan.2016.06.005.

** See also: Factsheet 13.2.2 Boulevards, section VIII. References and further reading.*

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

13.2.2 Boulevards

Boulevards

Fig. 9: Boulevards between streetcar tracks Stuttgart (source: Eisenberg)

Fig. 10: Kingsway, London circa 1950 (Photo: London County Council) (source: Administrative County of London Development Plan 1951, Analysis)

Fig. 11: Boulevard with three tree lines (source: LAND; https://www.landsrl.com/)

Fig. 12: Kingsway as it is today (Photo: Jim C. Smith, Forestry Commission) (source: Forestry Commission England 2009)

i. Basic information

Synonyms							
Type	1	2	3	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation			
Addressed challenges	Climate resilience	Water management	Natural and climate hazards	Biodiversity	Air quality	Public health and well-being	Social justice and cohesion
	X	X		X	X	X	X
Examples in UNaLab FRC							
Reference to other key studies	*Boulevard de Magenta, Paris FR*						

ii. General description

Boulevards represent a possibility to establish several trees in cities to mitigate urban heat stress and provide additional benefits. Within boulevards, trees are commonly arranged along streets, bicycle paths and sidewalks and, if circumstances allow, are established on both sides of the

	route. The treetops of opposite trees often form a (nearly) closed canopy. As a result, the street in the middle of two tree lines is shaded and the air temperature is lowered.
iii.	**Role of nature**
	Boulevards simulate those trees growing at the edge of the woods (fringe area) and their effects on the surrounding environment outside the tree-covered area. The trees shade adjoining land uses in natural or near-natural forest vegetated areas like fields, meadows or water surfaces. As a result, the shaded surface is cooler than surfaces without protection/tree cover. The shading effect is determined by the characteristics of the trees (tree/canopy density, leaf structure, seasonal appearance, etc.). Other effects are a reduced wind velocity; transpiration/air cooling, and air purification.
iv.	**Technical and design parameters**
	For boulevards in urban settings, only a limited number of tree species meet the selection criteria based on design principles, durability and resistance against environmental stress. The area of the root space for neighbouring trees can be connected in suitable conditions and if separated, root space should be 12 m³ with a minimum depth of 1.5 m. In most urban conditions the root space needs to be prepared with soil substrates for trees. Depending on local climatic conditions, permanent or temporary irrigation facilities need to be considered. The distance between the trees depend on road width, the maximum size of adult trees, and further design ideas. Protection measures (e.g. poles, wire mesh against animals) may also be needed.
v.	**Conditions for implementation**
	Local circumstances (e.g. topography, street haracteristics, surrounding land use, underground occupation with cables etc.) need to be considered when planning and establishing new boulevards. Planting location for the establishment of trees should offer enough space for trees to grow. Depending on site conditions and available space, suitable tree species have to be selected. The consideration of the maximum height of the trees is important to avoid space problems in the future. Trees that are not sufficiently rooted may cause accidents and constitute a danger for people on or beside the road. The soil and subsurface should generally be suitable for the establishment of street trees and may, if necessary, be replaced by standard soils. Species and sub species that are suitable for urban conditions should be planted, and are often suggested by local authorities.
vi.	**Benefits and limitations**
	Potential benefits: - Boulevards are associated with diverse benefits for urban ecosystems: o Microclimate regulation o Habitat provision o Aesthetics/recreation o Rainwater regulation (delayed runoff) *Potential limitations/disservices:* - Reduced airflow, potentially leading to higher pollution in street canyon - Allergenic potential of tree pollen and BVOC emissions.
vii.	**Performance**

P1	Transpiration	2
	Shading	2
	Evaporation	1
	Building (Insulation)	-
	Reflection (Albedo)	2
P2	Water conveyance	-
	Water infiltration	1
	Water retention	1
	Water storage	-

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

	Water reuse	-
P3	Water filtering	-
	Water bio-remediation	-
P4	Deposition	1
	Air biofiltration	1
	Noise reduction	-
P5	Habitat provision	1
	Connectivity	1
P6	Beauty / Appearance	2
	Usability / Functionality	1
	Social interaction	1
	Education	-
P7	Food / Energy / Material	1
P8	CO2 Sequestration	-

viii. Literature and further reading

City of Melbourne (2020). Urban forest visual: Explore Melbourne's urban forest. Retrieved March 20, 2021, from http://melbourneurbanforestvisual.com.au/.

Global Designing Cities Initiative. (n.d.). Case study: boulevard de Magenta; Paris, France. Retrieved from www.globaldesigningcities.org.

Grote, R., Samson, R., Alonso, R., Amorim, J. H., Cariñanos, P., Churkina, G., Fares, S., le Thiec, D., Niinements, Ü., Mikkelsen, T.N., Paoletti, E., Tiwary, A., & Calfapietra, C. (2016). Functional traits of urban trees: Air pollution mitigation potential. Frontiers in Ecology and the Environment, 14(10), 543-550. https://doi.org/10.1002/fee.1426.

Mullaney, J., Lucke, T., & Trueman, S. J. (2015). A review of benefits and challenges in growing street trees in paved urban environments. Landscape and Urban Planning, 134, 157-166. https://doi.org/10.1016/j.landurbplan.2014.10.013.New York City Department of Parks and Recreation (n.d.). MillionTreesNYC. Retrieved from https://web.archive.org/web/20220812121225/https://www.nycgovparks.org/trees/milliontreesnyc.

Pearlmutter, D., Calfapietra, C., Samson, R., O'Brien, L., Ostoić, S. K., Sanesi, G., & del Amo, R. A. (Eds.) (2017). The urban forest: Cultivating green infrastructure for people and the environment (Vol. 7). Springer. ISBN: 978-3-319-50280-9.

** See also: section viii. Literature and further reading of 12.2.1 Single line street trees.*

13.2.3 Group of trees

Group of trees

Fig. 135: Arboretum - A group of adult trees creates a microclimatic environment that mitigates heat stress on hot summer days (source: LAND; https://www.landsrl.com/)

Fig.14: Small Arboretum with seats *(source: LAND; https://www.landsrl.com/)*

i. Basic information

Synonyms	Arboretum							
Type	1	2	3	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation				

Addressed challenges	Climate resilience	Water management	Natural and climate hazards	Biodiversity	Air quality	Public health and well-being	Social justice and cohesion
	X	X		X	X	X	X

Examples in UNaLab FRC	*Tree groups, at Gavoglio barracks, Genova IT; Drought-resilient orchards at Gavoglio barracks, Genova IT*
Reference to other key studies	

ii. General description

Groups of trees mimic the gestalt of a forest in an urban setting. They may be an option for the design of shaded squares, as a contrasting element in densely built up areas, or for courtyard design.

In some urban areas, groups of trees are also developed out of existing, wild growing trees that established spontaneously and are typical pioneer species of urban forests.

iii. Role of nature

The group of trees create a shaded environment in summer, which is similar to a small patch of forest or the fringe area of larger forests.

iv. Technical and design parameters

In order to create a sufficient microclimate right from the start, mature trees from nurseries are needed. Trees are planted in a rather dense grid and need to be irrigated during the first years and possibly throughout their whole life time. Water for irrigation is ideally collected from surfaces and roofs.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

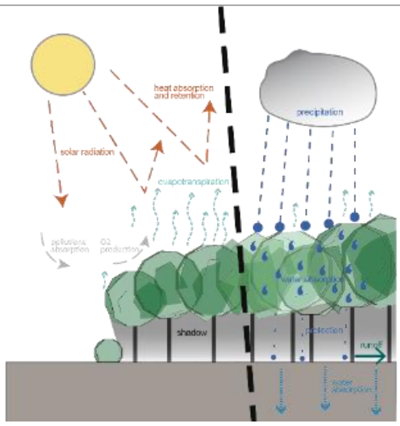


Fig. 15: Role of forests/group of trees (source: ILPOE, 2018)

v. Conditions for implementation

Species and sub species that are suitable for urban conditions should be planted. Selection of diverse, native, species (especially in combination understory vegetation) may enhance the likelihood of establishing more robust living conditions and support biodiversity. The group of trees may be planted on natural soils or on top of underground buildings if the soil depth is sufficient.

vi. Benefits and limitations

Potential benefits:

- Biodiversity/Habitat provision (depending on species selection)
- Improved aesthetics
- Meeting places
- Public spaces for heat reduction

Potential limitations/disservices:

- Allergic potential of pollen
- BVOC emissions, resulting in increased ozone emissions in warmer months

vii. Performance

P1	Transpiration	2
	Shading	2
	Evaporation	1
	Building (Insulation)	-
	Reflection (Albedo)	2
P2	Water conveyance	-
	Water infiltration	1
	Water retention	2
	Water storage	-
	Water reuse	-
P3	Water filtering	-
	Water bio-remediation	-
P4	Deposition	1
	Air biofiltration	1
	Noise reduction	
P5	Habitat provision	2
	Connectivity	2
P6	Beauty / Appearance	2
	Usability / Functionality	1
	Social interaction	1

	Education	-
P7	Food / Energy / Material	-
P8	CO2 Sequestration	-
viii.	**Literature and further reading**	

Ferrini, F., Van den Bosch, C. C. K., & Fini, A. (Eds.). (2017). Routledge handbook of urban forestry. Taylor & Francis.

Kowarik, I., Hiller, A., Planchuelo, G., Seitz, B., von der Lippe, M., & Buchholz, S. (2019). Emerging urban forests: Opportunities for promoting the wild side of the urban green infrastructure. Sustainability, 11(22), 6318.

Kowarik, I., & Körner, S. (2005). Wild urban woodlands. New perspectives for urban forestry.

Threlfall, C. G., Mata, L., Mackie, J. A., Hahs, A. K., Stork, N. E., Williams, N. S., & Livesley, S. J. (2017). Increasing biodiversity in urban green spaces through simple vegetation interventions. Journal of applied ecology, 54(6), 1874-1883.

** See also: section viii. Literature and further reading of 12.2.1 Single line street trees.*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

13.3 Soil conservation and quality management

13.3.1 Living fascine

Living Fascine

Fig. 16: Fascines as shoreline stabilisation in Templin, Germany

Fig. 17: Living Fascine (source: freitag-weidenart.com)

i. Basic information

Synonyms	Live fascines						
Type	1	2	3	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation			
Addressed challenges	Climate resilience	Water management	Natural and climate hazards	Biodiversity	Air quality	Public health and well-being	Social justice and cohesion
	X	X	X	X			
Examples in UNaLab FRC	*Natural slope securing at Gavoglio barracks, Genova IT*						
Reference to other key studies							

ii. General description

Fascines are used for stabilization of riversides and hills. By using bundles of living wood, sometimes mixed with dead wood, fascines can be established as habitat for plants and animals. Additionally, when placed near stream banks, fascines can provide food and shelter for aquatic organisms. In terms of stabilization, living fascines are superior in comparison to "dead" fascines, as plants readily develop from the living wood (vegetative growth), and developing roots provide soil protection. Also, other additional species may later settle within this new microhabitat.

iii. Role of nature

Fascines imitate or simulate natural vegetation by layers with strong and branched root networks, as well as aboveground biomass and habitat development.

iv. Technical and design parameters

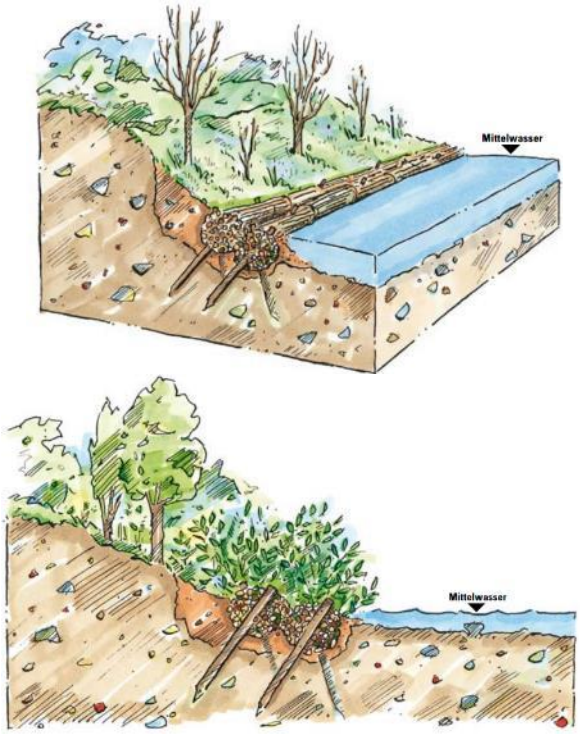


Fig. 186: Living fascine after implementation (left) and older fascine (source: Jany und Geitz 2013)

Living fascines are traditional bioengineering elements that are mainly used outside of urban areas to restore riversides and hilly terrain. Living fascines consist of living tree branches and twigs, but may comprise up to 50% dead wood. The wood is bundled with steel cables; fast-rooting plants and cuttings should be used. Bundles usually have about a 15-20 cm diameter and are about 2-3 m long, depending on site conditions and purpose. The prepared bundles are then installed horizontally along the water bank or hillside using hardwood (usually willow) cuttings or dowels as fixation. Rooting fascines give additional stabilization and reduce the risk of erosion, and are covered with bushes or other plants to support the stability of the water bank or hillside.
Willow is commonly used because of its favourable characteristics: length, flexibility, elasticity and form, but species selection depends on objective. For example, common bundle materials for hydraulic engineering are hazel and willow branches (e.g. *Salix viminalis, S. purpurea*), whereas for earthwork/hillside stabilization shrub and willow branches (e.g. *S. fragilis, S. alba*) are used. Choice of species may also depend on the local context, as species occurring on site may provide plant material for the fascines.

v. Conditions for implementation

Good timing for construction (low water flow, no rainfall) is needed, and vegetation material should be planted/included during suitable weather and season, thus allowing for vegetation development.

vi. Benefits and limitations

Potential benefits:
- Near-natural protection of hillsides and river banks
- Benefits for biodiversity through habitat creation

Potential limitations/disservices:
- Stability of river bank is difficult to calculate, foresee
- Pre-selection of only robust species

vii. Performance

P1	Transpiration	1

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

	Shading	-
	Evaporation	-
	Building (Insulation)	-
	Reflection (Albedo)	-
P2	Water Conveyance	-
	Water infiltration	1
	Water retention	1
	Water storage	-
	Water reuse	-
P3	Water filtering	1
	Water bio-remediation	-
P4	Deposition	-
	Air biofiltration	-
	Noise reduction	-
P5	Habitat provision	2
	Connectivity	1
P6	Beauty / Appearance	1
	Usability / Functionality	-
	Social interaction	-
	Education	-
P7	Food / Energy / Material	-
P8	CO2 Sequestration	1

viii. Literature and further reading

Graf, C., Böll, A., & Graf, F. (2003). Pflanzen im Einsatz gegen Erosion und oberflächennahe Rutschungen. Eid. Forschungsanstalt für Wald, Schnee und Landschaft.

Jany, A. & Geitz, P. (2013). Ingenieurbiologische Bauweisen an Fließgewässern, Teil 1. Leitfaden für die Praxis. Hg. V. WBW Fortbildungsgesellschaft für Gewässerentwicklung mbH.

Li, M. H., & Eddleman, K. E. (2002). Biotechnical engineering as an alternative to traditional engineering methods: A biotechnical streambank stabilization design approach. Landscape and Urban Planning, 60(4), 225-242.

Martin, F. M., Janssen, P., Bergès, L., Dupont, B., & Evette, A. (2021). Higher structural connectivity and resistance against invasions of soil bioengineering over hard-engineering for riverbank stabilisation. Wetlands Ecology and Management, 29(1), 27-39. https://doi.org/10.1007/s11273-020-09765-6.

Massachusetts clean water toolkit. (n.d.). Live fascines. Retrieved from https://megamanual.geosyntec.com/npsmanual/livefascines.aspx.

Riparian Habitat Restoration. (n.d.). Live fascines. Retrieved from http://riparianhabitatrestoration.ca/575/livefascines.htm.

Sotir, R.B. & Fischernich, C. (2001). Live and inert fascine streambank erosion control. [PDF]. Retrieved from http://www.marinrcd.org.

13.3.2 Revetment with cuttings

Revetment with cuttings

Fig. 19:Revetment under construction (source: (Jany, Angeika and Peter Geitz 2013)

Fig. 20:Revetment with cutting (source: (Jany, Angeika and Peter Geitz 2013)

i. Basic information

Synonyms	Spreitlage; brush mattress; brush and hedge layers						
Type	1 2 **3** — action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation						
Addressed challenges	Climate resilience	Water management	Natural and climate hazards	Biodiversity	Air quality	Public health and well-being	Social justice and cohesion
		X	X	X			
Examples in UNaLab FRC							
Reference to other key studies							

ii. General description

A revetment with cuttings covers eroded riversides with willow (able to root) and brushwood (not able to root). This is a simple method done with local material that stabilizes riverbanks against further erosion and leads to long-term stabilization by allowing plants to re-cultivate naturally.

iii. Role of nature

Imitates/simulates natural vegetation layers with strong and branched root networks, thereby offering natural production against erosion compared to bare hillsides with a high risk of water, wind and soil erosion.

iv. Technical and design parameters

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

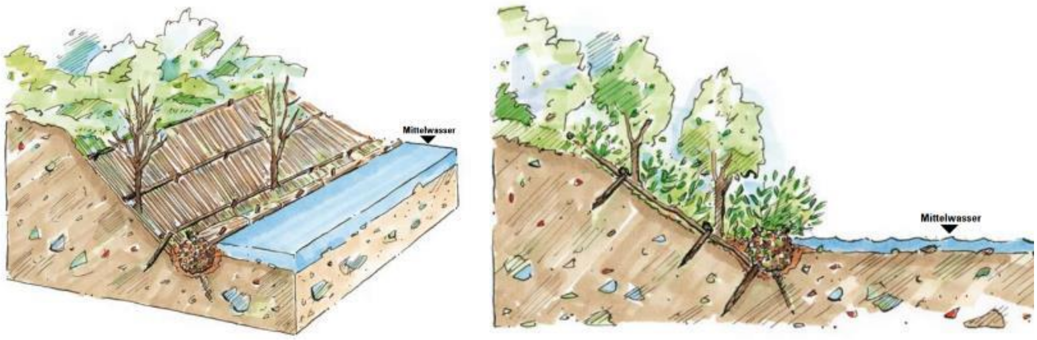


Fig. 21: Rewetment with cuttings after implementation (left) and after a few years (right) (source: (Jany, Angeika and Peter Geitz 2013)

For construction, two to five year old shrub branches with a length of 1.5 m are typically used. The stake length is usually between 3 to 5 m, with a diameter of 4 to 8 cm. Local (native) and typical plants for the specific location should be selected, both with regard to supporting local biodiversity and decreasing transportation costs.

v.	**Conditions for implementation**
	Good timing for construction (low water flow, no rainfall) and planting is needed
vi.	**Benefits and limitations**
	Potential benefits: - Hillside stabilization - Protection against erosion - Qater bank protection - Habitat for wildlife
vii.	**Performance**

P1	Transpiration	1
	Shading	-
	Evaporation	-
	Building (Insulation)	-
	Reflection (Albedo)	-
P2	Water conveyance	1
	Water infiltration	1
	Water retention	1
	Water storage	1
	Water reuse	1
P3	Water filtering	1
	Water bio-remediation	1
P4	Deposition	-
	Air biofiltration	-
	Nosie reduction	-
P5	Habitat provision	1
	Connectivity	1
P6	Beauty / Appearance	1
	Usability / Functionality	-
	Social interaction	-
	Education	-
P7	Food / Energy / Material	-
P8	CO2 Sequestration	1

viii.	Literature and further reading
	Graf, C., Böll, A., & Graf, F. (2003). Pflanzen im Einsatz gegen Erosion und oberflächennahe Rutschungen. Eid. Forschungsanstalt für Wald, Schnee und Landschaft. Jany, A. & Geitz, P. (2013). Ingenieurbiologische Bauweisen an Fließgewässern, Teil 1. Leitfaden für die Praxis. Hg. V. WBW Fortbildungsgesellschaft für Gewässerentwicklung mbH. Li, M. H., & Eddleman, K. E. (2002). Biotechnical engineering as an alternative to traditional engineering methods: A biotechnical streambank stabilization design approach. Landscape and Urban Planning, 60(4), 225-242. Soil bioengineering techniques (n.d.). Retrieved from https://web.archive.org/web/20220120062329/https://www.fs.fed.us/t-d/pubs/pdf/fs683/ch_05.pdf.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

13.3.3 Planted embankment mat

Planted embankment mat

*Fig. 22:*Planted embankment mat *(source: (Jany, Angeika and Peter Geitz 2013)*

i. Basic information

Synonyms	Vegetated erosion-control mat; vegetated erosion control blanket						
Type	1	2	3	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation			
Addressed challenges	Climate resilience	Water management	Natural and climate hazards	Biodiversity	Air quality	Public health and well-being	Social justice and cohesion
	X	X	X	X			
Examples in UNaLab FRC							
Reference to other key studies	*Garvey Park foreshore stabilization, Belmont AU*						

ii. General description

Planted embankment mats are a combination of biodegradable mats and a vegetation/seedling layer. These mats are used to re-cultivate riversides and to prevent erosion by slowing down water velocity and promoting sedimentation. Using local vegetation can create/restore habitats and promote biodiversity. Construction is simple and fast, and combination with living fascines or live stakes is possible.

iii. Role of nature

Imitates/simulates natural vegetation layers with strong and branched root networks, thereby offering natural protection against erosion compared to bare hillsides with a high risk of water, wind, and soil erosion.

iv. Technical and design parameters

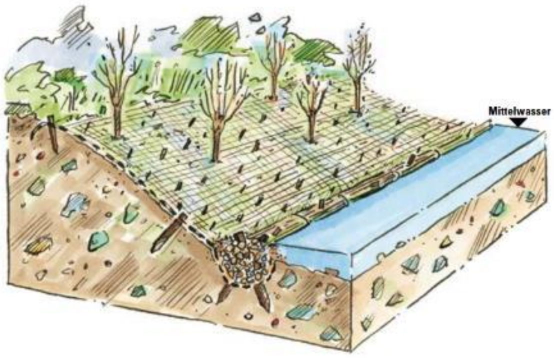


Fig. 23: Planted embankment mat (source: (Jany, Angeika and Peter Geitz 2013)

Mats are simply constructed using fast rotting, plant-based materials such as coir (coconut fibre) or jute, and installation is simple and fast.

v.	**Conditions for implementation**	
	Good timing for construction (low water flow, no rainfall), planting is needed	
vi.	**Benefits and limitations**	
	Potential benefits: - Protection against erosion - Habitat for wildlife	
vii.	**Performance**	
P1	Transpiration	1
	Shading	-
	Evaporation	-
	Building (Insulation)	-
	Reflection (Albedo)	-
P2	Water conveyance	-
	Water infiltration	1
	Water retention	1
	Water storage	-
	Water reuse	-
P3	Water filtering	1
	Water bioremediation	1
P4	deposition	-
	Air bio-filtration	-
	Noise reduction	-
P5	Habitat provision	1
	Connectivity	1
P6	Beauty / Appearance	1
	Usability / Functionality	-
	Social interaction	-
	Education	-
P7	Food / Energy / Material	-
P8	CO2 Sequestration	1
viii.	**Literature and further reading**	
	Graf, C., Böll, A., & Graf, F. (2003). Pflanzen im Einsatz gegen Erosion und oberflächennahe Rutschungen. Eid. Forschungsanstalt für Wald, Schnee und Landschaft.	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Government of Western Australia: natural resource management program. (n.d). 10008: Garvey Park foreshore stabilization- section 4. Retrieved from http://www.nrm.wa.gov.au/projects/10008.aspx.

Government of Western Australia: natural resource management program. (n.d). Best management practices for foreshore stabilization: erosion control matting. [PDF]. Retrieved from https://www.dpaw.wa.gov.au/.

Jany, A. & Geitz, P. (2013). Ingenieurbiologische Bauweisen an Fließgewässern, Teil 1. Leitfaden für die Praxis. Hg. V. WBW Fortbildungsgesellschaft für Gewässerentwicklung mbH.

Li, M. H., & Eddleman, K. E. (2002). Biotechnical engineering as an alternative to traditional engineering methods: A biotechnical streambank stabilization design approach. Landscape and Urban Planning, 60(4), 225-242.

Vishnudas, S., Savenije, H. H. G., Van der Zaag, P., Anil, K. R., & Balan, K. (2006). The protective and attractive covering of a vegetated embankment using coir geotextiles.

13.4 Blue-green space establishment or restoration

N/A

13.5 Green built environment

13.5.1 Extensive green roof

Extensive green roof

Fig. 24: Extensive green roof Oversum- Winterberg (source: Optigrün)

i. Basic information

Synonyms	Low-Profile; Eco-Roofs; Extensive roof greening						
Type	1 / 2 / **3**	<u>action type:</u> 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation					
Addressed challenges	Climate resilience	Water management	Natural and climate hazards	Biodiversity	Air quality	Public health and well-being	Social justice and cohesion
	X	X	X	X		X	
Examples in UNaLab FRC	*Green roof on city hall at Stadhuisplein 1, Eindhoven, NL*						
Reference to other key studies	*Green roofs, Basel CH;* *Urban storm water management in Augustenborg, Malmö SE*						

ii. General description

Extensive green roofs are basic, light weight systems, characterized by minimum maintenance and management (artificial irrigation, fertilization) after establishment of the system. According to the NBS catalogue, a minimum performance of 25 l/m² storage capacity and at least 95 % of vegetation coverage after three years is needed. The installation and management/maintenance of extensive green roofs is less expensive than that of intensive systems. Extensive green vegetation is often established on roofs that are not publicly accessible or with limited access for public or recreational purposes, and are partially characterized by steep slopes. Access is permitted for annual maintenance.

Appropriate plants for extensive green roofs are low growing, rapidly spreading and shallow-rooting plants/hardy perennials (succulents such as sedums, herbs, wildflowers, grasses, mosses) that are able to survive with minimum nutrient uptake and without additional nutrient supply. The selected plants for extensive green roofs are generally well adapted to alpine

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

	environments/climate and tolerate different climate conditions (e.g. drought) and temperature fluctuations. The number of different plant species is limited on extensive roofs, yet the biodiversity on extensive green roofs is generally greater than on other (intensive) green roof types. Through the establishment of (extensive) green roofs on rooftops, different services of natural vegetation layers are replicated. As a result, the potential to mitigate the urban heat island effect is increased compared to sealed surfaces without any vegetation. Extensive green roofs provide limited services and benefits for the surrounding environment. As described above, it is characterized by a low vegetation surface that covers the buildings surface. Although the surface covering is the main service of extensive roofs, it also leads to positive effects on microclimate: increased evaporation in comparison to black roofs that leads to heat reduction of the surrounding air temperature. Furthermore, the vegetation binds particulate matter. The growth medium is relatively thin compared to intensive green roofs. As a result, water buffering, temporary storage, retention and filtration services exist, albeit lower than for intensive green roofs.
iii.	**Role of nature**
	Through the establishment of green roofs on buildings, different services of natural vegetation layers are replicated. These include habitat creation (e.g. dry grassland types) or the establishment of stepping stones in the urban area.
iv.	**Technical and design parameters**
	There are different greening systems for extensive green roofs, and therefore no uniform construction/design exists. For example, vegetation can be planted directly on special 'biological' concrete, it can be established on a variety of substrate mixes, or on synthetic fibre mats -- alone or in combination with an underlying substrate. Although vegetation is usually restricted to non-woody plants (moss, sedum, herbs, grasses), there is still a great variety possible. Extensive green roofs typically bear less weight, require less water and investment, and can be planted on more steeply-pitched surfaces (up to 85° possible with technical devises) than intensive green roofs. Regular maintenance is necessary and special care needed to regularly remove spontaneous woody vegetation.
v.	**Conditions for implementation**
	Site characteristics are often dependent on project objectives. For example, if the objective is to improve aesthetics, then high density, visible sights are preferable. Regardless of location, solid, stable concrete buildings with a high bearing capacity and flat or relatively flat rooftops with underground concrete structures are necessary.
vi.	**Benefits and limitations**
	Potential benefits: - Human health and quality of life - Storm water/rainwater management and quality - Improved air quality - Aesthetic value/visual attractiveness - Thermal performance/temperature reduction (less than *intensive* green roofs) - Energy reduction for buildings (less than *intensive* green roofs) - Reduction of noise/sound transmission - Habitat provision for urban wildlife *Potential limitations/disservices:* - Limited development of undisturbed habitats because of human activities/public purposes - Limited space for roots
vii.	**Performance**

P1	Transpiration	-
	Shading	1

	Evaporation	1
	Building (Insulation)	1
	Reflection (Albedo)	1
P2	Water conveyance	1
	Water infiltration	-
	Water retention	1
	Water storage	-
	Water reuse	-
P3	Water filtering	-
	Water bio-remediation	-
P4	Deposition	-
	Air biofiltration	-
	Noise reduction	-
P5	Habitat provision	1
	Connectivity	1
P6	Beauty / Appearance	1
	Usability / Functionality	1
	Social interaction	-
	Education	-
P7	Food / Energy / Material	-
P8	CO2 Sequestration	1

viii. Literature and further reading

Climate Adapt (2020). Green roofs in Basel, Switzerland: Combining mitigation and adaptation measures. Retrieved from https://web.archive.org/web/20220812131938/https://climate-adapt.eea.europa.eu/metadata/case-studies/green-roofs-in-basel-switzerlandcombining-mitigation-and-adaptation-measures-1.

Climate Adapt (2020). Urban storm water management in Augustenborg, Malmö. Retrieved from https://web.archive.org/web/20220812132110/https://climate-adapt.eea.europa.eu/metadata/case-studies/urban-storm-water-management-in-augustenborgmalmo.

Elliott, R. M., Gibson, R. A., Carson, T. B., Marasco, D. E., Culligan, P. J., & McGillis, W. R. (2016). Green roof seasonal variation: Comparison of the hydrologic behavior of a thick and a thin extensive system in New York City. Environmental Research Letters, 11(7), 074020.

Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V. (FLL). (2002). Guidelines for the planning, execution and upkeep of green-roof sites. Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau, Bonn, Germany.

Lynch, A. J. (2019). Creating effective urban greenways and stepping-stones: Four critical gaps in habitat connectivity planning research. Journal of Planning Literature, 34(2), 131-155.

Schröder, R., & Kiehl, K. (2020). Extensive roof greening with native sandy dry grassland species: Effects of different greening methods on vegetation development over four years. Ecological Engineering, 145, 105728.

Snodgrass, E. C., & McIntyre, L. (2010). The green roof manual: a professional guide to design, installation, and maintenance. Timber Press.

U.S. Environmental Protection Agency (2008): Reducing Urban Heat Islands: Compendium of Strategies. Draft Heat Island Reduction Activities.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

13.5.2 Intensive green roof

Intensive green roof

Fig. 25: Intensive green roof (source: LAND; https://www.landsrl.com/)

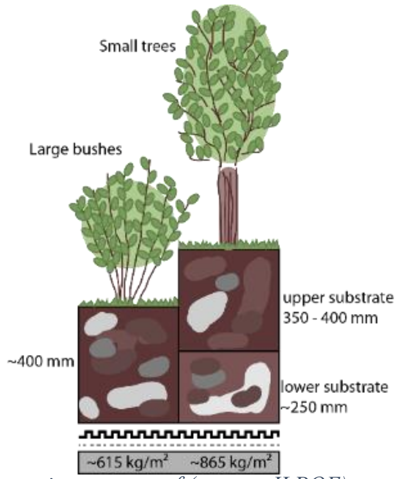


Fig. 26: Intensive green roof (source: ILPOE)

i. Basic information

Synonyms	High-Profile; Roof Gardens; Roof greening						
Type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation			
Addressed challenges	Climate resilience	Water management	Natural and climate hazards	Biodiversity	Air quality	Public health and well-being	Social justice and cohesion
	X	X	X	X	X	X	X
Examples in UNaLab FRC							
Reference to other key studies	*ERSI Green Roof, Toranto CA; Perot Museum of Nature and Science, Dallas US; City Hall Rooftop Garden, Chicago US; Project area in Augustenborg, Malmö SE*						

ii. General description

Intensive green roofs are often associated with residential buildings, hotels or parking structures. The more complex and heavier greening systems are characterized by a higher installation, maintenance, management effort (regular irrigation and fertilization) which leads to higher costs compared to extensive green roofs (see chapter 12.5.1). Intensive green vegetation is often established on roofs that are accessible for public or recreational purposes and for regular maintenance measures. The intensive green roof type is regularly frequented by humans: different activities including gardening, relaxing and socializing are designated for intensive green roofs. To enable human activities on green roofs and the integration of larger plants, trees and architectural elements, suitable rooftops need to be relatively flat, and fulfil technical requirements, e.g., regarding weight.

The choice of suitable plants is greater (than on extensive green roofs) because of their structural design. Appropriate plants for intensive green roofs include a variety smaller trees, shrubs and perennials. The growth media is relatively thick and notably deeper than for extensive systems with integrated low-growing plants (see chapter 12.5.1). The growth media of intensive green roofs needs to be relatively deep and nutrient rich to support the growth of plants such as trees. Green roofs with deeper substrates, like intensive green roofs, tend to have a greater positive impact on biodiversity. Combining this with natural, local soils and a variety of native vegetation types further supports biodiversity. Different kinds of architectural elements (buildings, solar panels) can be established on intensive green roofs.

iii. Role of nature

	The model for a green roof is soil with its vegetation cover. Through the establishment of (intensive) green roofs on buildings, different services of natural vegetation layers are replicated. As a result, the potential to mitigate the urban heat island effect is higher compared to sealed surfaces without any vegetation (black roof). Intensive green roofs can provide a variety of ecosystem services and benefits for the surrounding environment and microclimate. To enable these services a grown soil cover needs to be replicated. The vegetation layer absorbs solar radiation for photosynthesis, provides shade and decreases heat transmission into the building. Through the integration of vegetation, transpiration and evaporation is increased (in comparison to black roofs), reducing the surrounding air temperature (cooling effect). The retention of precipitation is a fundamental service of green roofs. Especially coarse-pored soils can store storm water for a longer period before it is transported. Based on the technical construction itself and the growing media, green roofs can temporarily store rain-/wastewater, and filter and bind impurities. The thick growing medium of intensive green roofs is positive in the context of water filtration, storage and retention.
iv.	**Technical and design parameters**
	There are many different greening systems for intensive green roofs, and therefore no uniform construction exists. The roof itself must be relatively flat (0-5°), and it is important to consider the weight load, irrigation system, growing medium, and maintenance. Depending on the construction of the intensive green roof, there is a large variety of vegetation (trees, shrubs and perennials) that can be planted.
v.	**Conditions for implementation**
	Site characteristics are often dependent on project objectives. For example, if the objective is to improve aesthetics, then high density, visible sights are preferable. Regardless of location, solid, stable concrete buildings with a high bearing capacity and flat or relatively flat rooftops with underground concrete structures are necessary. Additionally, an artificial irrigation system or rainwater irrigation facilities are needed for critical/dry periods. In some cases, special plates that distribute pressure on the rooftop are needed (for planters).
vi.	**Benefits and limitations**
	Potential benefits: - Human health and quality of life - Storm water/rainwater management and quality - Improves air quality (reduction of greenhouse gas emissions) - Aesthetic value/visual attractiveness - Food production (rooftop farms) - Additional space (intensive roof) - Thermal performance/temperature reduction - Energy reduction for buildings (heating/cooling) - Reduction of noise/sound transmission - Habitat provision for urban wildlife *Potential limitations/disservices:* - Limited development of undisturbed habitats because of human activities/public purposes - Limited space for rooting (although the growing media is relatively thick)
vii.	**Performance**

P1	Transpiration	2
	Shading	1
	Evaporation	1
	Building (Insulation)	2
	Reflection (Albedo)	1

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

P2	Water conveyance	2
	Water infiltration	-
	Water retention	2
	Water storage	1
	Water reuse	-
P3	Water filtering	1
	Water bio-remediation	-
P4	Deposition	1
	Air biofiltration	-
	Noise reduction	-
P5	Habitat provision	1
	Connectivity	1
P6	Beauty / Appearance	2
	Usability / Functionality	1
	Social interaction	1
	Education	-
P7	Food / Energy / Material	-
P8	CO2 Sequestration	1

viii. Literature and further reading

ESRI Canada. (n.d). Sustainable Prosperity: Green Roof. Retrieved from https://www.esri.ca/enca/about/sustainable-prosperity/green-roof.

Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V. (FLL). (2002). Guidelines for the planning, execution and upkeep of green-roof sites. Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau, Bonn, Germany.

Greenroofs.com. (n.d.). Chicago city hall. Retrieved from https://www.greenroofs.com/projects/chicago-city-hall/.

Gonsalves, S., Starry, O., Szallies, A., & Brenneisen, S. (2022). The effect of urban green roof design on beetle biodiversity. Urban Ecosystems, 25(1), 205-219. https://doi.org/10.1007/s11252-021-01145-z.

Hui, S. C., & Chan, K. L. (2011). Biodiversity assessment of green roofs for green building design. In Proceedings of Joint Symposium 2011 on Integrated Building Design in the New Era of Sustainability. ASHRAE-HKC/CIBSE-HKB/HKIE-BSD.

International Green Roof Association e.V. (IGRA). (2018). IGRA guidelines for green roofs. Green roof policies. Manual for decision makers and green roof supporters. Nürtingen.

Malmö stad. (n.d.). Green roofs throughout the city. Retrieved from https://malmo.se/Nice-to-know-about-Malmo/Technical-visits/Theme-Sustainable-City/-Ecology-Energy-and-Climate/Green-roofs.html.

Perot Museum of Nature and Science. (n.d.). Yes, it's an exhibit all by itself. Retrieved from https://www.perotmuseum.org/exhibits-and-films/permanent-exhibit-halls/the-building.html.

Snodgrass, E. C., & McIntyre, L. (2010). The green roof manual: a professional guide to design, installation, and maintenance. Timber Press.

U.S. Environmental Protection Agency (2008): Reducing Urban Heat Islands: Compendium of Strategies. Draft Heat Island Reduction Activities.

13.5.3 Constructed wet roof

Constructed wet roof

Fig. 27: Constrcuted wet roof (source: Rhizotech; www.rhizotech.com)

i. Basic information

Synonyms	Wetland roofs						
Type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation			
Addressed challenges	Climate resilience	Water management	Natural and climate hazards	Biodiversity	Air quality	Public health and well-being	Social justice and cohesion
	X	X	X	X	X	X	
Examples in UNaLab FRC							
Reference to other key studies	*Multifunctional urban greening, Malmö SE*						

ii. General description

The idea of constructed wet roofs (CWR) is to connect (extensive) green roofs and constructed wetlands for domestic wastewater (so-called grey water) treatment. Additionally, constructed wet roofs retain storm water for a certain period of time, gradually releasing rainwater and reducing the overall runoff. CWRs are also more physiologically active than extensive green roofs in summer heat/drought periods, which has positive impacts on microclimate, air quality and biodiversity.

CWRs consist of precultured mats with evergreen vegetation that are installed on rooftops. The plants are irrigated with storm- and wastewater to ensure the surface layer remains moist. Water impurities are filtered during their way through the vegetation layer and absorbed as plant nutrients. For classic CWRs, roofs need to have a moderate to high slope gradient to enable water flow. The processed water is used for irrigation as well as for disposal into receiving water or for toilets. The wastewater also maintains the green space on the rooftop. While CWRs with pitched roofs are more common, they can also be constructed on flat roofs, in which case about 10 to 30 cm of water is retained with floating plant mats.

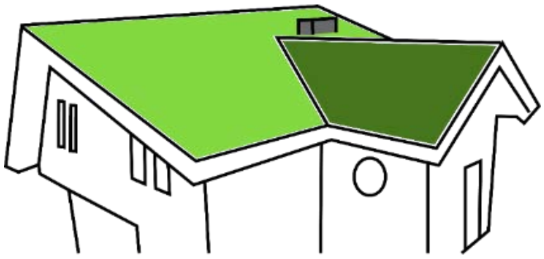
iii. Role of nature

Constructed wet roofs can provide a variety of benefits, replicated from natural processes especially in soils. The most important service in the context of constructed wet roofs is the treatment of wastewater e.g. domestic or industrial wastewater. Water impurities in grey water are filtered during their way through the vegetation layer and absorbed as plant nutrients.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

	Another important service is "storm and wastewater storage and retention". As a result, the risk for flooding during or after a storm water event is lowered. Water evaporates from the standing water surface and transpires from the plant surfaces and stomata. This process leads to a decrease of air temperature.
iv.	**Technical and design parameters**
	From the top down, a horizontal flow constructed wet roof typically consists of turf mats with sandy, fertilized, soil and grass roots/seeds situated on stabilization plates on a substratum of sand, light expanded clay aggregates (LECA) and polyactic acid beads (PLA). CWRs are usually construced on pitched roofs, with a waterproof (i.e. bituminous waterproofing) surface. Types of wastewater include domestic wastewater such as effluent of kitchen-, bathroom-, toilet sinks and dishwater from the building. Additional technical devices (tanks and pumps) include: septic tank, inlet tank, pumps for each bed, pressure pipes (influent and effluent pipe) and an infiltration pond.  *Fig. 28: Constrcuted wet roof (source: ILPOE 2019)*
v.	**Conditions for implementation**
	It is necessary that the roof is waterproofed, has a sufficient load-bearing capacity, a slope gradient to water outlets and emergency overflows.
vi.	**Benefits and limitations**
	Potential benefits: - Effect on microclimate: cooling of air temperature - Decreased probability and consequential effects of flooding (water retention) - Habitat for wildlife - Improves water quality - (Relative) water quantity (water can be used for different purposes after natural treatment)
vii.	**Performance**

P 1	Transpiration	2
	Shading	1
	Evaporation	1
	Building (Insulation)	2
	Reflection (Albedo)	1
P 2	Water conveyance	1
	Water infiltration	-
	Water retention	1
	Water storage	1
	Water reuse	1
P 3	Water filtering	1
	Water bio-remediation	1
P 4	Deposition	1
	Air biofiltration	-
	Noise reduction	-
	Habitat provision	1

P 5	Connectivity	-
P 6	Beauty / Appearance	1
	Usability / Functionality	1
	Social interaction	-
	Education	-
P 7	Food / Energy / Material	-
P 8	CO2 Sequestration	1

viii. Literature and further reading

Oppla. (n.d.) Multifunctional urban greening in Malmö, Sweden. Retrieved from https://oppla.eu/casestudy/19011.

Ingenieurbüro Blumberg (n.d.). Wetland roofs. Retrieved from https://web.archive.org/web/20201205141838/https://www.blumbergengineers.com/en/ecotechnologies/wetland-roofs.

Rhizotech. (2018). Retrieved from http://rhizotech.com/de/107/dachbegruenung.

Song, U., Kim, E., Bang, J. H., Son, D. J., Waldman, B., & Lee, E. J. (2013). Wetlands are an effective green roof system. Building and Environment, 66, 141-147.

William, R., Goodwell, A., Richardson, M., Le, P. V., Kumar, P., & Stillwell, A. S. (2016). An environmental cost-benefit analysis of alternative green roofing strategies. Ecological Engineering, 95, 1-9.

Zapater-Pereyra, M., Lavrnić, S., Van Dien, F., Van Bruggen, J. J. A., & Lens, P. N. L. (2016). Constructed wetroofs: A novel approach for the treatment and reuse of domestic wastewater. Ecological Engineering, 94, 545-554. https://doi.org/10.1016/j.ecoleng.2016.05.052.

Zehnsdorf, A., Willebrand, K. C., Trabitzsch, R., Knechtel, S., Blumberg, M., & Müller, R. A. (2019). Wetland roofs as an attractive option for decentralized water management and air conditioning enhancement in growing cities—A review. Water, 11(9), 1845.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

13.5.4 Smart roof

Smart roof

Fig. 29:"Polderdaken" (smart retention roof (source: Amsterdam Rainroof ; www.rainproof.nl)

Fig.30: Smart roof, Amsterdam (source: City of Tampere)

i. Basic information

Synonyms				
Type	1	2	3	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation

Addressed challenges	Climate resilience	Water management	Natural and climate hazards	Biodiversity	Air quality	Public health and well-being	Social justice and cohesion
	X	X	X	X	X		

Examples in UNaLab FRC	
Reference to other key studies	*ABG blue roof installed for a green extensive roof, Huddersfield UK*

ii. General description

Smart roofs are a special type of extensive green roof that fulfil different services to protect ecosystems in cities: (Capillar) smart roofs represent an extension of conventional green roofs because the system is equipped with a drainage system under the vegetation layer. The drainage layer retains storm water. Through capillary fibre cylinders' water is naturally returned to the vegetation layer during dry periods. Capillar smart roofs represent cyclic water management where additional plant irrigation is not needed (100% of the storm water can be reused for irrigation). Furthermore, technical devices (pumps, tanks, valves) are redundant.

iii. Role of nature

The model for a green roof is natural soil with its vegetation cover. Through the establishment of green roofs on buildings, different services of natural vegetation layers are replicated.

iv. Technical and design parameters

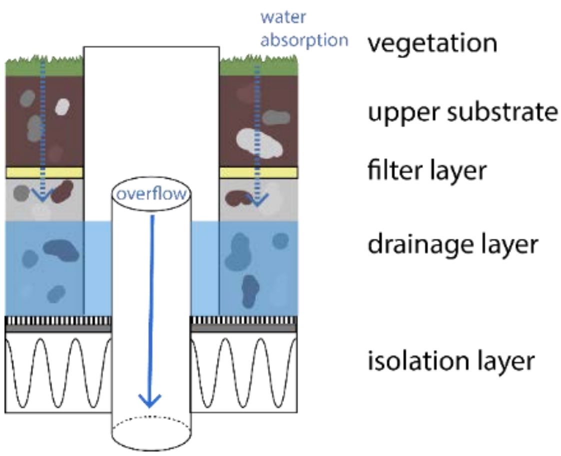


Fig. 31 smart roof scheme (source: ILPOE 2019)

v.	**Conditions for implementation**	
	The roof/surface must have sufficient load-bearing capacity and waterproofing.	
vi.	**Benefits and limitations**	
	Potential benefits: - Reduced flood risk - Water scarcity - Loss of biodiversity	
vii.	**Performance**	
P1	Transpiration	1
	Shading	1
	Evaporation	1
	Building (Insulation)	2
	Reflection (Albedo)	1
P2	Water conveyance	2
	Water infiltration	-
	Water retention	2
	Water storage	2
	Water reuse	1
P3	Water filtering	1
	Water bio-remediation	-
P4	Deposition	1
	Air biofiltration	-
	Noise reduction	-
P5	Habitat provision	-
	Connectivity	-
P6	Beauty / Appearance	1
	Usability / Functionality	-
	Social interaction	-
	Education	-
P7	Food / Energy / Material	-
P8	CO2 Sequestration	1
viii.	**Literature and further reading**	

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

	ABG (2020) ABG blue roof. Retrieved from http://www.abg-geosynthetics.com/case-studies/blueroof-green-extensive-roof-Huddersfield. Amsterdam Rainproof (2017). Project smart roof 2.0. Retrieved from https://web.archive.org/web/20220812141308/https://www.rainproof.nl/project-smartroof-20. Marineterrein Amsterdam (n.d.). From blazing hot to cool and green. Retrieved from https://web.archive.org/web/20220211131810/https://www.marineterrein.nl/en/project/project-smartroof-2-0/.

13.5.5 Green façades

Green façades


Fig. 32: Vertical Garden, façade-bound greening by Patrick Blanc, Paris (source: Eisenberg)


Fig. 33: Ground-based greening with climbers (source: Eisenberg)


Fig. 34: Façade-bound greening, Amsterdam (source: City of Tampere)

i. Basic information

Synonyms	Façade-bound greening; Ground-based greening; Green wall; Living wall						
Type	1 | 2 | **3** — action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation						
Addressed challenges	Climate resilience	Water management	Natural and climate hazards	Biodiversity	Air quality	Public health and well-being	Social justice and cohesion
	X	X		X	X		
Examples in UNaLab FRC	*Green façades at former Nutsbedrijven, Vestdijk/Oude Stadsgracht, and on Mathildelaan street, Eindhoven NL*						
Reference to key studies	*Museé du Quai Branly, Paris FR; Lise-Meitner-Haus / Physik Gebäuse Humboldt Universität Berlin, DE; MFO Park Zurich, CH*						

ii. General description

Planted walls with controlled cultivation are called green façades. Façade greenings are divided into two types: *façade-bound* greening and *ground-based* greening.

Façade-bound greening is a part of the façade or uses the façade for fixing panels and containers to it. In most cases it very intensively uses technology for irrigation and special substrates for reducing the weight of the green façade. Pre-cultivated panels or special plant pot systems are most frequently used. For light weight structures special tissues are used. Because of the thinness of the soil/substrate layer temperatures below 0° C may be a problem. Therefore, some greening systems have panels that can be removed during winter. *Façade-bound* greening does not rely on climbing plants, as vegetation is usually planted along the panel, and elevated.

Ground-based green façades are made of climbing plants. The climber plants are planted in the ground and grow directly on the wall, or climb on a frame that is connected to the wall and keeps a distance from it. The plants extract water and nutrients from the soil.

iii. Role of nature

Façade-bound greening has similar services as a very thin natural soil, which deals as a basis for vegetation. Depending on the type and level of engineering for irrigation, for nutrient supply and for the substrate the vegetation covers, *façade-bound* greening can perform highly; included vegetation can range from plants of rather wet environments to very dry environments.

European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Also, climbing plants used in *ground-based* greening grow from rather small areas of natural soil and often need supporting vertical elements or a porous surface (roots). A comparable natural situation may be bright areas of forests and their fringes (e.g. *Clematis* species).

iv. Technical and design parameters

Façade-bound greening

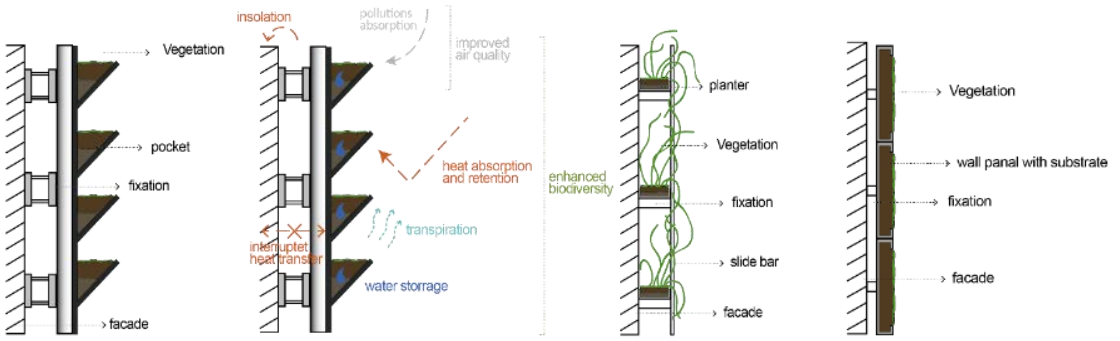


Fig. 7: Façade-bound greening: substrate in planter (a-c); mesh bakets made of plastic or metal (d) (source: ILPOE, 2018 based on Pfoser 2009 provided in: (Pfoser 2016a); page 58 ff.)

Options depend highly on the character of the building (new construction, refurbishment, restoration) and on structural engineering. For new constructions integrated façade systems can be used with vegetation panels (0.5 m² - 1 m²).

For regeneration projects a separate scaffolding is often needed. Typical specifications include:

- Panel: 0.5 – 1.0 m²
- Variety of 10 – 15 species of plants may be used
- Regular irrigation and special substrate is necessary
- Usually small plants are used

Ground-based greening

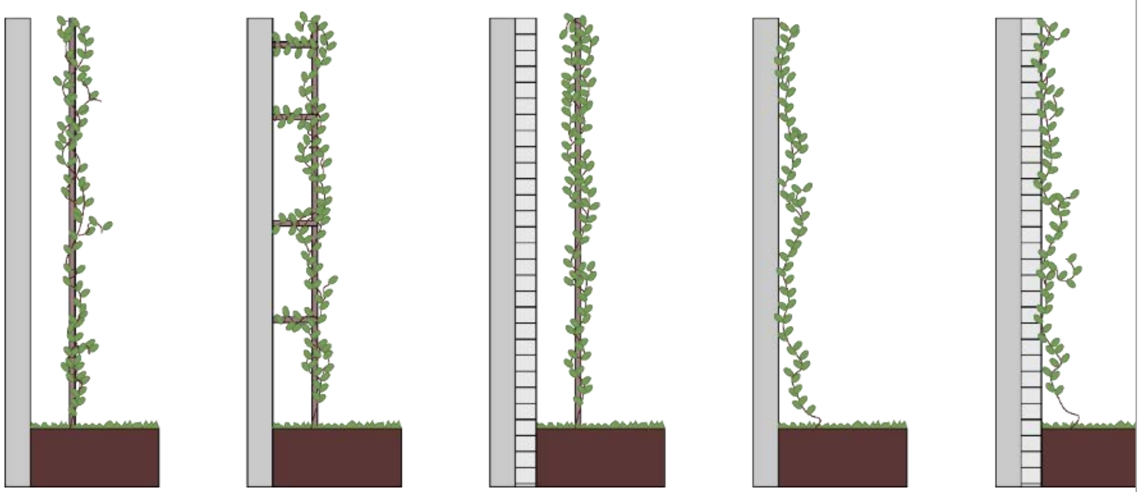


Fig. 8: Ground-based greening: vegetation with and without a support system (source: ILPOE 2019)

It is important to differentiate between self-climbing plants and climbers that need a support system. A façade without gaps is necessary for self-climbers to avoid intrusion of roots into the façade, whereas a supporting frame is needed for climbers. Climbing plants can grow up to 25 m high, however plant selection depends on environmental factors, and usually only a low number of species can be combined.

v. Conditions for implementation

	While all surfaces are potentially usable for a green façade, areas with plenty of sun exposure and with mild climatic conditions (not very dry, hot or cold) tend to perform best. For *façade-bound* greening, in general mosses and small perennial plants are appropriate, but other suitable vegetation can also be selected. For *ground-based* greening, good soil/substrate and a strong façade without gaps is necessary. It takes about 5-20 years for *ground-based* greening to fully cover a medium-sized house façade. It is important to use material that can withstand high temperatures, and if the substrate or vegetation dries out, there is a risk of fire. Special care of professional gardeners (particularly for *façade-bound* greening) is usually needed for maintenance.
vi.	**Benefits and limitations**
	Potential benefits: - Air pollution is reduced by plants, they bind high proportions of the particulate matter and polluting gases and green façades additional produce fresh air - A greened façade reduces the temperature about 2-10 K (compared to natural stone) - Green façades have good evaporation services - Evapotranspiration: 5-20 % sunlight is used for photosynthesis, 20-40% is used for evapotranspiration 10-50 % transformed into heat 5-30% reflection - Water retention: 15-30% - Biodiversity/Habitat provision: birds, bats (nesting and breeding) - Natural noise protection - Improved aesthetics - *Ground-based* green façades that are irrigated by surface water runoff replace a part of the surface water regulation service of a natural soil. *Potential limitations/disservices:* - High dependency on irrigation system, - Frost risk - Relatively long time span before walls are fully covered for *ground-based* greening
vii.	**Performance**

P1	Transpiration	2
	Shading	-
	Evaporation	-
	Building (Insulation)	2
	Reflection (Albedo)	-
P2	Water conveyance	-
	Water infiltration	-
	Water retention	-
	Water storage	-
	Water reuse	-
P3	Water filtering	-
	Water bioremediation	-
P4	Deposition	1
	Air bio-filtration	1
	Noise reduction	-
P5	Habitat provision	1
	Connectivity	1
P6	Beauty / Appearance	2
	Usability / functionality	1
	Social interaction	-
	Education	-

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

P7	Food / Energy / Material	-
P8	CO2 Sequestration	1

viii. Literature and further reading

Gandy, M. (2010). The ecological facades of Patrick Blanc. Architectural Design, 80(3), 28-33.

Greenroofs.com (2018). GPW: Musée du quai Branly. Retrieved March 20, 2021, from https://www.greenroofs.com/2011/09/26/gpw-museedu-quai-branly/.

Hancvencl, G. (2013). Fassadengebundene Vertikalbegrünung. Untersuchungen des Mikroklimas fassadengebundener Begrünungssystem.Masterabeit. Universität für Bodenkultur Wien, Wien. Retrieved March 20, 2021, from https://abstracts.boku.ac.at/oe_list.php?paID=3&paLIST=0&paSID=10671.

Humbolt-Universität Berlin (n.d). Das Lise-Meitner-Haus (Institut für Physik). Retrieved March 20, 2021, from https://www.physik.hu-berlin.de/de/institut/ueber/lise-meitner-haus/das-institutsgebaeude.

Hien, W. N., & Jusuf, S. K. (2010). Air temperature distribution and the influence of sky view factor in a green Singapore estate. Journal of urban planning and development, 136(3), 261-272. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000014.

Köhler, M. (2008). Green facades—a view back and some visions. Urban Ecosystems, 11(4), 423.

Köhler, M. & Nistor, C.R. (2015). Wandgebundene Begrünunugen. Quantifizierungen einer neuen Bauweise in der Klima architektur. Endbericht. Bundesinstitut für Bau-, Stadt-, und Raumordung im Bundesamt für Bauwesen und Raumordung. Bonn.

Ottelé, M. (2011). The green building envelope. Vertical Greening, Delft.

Paull, N. J., Krix, D., Irga, P. J., & Torpy, F. R. (2020). Airborne particulate matter accumulation on common green wall plants. International Journal of Phytoremediation, 22(6), 594-606. https://doi.org/10.1080/15226514.2019.1696744.

Pfoser, N. (2016). Fassade und Pflanze. Potenziale einer neuen Fassadengestaltung (Doctoral dissertation, Technische Universität Darmstadt).

Pfoser, N. (2017). Gebäude Begrünung Energie. Potentiale und Wechselwirkungen.

Schmidt, M. (2018) Cooling Urban Heat. In: Grüntuch-Ernst, A. (2018) Hortitecture. Jovis Verlag GmbH Berlin, Germany.

Stadt Zürich. (n.d.). Tiefbau- und Entsorgungsdepartement: MFO-Park. Retrieved from https://www.stadt-zuerich.ch/ted/de/index/gsz/planung-und-bau/abgeschlossene- projekte/mfo-park.html.

Wong, N. H., & Jusuf, S. K. (2010b). Air temperature distribution and the influence of sky view factor in a green Singapore estate. Journal of urban planning and development, 136(3), 261-272.

Wong, N. H., Tan, A. Y. K., Chen, Y., Sekar, K., Tan, P. Y., Chan, D., ... & Wong, N. C. (2010a). Thermal evaluation of vertical greenery systems for building walls. Building and environment, 45(3), 663-672.

13.5.6 Free standing living wall

Free standing living wall

Fig. 35: Constructing a living wall, Ludwigsburg (souce: (Helix Pflanzensysteme GmbH n.d.)

Fig. 36: Green Living Room Ludwigsburg (souce:(Helix Pflanzensysteme GmbH n.d.)

i. Basic information

Synonyms	Living wall						
Type	1	2	3	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation			
Addressed challenges	Climate resilience	Water management	Natural and climate hazards	Biodiversity	Air quality	Public health and well-being	Social justice and cohesion
	X			X	X		X
Examples in UNaLab FRC	*Gabions as retaining walls with vegetation at Gavoglio brracks, Genova IT*						
Reference to other key studies	*Green living room Ludwigsburg, part III*						

ii. General description

Verticalization of green spaces is an adequate way to increase vegetated surfaces with many ecological services in urban environments. Free standing living walls serve as adaptation measures for the urban heat island effect. Furthermore, they create space with high amenity value and potentially high biodiversity. Free standing living walls can also be used as a noise barriers along highly frequented roads. They are suitable to re-use run-off water and have a high rate of evapotranspiration. With extensive vegetation they also sustain longer periods of drought.

iii. Role of nature

Natural soil with vegetation cover (perennials and shrubs/trees) is the model for living walls. They consist of vertical layering of soil with plants growing on a vertical surface as well as on top of the wall. Function depends on the thickness of the living wall (approx. 40 cm) as well as the height normal soil functions can evolve, and filtering potential along the passage through the soil. Evaporation from vertical soil is one major effect. Transpiration from vegetation depends on plant selection, exposition and level of irrigation.

iv. Technical and design parameters

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Fig. 37: The functions of the green living room (souce:(Helix Pflanzensysteme GmbH n.d.)

Vertical layering of soil/substrate that is stored in metal cages with supporting elements to create walls of up to 4 m. Fabric (organic or un organic) is used to prevent the substrate / soil from eroding from the cages. It is fairly heavy construction that rests on a simple strip foundation. Living walls need to be constructed in two segments (minimum) that form a right angle in order to stabilize the living wall.
Very flexible with regard to plant selection, as long as irrigation and fertilizer can be managed accordingly.

v. Conditions for implementation

Because of the thickness of the living wall there is hardly any problem with central European frost periods
Underground needs to be loadable in order to support the wall. Little risk of fire because of constant irrigation

vi. Benefits and limitations

Potential benefits:

- Living walls provide direct shelter from the sun and depending on the vegetation indirect shelter (e.g. tree wall with trees growing from the wall).
- High evapotranspiration of vegetation helps to decrease heat island effect.
- Beneficial for selected species if respective plants are used.
- Noise reduction
- Surface water can be used for irrigation of living wall.

Potential limitations/disservices:

- Irrigation is needed (summer and winter) but it should not rely on drinking water.
- Underground support is needed.
- Free standing living wall may act as a barrier for pedestrian movement.

vii. Performance

P1	Transpiration	2
	Shading	2
	Evaporation	1
	Building (Insulation)	-
	Reflection (Albedo)	2
P2	Water conveyance	-
	Water infiltration	-
	Water retention	-
	Water storage	-
	Water reuse	-
P3	Water filtering	-
	Water bioremediation	-

P4	Deposition	1
	Air bio-filtration	1
	Noise reduction	-
P5	Habitat provision	2
	Connectivity	1
P6	Beauty / Appearance	2
	Usability / Functionality	1
	Social interaction	1
	Education	-
P7	Food / Energy / Material	-
P8	CO_2 Sequestration	1

viii. Literature and further reading

Eisenberg, B., Gölsdorf, K., Weidenbacher, S., & Schwarz-von Raumer, H. G. (2016). Report on Urban Climate Comfort Zones and the Green Living Room Ludwigsburg.

Lacasta, A. M., Penaranda, A., Cantalapiedra, I. R., Auguet, C., Bures, S., & Urrestarazu, M. (2016). Acoustic evaluation of modular greenery noise barriers. Urban Forestry & Urban Greening, 20, 172-179. https://doi.org/10.1016/j.ufug.2016.08.010.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

13.5.7 Mobile Vertical Greening/Mobile Green Living Room

Mobile Vertical Greening / Mobile Green Living Room

Fig. 38: Mobile Green Living Room (source: Eisenberg)

i. Basic information

Synonyms							
Type	1	2	3	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation			
Addressed challenges	Climate resilience	Water management	Natural and climate hazards	Biodiversity	Air quality	Public health and well-being	Social justice and cohesion
	X			X	X		X
Examples in UNaLab FRC							
Reference to other key studies	*Mobile Green Living Room 2016 Tour, Europe*						

ii. General description

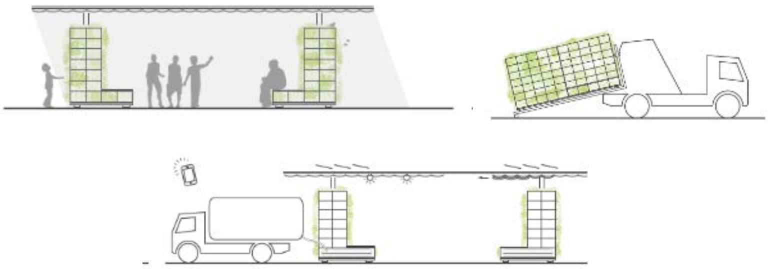


Fig. 39: Mobile green living room (source: Ludwig.Schoenle)

The mobile Green Living Room consists of living wall modules (wire frame cubes) that are fixed to a hook lift container platform. The vegetation cover is very diverse in order to illustrate the high potential of living walls to increase amenity value and stimulate biodiversity. A light open roof structure, partly covered with vegetation, provides shade. The Green Living Room instantly provides services for clean air provision, cooling and shading, and a habitat for urban biodiversity. It can be used as a mobile demonstration for green infrastructure, as a test feature, a temporary green installation or as an open green office for information and communication purposes.

iii. Role of nature

	Natural soil with vegetation cover (perennials and shrubs/trees) is the model for living walls but for "mobile vegetation" there is no space for loading and unloading example from nature.
iv.	**Technical and design parameters**
	The Green Living Room can be trucked to any location that has truck access. It acts as a semi-autonomous unit with an on-board water tank that lasts for up to a week and an irrigation system that needs a temporary energy supply.
v.	**Conditions for implementation**
	Space for loading and unloading is needed, surface has to be flat (<3°), permissions needed for installation.
vi.	**Benefits and limitations**
	Potential benefits: - Mobile vertical elements serve as models for large scale interventions, they can be used for testing the suitability of a location and in participation processes - In combination with more elements the performance increases significantly - Raises awareness and offers educational opportunities for NBS use in urban areas *Potential limitations/disservices:* - The requirements for transporting mobile elements dominate other aspects of vertical greening - The average performance of vertical greening, such as heat reduction, cannot be replicated completely in mobile elements due to the limited space - The height is limited, also width and length are smaller - Maintenance and supervision is high - Transportation and production produce emissions
vii.	**Performance**

P1	Transpiration	1
	Shading	2
	Evaporation	-
	Building (Insulation)	-
	Reflection (Albedo)	1
P2	Water conveyance	-
	Water infiltration	-
	Water retention	-
	Water storage	-
	Water reuse	-
P3	Water filtering	-
	Water bio-remediation	-
P4	Deposition	1
	Air biofiltration	-
	Noise reduction	1
P5	Habitat provision	1
	Connectivity	1
P6	Beauty / Appearance	1
	Usability / Functionality	2
	Social interaction	1
	Education	2
P7	Food / Energy / Material	-
P8	CO2 Sequestration	1

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

viii.	Literature and further reading
	Climate Alliance. (2016). The mobile green living room roadshow – a feast for the senses. Retrieved from http://www.climatealliance.org. Müller, H. & Eisenberg, B. (2016). Green Living Room Roadshow. A mobile exhibition demonstrating innovative green infrastructure -designed by TURAS for citizens and the cities they live in. TURAS project. Urban GreenUP. (n.d.) Vertical mobile garden. Retrieved from https://www.urbangreenup.eu/solutions/vertical-mobile-garden.kl.

13.5.8 Moss wall

Moss wall

Fig. 40: MoosTex: Test site for pollution absorbing noise protection wall (source: Helix-Pflanzen)

Fig. 41: City tree (source: Eisenberg)

i. Basic information

Synonyms	City tree						
Type	1	2	3	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation			
Addressed challenges	Climate resilience	Water management	Natural and climate hazards	Biodiversity	Air quality	Public health and well-being	Social justice and cohesion
	X				X		X
Examples in UNaLab FRC							
Reference to other key studies	*City tree, Stuttgart DE*						

ii. General description

Compared to other plants, mosses have a large bio-active surface, they transpire more, and actively reduce some pollutants. There is a range of test sites with open air experiments in order to test the effectiveness for fine dust reduction and air quality improvement.

To exemplify a potential product that makes use of moss capacities, The City Tree is described for this NBS type. The City Tree is a bio-tech-filter with the aim to improve air quality in cities. The City Tree is a compact and mobile construction, vertically planted with different species of mosses on its front and back side. The moss surface contributes to the improvement of air quality through the binding of air pollutants like particulate matter and nitrogen oxide. Due to its large surface area (in comparison to many other plants), mosses store a relatively high amount of water while simultaneously providing a relatively large surface area for water transpiration. As a consequence, the transpiration of water leads to a reduction of air temperature on a local scale.

iii. Role of nature

The City Tree and moss walls in general, maximize the ecological function of natural moss capacity, by utilizing their large surface area for the filtering of air pollutants and transpiration.

iv. Technical and design parameters

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

	City Trees are equipped with additional technical solutions. For example, externally controllable ventilators inside the vertical construction and underneath the moss surface strengthen the air flow through the installation, thereby increasing air filtering and water transpiration capacity. Furthermore, The City Tree is equipped with a technical device that provides real-time information about The City Tree and the surrounding environmental conditions. Depending on the local climate conditions, The City Tree has an additional irrigation system. Solar panels can supply electricity, or The City Tree may be connected to the main power line.
v.	**Conditions for implementation**
	Flat surfaces for installation and enough space for loading and unloading is needed.
vi.	**Benefits and limitations**
	Potential benefits: - Air filtering - Mitigation against heat stress - Recreation/relaxing *Potential limitations/disservices*: - Real performance is still under discussion, further independent studies needed - Transportation and production produce emissions.
vii.	**Performance**

P1	Transpiration	2
	Shading	1
	Evaporation	1
	Building (Insulation)	-
	Reflection (Albedo)	-
P2	Water conveyance	-
	Water infiltration	-
	Water retention	-
	Water storage	-
	Water reuse	-
P3	Water filtering	-
	Water bio-remediation	-
P4	Deposition	1
	Air biofiltration	1
	Noise reduction	1
P5	Habitat provision	-
	Connectivity	-
P6	Beauty / Appearance	1
	Usability / Functionality	1
	Social interaction	1
	Education	1
P7	Food / Energy / Material	-
P8	CO2 Sequestration	-

viii. Literature and further reading

Enercity. (2017). Der “City Tree” eine multifunktionale Grünfläche. [Power Point slides]. Retrieved from https://e-government.hannover-stadt.de/.

Greencity solutions (2020). Der City Tree- der weltweit erste Bio-Tech-Filter zur nachweisbaren Verbesserung der Luftqualität. Retrieved from https://greencitysolutions.de/.

Haynes, A., Popek, R., Boles, M., Paton-Walsh, C., & Robinson, S. A. (2019). Roadside moss turfs in South East Australia capture more particulate matter along an urban gradient than a common native tree species. Atmosphere, 10(4), 224. https://doi.org/10.3390/atmos10040224.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

13.5.9 Living plant constructions

Living plant constructions

Fig. 42: Botanical tower, neue Kunst am Ried, Germany (source: Ferdinand Ludwig; http://www.ferdinandludwig.de/baubotanischer-turm.html)

Fig. 43: Plane-Tree-Cube, Nagold (source: Ludwig.Schoenle; https://www.baubotanik.org/de/bauten/kubus/)

i. Basic information

Similar terminology	Baubotanik						
Type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation			
Addressed challenges	Climate resilience	Water management	Natural and climate hazards	Biodiversity	Air quality	Public health and well-being	Social justice and cohesion
	X			X	X	X	X
Examples in UNaLab FRC							
reference to other key studies	*Plane-Tree-Cube, Nagold DE*						

ii. General description

Living plant constructions use living trees with all their biological services for construction purposes in order to create living architecture. An essential feature of *Baubotanik* buildings is that they fundamentally change their general shape, appearance and spatial effect from season to season and over time.

Fig. 44: House of future competition, visualization of façade with living plant construction, winter and summer expression (source: Ludwig.Schoenle)

iii. Role of nature

Living plant constructions use the natural process of inosculation, a process that can occur in nature when trunks, roots, or branches in close proximity slowly fuse together. This process also known as approach grafting, can arise within a single tree or neighbouring trees of same or different species. As the limbs grow, they exert increasing pressure on each other causing the bark to break off and the inner tissue of the trees to join. (Oommen 2015).

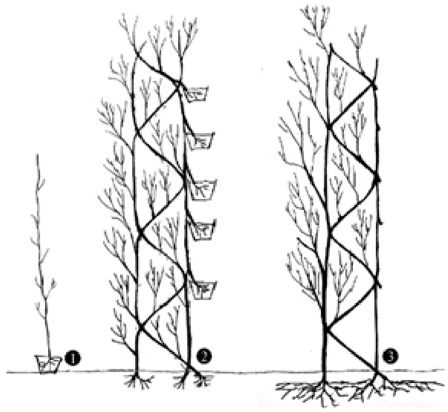


Fig. 45: Principle sketch of plant addition (source: Ludwig.Schoenle)

iv. Technical and design parameters

The lowest plants are rooted in the ground, while the rest are planted into special containers on scaffolding or into living wall segments with an irrigation system. Once the in-ground and scaffolding plants fuse, the containers and additional irrigation system is no longer needed, as the plants are fully supported from the ground. Secondary growth increases the strength of the structure, and the living plant construction is eventually self-sufficent.

Living plant construction can be implemented on any site, also on top of buildings. For the upper containers of the plants supporting structure is needed that either has a function in itself (e.g. staircase), is a living wall (example Green Living Room), or a separate structure.

v. Conditions for implementation

Due to regulations living plant construction may need special building permissions for implementation.

vi. Benefits and limitations

Potential benefits:

- The performance that adult trees deliver after decades can be achieved within a couple of years by living plant construction.
- Depending on the implementation living plant constructions serve as green façades or three dimensional open spaces and deliver respective services like:
    - Heat reduction for buildings
    - Shading for people
    - Cooling ambient temperature
    - Improving amenity value

Potential limitations/disservices:

- Maintenance, supervision, and irrigation systems are essential in the initial phase
- Difficult to retrofit buildings with living plant constructions (with new buildings all required elements can be integrated from the start)
- A standardized procedure for building and maintenance needs to be developed

vii. Performance

P1	Transpiration	1
	Shading	2
	Evaporation	-
	Building (Insulation)	-

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

	Reflection (Albedo)	1
P2	Water conveyance	-
	Water infiltration	-
	Water retention	-
	Water storage	-
	Water reuse	-
P3	Water filtering	-
	Water bioremediation	-
P4	Deposition	1
	Air bio-filtration	-
	Noise reduction	1
P5	Habitat provision	1
	Connectivity	1
P6	Beauty / Appearance	1
	Usability / Functionality	2
	Social interaction	1
	Education	2
P7	Food / Energy / Material	-
P8	CO2 Sequestration	1

viii. References and further reading

Ludwig, F. (2016). Designing with living material. Materiality and Architecture, 182.

Ludwig, F., Middleton, W., Gallenmüller, F., Rogers, P., & Speck, T. (2019). Living bridges using aerial roots of ficus elastica–an interdisciplinary perspective. Scientific reports, 9(1), 1-11.

Ludwig, F. (n.d.). Living plant constructions: plane-tree-cube Nagold. Retrieved from http://www.ferdinandludwig.com/plane-tree-cube-nagold/articles/plane-tree-cube-nagold.html.

13.6 Natural and semi-natural water storage and transport structures

13.6.1 Constructed wetlands

Constructed wetlands

Fig.46: Urban Constructed wetland (source: LAND; https://www.landsrl.com/)

Fig. 47: Constructed wetland (source: LAND; https://www.landsrl.com/)

i. Basic information

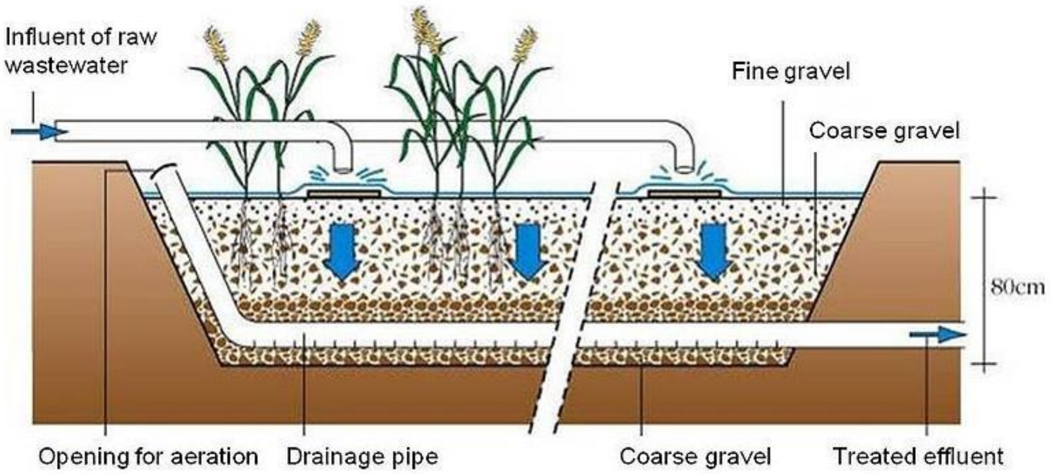
Synonyms	Alluvial meadow; Urban constructed wetland; constructed floodplain; constructed surface wetland; constructed marsh or reed bed						
Type	1	2	3	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation			
Addressed challenges	Climate resilience	Water management	Natural and climate hazards	Biodiversity	Air quality	Public health and well-being	Social justice and cohesion
	X	X	X	X			X
Examples in UNaLab FRC	*Alluvial Meadows at Tervaslampi Park in Vuores, Tampere FI*						
Reference to other key studies	*Trin Warren Tam-boore wetland, Melbourne AU;* *Urban wetland Tanner Springs Park, Portland, Oregon US* *Urban wetlands, London UK*						

ii. General description

Constructed wetlands (CW) represent artificial wetlands with the main objective to harvest, treat, and store storm-/grey water runoff in urban areas. Processes and services of natural wetlands are adapted to constructed wetlands focusing on water purification and underground storage. Hydrological processes of natural wetlands are simulated in constructed wetlands. Wetlands are complex systems where established vegetation and soil and microbiological activity play an important role for the filter performance of constructed wetlands. Furthermore, biodiversity in constructed wetlands can be improved by including design elements such as diverse vegetation and barrier-free shores.

Constructed wetlands are shallow basins that are filled with substrate. The substrate type is variable but usually CWs are filled with sand or gravel. The substrate layer is planted with aquatic or semi-aquatic vegetation. Constructed wetlands have an inlet pipe for storm water runoff. The storm water runoff can then flow over or through the substrate layer and vegetation while it is naturally filtered and cleaned. The constructed wetland is equipped with an outlet (pipe, weir) for controlled water discharge. The purified water flows into another pond where it is stored. The treated storm water can be used for different purposes (e.g. for

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

	green space irrigation). According to the type of CW wastewater flows 1) horizontally over the ground surface, 2) horizontally under the ground surface and through the substrate layer or 3) vertically through the constructed wetland (hybrid systems).
iii.	**Role of nature**
	Processes and services of natural wetlands are adapted to constructed wetlands focusing on water purification and storage. The main processes in a constructed wetland are: settling of particles, filtration, chemical transformation, adsorption, and positive ion exchange e.g. on plants and substrates, uptake/breakdown/transformation of pollutants and nutrients by microorganisms and plants.
iv.	**Technical and design parameters**
	Constructed wetlands are cost-effective, as they are less expensive than conventional wastewater treatment options. They can be included in greenspaces as landscaping elements. Installation of water control measures and regular inspections, monitoring and maintenance are necessary.  *Fig. 48: Structure of constructed wetlands (source: Sustainable Sanitation Alliance; https://www.susana.org/en/)*
v.	**Conditions for implementation**
	Suitable locations must be selected for constructed wetlands. There should be enough accessible land (with compact soils to minimize infiltration into groundwater) and they should be located upland, near a wastewater source, and outside floodplains. They should also be built on a gentle slope, as water flows by gravity through constructed wetlands. Furthermore, the protection of biodiversity should be considered and therefore construction should not displace endangered or threatened species or disturb archaeological or historic resources.
vi.	**Benefits and limitations**
	Potential benefits: - Water supply regulation - Water temperature control - Improve water quality/water purification - Provide water for different purposes (e.g. irrigation) - Flood control/mitigation - Habitat for wildlife, support of wetland biodiversity - Recreation (watching birds) - Aesthetic value *Potential limitations/disservices:* - Require relatively large areas, so implement where free space is available
vii.	**Performance**

P1	Transpiration	1
	Shading	-
	Evaporation	2
	Building (Insulation)	-
	Reflection (Albedo)	-
P2	Water conveyance	1
	Water infiltration	1
	Water retention	1
	Water storage	1
	Water reuse	2
P3	Water filtering	1
	Water bio-remediation	2
P4	Deposition	-
	Air biofiltration	-
	Noise reduction	-
P5	Habitat provision	2
	Connectivity	2
P6	Beauty / Appearance	2
	Usability / Functionality	1
	Social interaction	2
	Education	1
P7	Food / Energy / Material	1
P8	CO2 Sequestration	-

viii. Literature and further reading

Andreo-Martínez, P., García-Martínez, N., Quesada-Medina, J., & Almela, L. (2017). Domestic wastewaters reuse reclaimed by an improved horizontal subsurface-flow constructed wetland: a case study in the southeast of Spain. Bioresource Technology, 233, 236-246.

City of Melbourne. (2015). Urban water: discover how water creates a liveable city, a case study. Trin Warren Tam-boore wetlands.

City of Melbourne. (n.d.). Urban Water: constructed wetlands. Retrieved from http://urbanwater.melbourne.vic.gov.au/industry/treatment-types/constructed-wetlands/.

Davis, L. (1995). A handbook of constructed wetlands: A guide to creating wetlands for: agricultural wastewater, domestic wastewater, coal mine drainage, stormwater. In the Mid-Atlantic Region. Volume 1: General considerations. USDA-Natural Resources Conservation Service.

GreenWorks. (n.d). Tanner Springs Park. Retrieved from https://greenworkspc.com/ourwork/tanner-springs-park.

Jácome, J. A., Molina, J., Suárez, J., Mosqueira, G., & Torres, D. (2016). Performance of constructed wetland applied for domestic wastewater treatment: Case study at Boimorto (Galicia, Spain). Ecological Engineering, 95, 324-329.

Kilian Water. (2020). Types of constructed wetlands. Retrieved from http://www.kilianwater.nl/en/constructed-wetlands/solar-powered-water-treatment.html.

Knapp, S., Schmauck, S., & Zehnsdorf, A. (2019). Biodiversity Impact of Green Roofs and Constructed Wetlands as Progressive Eco-Technologies in Urban Areas. Sustainability, 11(20), 5846.

Moinier, S. (2013). Constructed Wetlands Redefined as Functional Wetlands. Deltares SO MT Kennis

Sample, D., Wang, C. Y., & Fox, L. (2013). Innovative Best Management Fact Sheet. No. 1, Floating Treatment Wetlands.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Zhang, C., Wen, L., Wang, Y., Liu, C., Zhou, Y., & Lei, G. (2020). Can constructed wetlands be wildlife refuges? A review of their potential biodiversity conservation value. Sustainability, 12(4), 1442. https://doi.org/10.3390/su12041442.

13.6.2 Retention- and detention pond

Retention-/Detention Pond

Fig. 49: Detention Pond (source: www.susdrain.org)

Fig. 50: Wet Retention Pond in Vuores, Tampere (source: City of Tampere)

i. Basic information

Synonyms	*Detention pond*: dry detention pond, dry detention basin *Retention pond*: wet retention pond, wet retention basin						
Type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation			
Addressed challenges	Climate resilience	Water management	Natural and climate hazards	Biodiversity	Air quality	Public health and well-being	Social justice and cohesion
	X	X	X				X
Examples in UNaLab FRC	*Retention pond at Tervaslampi Park in Vuores, Tampere FI*						
Reference to other key studies							

ii. General description

Dry detention ponds are surface storage basins that retain storm water. During periods of heavy rain, the area gets flooded and could fill the detention pond in cases of longer duration of rainfall. After the rain ends, the water flows in the sewer system or infiltrates through the soil and recharges the groundwater. If there is no event of heavy rainfall the detention ponds are dry and could be used as a green area.
Retention ponds retain storm water continuously. In dry periods they also hold water. They can also improve the water quality, for example with downstream infiltration or sedimentation.

iii. Role of nature

Detention ponds mimic a natural landscape that contains a heterogeneous surface with slightly elevated areas and lower parts in close proximity, forming a mosaic of micro conditions. Water stays in the lower parts for some time until it infiltrates or evaporates.

iv. Technical and design parameters

Retention and detention ponds can be incorporated into public areas like parks and sports fields, but must always be at the lowest part of the park /green space. Additionally, *dry detention ponds* can be used as a green areas in times without heavy rainfall events.

v.	**Conditions for implementation**	
	There needs to be appropriate available area (enough space to flood) with the proper soil and rainfall conditions. While there are limited design options, they could be considered in park planning.	
vi.	**Benefits and limitations**	
	Potential benefits: - Regulates heavy rain - Multifunctional use of detention pond is possible - Retention of storm water - Potentially re-use water for irrigation (wet) *Potential limitations/ disservice:* - Green space with too many functions may lead to reduced recreation space	
vii.	**Performance**	
P1	Transpiration	-
	Shading	-
	Evaporation	1
	Building (Insulation)	-
	Reflection (Albedo)	-
P2	Water conveyance	-
	Water infiltration	-
	Water retention	2
	Water storage	1
	Water reuse	1
P3	Water filtering	1
	Water bio-remediation	-
P4	Deposition	-
	Air biofiltration	-
	Nosie reduction	-
P5	Habitat provision	-
	Connectivity	-
P6	Beauty / Appearance	1
	Usability / Functionality	1
	Social interaction	1
	Education	1
P7	Food / Energy / Material	-
P8	CO2 Sequestration	-
viii.	**Literature and further reading**	

Monberg, R. J., Howe, A. G., Ravn, H. P., & Jensen, M. B. (2018). Exploring structural habitat heterogeneity in sustainable urban drainage systems (SUDS) for urban biodiversity support. Urban Ecosystems, 21(6), 1159-1170. https://doi.org/10.1007/s11252-018-0790-6.

Schifman, L. A., Kasaraneni, V. K., & Oyanedel-Craver, V. (2018). Contaminant Accumulation in Stormwater Retention and Detention Pond Sediments: Implications for Maintenance and Ecological Health. In Integrated and Sustainable Environmental Remediation (pp. 123-153). American Chemical Society.

Stormwater Equipment manufacturers association. (n.d.). Detention/Retention ponds. Retrieved from https://www.stormwaterassociation.com/detention-retention-ponds.

Susdrain. (n.d.). Component: retention ponds. Retrieved from https://www.susdrain.org/delivering-suds/.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

13.6.3 Daylighting

Daylighting

Fig. 51: Small stream after Daylighting (source: LAND; https://www.landsrl.com/)

Fig. 52: Daylighting of a small stream in work (source: LAND; https://www.landsrl.com/)

i. Basic information

Synonyms	River daylighting; culvert removal						
Type	1	2	3	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation			
Addressed challenges	Climate resilience	Water management	Natural and climate hazards	Biodiversity	Air quality	Public health and well-being	Social justice and cohesion
	X	X	X	X			X
Examples in UNaLab FRC	*Daylighting and connecting stream in Grote Beek, Eindhoven NL*						
Reference to other key studies	*River Ravensbourne, Bromley UK*						

ii. General description

Daylighting describes the opening of buried or covered watercourses, such as rivers and drainage systems, by removing concrete layers. This creates more space for the river, which allows for increased storage capacity of the channel, thus decreasing flood risk. Daylighting also results in a more natural development of the riverbed and riparian zone, thereby enhancing aesthetics and supporting biodiversity through improved habitat quality / habitat creation. Both natural and architectural restoration can be considered when daylighting. *Natural restoration* refers to the daylighting of channels followed by a natural development of the riverbed and riparian zone, whereas *architectural restoration* describes the daylighting of a watercourse that still follows a concrete/constructed channel.

iii. Role of nature

Daylighting allows the natural development of a water channel that fulfils services of a natural water channel/river. For example, it provides habitat for wildlife, aquatic life and plants, and increases the regulation/uptake of stormwater runoff. Natural channels enable the water to flow and expand to its riversides, and natural vegetation contributes to reducing water velocity.

iv. Technical and design parameters

There are a variety of designs and levels of intervention possible that are dependent upon the intention of the planned project. For example, the whole culverted structure or just parts of it

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

	(top layer) may be removed, or gaps can be created. Natural restoration is associated with more effort than only removing the top layer of a culvert that results in an open constructed channel. However, with natural restoration the water channel is shaped by nature leading to a dynamic water channel and a riparian zone with a natural shape that includes plants and rocks.
v.	**Conditions for implementation**
	There may be restrictions or limited possibilities in dense and highly built areas because of high costs for shifting or removing infrastructure. Additionally there needs to be enough space and a certain channel width to deculvert the watercourse. Furthermore, information about soil types under and surrounding the channel need to be collected to guarantee the performance of the daylighting measure.
vi.	**Benefits and limitations**
	Potential benefits: - Storm water management - Benefits for many aquatic organisms (light plays a role for population movement) - Benefits for flora and fauna frequenting the banks/habitat provision for flora and fauna - Improving physical habitat conditions of the watercourse, habitat niches - Natural bank development/profile; creating natural watercourses - Enables natural processes (erosion; deposition) - Aesthetic value; human recreation - Educational resource *Potential limitations/disservices:* - Architectural restoration is less near-natural than the natural restoration. As a result the development and establishment of flora and fauna is limited
vii.	**Performance**

P1	Transpiration	1
	Shading	-
	Evaporation	1
	Building (Insulation)	-
	Reflection (Albedo)	-
P2	Water conveyance	1
	Water infiltration	1
	Water retention	1
	Water storage	-
	Water reuse	-
P3	Water filtering	1
	Water bio-remediation	1
P4	Deposition	-
	Air biofiltration	-
	Noise reduction	-
P5	Habitat provision	2
	Connectivity	1
P6	Beauty / Appearance	2
	Usability / Functionality	1
	Social interaction	1
	Education	1
P7	Food / Energy / Material	-
P8	CO2 Sequestration	1

viii. Literature and further reading

Addy, S., Cooksley, S., Dodd, N., Waylen, K., Stockan, J., Byg, A., & Holstead, K. (2016). River Restoration and Biodiversity. IUCN.

Addy, S., Cooksley, S., Dodd, N., Waylen, K., Stockan, J., Byg, A., & Holstead, K. (2016). River Restoration and Biodiversity. IUCN. Retrieved August 12, 2022, from https://portals.iucn.org/library/sites/library/files/documents/2016-064.pdf.

American Planning Association, the American Society of Civil Engineers, the Association of State and Floodplain Mangers and the National Association of Counties and The Nature Conservancy. (n.d.). Solution: daylighting rivers and streams.

Boffa Miskell. (2017). Stream daylighting: identifying opportunities for central Auckland. Retrieved from https://www.boffamiskell.co.nz/project.php?v=stream-daylighting.

Baho, D. L., Arnott, D., Myrstad, K. D., Schneider, S. C., & Moe, T. F. (2021). Rapid colonization of aquatic communities in an urban stream after daylighting. Restoration Ecology, 29(5), 73394. https://doi.org/10.1111/rec.13394.

European Center for River Restoration (ECRR, 2019). Remove culverts. Retrieved March 20, 2021, from http://www.ecrr.org/River-Restoration/Flood-risk-management/Healthy-Catchments-managing-for-flood-risk-WFD/Environmental-improvements-case-studies/Remove-culverts.

European Centre for River Restoration (ECRR). (2019). Allow the river to flood its floodplain. Retrieved from http://www.ecrr.org/River-Restoration/Flood-risk-management/Healthy-Catchments-managing-for-flood-risk-WFD/Environmental-improvements-case-studies/Allow-the-river-to-flood-its-floodplain.

European Centre for River Restoration (ECRR). (n.d). Reopening existing culverts.

National Environmental Assessment Service, Solent and South Downs Area, South East Region.(n.d.). Remove culverts.

Parks and Open Spaces, London Borough of Croydon. (n.d.) Reopening existing culverts. [PDF]. Retrieved from http://www.ecrr.org/Portals/27/Wandle%20Park%20River%20Restoration.pdf.

River Restoration Centre. (n.d.) Manual of river restoration techniques: opening up a culverted stream, River Ravensbourne. [PDF]. Retrieved from www.therrc.co.uk.pdf.

The River Restoration Centre (2020). Manual of river restoration techniques. Retrieved August 12, 2022, from https://www.therrc.co.uk/manual-river-restoration-techniques.

Trice, A. (n.d.). American Rivers. Daylighting streams: breathing life into urban streams and communities. [PDF]. Retrieved from https://americanrivers.org/wp-content/uploads/2016/05/AmericanRivers_daylighting-streams-report.pdf.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

13.6.4 Underground water storage

Underground water storage

Fig 53: Underground water storage (source: Commune di Genova)

Fig 54: Zollhallen Plaza (source: Land8 Media, LLC; land8.com)

i. Basic information

Synonyms	Underground retention basin						
Type	1 2 **3**	<u>action type:</u> 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation					
Addressed challenges	Climate resilience	Water management	Natural and climate hazards	Biodiversity	Air quality	Public health and well-being	Social justice and cohesion
		X	X	X			
Examples in UNaLab FRC	*Rainwater storage in Clausplein Square, Eindhoven NL;* *Underground retention basin at Gavoglio barracks, Genova IT*						
Reference to other key studies	*Zollhallen Plaza, Freiburg DE*						

ii. General description

Underground systems below public open spaces such as sports fields composed of modular elements to retain flash floods and to store water for irrigation purposes nearby.

iii. Role of nature

Depending on the geology of an area, underground storage capacity retains and stores water after flash floods. Examples from Peru show that already in Pre – Inca time, people made use of these qualities and directed water in channels to storage areas or to feed artificial ponds or springs.

iv. Technical and design parameters

Underground water storage can be incorporated into larger water management projects, as long as it is disconnected from the sewage system. Above the water storage tanks, there is a top layer consisting of vegetation or a permeable pavement, followed by a load-bearing substrate layer. Underneath the tanks, the lower substrate acts as a filtration layer. Other aspects should also be considered such as the drainage gradient and overflow pipes and systems.

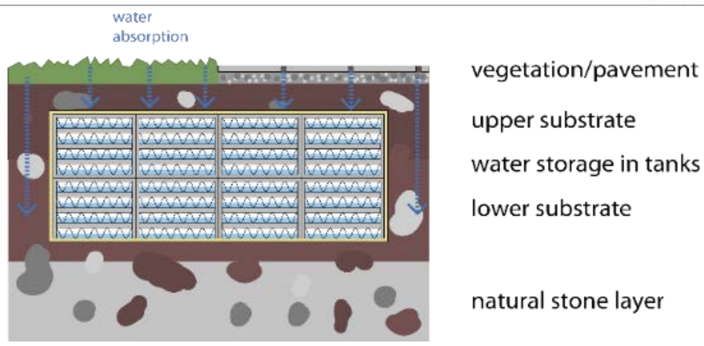


Fig. 55: Underground water storage (source: ILPOE 2019)

v. Conditions for implementation

Space for underground storage needs to be excavated. They are relatively difficult to build for already existing infrastructure.

vi. Benefits and limitations

Potential benefits:

- On site storage of water helps minimizing or delaying run-off
- Re-use of water on site can be used for irrigation during hot, dry season

Potential Limitations/disservices:

- Minimum water quality needed for storage
- Space for underground storage required

vii. Performance

P1	Transpiration	-
	Shading	-
	Evaporation	-
	Building (Insulation)	-
	Reflection (Albedo)	-
P2	Water conveyance	-
	Water infiltration	2
	Water retention	1
	Water storage	1
	Water reuse	2
P3	Water filtering	1
	Water bio-remediation	-
P4	Deposition	-
	Air biofiltration	-
	Noise reduction	-
P5	Habitat provision	1
	Connectivity	1
P6	Beauty / Appearance	-
	Usability / Functionality	1
	Social interaction	-
	Education	-
P7	Food / Energy / Material	-
P8	CO2 Sequestration	-

viii. Literature and further reading

UrabnNext (n.d.). Zollhallen Plaza: A climate adaptation tool. Retrieved from https://web.archive.org/web/20220812153514/https://urbannext.net/zollhallen-plaza/.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

WLA (2012). Zollhallen Plaza. Retrieved from https://web.archive.org/web/20220812153630/https://worldlandscapearchitect.com/zollhallen-plaza-freiburg-germany-atelier-dreiseitl/.

13.7 Infiltration, filtration and biofiltration structures

13.7.1 Bioswale

Bioswale

Fig. 56: Eindhoven, Bioswale (source: Eisenberg)

i. Basic information

Synonyms	Swale; Grassed swale; Vegetated filter strip; Stripswale						
Type	1 / 2 / **3** — action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation						
Addressed challenges	Climate resilience	Water management	Natural and climate hazards	Biodiversity	Air quality	Public health and well-being	Social justice and cohesion
		X	X	X			
Examples in UNaLab FRC	*Grassed swale on Waagstraat, Eindhoven NL;* *Bioswale at Gavoglio barracks, Genova IT*						
Reference to other key studies	*Queen Mary's Walk, Llanelli UK;* *Houndsden Road Rain Gardens, Enfield UK*						

ii. General description

A bioswale is a vegetated, linear, and low sloped pit often established in urban areas near or between roads with the objective to reduce flood risk during or after heavy rain events. The intention of bioswales is comparable to rain gardens. Bioswales absorb, store and convey surface water runoff (mainly draining from roadways) and also remove pollutants and sediments, as the water trickles through the vegetation and soil layer. The choice of vegetation for bioswales is variable but deep-rooted, native plants are common and preferred. To support infiltration of water runoff, some swales are equipped with dams or similar constructions.

	If properly planned and planted with native plants, a bioswale is a reasonable contribution to local storm water management and control and can help support biodiversity.	
iii.	**Role of nature**	
	There are several processes in bioswales (vegetation and soil) that are inspired by nature, including: - Water retention and storage as vegetation and soil layer retains and stores water - Water infiltration as water infiltrates into natural soils, whereas soil substance has an influence on infiltration rate - Water filtering as plants and soil are natural filters for organic pollutants, sediments and other substances - Water conveyance as the constructed 'riverbed' conveys water - Water evapotranspiration as plants take up and transpire water	
iv.	**Technical and design parameters**	
	While similar to the smaller raingardens, bioswales are usually medium to larger scale installations. They must have relatively dense vegetation to slow water flow, without being so dense as to negatively affect water conveyance. It is best to select native, deep-rooted plants that can withstand occasional flooding, this is often a mixture of grass and other vegetative plants. Access for maintenance (grass cutting/removal and sediment removal), inspection, and management is also necessary. Bioswales can be combined with other sustainable drainage systems (SuDS) such as rainwater harvesting measures and permeable paving. Trampling or any other (soil) compaction within bioswales should be avoided to ensure water infiltration capacity.	
v.	**Conditions for implementation**	
	Storm water from roofs or paved areas need to be collected in order to lead them into a bio swale. Space for implementation is needed, multifunctional uses may be possible.	
vi.	**Benefits and limitations**	
	Potential benefits: - Storm water management and control - Reduced flood risk - Improvement of water quality - Habitat provision for wildlife - Improvement of amenity value *Potential limitations/disservices:* - Trees need to be managed / limited to allow water conveyance	
vii.	**Performance**	
P1	Transpiration	-
	Shading	-
	Evaporation	1
	Building (Insulation)	-
	Reflection (Albedo)	-
P2	Water conveyance	1
	Water infiltration	2
	Water retention	1
	Water storage	1
	Water reuse	-
P3	Water filtering	1
	Water bio-remediation	1
P4	Deposition	-
	Air biofiltration	-

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

	Noise reduction	-
P5	Habitat provision	1
	Connectivity	1
P6	Beauty / Appearance	2
	Usability / Functionality	-
	Social interaction	-
	Education	-
P7	Food / Energy / Material	-
P8	CO2 Sequestration	-

viii. Literature and further reading

Anderson, B. S., Phillips, B. M., Voorhees, J. P., Siegler, K., & Tjeerdema, R. (2016). Bioswales reduce contaminants associated with toxicity in urban storm water. Environmental toxicology and chemistry, 35(12), 3124-3134. https://doi.org/10.1002/etc.3472.

Bray, B., Gedge, D., Grant, G. & Leuthvilay, L. (2018). Rain garden guide. [PDF]. Retrieved from www.raingardens.info.

Ekka, S. A., Rujner, H., Leonhardt, G., Blecken, G. T., Viklander, M., & Hunt, W. F. (2021). Next generation swale design for stormwater runoff treatment: A comprehensive approach. Journal of Environmental Management, 279, 111756. https://doi.org/10.1016/j.jenvman.2020.111756.

European Commission (EC, n.d.). Individual NWRM swales. Retrieved August 12, 2022 from http://nwrm.eu/sites/default/files/nwrm_ressources/u4-swales.pdf.

Everett, G., Lamond, J. E., Morzillo, A. T., Matsler, A. M., & Chan, F. K. S. (2018). Delivering green streets: An exploration of changing perceptions and behaviours over time around bioswales in Portland, Oregon. Journal of Flood Risk Management, 11, S973-S985. https://doi.org/10.1111/jfr3.12225.

Kazemi, F., Beecham, S., & Gibbs, J. (2011). Streetscape biodiversity and the role of bioretention swales in an Australian urban environment. Landscape and Urban Planning, 101(2), 139-148.

Susdrain. (2020). Component: swales. Retrieved from https://www.susdrain.org/delivering-suds/using-suds/suds-components/swales-and-conveyance-channels/swales.html.

Susdrain. (n.d.). Houndsden road rain gardens, London. Retrieved from https://www.susdrain.org/case-studies/case_studies.html.

Susdrain. (n.d). Queen Mary's walk, Llanelli. Retrieved from https://www.susdrain.org/case-studies/case_studies.html.

United States Department of Agriculture (USDA): Natural Resources Conservation Service. (2005). Bioswales.

13.7.2 Rain garden

Rain garden

i. Basic information

Synonyms	Bioretention area; Biorentention swale						
Type	1	2	3	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation			
Addressed challenges	Climate resilience	Water management	Natural and climate hazards	Biodiversity	Air quality	Public health and well-being	Social justice and cohesion
	X	X	X	X			X
Examples in UNaLab FRC	*Rain gardens on Vestdijk street, Eindhoven NL; Rain garden at Gavoglio barracks, Genova IT*						
Reference to other key studies	*Greening streets, retrofit rain gardens, Nottingham UK;* *Ashby Grove residential retrofit rain garden, London UK;* *Roadside rain gardens, Seattle US*						

ii. General description

A rain garden primarily serves as an area for small-scale water control (storage and infiltration), especially in urban areas. Rain gardens are established in artificial surroundings and catch water runoff from roofs, roads and other sealed surfaces. Storm water runoff is drained into rain gardens, where it is stored for a certain period, and then infiltrates either into the ground soil or flows into the sewage system. A certain amount of water is also taken up and transpired by plants.

Different designs and arrangements of rain gardens are established and a variety of elements are used to create a rain garden such as grass filter strips, water ponds, mulch areas, planting soil, vegetation (e.g. herbaceous plants) and sand beds. Each of these elements has a particular function, for example to slow down, reduce, filter and store water runoff or increase evapotranspiration. Besides their function to store and infiltrate storm water, rain gardens are also aesthetically pleasing and increase amenity value.

Raingardens are not restricted to a certain climate condition and can be found in many European countries. However, the selected components (plants) should be native and well adapted to local climate conditions.

iii. Role of nature

There are several processes in rain gardens (vegetation and soil) that are inspired by nature, including:

- Vegetation and soil layer retains and stores water, water infiltrates into natural soils (soil substance has an influence on infiltration rate)
- Plants and soil are natural filters for organic pollutants, sediments and other substances
- A natural riverbed is mimicked and conveys water
- Plants uptake and transpire water

iv. Technical and design parameters

Rain gardens are private or public small-scale installations. They should be planted with relatively dense, native vegetation that can withstand occasional flooding. A gentle slope positively affects infiltration. Access for regular maintenance, management and inspection is necessary. Rain gardens can also be combined with other water management solutions like permeable paving and rainwater harvesting.

v. Conditions for implementation

The amount of available space, selection of adapted plant species, and maintenance need to be considered for implementation.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

vi.	**Benefits and limitations**	
	Potential Benefits: - Water retention and storage - Water infiltration - Water filtering - Water conveyance - Water evapotranspiration	
vii.	**Performance**	
P1	Transpiration	1
	Shading	-
	Evaporation	1
	Building (Insulation)	-
	Reflection (Albedo)	-
P2	Water conveyance	-
	Water infiltration	1
	Water retention	1
	Water storage	1
	Water reuse	2
P3	Water filtering	1
	Water bio-remediation	1
P4	Deposition	-
	Air biofiltration	-
	Noise reduction	-
P5	Habitat provision	2
	Connectivity	1
P6	Beauty / Appearance	2
	Usability / Functionality	1
	Social interaction	1
	Education	-
P7	Food / Energy / Material	-
P8	CO2 Sequestration	-
viii.	**Literature and further reading**	

Braskerung, B.C. (2015). Raingardens in Norway – the work to introduce SUDS into routine business. [Power Point slides]. Retrieved from http://sgif.org.uk/index.php/docman/events/11-bent-braskerud/file.

Bray, B., Gedge, D., Grant, G. & Leuthvilay, L. (2018). Rain garden guide. [PDF]. Retrieved from https://raingardens.info/wp-content/uploads/2012/07/UKRainGarden-Guide.pdf.

European Commission (EC). (n.d.). Individual NWRM: rain gardens. [Power Point slides]. Retrieved from http://nwrm.eu/sites/default/files/nwrm_ressources/u9_-_rain_gardens.pdf.

Everett, G., Lamond, J. E., Morzillo, A. T., Matsler, A. M., & Chan, F. K. S. (2018). Delivering green streets: An exploration of changing perceptions and behaviours over time around bioswales in Portland, Oregon. Journal of Flood Risk Management, 11, S973-S985. https://doi.org/10.1111/jfr3.12225.

National Association of City Transportaion Officials (NACTO). (2017). Case study: Barton CSO control with roadside rain gardens retrofit, Seattle. Retrieved from https://nacto.org/case-study/barton-cso-control-seattle/.

Sharma, R., & Malaviya, P. (2021). Management of stormwater pollution using green infrastructure: The role of rain gardens. Wiley Interdisciplinary Reviews: Water, 8(2), e1507. https://doi.org/10.1002/wat2.1507.

Shuster, W. D., Darner, R. A., Schifman, L. A., & Herrmann, D. L. (2017). Factors contributing to the hydrologic effectiveness of a rain garden network (Cincinnati OH USA). Infrastructures, 2(3), 11. https://doi.org/10.3390/infrastructures2030011.

Susdrain. (n.d.). Ashby grove residential retrofit rain garden, London. Retrieved from https://www.susdrain.org/casestudies/case_studies/ashby_grove.html.

Susdrain. (2020). Component: rain gardens. Retrieved from https://www.susdrain.org/deliveringsuds/using-suds/suds-components/infiltration/rain-gardens.html.

Susdrain. (n.d.). Greening streets, retrofit rain gardens, Nottingham. Retrieved from https://www.susdrain.org/casestudies/case_studies/greening_streets_retrofit_rain_gardens nottingham.html.

Yuan, J., Dunnett, N., & Stovin, V. (2017). The influence of vegetation on rain garden hydrological performance. Urban Water Journal, 14(10), 1083-1089. https://doi.org/10.1080/1573062X.2017.1363251.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

13.7.3 Infiltration basin

Infiltration basin

Fig. 57: Infiltration basin (source: www.susdrain.org)

Fig. 58: Infiltration basin (source: SuDS Wales; www.sudswales.com)

i. Basic information

Synonyms	Infiltration planter (*see also: chapter 12.7.2 Rain gardens*) ; Infiltration pond; Recharge basin						
Type	1	2	3	<u>action type:</u> 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation			
Addressed challenges	Climate resilience	Water management	Natural and climate hazards	Biodiversity	Air quality	Public health and well-being	Social justice and cohesion
		X	X	X			
Examples in UNaLab FRC	*Infiltration pond at Gavoglio barracks, Genova IT*						
Reference to other key studies	*Queen Mary's Walk, Llanelli UK;* *Leidsche Rijn sustainable urban development, Utrecht NL*						

ii. General description

Infiltration basins are flat, vegetated areas that are usually dry. After heavy rainfall, the water fills up the basin and soaks into the ground. Infiltration basins are usually built with the additional goal to recharge the water table, which differentiates them from retention basins in general. While often planted with grass, additional vegetation types can be integrated into infiltration basins, creating habitats for wildlife thereby supporting biodiversity and improving aesthetic appeal.

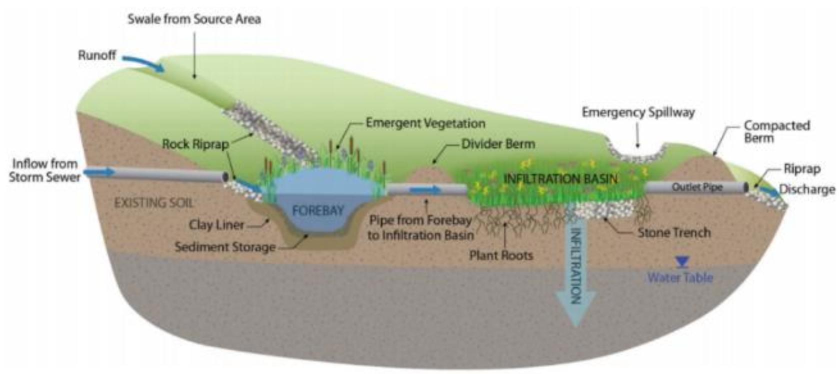


Fig.59: Infiltration basin *(source: provided in: Massachusetts Department of Environmental Protection; geosyntec.com/)*

iii. Role of nature

Filtration of surface water by different soil layers (for example sand).

iv. Technical and design parameters

Infiltration basins are simple to construct. They must be lower than ground level, should be flat, and grass and other vegetation should be taller than 3 inches in order to survive flooding. Infiltration basins should have the capacity to infiltrate 50% of their storage volume within 24 hours of filling.

Some maintenance is required including: removal of litter and debris, grass cutting, and annual removal of sediment from inlets and outlets.

v. Conditions for implementation

Local soil conditions, available space, and highly specific rainwater intensities must be considered when implementing infiltration basins. They can be integrated into personal gardens, public green space, and driveways, but should not be directly connected to aquifers (even if there is a permeable layer in between).

vi. Benefits and limitations

Potential benefits:

- Remove pollution from the rainwater

vii. Performance

P1	Transpiration	-
	Shading	-
	Evaporation	1
	Building (Insulation)	-
	Reflection (Albedo)	-
P2	Water conveyance	-
	Water infiltration	2
	Water retention	1
	Water storage	-
	Water reuse	-
P3	Water filtering	1
	Water bio-remediation	-
P4	Deposition	-
	Air biofiltration	-
	Noise reduction	-
P5	Habitat provision	1

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

	Connectivity	1
P6	Beauty / Appearance	1
	Usability / Functionality	-
	Social interaction	-
	Education	-
P7	Food / Energy / Material	-
P8	CO2 Sequestration	-

viii. Literature and further reading

Bean, E. Z., & Dukes, M. D. (2016). Evaluation of infiltration basin performance on coarse soils. Journal of Hydrologic Engineering, 21(1), 04015050. doi: 10.1061/(ASCE)HE.1943-5584.0001258.

European Commission (n.d). Natural water retention measures: Individual NWRM, infiltration basins. Retrieved August 12, 2022, from http://nwrm.eu/sites/default/files/nwrm_ressources/u12infiltration_basins.pdf.

Natural Water Retention Measures (NWRM). (2015). Leidsche Rijn sustainable urban development, Netherlands. Retrieved from http://nwrm.eu/case-study/leidsche-rijn-sustainable-urban-development-netherlands.

Susdrain (n.d.). Component: infiltration basins. Retrieved from https://www.susdrain.org/deliveringsuds/using-suds/suds-components/infiltration/infiltrationbasin.html.

13.7.4 Permeable paving system

Permeable paving system

Fig.60: Permeable pavement (source: LAND; https://www.landsrl.com/)

Fig. 61: Permeable pavement (source: Eisenberg)

i. Basic information

Synonyms	Permeable pavement; Draining pavements
Type	1 / 2 / **3** — action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation

Addressed challenges	Climate resilience	Water management	Natural and climate hazards	Biodiversity	Air quality	Public health and well-being	Social justice and cohesion
	X	X	X				X

Examples in UNaLab FRC	*Draining pavements at Gavoglio barracks, Genova IT; Sand playground at Gavoglio barracks, Genova IT*
Reference to other key studies	*Westmoreland Pervious Pavers, Portland, OR US*

ii. General description

Permeable paving systems are surfaces that are able to absorb (storm) water, thereby minimizing and delaying surface water runoff, while reducing the amount of some pollutants. After storm events, the water either trickles through the permeable surface itself, or through gaps or funnels between pavers. Water is then temporarily stored in the underlying stone layer and infiltrates into the soil or to an additional drainage layer that conveys water into the sewage system (subsurface drain). They are commonly installed in parking lots, residential streets, and sidewalks. There are many different systems of permeable pavements. For example, porous asphalt and permeable concrete improves infiltration of homogeneous surfaces. Other solutions such as vegetated grid pavers increase the share of substrate or vegetation cover for better infiltration and allow for water uptake by plants. Solutions such as permeable stone carpets provide macropores for gravity driven percolation.

iii. Role of nature

Permeable paving systems imitate the permeability and drainage effect of natural soils. Soil permeability depends on soil type and degree of water saturation, which affects infiltration potential. Soil with large pores absorbs more water compared to sealed surfaces, and filling material between bricks enables a high level of water infiltration.

iv. Technical and design parameters

Technical and design parameters are dependant upon the specific implemented solution. For example, permeable pavers have a relatively simple construction consisting of a single layer of

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

bricks, followed by an underlying gravel layer, a drainage layer, and filling material that consists of gravel or sand. While technical and design parameters differ among permeable paving systems, all require regular maintenance.

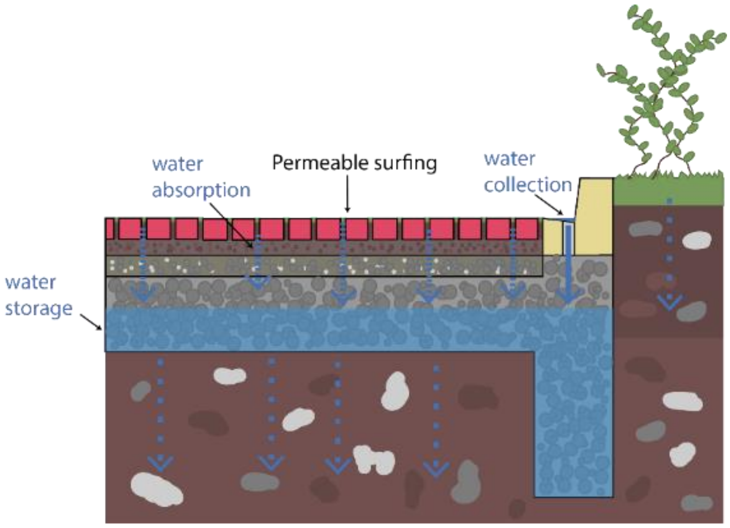


Fig.62: Permeable pavers functions *(source: ILPOE 2019)*

v.	**Conditions for implementation**
	Permeable pavements can be implemented on new or previously existing building sites. Prior analysis of the soil is necessary, and compatibility with all kinds of street usage should be considered.
vi.	**Benefits and limitations**
	Potential benefits: - Water quality protection - Storm water management - Reduced surface runoff - Controlled infiltration - Temporary water storage - Water filtering *Potential limitations /disservices* - Limited load on paved area
vii.	**Performance**

P1	Transpiration	1
	Shading	-
	Evaporation	1
	Building (Insulation)	-
	Reflection (Albedo)	1
P2	Water conveyance	-
	Water infiltration	1
	Water retention	1
	Water storage	-
	Water reuse	-
P3	Water filtering	1
	Water bio-remediation	-
P4	Deposition	-
	Air biofiltration	-
	Noise reduction	-
P5	Habitat provision	-

	Connectivity	-
P6	Beauty / Appearance	-
	Usability / Functionality	1
	Social interaction	1
	Education	-
P7	Food / Energy / Material	-
P8	CO2 Sequestration	-

viii. Literature and further reading

City of Portland. (n.d.). Environmental services: pervious pavement projects. Retrieved from https://www.portlandoregon.gov/bes/article/77074.

City of Portland. (n.d.) Westmoreland pervious pavers, Portland, Oregon: project summary. [PDF]. Retrieved from https://www.portlandoregon.gov/shared/cfm/image.cfm?id=174662.

Eisenberg, B., Lindow, K. C., & Smith, D. R. (Eds.). (2015, March). Permeable pavements. American Society of Civil Engineers.

Hein, D. K., & Eng, P. (2014). Permeable pavement design and construction case studies in North America. In Transportation 2014: Past, Present, Future-2014 Conference and Exhibition of the Transportation Association of Canada//Transport 2014: Du passé vers l'avenir-2014 Congrès et Exposition de'Association des transports du Canada.

Future-2014 Conference and Exhibition of the Transportation Association of Canada//Transport 2014: Du passé vers l'avenir-2014 Congrès et Exposition de'Association des transports du Canada.

Kuruppu, U., Rahman, A., & Rahman, M. A. (2019). Permeable pavement as a stormwater best management practice: A review and discussion. Environmental Earth Sciences, 78(10), 1-20. https://doi.org/10.1007/s12665-019-8312-2.

Sambito, M., Severino, A., Freni, G., & Neduzha, L. (2021). A systematic review of the hydrological, environmental and durability performance of permeable pavement systems. Sustainability, 13(8), 4509. https://doi.org/10.3390/su13084509.

Tip of the Mit Watershed Council. (2019). Permeable Pavers. Retrieved from https://www.watershedcouncil.org/permeable-pavers.html.

Watershed Council (2019). Permeable Pavers. Retrieved from https://web.archive.org/web/20220812161536/https://www.watershedcouncil.org/permeable-pavers.html.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

13.7.5 Biofilter (water purification)

Biofilter (water purification)

Fig.63: Biofilter (source: Monash University; https://www.monash.edu)

i. Basic information

Synonyms							
Type	1	2	3	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation			
Addressed challenges	Climate resilience	Water management	Natural and climate hazards	Biodiversity	Air quality	Public health and well-being	Social justice and cohesion
		X	X	X		X	
Examples in UNaLab FRC	*Biofilter in Virolainen Park in Vuores, Tampere FI;* *Biofilter for seepage waters in Hiedanranta, Tampere FI*						
Reference to other key studies	*Biofilter at Clayton Campus of Monash University, Melbourne AU*						

ii. General description

Water biofilters are developed to collect and purify storm- and wastewater and represent a promising system for storm water treatment. Bacteria and microorganisms are located on a filter medium (biofilm), which often consists of sand or granular activated carbon. The biofilm degrades nutrients and contaminats in the wastewater (influent) that is pumped through the filter material. The term “filter,” however, can be misleading. Biofilters separate/remove nutrients and organic carbons from waste- and stormwater through biodegradation. As a result biofiltration improves the quality of wastewater (reduction of nutrients, metals, sediments) and storm water, while harvesting storm water and storing it for a certain period.

iii. Role of nature

Biodegradation is a natural process e.g. in soils. This natural degradation is used for different processes, for example in anaerobic digestion (biogas production). Microorganisms and bacteria degrades/removes/ nutrients and contaminations and biological substances.

iv. Technical and design parameters

In biofilters, water is stored in an ornamental pond, and water runoff is reused after treatment. Below a vegetation layer, different layers of soil media are continuously saturated with water to maintain anaerobic conditions.

In general, biofilters improve the removal of difficult pollutants such as nitrate, and can be integrated into any bioretention facility. Examples show that biofilters can remove a large amount of nitrogen, phosphorus and heavy metals.

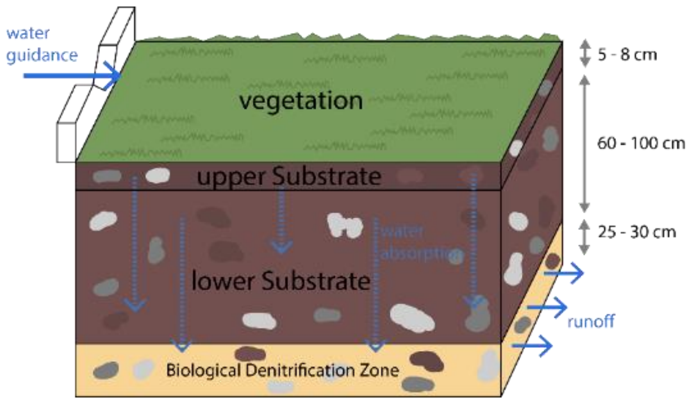


Fig. 64: Innovative bioretention process (ILPOE 2019)

v.	**Conditions for implementation**	
	Adequate space for construction and flat terrain are needed.	
vi.	**Benefits and limitations**	
	Potential benefits: - Water purification - Improving quantity of storm- and wastewater - Storm water regulation/management - Quality of live (reduction of odours) - Habitat for wildlife (yet limited service)	
vii.	**Performance**	
P1	Transpiration	-
	Shading	-
	Evaporation	-
	Building (Insulation)	-
	Reflection (Albedo)	-
P2	Water conveyance	1
	Water infiltration	2
	Water retention	1
	Water storage	2
	Water reuse	1
P3	Water filtering	2
	Water bio-remediation	2
P4	Deposition	-
	Air biofiltration	-
	Noise reduction	-
P5	Habitat provision	1
	Connectivity	-
P6	Beauty / Appearance	1
	Usability / Functionality	-
	Social interaction	-
	Education	-
P7	Food / Energy / Material	-
P8	CO2 Sequestration	-
viii.	**Literature and further reading**	

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052
Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Deletic, A., McCarthy, D., Chandrasena, G., Li, Y., Hatt, B., Payne, E., ... & Meng, Z. (2014). Biofilters and wetlands for stormwater treatment and harvesting. Cooperative Research Centre for Water Sensitive Cities, Monash University, Melbourne, 67.

Feng, W., Hatt, B. E., McCarthy, D. T., Fletcher, T. D., & Deletic, A. (2012). Biofilters for stormwater harvesting: Understanding the treatment performance of key metals that pose a risk for water use. Environmental science & technology, 46(9), 5100-5108.

Hatt, B. E., Fletcher, T. D., & Deletic, A. (2009). Pollutant removal performance of field-scale stormwater biofiltration systems. Water science and technology, 59(8), 1567-1576.

Payne, E. G. I., Pham, T., Cook, P., Fletcher, T., Hatt, B. E., & Deletic, A. (2014). Biofilter design for effective nitrogen removal from stormwater - influence of plant species, inflow hydrology and use of a saturatedzone. Water Science and Technology, 69(6), 1312 - 1319.

Shen, P., Deletic, A., Urich, C., Chandrasena, G. I., & McCarthy, D. T. (2018). Stormwater biofilter treatment model for faecal microorganisms. Science of the Total Environment, 630, 992-1002.

[i] McMichael, 2014. *Int J Health Policy Manag* 2:9; Mills et al. 2017. *Restor Ecol* 25:866; Siri, 2016. *Public Health Rev* 37:22.

Next stand-alone document

Nature-Based Solutions Implementation Handbook: A Summary for Practitioners




UNaLab
URBAN NATURE LABS

Nature-Based Solutions Implementation Handbook: A Summary for Practitioners

Authors

Maria Dubovik Ville Rinta-Hiiro Malin zu Castell-Rüdenhausen Laura Wendling Arto Laikari Johannes Jermakka Zarrin Fatima	*VTT Technical Research Centre of Finland*
Kristen Jakstis Leonie K. Fischer	*University of Stuttgart*
Piersaverio Spinnato	*Engineering Ingegneria Informatica*
Ana Ascenso Ana Isabel Miranda Peter Roebeling Ricardo Martins Rita Mendonça	*University of Aveiro*
Silvia Vela Margherita Cioffi Sara Botto Eleonora Gambucci	*RINA Consulting*
Sophie Mok	*Fraunhofer Institute for Industrial Engineering*

About UNaLab

The UNaLab project is contributing to the development of smarter, more inclusive, more resilient and more sustainable urban communities through the implementation of nature-based solutions (NBS) co-created with and for local stakeholders and citizens. Each of the UNaLab project's three Front-Runner Cities – Eindhoven (NL), Genova (IT) and Tampere (FI) – has a strong commitment to smart, citizen-driven solutions for sustainable urban development. The establishment of Urban Living Lab (ULL) innovation spaces in Eindhoven, Genova and Tampere supports on-going co-creation, demonstration, experimentation and evaluation of a range of different NBS targeting climate change mitigation and adaptation along with the sustainable management of water resources. The Front-Runner Cities actively promote knowledge- and capacity-building in the use of NBS to enhance urban climate and water resilience within a network of committed partner cities, including seven Follower Cities – Stavanger, Prague, Castellón, Cannes, Başakşehir, Hong Kong and Buenos Aires – and the Observers, Guangzhou and the Brazilian Network of Smart Cities. Collaborative knowledge production among this wide network of cities enables UNaLab project results to reflect diverse urban socio-economic realities, along with differences in the size and density of urban populations, local ecosystem characteristics and climate conditions. Evidence of NBS effectiveness to combat the negative impacts of climate change and urbanisation will be captured through a comprehensive monitoring and impact assessment framework. Further replication and up-scaling of NBS is supported by development of an ULL model and associated tools tailored to the co-creation of NBS to address climate- and water-related challenges, a range of applicable business and financing models, as well as governance-related structures and processes to support NBS uptake. The results of the project will be a robust evidence base and go-to-market environment for innovative, replicable, and locally-attuned NBS.

Partners

Table of Contents

1. NATURE-BASED SOLUTIONS FOR URBAN CHALLENGES

Nature-based solutions (NBS) have emerged as an umbrella concept that encompass and build upon previous concepts that aimed at actions for enhancing climate change adaptation (CCA) and disaster risk reduction (DRR). These concepts include but are not limited to Ecosystem-based Adaptation (EbA), low-impact development (LID) and sustainable urban drainage systems (SUDS), ecological engineering, green infrastructure and ecosystem services. The distinguishing feature of NBS is simultaneously providing economic, social and environmental benefits and co-benefits. Many definitions of the NBS concept have been developed over the years, including those by IUCN and European Commission and the latest definition by the UN.

> *"… actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits." - Fifth Session of the United Nations Environment Assembly (UNEA-5)*

The lifecycle of an NBS project comprises six equally important steps or phases (Figure 1). The lifecycle begins with a framework identification phase, which will be adopted first in the project, and which will drive the implementation of the next actions. The following phases of identifying the relevant NBS given the identified urban pressures and challenges and the key performance indicators (KPIs), and developing a monitoring scheme to capture the change from the baseline conditions – are crucial for evaluating the NBS performance and impact. Once the monitoring scheme is defined and monitoring equipment is tendered, a prolonged period of NBS monitoring begins. The monitoring outputs are continuously reviewed to assess NBS performance and impact, and to ensure the soundness of the equipment and the methods of data acquisition. Ideally, NBS monitoring should span several years for critical evaluation of NBS performance and impact to support future development proposals. Several phases of the NBS project lifecycle directly contribute to the NBS Knowledge Base, which can be perceived as a collection of good practices regarding NBS implementation across the EU Member States.

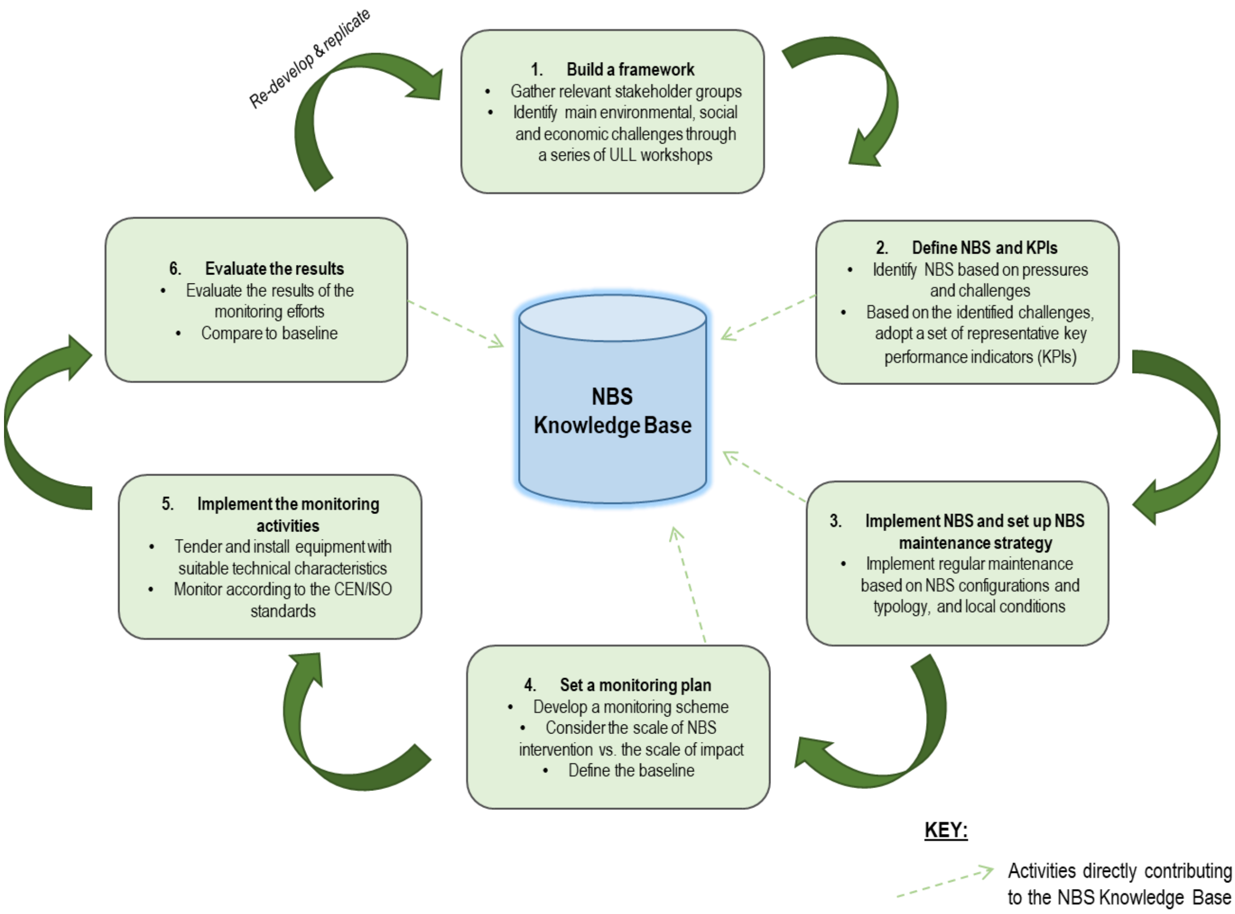


Figure 1. Lifecycle of an NBS project.

This publication presents a high-level summary of the highly detailed *Nature-Based Solutions Implementation Handbook*. The handbook aims to provide the key messages and outcomes of the NBS implementation process generated within the UNaLab project from co-identification of challenges and NBS co-creation via co-monitoring to co-maintenance and evaluating the impacts of NBS interventions. The knowledge and resources developed throughout the UNaLab project aim to serve as a reference for the NBS practitioners and other involved parties in developing, executing and evaluating the NBS projects in different socio-economic and climatic contexts.

2. Nature-based solutions in the policy context and global agenda

NBS are essential elements in some of the major European and global policies and strategies that shape and direct the actions at building the structural, environmental and social resilience (Figure 2). European policies and the current development agenda generally support the implementation and uptake of NBS, and some directly mention NBS as means for achieving certain goals. International policies may not directly mention NBS but they all focus on CCA and DRR which is inherent to all NBS activities.

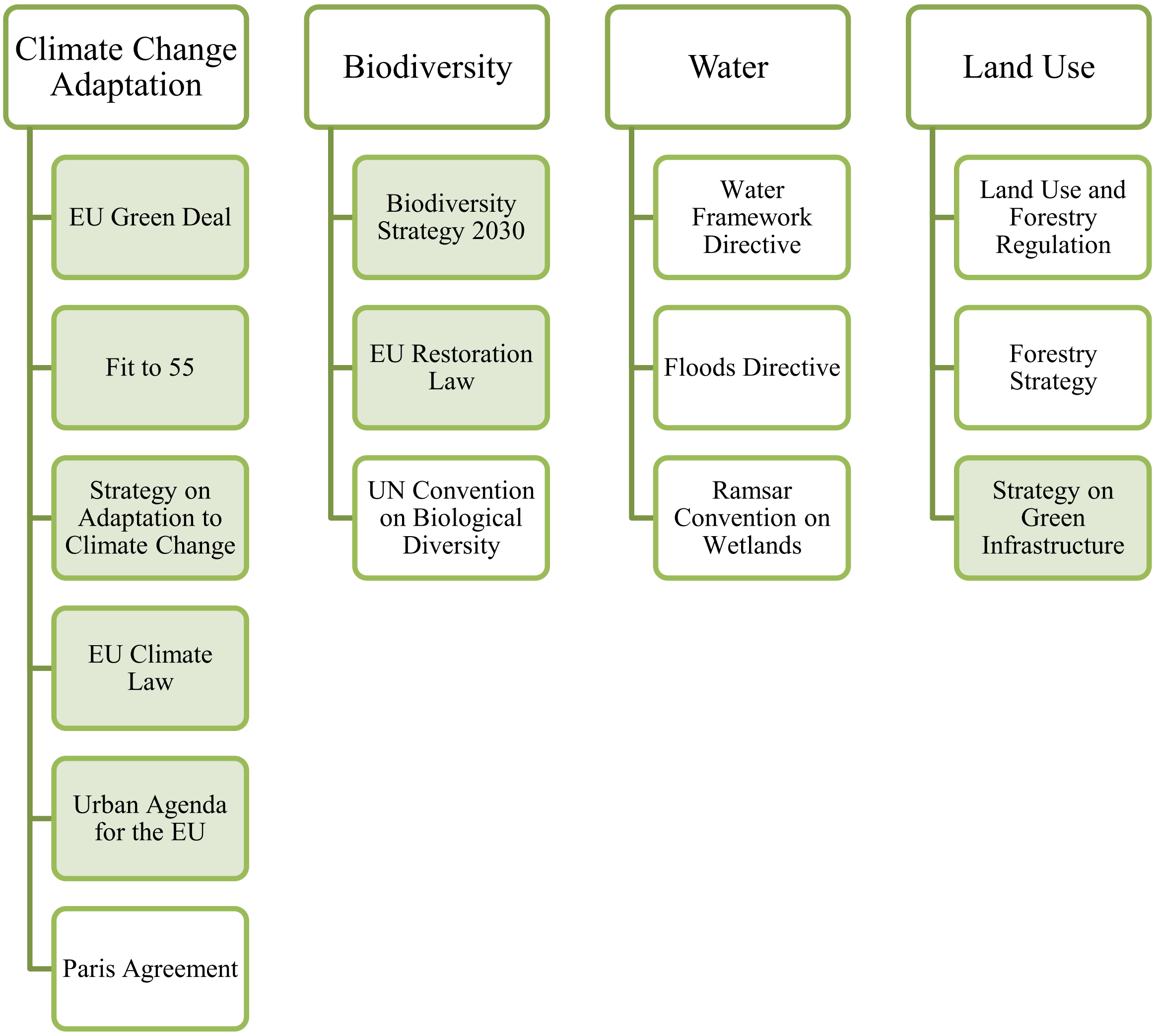


Figure 2. NBS in the European and international policy agenda. Green boxes highlight policy instruments that explicitly mention NBS.

The International Union for the Conservation of Nature (IUCN) recently released standards for the design and assessment of NBS in order to support mainstreaming of nature conservation and consistency of NBS application (IUCN, 2020). Whilst the IUCN standard lacks definitive thresholds, it provides a systematic framework to support consistency in NBS design and assessment based on solutions-oriented outcomes. The eight criteria and sub-indicators that comprise the standard framework for NBS design and assessment defined by the IUCN (2020) can be directly linked to specific quantitative indicators and methods of evaluation previously identified by the UNaLab project and/or the IEF Taskforce.

3. NATURE-BASED SOLUTIONS INITIATION AND CO-CREATION

NBS as socio-ecological-technological innovations are characterised by multiple uncertainties and require a participatory approach to account for them. Co-creation process requires supportive environments where experimentation and learning are part of the development process and where different stakeholders can safely engage and actively participate in a dialogue. Innovative solutions spring from the outcomes of complex co-creation process involving knowledge flows among all actors involved across the entire economic and social environment. Industry, academia, public authorities and citizens are part of the Quadruple Helix (Figure 3), where users are placed at the heart of the innovation ecosystem. The Urban Living Lab (ULL) approach provides a safe environment for providing stakeholders with opportunities to express their ideas and preferences and iterate the solutions.

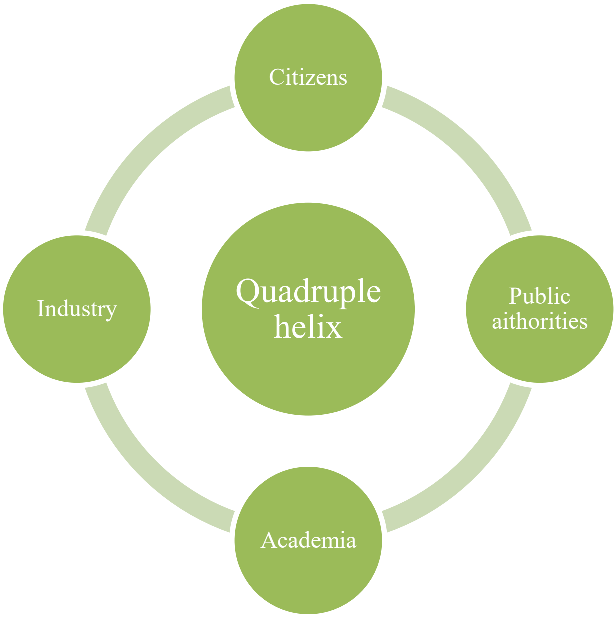


Figure 3. Quadruple helix approach to co-creating NBS innovations.

Within the UNaLab project, a series of Urban Living Lab (ULL) NBS co-creation workshops were organised in the UNaLab front-runner cities. The UNaLab front-runner cities are geographically widespread, representing diverse climates and cultures and having organisational differences. This resulted in different approaches by UNaLab front-runner cities to their co-creation workshops, evidenced by a mix of selected techniques, participants and results. Yet, because the co-creation process was coordinated through the UNaLab project, the execution and goals of the workshops were similar. The first workshops aimed at familiarising participants with the subject, UNaLab project methodologies and aims, and sharing views. In the second step, workshop participants mainly focused on creating NBS solutions to be implemented in the UNaLab project sites, and these were then evaluated in each of the third and final workshops.

Engagement through multiple channels

- Online & F2F meetings and workshops
- Training & DIY sessions
- Peer learning through webinars & open days
- Public events
- Partnerships with schools and universities

Each UNaLab FRC selected either the European Awareness Scenario Workshops (EASW) method or the Design Thinking method for use in their respective ULL co-creation workshops. The steps followed by each of these methods are similar, as are the stakeholders that can be involved. In both methods, the groups get together to understand a problem, find solutions, and test them. The stakeholders that can be engaged in both cases are policy makers, technical experts, entrepreneurs/businesspeople, local citizens and designers.

Naturally, co-creation has its tangible outcomes. However, it is beneficial to evaluate and quantify its impacts on a variety of topics, including enabling participatory decision-making, inclusivity, social cohesion and justice, and gender dimension, to deeper explore the NBS impact on the social domain and the co-creation process, which is a critical part of the successful implementation of effective NBS. Co-creation is evaluated using the process-based indicators, which assess the efficiency, quality, or consistency of specific actions employed to achieve the goals. For evaluating the success of co-creation process, it is necessary to establish a pre-co-creation baseline capturing the degree of stakeholder involvement or other relevant aspects.

Two workshops involving representatives from the front-runner and follower cities, and a follow-up open-ended questionnaire aimed at refining the ULL concept based on the combined experience of the UNaLab front-runner cities. The resulting ULL Framework is based on theories and practices for Living Labs, Action Design Research, methods for co-creation and data from workshops with the front-runner cities.

The key components include the *governance and management structure* as the basis for the strategic and operational management and organisation of the ULL, which requires support from the local governments and decision-makers. The governance component is followed by *financing and business models* that create and deliver value for the ULL stakeholders and that are essential for running the ULL, including the vision and scope, risk management and dissemination. Business models determine who will finance the ULL activities and whether the commitment will be supported in the long term. The *urban context* defines a physical setting, in which NBS will be implemented (street, neighbourhood, or city). The physical setting should be considered in terms of ownership and responsibility, existing infrastructure and future development plans. The *Nature-based solutions* component should be innovative and address local challenges and pressures; here, the (co-)created NBS aims and values should be clearly identified. The innovation component is followed by the partners and users, or *key stakeholders*, adopting the Quadruple Helix approach. This approach uses the innovation and collaboration model of Triple Helix (academia–authorities–industry) whilst adding a fourth pillar – a citizen perspective, which leads to more transparent and end-user-friendly innovations. The *methods* and the *ICT infrastructure* components relate to the various data collection, analysis and tool to support and engage stakeholders in the ULL activities.

The best tips to engage people in the ULL workshops

- ✓ Citizen participation must be voluntary
- ✓ Adjust the length of the talks in the workshops, especially for children
- ✓ Connect the workshop to an existing (popular) event
- ✓ Go on walking tours
- ✓ Give detailed information in the invitation
- ✓ Work with maps
- ✓ Various communication channels are required
- ✓ If participants show hesitation about their presence, discuss this in the group
- ✓ Responsible people from the city should take part directly
- ✓ Beyond the workshops, involve the participants in site activities, managed and supported by planners and technicians
- ✓ Native language will facilitate the true engagement

4. NATURE-BASED SOLUTIONS GOVERNANCE AND FINANCING OPTIONS

Next to the potential of nature-based solutions to directly contribute to increased climate resilience in cities, their multifunctional nature can also provide a wide range of social, environmental and economic co-benefits. Whilst this diversity of benefits and the context-specificity of NBS performance make it difficult to capture and communicate the overall value, they also hold a great potential for engaging more urban stakeholders in the planning, implementation and financing of such solutions.

Behind this background, the UNaLab Value Model seeks to explore the multiple and often intangible values of NBS and enable a structured navigation through the complex issue of NBS valuation. The underlying assumptions are that the different technical functions of NBS (as outlined in the *NBS Technical Handbook*) can be translated into individual benefits of different urban stakeholders. Based on a given urban context and the actual type and performance of the NBS, different beneficiary structures will emerge. If the individual benefits are well communicated to those, their willingness to invest could be enhanced, opening the way to alternative co-investment and financing options. In *UNaLab Value Model* (Mok et al., 2019), these relationships and the underlying logic are further highlighted and explored. Additionally, it describes a potential clustering of different benefit types and discusses their value capture potential. For different types of NBS, it provides an overview of potential 'usual suspect beneficiaries' and hints at available evaluation tools for further value assessment. Figure 4 summarizes different financing options in relation to private, public and civil society actors.

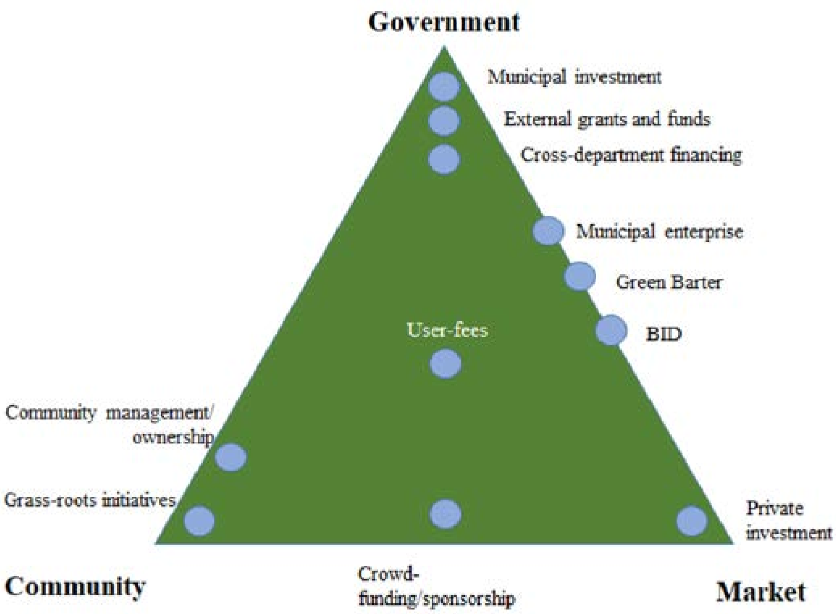


Figure 4. Financing options for NBS.

Traditionally, governance has been approached as a top-down process, where managing urban challenges was administered by the public authorities. The modern cities face the transformation by involving other stakeholders, such as citizens, companies and other actors, in the urban development. A combined effort of the emerging city actors can target topics such as climate change adaptation and sustainable urban development. Although viable in their nature, these actor networks require certain rules to steer the ways city actors can act to change governance structures to better facilitate the uptake of NBS. The four key areas, or themes, considered include (1) cross-departmental communication and cooperation, (2) policies, (3) financing and procurement and (4) data governance.

The governance examination in UNaLab front-runner cities consisted of three parts:

(i) Municipal governance survey to identify the central governance-related challenges and conduct a preliminary assessment of potential key research points according to the four themes
(ii) High-level workshops to elaborate on the identified challenges and develop potential solutions for the four key themes on a more general level, and
(iii) Development and application of the assessment framework

The NBS development and uptake require a mix of policy instruments, both command and control mechanisms (e.g., binding regulations) and market-based instruments (e.g., tax incentives), which are also reflected in the planning tools and mechanisms to enhance the visibility of targets. Integration of policies from a variety of sectors (e.g., water, construction) was deemed beneficial to promote interdisciplinarity of NBS. The policy instruments may further prove a valuable asset for attracting private engagement and local business owners to develop and invest in NBS. Three enablers identified for the NBS-supportive policies included simple access to existing policies, good communication and stakeholder involvement, which also enables feedback mechanisms.

On data governance

The amount of data generated throughout the duration of the NBS implementation process, including co-creation, co-implementation, co-management, and monitoring of NBS performance and impact, is vast. Storage, management, ownership and access are among the critical issues for governing data at a municipal scale. To ensure the smooth management of data, municipalities should define a data management plan during the initial stages of NBS implementation.

5. NATURE-BASED SOLUTIONS CO-MONITORING AND IMPACT ASSESSMENT

In times of rapid urbanization and anthropogenic climate change, urban areas face an increasing number of extreme weather events and other environmental burdens such as water and air pollution. NBS are associated with distinct impacts on ecosystem services and improvement of a range of environmental aspects hindered by urban growth. However, a selection of NBS to address the identified challenges and pressures should demonstrate its impact and indicate whether the anticipated outcomes are achieved, including monetary and environmental targets, to consolidate the future investments into wider NBS implementation. Monitoring is one of the central factors determining the success of the NBS impact assessment as it provides quantitative and qualitative evidence of the impact generated by the NBS interventions (Figure 5).

NBS monitoring involves a collection of measurements used for assessing the state of environment and subsequently the change that signifies either its degradation or restoration. Prior to monitoring, goals and data analysis methods must be well defined to ensure accurate monitoring and understanding of physical, chemical and biological variables and processes occurring in the studied environment.

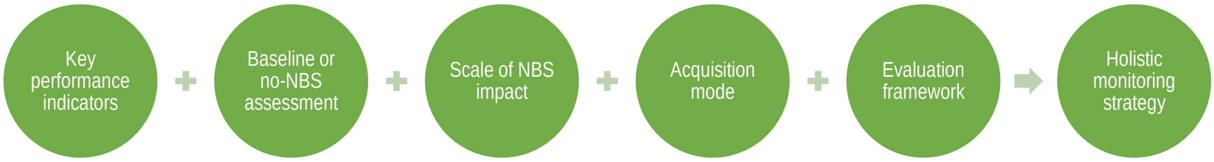


Figure 5. A 'recipe' for a successful monitoring strategy.

Co-definition of **NBS performance and impact indicators** can be viewed as an intermediate step between setting the goals and targets and formulating a sound plan for NBS monitoring (Figure 6). The first and foremost requirement for the NBS performance and impact indicators is to reflect the targets and objectives set in the beginning of NBS co-creation process.

Monitoring and impact assessment are supported by NBS performance and impact indicators over the biophysical, socio-economic and sustainability domains, which target the evaluation and, whenever possible, quantification of NBS effectiveness. They can be divided into three basic classes:

- **Structural indicators (S)** – refer to all the factors that affect the context in which NBS are implemented. This typically includes the supporting infrastructures and resources in place to achieve the desired goals (e.g., physical facilities, equipment, human resources, organisational characteristics, policies and procedures).
- **Process indicators (P)** – refer to the actions that are involved in NBS co-creation, co-implementation and co-management. These indicators are used to assess the efficiency, quality, or consistency of specific procedures employed to achieve the desired goals as well as the impacts of co-creation.
- **Outcome indicators (O)** – refer to all the effects of NBS. These include social, environmental and economic effects or impacts. Outcome-based indicators comprise the greatest proportion of all indicators.

There are numerous NBS performance and impact indicators, and selecting them can be challenging for an inexperienced person. The Task Force 2 handbook *Evaluating the Impact of*

Nature-based Solutions: A Handbook for Practitioners (Dumitru & Wendling, 2021a) and its *Appendix of Methods* (Dumitru & Wendling, 2021b) alone collects more than 400 recommended and additional indicators over 12 key societal challenge areas:

1. Climate Resilience
2. Water Management
3. Natural and Climate Hazards
4. Green Space Management
5. Biodiversity Enhancement
6. Air Quality
7. Place Regeneration
8. Knowledge and Social Capacity Building for Sustainable Urban Transformation
9. Participatory Planning and Governance
10. Social Justice and Social Cohesion
11. Health and Wellbeing
12. New Economic Opportunities and Green Jobs

Indicators of NBS performance and impact should be selected to reflect both primary benefits as well as any associated co-benefits.

It is equally important to **establish baseline** (pre-NBS) measurements for understanding the reference conditions and quantifying the actual impact, i.e., the change, further refining the NBS design Ideally, the baseline measurements should be ongoing prior to NBS implementation. Nevertheless, in cases, when the baseline measurements are not available from the area of interest, a similar reference area without NBS can be employed as a "baseline".

On data outputs

Granularity is different from *accuracy*, the degree of correctness of the outputs with respect to the true value, and from *precision*, the accuracy when the observations are repeated.

Instead, *resolution* is a specification of *granularity*, and it indicates the size of the minimum unit/area in a data output (e.g., spatial data).

Once the monitoring scheme is defined and set, establishing the **appropriate data acquisition** means will ensure careful data collection at relevant scales. A number of data acquisition options exist that could be employed for NBS performance and impact monitoring. In this Handbook, they are presented as the broad major categories comprising remote sensing and earth observations, ground (*in situ*) observations, statistical and legacy datasets, and citizen science. These monitoring means produce reliable quantitative and/or qualitative data only when applied at appropriate scales and periods of time.

On monitoring scales

The choice of scale and resolution/granularity is subjective and is typically informed by prior experience, but they should not be selected arbitrarily or haphazardly (Scholes *et al.*, 2013). Careful considerations for the suitability of scales and their interactions will produce the most reliable outcomes.

Considerations of the **scale of NBS monitoring** and the **frequency** of recorded intervals are of outmost importance due to their effect on the quality of monitoring efforts. Ranges of scales at which KPIs can be observed and quantified vary substantially, and usually the overall visibility of impacts associated with certain NBS are scale sensitive.

6. NATURE-BASED SOLUTIONS IMPACT ASSESSMENT

NBS impact assessment is the essential step when targets and objectives are evaluated against the measured performance during the NBS monitoring stages (Figure 6). Impact assessment identifies causalities and aids in determining the supporting or additional interventions necessary for achieving the goals. This makes the NBS implementation process cyclical enabling the adaptive management cycle of every NBS project.

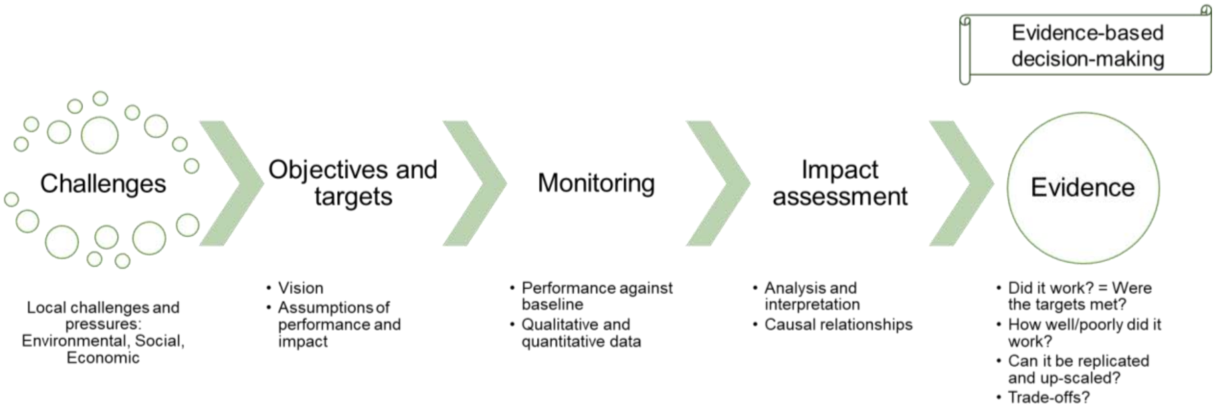


Figure 6. From challenges to evidence: setting targets and aligning monitoring activities to generate evidence of NBS performance and impact leading to evidence-based decision-making.

The UNaLab project used a highly participatory approach to produce evidence of NBS impact, including co-creation, co-development, and co-monitoring activities. In the NBS impact assessment process in the UNaLab front-runner cities first involved co-definition of NBS performance and impact indicators in an interactive way with a wide range of local stakeholders. After co-definition of indicators, the UNaLab front-runner cities iteratively co-developed the monitoring and evaluation strategies together with project partners and other technical experts to assess NBS performance and associated impacts in a cost-effective way.

The UNaLab approach to co-development of the monitoring strategy relied on a diverse group of participants, in terms of cultural and educational background and needs. Deep stakeholder engagement was important for identifying the local challenges and monitoring and evaluation needs and capabilities. The selection of suitable performance and impact indicators and identification of the monitoring needs were facilitated through engagement of a wide range of experts during NBS monitoring and impact assessment planning.

NBS impact assessment in UNaLab was facilitated by the development of an ICT platform and other NBS monitoring and evaluation tools developed by UNaLab project partners. Automated collection of NBS monitoring data from IoT sensors complemented by manual entries supports long-term NBS monitoring and impact evaluation.

7. NATURE-BASED SOLUTIONS CO-MAINTENANCE

As NBS remain to be a relatively new concept, there is an existing need for support and encouragement for the implementation of NBS. To date, knowledge gaps in NBS implementation and maintenance of different types of NBS still exist. This is especially true with respect to the costs of NBS maintenance. This and other knowledge gaps in the maintenance might be one of the barriers for the larger scale of NBS implementation.

Maintenance of NBS should be considered throughout the lifecycle of NBS. Maintenance should ideally be involved already in the planning process of NBS. Needs for maintenance might even affect the decisions whether the NBS should be implemented and which type of the NBS should be chosen. Usually, NBS do not have high maintenance needs. However, some NBS require a lot of maintenance for them to work properly. In each case, sufficient maintenance is desirable to enable proper functioning and long lifetime of NBS which is why long-term maintenance strategy should be created for each NBS. Naturally, some NBS require constant and extensive maintenance action whereas some NBS only need minimal maintenance. However, it should be noted that all types of NBS require regular maintenance.

Maintenance needs for NBS, including costs, are often smaller than they are for grey infrastructure solutions. Due to some lack of knowledge and missing technology in the NBS maintenance, there is a lot of potential to develop the technology (digitalisation and smart technologies) and methods for maintenance activities. This could potentially create more cost-effective solutions for the NBS maintenance.

NBS maintenance activities (Table 1) can have participatory and well-being aspects. For example, property owners can maintain vegetation and other green solutions around their houses. These kinds of activities can increase social interaction among the residents which can have positive impacts on the property maintenance in general and increase the flow of information. Increased social interaction and activities done outside can also have positive impacts on mental and physical well-being. In addition, proper maintenance can potentially impact positively on the property values.

Costs of the NBS operation and maintenance should be estimated for the whole lifecycle of NBS. The cost estimation should be done in the early phases of NBS design and the cost estimation should be updated when more data and knowledge are available, during design, construction, and operation of NBS. Update of the cost estimation is important due to the difficulty in estimating the accurate costs of many NBS during the design phase. However, some data and knowledge gathered from experiences in NBS maintenance exist, which can help in estimating the costs before the NBS implementation. This information could be received for example from designers or maintenance companies. Some publicly available data and guidelines already exist but it should be noted that there are many things affecting the maintenance costs and the initial cost estimations may differ from the realised costs.

Table 1. Typical maintenance activities of different NBS (modified from Woods Ballard et al. 2015).

	Green roof	Rain garden	Daylighted river	Bioswale	Trees	Residential park	Vertical greening	Infiltration basin	Permeable pavements	Wetland	Biofilter
Regular maintenance											
Inspection	x	x	x	x	x	x	x	x	x	x	x
Litter and debris removal	(x)	x	x	x	x	x	x	x	x	x	x
Grass cutting	(x)	x	(x)	x	(x)	x	--	x	(x)	x	(x)
Weed and invasive plant control	x	x	x	x	x	x	x	(x)	(x)	(x)	(x)
Shrub management	-	(x)	(x)	(x)	(x)	(x)	-	(x)	(x)	(x)	(x)
Shoreline vegetation management	-	-	x	-	-	(x)	-	-	-	x	(x)
Aquatic vegetation management	-	-	x	-	-	(x)	-	-	-	x	(x)
Vacuum sweeping and brushing	-	-	-	-	-	-	-	-	x	-	-
Checking mechanical devices	(x)	-	(x)	-	-	(x)	(x)	(x)	-	(x)	(x)
Irregular/occasional maintenance											
Sediment management	-	x	(x)	x	x	(x)	-	x	x	x	x
Vegetation replacement	x	(x)	(x)	(x)	(x)	(x)	(x)	(x)	-	(x)	(x)
Repairing maintenance											
Structure rehabilitation/repair	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)
Infiltration surface reconditioning	-	(x)	-	(x)	(x)	(x)	-	(x)	(x)	-	(x)
Erosion damage control	(x)	x	(x)	x	(x)	(x)	-	x	-	(x)	(x)

Key:
x denotes “Required maintenance action”
(x) denotes “Possible maintenance action”
- denotes “Usually not needed”

Maintenance costs are dependent on the NBS type and size and are usually higher during the first years after construction or installation of maintenance. In most cases, smaller NBS require less maintenance work and budget for the maintenance works. There are also some specific cases that can increase the costs compared to standard NBS structures, for example special equipment used, challenging access of NBS or contaminated sediments that need processing after their removal. Besides functional requirements of NBS, also aesthetic requirements of NBS play a role in maintenance costs as more strict requirements (e.g., more frequent maintenance work) need greater maintenance budget.

8. FURTHER READING AND RESOURCES

Primary reference for this summary

Dubovik, M., Rinta-Hiiro, V., zu Castell-Rüdenhausen, M., Wendling, L., Laikari, A., Jakstis, K., Fischer, L. K., Spinnato, P., Jermakka, J., Fatima, Z., Ascenso, A., Miranda, A. I., Roebeling, P., Martins, R., Mendonça, R., Vela, S., Cioffi, M., Mok, S., Botto, S., & Gambucci, E. (2022). *Nature-Based Solutions Implementation Handbook*. Urban Nature Labs (UNaLab) Deliverable D5.5.

Co-creation and NBS selection

Habibipour, A. & Ståhlbröst, A. (2020). *UNaLab Living Lab Handbook*. Urban Nature Labs (UNaLab) Deliverable D2.4.

Habibipour, A., Ståhlbröst, A., Zalokar, S. & Vaittinen, I. (2020). *Living Lab Handbook for Urban Living Labs Developing Nature-Based Solutions*. Urban Nature Labs (UNaLab) project.

Fischer, L., Jakstis, K., Eisenberg, B. & Polcher, V. (2022). *Nature-Based Solutions Technical Handbook.*

Laikari, A., Dubovik, M., Rinta-Hiiro, V., Wendling, L., Postmes, L., van Dinter, M., den Hollander, M., van der Putten, P., Särkilahti, M., Leppänen, S., Palmolahti, E., Inha, L., Mustajärvi, K., Kettunen, A., Zarino, S., Campailla, S., Balestrini, A., Chirulli, I., Facco, L., Vela, S., Cioffi, M., Gambucci, E., Botto, S., Hapuoja, A. & Hannonen, P. (2021). *NBS Demonstration Site Start-Up Report*. Urban Nature Labs (UNaLab) Deliverable D5.4.

van Dinter, M. & Habibipour, A. (2019). *Co-creation Workshops Report*. Urban Nature Labs (UNaLab) project deliverable D2.2.

Business and governance models

Cioffi, M., Zappia, F. & Raggi, E. (2019). *Value Chain Analysis of Selected NBS*. Urban Nature Labs (UNaLab) Deliverable D6.1.

Hawxwell, T., Mok, S., Mačiulyte, E., Sautter, J., Theobald, J.A., Dobrokhotova, E. & Suska, P. (2018). *Municipal Governance Guidelines*. Urban Nature Labs (UNaLab) Deliverable D6.2.

Mačiulyte, E., Cioffi, M., Zappia, F., Duce, E., Ferrari, A., Kelson Batinga de Mendonça, M.F., Loriga, G., Suska, P., Vaccari Paz, B.L., Zangani, D. & Hein Bult, P. (2019). *Business Models & Financing Strategies*. Urban Nature Labs (UNaLab) Deliverable D6.3.

Mok, S., Hawxwell, T., Kramer, M. & Mačiulyte, E. (2019). *NBS Value Model.* Urban Nature Labs (UNaLab) Deliverable D6.4.

Monitoring and impact assessment

Wendling, L., Rinta-Hiiro, V., Jermakka, J., Fatima, Z., Ascenso, A., Miranda, A.I., Roebeling, P., Martins, R. & Mendonça, R. (2019). *Performance and Impact Monitoring of Nature-Based Solutions*. Urban Nature Labs (UNaLab) Deliverable D3.1.

Dumitru, A. & Wendling, L. (Eds.). (2021a). *Evaluating the Impact of Nature-based Solutions: A Handbook for Practitioners.* Luxembourg: Publications Office of the European Union. 373 pp.

Dumitru, A. & Wendling, L. (Eds.). (2021b). *Evaluating the Impact of Nature-based Solutions: Appendix of Methods*. Luxembourg: Publications Office of the European Union.

Dumitru, A. & Wendling, L. (Eds.). (2021c). *Evaluating the Impact of Nature-based Solutions: Summary for Policymakers*. Luxembourg: Publications Office of the European Union.

IUCN. (2020). IUCN Global Standard for Nature-based Solutions. A user-friendly framework for the verification, design and scaling up of NbS. First Edition. Gland, Switzerland: International Union for the Conservation of Nature. Available from https://www.iucn.org/theme/nature-based-solutions/iucn-global-standard-nbs

Roebeling, P., Dubovik, M., Ascenso, A., Augusto, B., Bastos, I., Costa, S., … (2022). *Impacts of NBS Demonstrations.* Urban Nature Labs (UNaLab) Deliverable D3.4.

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052

Topic: SCC-2-2016-2017: Smart Cities and Communities Nature based solutions

Next stand-alone document

Nature-based Solutions

Technical Handbook Factsheets




Nature-based Solutions

Technical Handbook Factsheets

UNaLab
URBAN NATURE LABS

Publisher
UNaLab URBAN NATURE LABS
Institut für Landschaftsplanung und Ökologie - ILPÖ

Authors
Bernd Eisenberg
Cecilia Chiesa
Leonie K. Fischer
Kristen Jakstis
Vera Polcher
Hans-Georg Schwarz-v.Raumer

Layout
Jesús Martínez
Vishal Kumar
Alfred Palacios

Funding
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 730052; Topic: SCC-2-2016-2017: Smart Cities and Communities Nature-based Solutions.

Stuttgart - October 2022

UNaLab URBAN NATURE LABS ILPÖ INSTITUT FÜR LANDSCHAFTSPLANUNG UND ÖKOLOGIE Universität Stuttgart

Content

List of abbreviations

BVOC	Biogenic volatile organic compound
CWR	Constructed wet roof
EC	European Commission
Fig.	Figure
FHG	Fraunhofer
ha	Hectar
m	Meter
NBS	Nature-based solutions
P1-P8	Performance indicator 1 – Performance indicator 8
STU	University of Stuttgart
SUDS	Sustainable drainage systems
UAV	University of Aveiro
UNaLab	Urban Nature Labs project
VTT	Technical research center of Finland

List of icons

Climate resilience, performance indicator P1: Cooling services

Water management, performance indicators P2 & P3: Water balance and purification services

Natural hazards and other related impacts

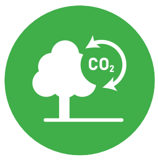
Air quality and performance indicator P4: Air purification services

Biodiversity and performance indicator P5: Biodiversity services

Public health and well being

Social justice, cohesion and performance indicator P6: Amenity value services

Performance indicator P7: Food, energy and materials



Performance indicator P8: Carbon sequestration

About the Urban Nature Labs (UNaLab) Project

The UNaLab project is contributing to the development of smarter, more inclusive, more resilient, and more sustainable urban communities through the implementation of nature-based solutions (NBS) co-created with and for local stakeholders and citizens. UNaLab's three Front-Runner Cities – Eindhoven (The Netherlands), Genova (Italy), and Tampere (Finland) – have a strong commitment to smart, citizen-driven solutions for sustainable urban development. The establishment of Urban Living Lab innovation spaces in Eindhoven, Genova, and Tampere supports on-going co-creation, demonstration, experimentation, and evaluation of a range of different NBS targeting climate change mitigation and adaptation, along with the sustainable management of water resources.

The Front-Runner Cities actively promote knowledge- and capacity-building in the use of NBS to enhance urban climate and water resilience within a network of committed partner cities, including seven Follower Cities – Stavanger (Norway), Prague (Czech Republic), Castellón (Spain), Cannes (France), Başakşehir (Turkey), Hong Kong, and Buenos Aires (Argentina) – and the Observers, Guangzhou (China) and the Brazilian Network of Smart Cities. Collaborative knowledge production among this wide network of cities enables UNaLab project results to reflect diverse urban socio-economic realities, along with differences in the size and density of urban populations, local ecosystem characteristics, and climate conditions.

Introduction

The following Nature-based Solutions (NBS) Factsheets were originally developed for UNaLab's Nature Based Solutions Technical Handbook. The original version of the handbook was created at the beginning of the UNaLab project in 2018 by University of Stuttgart's Institute for Landscape Planning and Ecology (STU, ILPÖ) in an iterative process together with the University of Aveiro (UAV), the Technical Research Centre of Finland (VTT), Fraunhofer (FHG), and the front-runner cities of Eindhoven, Genova, and Tampere [1]. Its main objective was to provide front-runner cities with accurate information about potentially applicable NBS to support climate and water resilience, and therefore facilitate informed decision making during the NBS co-creation process.

Since the publication of the first version of the NBS Technical Handbook in 2018, the European Commission (EC) has adopted a more robust definition of NBS with a greater emphasis on biodiversity. The EC currently defines NBS as follows:

> "Nature-based solutions to societal challenges are solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systematic interventions. Nature-based solutions must therefore benefit biodiversity and support the delivery of a range of ecosystem services" [2].

The NBS Technical Handbook was periodically updated throughout the UNaLab project as the field of NBS and the project itself progressed. Rather than offer an exhaustive catalogue and summaries of all existing NBS, the NBS Technical Handbook Factsheets aim to provide inspiration and easily digestible information directed towards practitioners. Because of this focus on practitioners, the NBS Factsheets were originally organized according to planning and construction terminology. However, since the publication of the first version of the NBS Technical Handbook in 2018, a unified classification system for NBS has been adopted by the European Commission [3], and is used in other recent UNaLab documents. Therefore, the following NBS Factsheets are now organized following this unified classification system.

According to this new classification system, there are three main types of NBS that are categorized by function and increasing level of ecosystem intervention, with Type 1 involving the least intervention, and Type 3 the greatest amount of ecosystem intervention [3]. All NBS described in the Technical Handbook Factsheets are Type 3: Highly intensive ecosystem management or the creation of new ecosystems. Type 3 NBS are further subdivided into seven main categories: Green space, trees and shrubs, soil conservation and quality management, blue-green space establishment or restoration, green built environment, natural or semi-natural water storage and transport structures, and infiltration, filtration and biofiltration structures. Six of these categories are represented in the NBS Technical Handbook Factsheets and are organized into the following chapters:

01 Green space
02 Trees and shrubs
03 Soil conservation and quality management
04 Green built environment
05 Natural or semi-natural water storage and transport structures
06 Infiltration, filtration and biofiltration structures

For the final version of the Technical Handbook Factsheets, each NBS Factsheet is structured in a semi-tabular layout to ensure comparability between methods, general benefits, and performances. Each NBS Factsheet is structured as follows:

i. Basic information
   What kind of NBS is considered and what challenges does it address?
ii. Role of nature
   How is the NBS inspired by or make use of nature?
iii. Technical and design parameters
   What are the main technical and design considerations?
iv. Conditions for implementation
   Which site conditions should be considered?

v. Benefits and limitations
How does it contribute to or limit the functionality of urban ecosystems?

vi. Performance
What is the performance of the NBS with regard to the following performance indicators established according to ecological services: P1 cooling service; P2 water balance and regulation service; P3 water purification service; P4 air purification service; P5 biodiversity service; P6 amenity value service; P7 food /energy/ material services; P8 carbon sequestration service.

vii. References and further reading
Which sources were used to develop the factsheet?

Workpackages 3 and 5 of the UNaLab project developed a set of indicators for measuring the performance of NBS in general, as well as on the city and neighborhood or project level. The general NBS indicators try to ascertain what can be measured in different cities to compare overall performance. For example, the indicator "heat reduction" at the city scale is measured by the temperature difference between the inner city heat island effect and the surrounding rural areas. After implementation of the NBS, effectiveness can be measured by comparing the temperature difference of city and rural areas before and after implementation [4].

Evaluating the overall success of NBS in a city can be done with these performance indicators, however, a different form of evaluation is needed to identify differences between various NBS. Therefore, a detailed performance evaluation was created for the NBS Technical Handbook Factsheets based on ecological services and processes. Eight relevant ecological services in terms of NBS performance indicators (see P1-P8 above) with 23 specifications were selected for the performance evaluation. For example, P5 biodiversity service has two associated specifications: Habitat provision and connectivity. While slightly different than the previously mentioned general indicators for measuring NBS performance, each of the services and specifications can be related back to the key performance indicators [4] at the city or neighborhood level.

As NBS performance is dependent on the climate and geomorphological conditions (e.g., soil conditions, slope and aspect of a surface, etc.) of each city or even site, a location-specific evaluation of NBS considering all relevant factors would be ideal. However, this is not feasible for all three UNaLab front-runner cities and five follower cities for each permutation of conditions, and is outside the scope of the NBS Technical Handbook Factsheets. Therefore, a panel of experts, following a general approach, evaluated the potential performance of each NBS in suitable conditions. The performance under suitable conditions is rated as very good (●●), good (●○), or is not applicable (○○).

The NBS Technical Handbook Factsheets were fundamentally a "living document" whose purpose and construction continued to evolve with the progression of the UNaLab project. For example, while its original intent was to provide information about potentially applicable NBS to front-runner cities, so called "Inspiration Cards" were developed from the NBS Technical Handbook and used in Road Mapping Workshops to inform follower cities about NBS relevant to their identified challenges. The NBS Technical Handbook Factsheets are now publically available in their final form to move beyond the UNaLab cities and offer inspiration to other cities and practitioners interested in NBS. To this end, information from the NBS Technical Handbook Factsheets was also used in the production of the NBS Replication Framework - an online resource built using the knowledge produced within the UNaLab project to support the continued implementation and upscaling of NBS in cities and municipalities after the culmination of the UNaLab project (www.unalab.eu).

1. Green space

Fig 1.0 Residential park in Stuttgart, Germany.

The importance of rus in urbe (translated: country in the city) has been recognized since the ancient Romans began incorporating natural elements and green spaces into their cities for recreation and leisure [5]. For many centuries, however, urban green spaces were largely private with restricted access. While some European cities began opening palace gardens and parks to the general public in the 16th and 17th centuries [6], public green spaces were relatively uncommon until the rise of the urban park in the 19th century. Although the design and objectives of parks have evolved over the past centuries, they remain a fundamental part of the urban green infrastructure and are an essential component of healthy and resilient cities.

In an integrated system, often connected by tree lined streets or green corridors, green spaces serve as the backbone of urban green infrastructure and support many of the beneficial services that nature can provide in cities including positive effects for urban climate, human health, recreation, and biodiversity. Urban green spaces are categorized according to size, catchment area, services provided, and urban design aspects. Three examples of green spaces (i.e., residential parks, green corridors, and urban gardens) are described in more detail below.

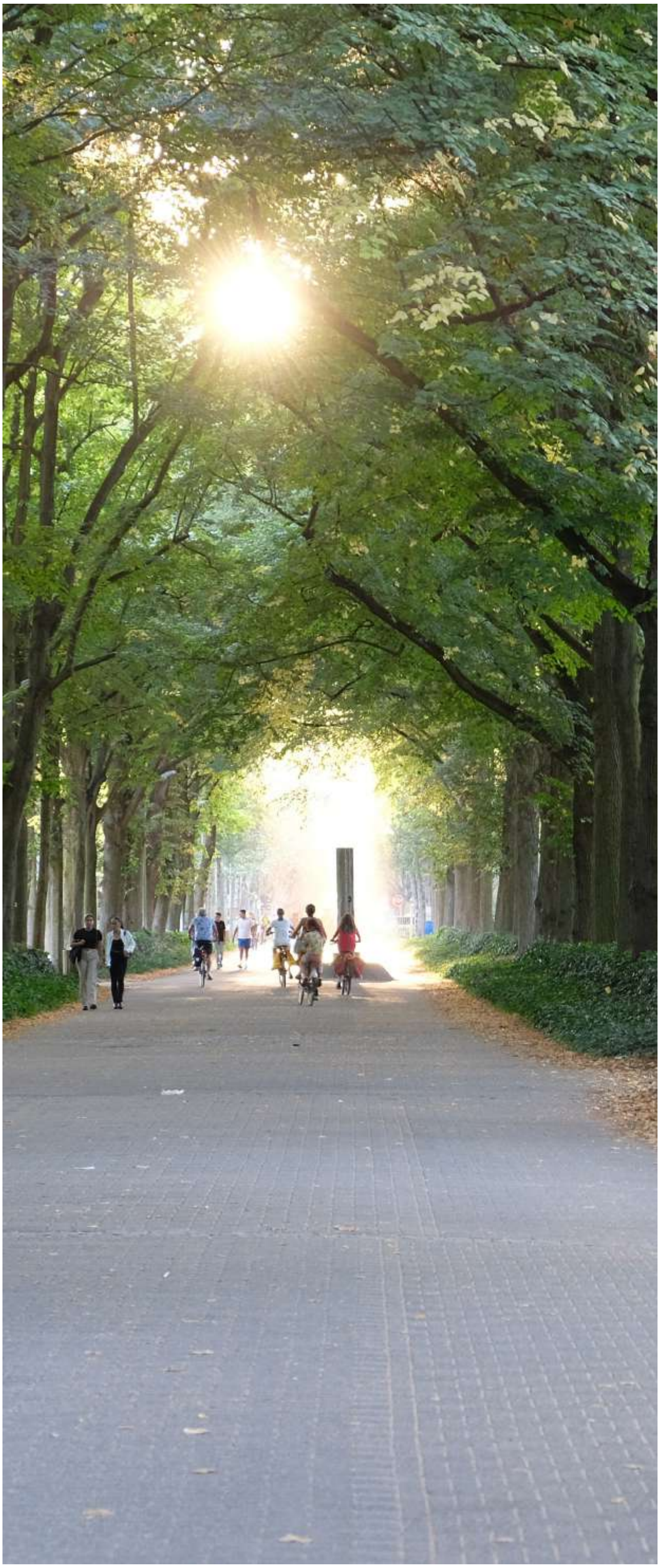


Fig 1.1 Residential park in Antwerp, Belgium.

1.1 Residential park

Residential and urban parks are essential components of the green infrastructure of cities. For many people, they are often the nearest and most convenient green space for nature interaction and nature-based recreation. Larger spatial elements of green infrastructre are district parks that often have greater multifuntionality by combining various uses (e.g., sport fields or other NBS like water retention basins). Playgrounds, connecting green strips of land, and pocket parks are examples of smaller spatial elements of green infrastructure that can also be classified as residential parks.

I. Basic information

Synonyms: Urban park; Pocket park; Parklet

Addressed challenges:

Climatic resilience | Water management | Natural & climatic hazards | Air quality | Biodiversity | Public health & well-being | Social justice & cohesion

II. Role of nature

The residential park acts like an oasis in an urban environment, with positive effects for urban climate, recreation, and biodiversity that extend into the neighbouring residential areas.

III. Technical and design parameters

The design of residential parks is relatively flexible, but they should be well connected with other natural areas or natural elements, and be easily accessible to residents and pedestrians. Typically, parks are at least 1.5 ha size and have a compact form (e.g., 120 m x 20 m) with a high proportion of trees or a small forest (> 50 % canopy cover), and few sealed surfaces. The layout of the typical London Residential Park with a central open area surrounded by trees and shrub lined streets and paths can be seen as a model, however, the specific ecological conditions, as well as the needs and desires of the community, should be considered in the design process.

Pocket parks are a good alternative where space is limited. These urban parks are typically around 1200 m^2 (no greater than 5000 m^2) and can offer similar, although smaller-scale, benefits as larger urban parks.

IV. Conditions for implementation

New urban development areas allow for the establishment of residential parks at the most suitable location, thereby maximizing the effects on urban climate, storm water management, and biodiversity. However, the establishment of new parks or improving existing parks (e.g., in urban regeneration projects) can also provide many benefits with proper planning. Spatially equal distribution of high-qualtiy parks is important to maximize their impact on the urban climate, biodiversity, and residents.

V. Benefits and limitations

⊕ Potential benefits:

- Residential parks are multifunctional and deliver all benefits of green infrastructure.

⊖ Potential limitations / disservices:

- Accessibility and equitable distribution is a key factor for the success of residential parks.

VI. Performance

P1 Cooling service

Transpiration	● ●
Shading	● ●
Evaporation	● ●
Building (Insulation)	○ ○
Reflection (Albedo)	● ●

P2 Water balance regulation service

Water conveyance	● ●
Water infiltration	● ●
Water retention	● ●
Water storage	● ●
Water reuse	○ ○

P3 Water purification service

Water filtering	● ●
Water bio-remediation	○ ○

P4 Air purification service

Deposition	● ●
Air biofiltration	● ●
Noise reduction	○ ○

P5 Biodiversity service

Habitat provision	● ●
Connectivity	● ●

P6 Amenity value service

Beauty / Appearance	● ●
Usability / Functionality	● ●
Social interaction	● ●
Education	○ ○

P7 Food / Energy / Material

Food / Energy / Material	● ○

P8 CO_2 Sequestration

CO_2 Sequestration	● ○

VII. References and further reading

Algretawee, H., Rayburg, S., & Neave, M. (2019). Estimating the effect of park proximity to the central of Melbourne city on Urban Heat Island (UHI) relative to Land Surface Temperature (LST). Ecological Engineering, 138, 374-390. https://doi.org/10.1016/j.ecoleng.2019.07.034.

Blake, A. (2014). Urban parks: pocket parks. Retrieved from https://web.archive.org/web/20220823093632/https:/depts.washington.edu/open2100/pdf/.

Oppla (2020). Schansbroek, Genk-brownfield regeneration. Retrieved March 20, 2021, from https://connectingnature.eu/oppla-case-study/19379.

Pearlmutter, D., Calfapietra, C., Samson, R., O'Brien, L., Ostoić, S. K., Sanesi, G., & del Amo, R. A. (Eds.) (2017). The urban forest: Cultivating green infrastructure for people and the environment (Vol. 7). Springer. ISBN: 978-3-319-50280-9.

Peschardt, K. K. (2014). Health promoting pocket parks in a landscape architectural perspective. Department of Geosciences and Natural Resource Management, University of Copenhagen. ISBN: 978-87-7903-659-8.

Peschardt, K. K., Schipperijn, J., & Stigsdotter, U. K. (2012). Use of small public urban green spaces (SPUGS). Urban Forestry & Urban Greening, 11(3), 235-244. https://doi.org/10.1016/j.ufug.2012.04.002.

Ravnikar, Ž., & Marušić, B. G. (2019). Nature-based solutions (NBS). Urbani Izziv, 30(1), 144-146. Retrieved from https://www.jstor.org/stable/26654424.

Urban Nature Atlas. (2021). Pocket parks in Budapest. Retrieved from https://web.archive.org/web/20220823092609/https:/una.city/nbs/budapest/pocket-parks-budapest.

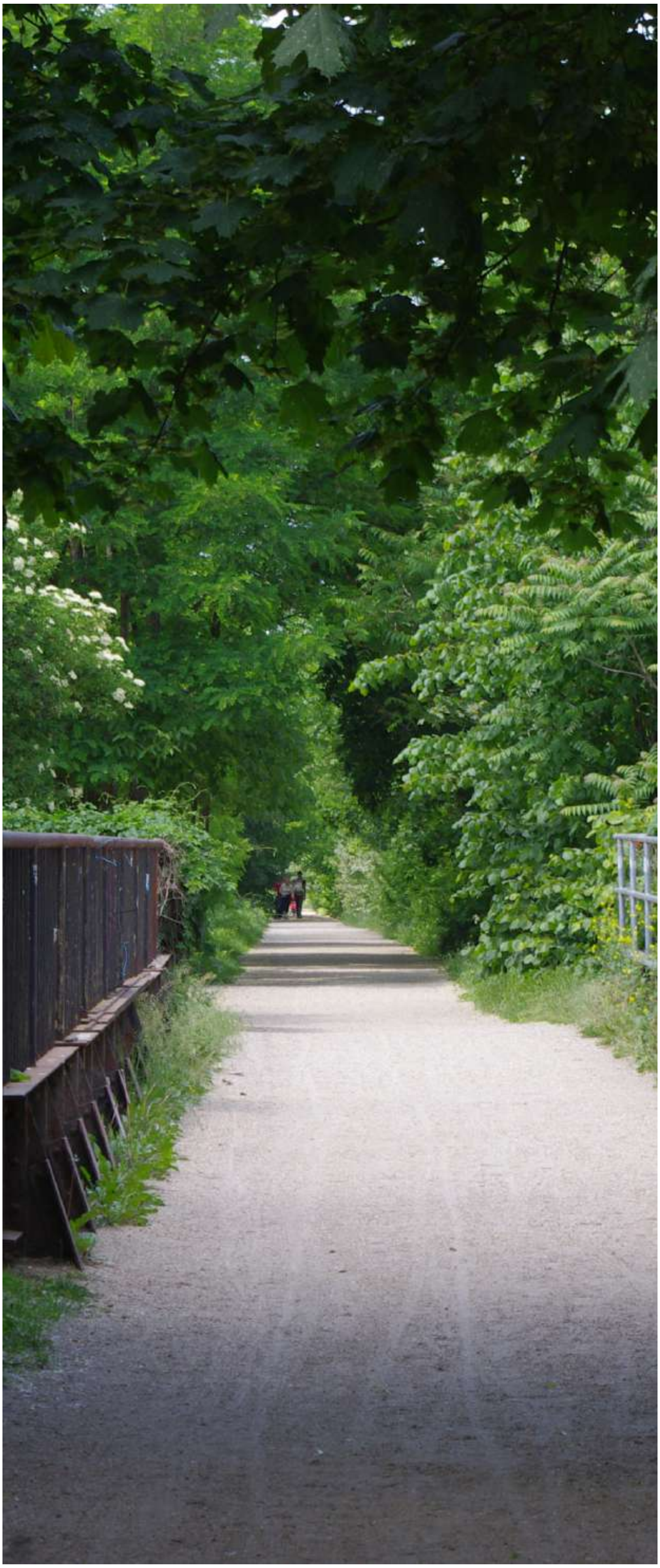


Fig 1.2 Green corridor in Berlin, Germany.

1.2 Green corridor

Areas of derelict infrastructure, e.g., railway lines, that are transformed into green corridors play an important role in urban green infrastructure networks and help to re-nature cities. Regeneration along waterways and rivers can also result in linear interconnecting parks. Green corridors can increase accessibility to green spaces while promoting environmentally sustainable transportation like walking and cycling. Additionally, they support biodiversity through improved ecological networks and habitat connectivity.

I. Basic information

Synonyms: Linear park; Green belt

Addressed challenges:

Climatic resilience | Water management | Air quality | Biodiversity | Public health & well-being | Social justice & cohesion

II. Role of nature

Transition areas between biomes are called ecotones. Green corridors with their linear, natural elements can be seen as ecotones that connect neighbouring and distant areas. Ecotones are often rich in biodiversity because they are connected to two or more different biotopes.

III. Technical and design parameters

When green corridors are based on derelict infrastructure, the location and network properties are more or less fixed. However, green corridors can also be designed as connecting elements or active transportation corridors within new developments.

IV. Conditions for implementation

Abandoned and transformed traffic infrastructure may be the most convenient way to establish linear parks and green corridors. The lack of care and sustained neglect of the area often results in spontaneous vegetation, but these areas can also be intentionally designed.

V. Benefits and limitations

⊕ Potential benefits:

- Linear elements help improve green infrastructure and habitat connectivity.
- The re-use of old grey infrastructure opens up a great potential for creating an interconnected system.

⊖ Potential limitations / disservices:

- Depending on the previous use, the green corridor may need a high level of maintenance (e.g., bridges).

VI. Performance

P1 Cooling service

Transpiration	●	○
Shading	●	○
Evaporation	●	○
Building (Insulation)	●	○
Reflection (Albedo)	○	○

P2 Water balance regulation service

Water conveyance	●	○
Water infiltration	●	○
Water retention	●	○
Water storage	●	○
Water reuse	○	○

P3 Water purification service

Water filtering	●	○
Water bio-remediation	○	○

P4 Air purification service

Deposition	●	●
Air biofiltration	●	○
Noise reduction	○	○

P5 Biodiversity service

Habitat provision	●	●
Connectivity	●	●

P6 Amenity value service

Beauty / Appearance	●	●
Usability / Functionality	●	○
Social interaction	●	●
Education	○	○

P7 Food / Energy / Material

Food / Energy / Material	●	○

P8 CO_2 Sequestration

CO_2 Sequestration	○	○

VII. References and further reading

High Line (2020). The High Line: Overview. Retrieved from https://web.archive.org/web/20220812112126/https://www.thehighline.org/about/.

Senate Department for the Environment, Transport and Climate Protection (n.d.). 20 green walks in Berlin. Retrieved from https://web.archive.org/web/20220812112325/https://www.berlin.de/sen/uvk/en/nature-and-green/landscape-planning/20-green-walks-in-berlin/.

Strand, D. (2018). Singapore's green corridor park as a homegrown import. International Communication of Chinese Culture, 5(1-2), 61-81. https://doi.org/10.1007/s40636-018-0122-9.

Zhang, Z., Meerow, S., Newell, J. P., & Lindquist, M. (2019). Enhancing landscape connectivity through multifunctional green infrastructure corridor modeling and design. Urban Forestry & Urban Greening, 38, 305-317. https://doi.org/10.1016/j.ufug.2018.10.014.

Žlender, V., & Thompson, C. W. (2017). Accessibility and use of peri-urban green space for inner-city dwellers: A comparative study. Landscape and Urban Planning, 165, 193-205. https://doi.org/10.1016/j.landurbplan.2016.06.011.

Fig 1.3 Temporary urban garden in Stuttgart, Germany

1.3 Urban garden

Urban gardening is a common way to establish garden space and encourage nature interaction for residents. There are many different concepts of urban gardening, but mostly they are semi-private with a possibility to rent or care for individual beds (e.g., within community gardens or urban garden projects) or plots (e.g., allotment gardens). Urban gardens, especially smaller community gardens, can be established in many diverse locations such as courtyards or public spaces. Depending on the size and intent of the garden, they offer a variety of benefits. For example, they can be sources for locally produced food, promote social interaction, and support mental health.

I. Basic information

Synonyms: Community gardens; Intercultural gardens; Allotment gardens; Urban farming; Urban agriculture

Addressed challenges:

Climatic resilience | Water management | Air quality | Biodiversity | Public health & well-being | Social justice & cohesion

III. Role of nature

Urban gardens act as small oases in an urban environment, with positive effects for urban climate, recreation, and biodiversity that extend into the neighbouring residential areas.

IV. Technical and design parameters

There are many possible designs for urban gardens. They are often constructed according to the space available, and needs or intentions of the organizing community. Often urban gardens are built using raised beds, which allows for flexibility in establishment. However, gardens planted directly in the soil at a site can help mitigate additional challenges like stormwater management. Care must be taken with regard to previous or neighbouring land uses that may have caused soil contamination (e.g., transformed parking lots, industrial sites).

V. Conditions for implementation

In order to implement urban gardens, an organized, caring community with initiative and an appropriate space are necessary. Urban gardens can be permanent or temporary installations.

VI. Benefits and limitations

⊕ Potential benefits:

- Urban gardens are multifunctional and deliver many benefits of green infrastructure.
- Provide locally sourced food.
- Encourage social interaction.
- Support pollinators.

⊖ Potential limitations / disservices:

- Accessibility and community engagement are key factors for the success of urban gardens.

VI. Performance

P1 Cooling service

Transpiration	● ●
Shading	○ ○
Evaporation	● ●
Building (Insulation)	○ ○
Reflection (Albedo)	○ ○

P2 Water balance regulation service

Water conveyance	○ ○
Water infiltration	● ○
Water retention	● ○
Water storage	● ○
Water reuse	○ ○

P3 Water purification service

Water filtering	● ○
Water bio-remediation	○ ○

P4 Air purification service

Deposition	○ ○
Air biofiltration	● ●
Noise reduction	○ ○

P5 Biodiversity service

Habitat provision	● ●
Connectivity	○ ○

P6 Amenity value service

Beauty / Appearance	● ●
Usability / Functionality	● ●
Social interaction	● ●
Education	○ ○

P7 Food / Energy / Material

Food / Energy / Material	● ●

P8 CO_2 Sequestration

CO_2 Sequestration	○ ○

VII. References and further reading

Allmende-Kontor (n.d.). Der Garten. Retrieved from https://web.archive.org/web/20220812112954/https://www.allmende-kontor.de/der-garten/.

van der Jagt, A.P.N., Szaraz, L.R., Delshammar, T., Cvejić, R., Santos, R., Goodness, J., & Buijs, A. (2017). Cultivating nature-based solutions: The governance of communal urban gardens in the European Union. Environmental Research, 159, 264–275. https://doi.org/10.1016/j.envres.2017.08.013.

Lin, B.B., Egerer, M.H., & Ossola, A. (2018). Urban gardens as a space to engender biophilia: Evidence and ways forward. Frontiers in Built Environment, 4, 79. DOI: 10.3389/fbuil.2018.00079.

Park, H., Kramer, M., Rhemtulla, J.M., & Konijnendijk, C.C. (2019). Urban food systems that involve trees in Northern America and Europe: A scoping review. Urban Forestry & Urban Greening, 45, 126360. https://doi.org/10.1016/j.ufug.2019.06.003.

Petrovic, N., Simpson, T., Orlove, B., & Dowd-Uribe, B. (2019). Environmental and social dimensions of community gardens in East Harlem. Landscape Urban Planning, 183, 36–49. https://doi.org/10.1016/j.landurbplan.2018.10.009.

Russo, A., Escobedo, F.J., Cirella, G.T., & Zerbe, S. (2017). Edible green infrastructure: An approach and review of provisioning ecosystem services and disservices in urban environments. Agriculture, Ecosystems & Environment, 242, 53–66. https://doi.org/10.1016/j.agee.2017.03.026.

Sowińska-Świerkosz, B., Michalik-Śnieżek, M., & Bieske-Matejak, A. (2021). Can allotment gardens (AGs) be considered an example of nature-based solutions (NBS) based on the use of historical green infrastructure? Sustainability, 13(2), 835. https://doi.org/10.3390/su13020835.

2. Trees and shrubs

Fig 2.0 Trees and shrubs at the Wilhelma zoological-botanical garden in Stuttgart, Germany.

Planting or protecting existing trees and shrubs are often employed in urban greening interventions and can be important NBS themselves, or elements within other NBS. Some main benefits include the provision of habitat for urban wildlife, temperature and stormwater regulation, and the mitigation of gaseous and particulate air pollutants [7-10]. Urban trees may also be associated with human health benefits like the reduction of stress, obesity, cardiac disease, and asthma [11]. Larger, older trees generally have greater positive environmental effects in comparison to smaller, newly planted trees and therefore their conservation and professional maintenance should be prioritized [12].

Trees are often seen as “the nature solution” and there has been a push in recent decades in many cities to increase tree plantings often in conjunction with lofty goals like planting one million trees [13]. However, while urban trees offer many benefits, there are some potential disservices to consider. For example, some species may increase allergic symptoms in those with hay fever or produce compounds that can react to form ozone under certain conditions [11]. Additionally, if planted without regard to location, street trees can actually trap pollutants at the pedestrian-level in traffic-heavy areas [14]. However, these disservices can be avoided with proper species selection and planning. Single trees or shrubs are not considered NBS themselves, because the positive effects of a single tree on the environment are usually local and limited to the immediate area near the tree. Examples of trees and shrubs as NBS in urban areas include orchards, vineyards, forests (including afforestation), hedges or green fences, and street trees [4]. Three examples of trees and shrubs as NBS (i.e., single line street trees, boulevards, and tree groups) are described in more detail below.

Fig 2.1 Single line street trees in the city center of Magdeburg, Germany.

2.1 Single line street trees

Single line street trees represent one possibility to establish several trees in urban areas. As the name implies, single line trees are arranged along one side of streets, bicycle paths, sidewalks, or other pathways.

Trees in general can positively affect local microclimate conditions, absorb gaseous pollutants, intercept particulate matter, and provide shade for people and buildings. One of the main positive effects for human well-being in warmer periods is the mitigation of urban heat stress due to shading and plant transpiration. The potential effects of street trees depend on factors such as tree size, canopy cover, planting density, species, tree health, location, availability of root water, and leaf area index.

I. Basic information

Synonyms: Street trees

Addressed challenges:

Climatic resilience | Water management | Air quality | Biodiversity | Public health & well-being | Social justice & cohesion

II. Role of nature

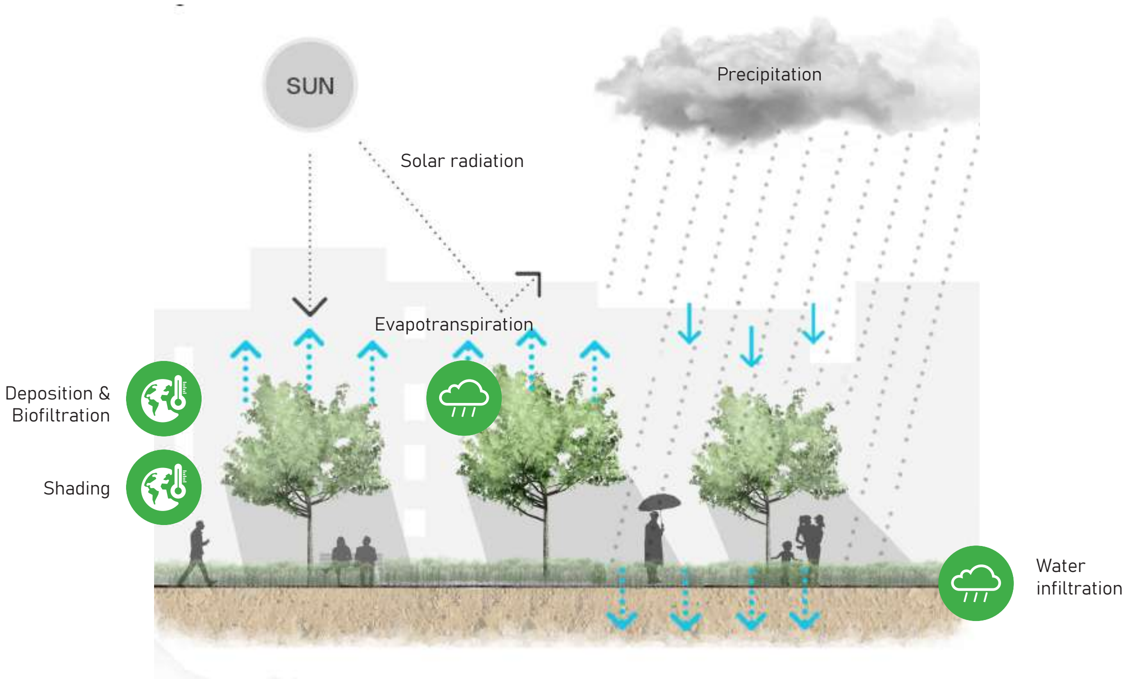


Fig 2.2 Single line street trees and their associated natural processes and benefits.

Single line trees simulate those trees growing at the edge of a forest (i.e. fringe area) and their effects on the surrounding environment outside the tree-covered area. In a natural or semi-natural forest, the edge trees would shade adjoining land uses like fields, meadows, or water surfaces. As a result, those shaded surfaces are cooler than surfaces without the protective tree cover.

The shading effect of single line street trees is determined by the environmental conditions (e.g., season and climate) and structural and species specific characteristics of the trees (e.g., tree canopy cover, crown density, deciduous vs. evergreen, age, height). Other effects are a reduced wind velocity, local temperature reduction due to evapotranspiration, and reduction of air pollution.

III. Technical and design parameters

The most important aspect is the selection of suitable trees that serve the intended purpose and are fit for the current and future geo-environmental conditions. Additionally, selected trees should have low biogenic volatile organic compound (BVOC) production potential to reduce the possible negative effect of ozone production in warmer months. This is especially important in areas with heavy vehicular traffic. There are tools available that can be useful as a first step in appropriate species selection (for temperate regions, see, e.g., Citree), and suitable species are often recommend by local authorities.

The area of the root space for neighbouring trees can be connected in suitable conditions and, if separated, root space should be 12 m^3 with a minimum depth of 1.5 m. Ideally, the available root space should be equal in size to the fully mature crown, but this is often not possible in urban areas. Depending on local climatic conditions, newly planted street trees need about three years of regular watering, often followed by supplemental irrigation thereafter. Therefore, permanent or temporary irrigation facilities need to be considered and sustainable irrigation methods (e.g., using harvested rainwater) should be preferentially used whenever possible. The distance between the trees depends on the maximum size of the adult tree, but also on the size of the planted tree and design ideas. Protection measures (e.g., poles against car parking, wire mesh against animals) may also be necessary. Because it takes decades until newly planted trees fulfil the services of mature trees, individually, as well as in combination, initiatives to protect existing trees are essential.

IV. Conditions for implementation

Local circumstances (e.g., topography, street characteristics, soil conditions, surrounding land use, and underground uses) need to be considered when planning and establishing new single line trees. A suitable location for the establishment of trees should offer enough space for trees to grow, both below and above ground. For example, considering the maximum height and canopy cover of the trees is important to avoid space problems in the future. Depending on site conditions and available space, appropriate tree species must be selected.

Trees that are not sufficiently rooted may cause accidents and constitute a danger for people on or beside the road. The soil and subsurface should generally be suitable for the establishment of street trees and may need to be replaced with structural soils if necessary. The use of structural soils and permeable pavements may help improve growing conditions for urban street trees and support deeper root growth. The selection of suitable tree species should also consider local conditions like topography. For example, when used for the stabilization of banks or small hills, steadfast trees are necessary.

Species and sub species that are suitable for urban conditions should be planted, and are often suggested by local authorities.

V. Benefits and limitations

⊕ Potential benefits:

- Microclimate regulation.
- Habitat provision.
- Aesthetics / recreation.
- Rainwater regulation (delayed stormwater runoff).

⊖ Potential limitations / disservices:

- Allergic potential of pollen.
- BVOC emissions, resulting in increased ozone emissions in warmer months.

VI. Performance

P1 Cooling service

Transpiration	● ○
Shading	● ○
Evaporation	○ ○
Building (Insulation)	○ ○
Reflection (Albedo)	● ○

P2 Water balance regulation service

Water conveyance	○ ○
Water infiltration	● ○
Water retention	● ○
Water storage	○ ○
Water reuse	○ ○

P3 Water purification service

Water filtering	○ ○
Water bio-remediation	○ ○

P4 Air purification service

Deposition	● ○
Air biofiltration	● ○
Noise reduction	○ ○

P5 Biodiversity service

Habitat provision	● ○
Connectivity	● ○

P6 Amenity value service

Beauty / Appearance	● ●
Usability / Functionality	● ○
Social interaction	● ○
Education	○ ○

P7 Food / Energy / Material

Food / Energy / Material	○ ○

P8 CO_2 Sequestration

CO_2 Sequestration	○ ○

VII. References and further reading

Abd Kadir, M. A., & Othman, N. (2012). Towards a better tomorrow: Street trees and their values in urban areas. Procedia-Social and Behavioral Sciences, 35, 267-274. https://doi.org/10.1016/j.sbspro.2012.02.088.

Armson, D., Stringer, P., & Ennos, A. R. (2013). The effect of street trees and amenity grass on urban surface water runoff in Manchester, UK. Urban Forestry & Urban Greening, 12(3), 282-286. https://doi.org/10.1016/j.ufug.2013.04.001.

Burden, D. (2006). Urban street trees: 22 benefits specific applications. Retrieved March 20, 2021, from https://www.walkable.org/download/22_benefits.pdf.

Fitzky, A. C., Sandén, H., Karl, T., Fares, S., Calfapietra, C., Grote, R., Saunier, A., & Rewald, B. (2019). The interplay between ozone and urban vegetation: BVOC emissions, ozone deposition and tree ecophysiology. Frontiers in Forests and Global Change, 2, 50. https://doi.org/10.3389/ffgc.2019.00050.

Green Blue Urban (n.d.). Sauchiehall Street Glasgow. Retrieved from https://web.archive.org/web/20220812120331/https://greenblue.com/gb/case-studies/sauchiehall-street-glasgow/.

McDonald, R., Kroeger, T., Boucher, T., Wang, L., & Salem, R. (2016). Planting healthy air: A global analysis of the role of urban trees in addressing particulate matter pollution and extreme heat. The Nature Conservancy. Retrieved March 20, 2021, from https://www.nature.org/content/dam/tnc/nature/en/documents/20160825_PHA_Report_Final.pdf.

Vogt, J., Gillner, S., Hofmann, M., Tharang, A., Dettmann, S., Gerstenberg, T., Schmidt, C., Gebauer, H., van de Riet, K., Berger, U., & Roloff, A. (2017). Citree: A database supporting tree selection for urban areas in temperate climate. Landscape and Urban Planning, 157, 14-25. https://doi.org/10.1016/j.landurbplan.2016.06.005.

* See also: Factsheet 2.2 Boulevards, section VII. References and further reading.

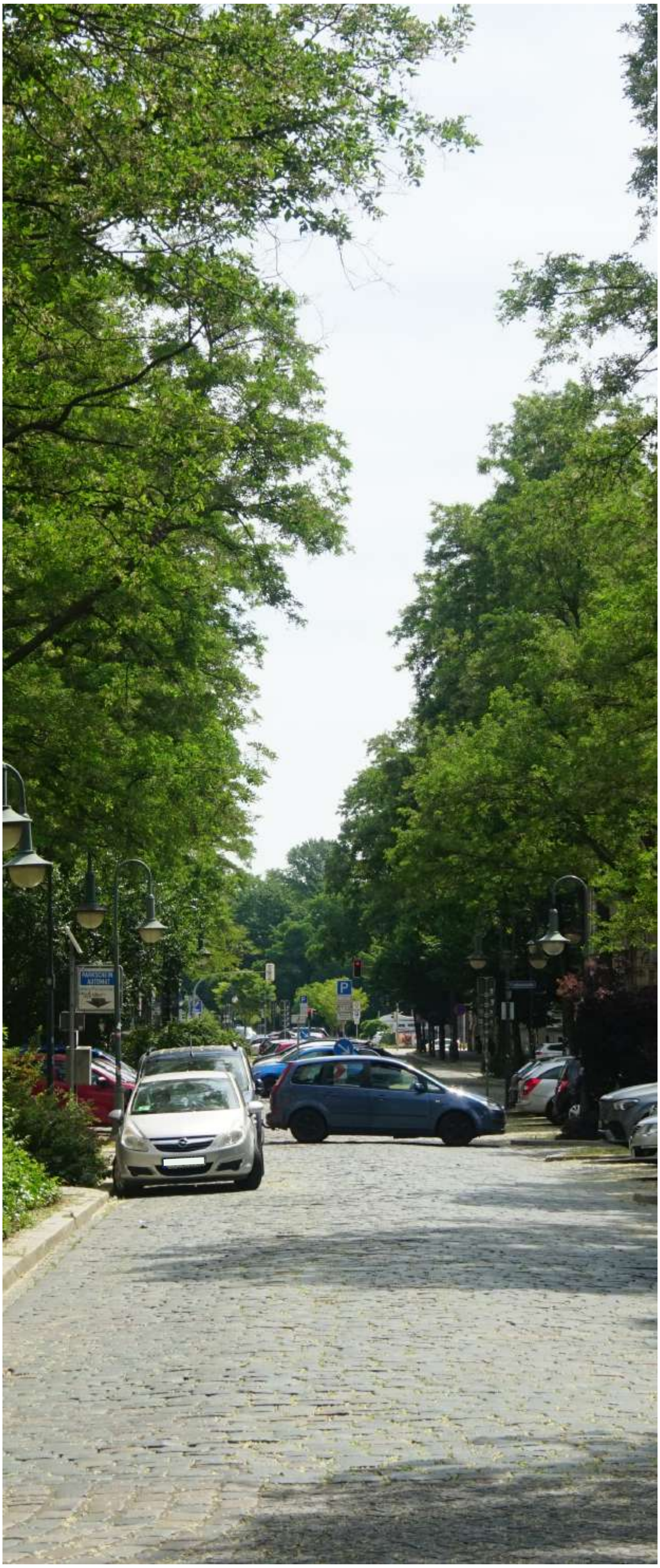


Fig 2.3 Boulevard in the city center of Magdeburg, Germany.

2.2 Boulevards

Boulevards represent a possibility to establish several trees in cities to mitigate urban heat stress, while providing additional benefits like improving water management and climate resilience. Within boulevards, trees are commonly arranged along streets, bicycle paths, and sidewalks on both sides of the route. The canopies of opposite trees often form a (nearly) closed canopy. As a result, the area between the two tree lines is shaded and the air temperature cooler.

I. Basic information

Synonyms: Double line street trees, Double row street trees

Addressed challenges:

Climatic resilience | Water management | Air quality | Biodiversity | Public health & well-being | Social justice & cohesion

II. Role of nature

Boulevards simulate those trees growing at the edge of a forest (i.e., fringe area) and their effects on the surrounding environment outside the tree-covered area. In a natural or semi-natural forest, the edge trees would shade adjoining land uses like fields, meadows, or water surfaces. As a result, those shaded surfaces are cooler than surfaces without the protective tree cover. The shading effect of boulevards is determined by the environmental conditions (e.g., season and climate) and structural and species specific characteristics of the trees (e.g., tree canopy cover, crown density, deciduous vs. evergreen, age, height). Other effects are a reduced wind velocity, local temperature reduction due to evapotranspiration, and reduction of air pollution.

III. Technical and design parameters

For boulevards in urban settings, only a limited number of tree species meet the selection criteria based on design principles, durability, and resistance against environmental stress. The area of the root space for neighbouring trees can be connected in suitable conditions and, if separated, root space should be 12 m^3 with a minimum depth of 1.5 m. Ideally, the available root space should be equal in size to the fully mature crown, but this is often not possible in urban areas. In most urban conditions, the root space needs to be prepared with soil substrates for trees.

Depending on local climatic conditions, newly planted street trees need about three years of regular watering, often followed by supplemental irrigation thereafter. Therefore, permanent or temporary irrigation facilities need to be considered and sustainable irrigation methods (e.g., using harvested rainwater) should be preferentially used whenever possible. The distance between the trees depend on road width, the maximum size of adult trees, and further design ideas. Protection measures (e.g., poles, wire mesh against animals) may also be needed.

IV. Conditions for implementation

Local circumstances (e.g., topography, street characteristics, soil conditions, surrounding land use, and underground uses) need to be considered when planning and establishing new boulevards. Planting location for the establishment of trees should offer enough space for trees to grow. Depending on site conditions and available space, suitable tree species must be selected. Considering the maximum height of the trees is important to avoid space problems in the future. Trees that are not sufficiently rooted may cause accidents and constitute a danger for people on or beside the road. The soil and subsurface should generally be suitable for the establishment of street trees and may, if necessary, be replaced by structural soils.
The use of structural soils and pervious pavements may help improve growing conditions for urban street

trees and support deeper root growth. Species and sub species that are suitable for urban conditions should be planted, and are often suggested by local authorities. Additionally, special considerations should be made when planning boulevards specifically in areas with heavy vehicular traffic, as structural characteristics like closed or dense canopies could increase pedestrian-level pollution in certain conditions.

V. Benefits and limitations

Potential benefits:

- Microclimate regulation.
- Habitat provision.
- Aesthetics / recreation.
- Rainwater regulation (delayed stormwater runoff).

Potential limitations / disservices:

- Reduced airflow, potentially leading to higher pollution in street canyon.
- Allergenic potential of tree pollen and BVOC emissions.

VI. Performance

P1 Cooling service

Transpiration	●●
Shading	●●
Evaporation	●○
Building (Insulation)	○○
Reflection (Albedo)	●●

P2 Water balance regulation service

Water conveyance	○○
Water infiltration	●○
Water retention	●○
Water storage	○○
Water reuse	○○

P3 Water purification service

Water filtering	○○
Water bio-remediation	○○

P4 Air purification service

Deposition	●○
Air biofiltration	●○
Noise reduction	○○

P5 Biodiversity service

Habitat provision	●○
Connectivity	●○

P6 Amenity value service

Beauty / Appearance	●●
Usability / Functionality	●○
Social interaction	●○
Education	○○

P7 Food / Energy / Material

Food / Energy / Material	●○

P8 CO_2 Sequestration

CO_2 Sequestration	○○

VII. References and further reading

City of Melbourne (2020). Urban forest visual: Explore Melbourne's urban forest. Retrieved March 20, 2021, from http://melbourneurbanforestvisual.com.au/.

Global Designing Cities Initiative (n.d.). Case study: boulevard de Magenta; Paris, France. Retrieved from https://web.archive.org/web/20220812121733/https://globaldesigningcities.org/.

Grote, R., Samson, R., Alonso, R., Amorim, J. H., Cariñanos, P., Churkina, G., Fares, S., le Thiec, D., Niinements, Ü., Mikkelsen, T.N., Paoletti, E., Tiwary, A., & Calfapietra, C. (2016). Functional traits of urban trees: Air pollution mitigation potential. Frontiers in Ecology and the Environment, 14(10), 543-550. https://doi.org/10.1002/fee.1426.

Mullaney, J., Lucke, T., & Trueman, S. J. (2015). A review of benefits and challenges in growing street trees in paved urban environments. Landscape and Urban Planning, 134, 157-166. https://doi.org/10.1016/j.landurbplan.2014.10.013.

New York City Department of Parks and Recreation (n.d.). MillionTreesNYC. Retrieved from https://web.archive.org/web/20220812121225/https://www.nycgovparks.org/trees/milliontreesnyc.

Pearlmutter, D., Calfapietra, C., Samson, R., O'Brien, L., Ostoić, S. K., Sanesi, G., & del Amo, R. A. (Eds.) (2017). The urban forest: Cultivating green infrastructure for people and the environment (Vol. 7). Springer. ISBN: 978-3-319-50280-9.

* See also: Factsheet 2.1 Single line street trees, section VII. References and further reading.

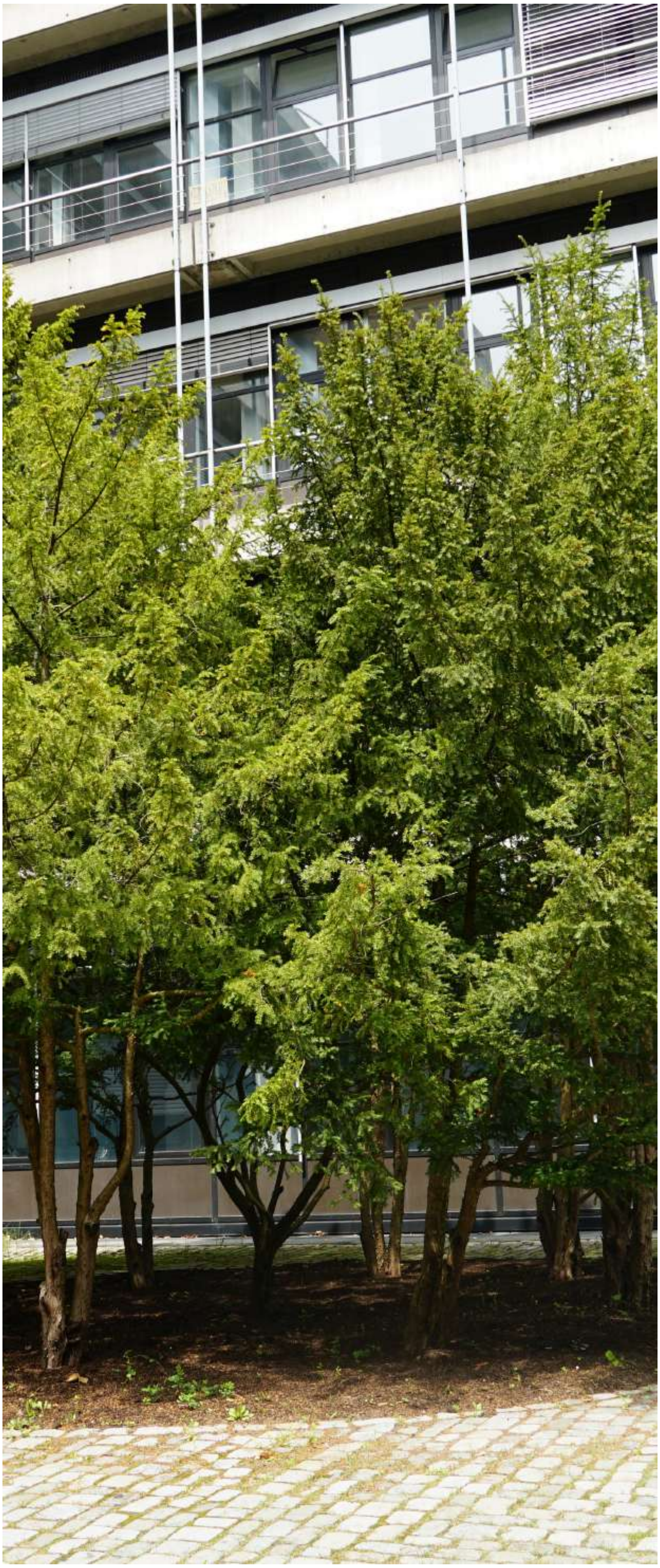


Fig 2.4 Group of trees in a courtyard in Stuttgart, Germany.

2.3 Group of trees

Groups of trees mimic the gestalt of a forest in an urban setting. They may be an option for the design of shaded squares, as a contrasting element in densely built areas, or for courtyard design. In some urban areas, groups of trees may also be developed from existing, wild growing trees that established spontaneously and are typical pioneer species of urban forests. Urban groups of trees offer many benefits like improved water management and climate resilience and contribute to the mitigation of urban heat stress. Additionally, selection of diverse native species, especially in combination with understory vegetation, can help support and enhance biodiversity.

I. Basic information

Synonyms: Arboretum; Tree groups; Sustainable urban groves

Addressed challenges:

II. Role of nature

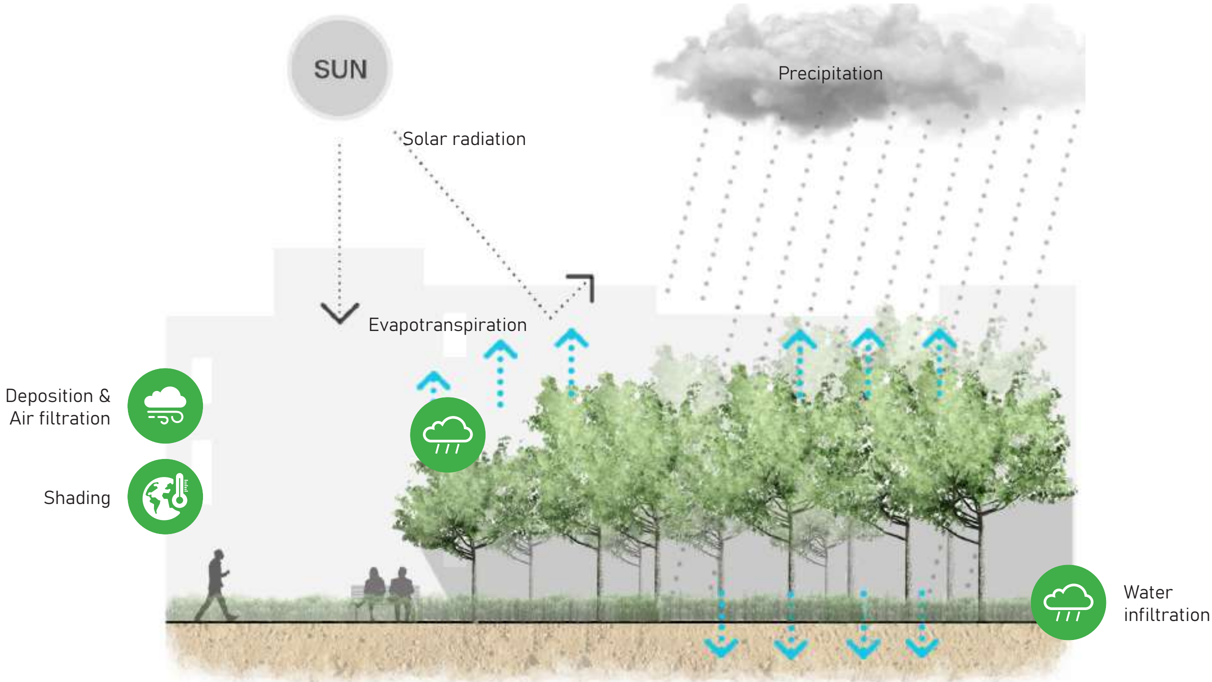


Fig 2.5 Group of trees and their associated natural processes and benefits. A shaded environment in summer, which is similar to a small patch of forest or the fringe area of larger forests..

III. Technical and design parameters

If improvements to the microclimate are desired shortly after implementation, mature trees from nurseries should be planted. If saplings are planted, it will take longer for the maximum benefit of the group of trees to be achieved. If younger trees are used, their mature height and density need to be considered when planting to avoid future above and below ground spatial issues. The trees should be planted in a rather dense grid and need to be irrigated during their first years and possibly throughout their whole lifetime. Ideally, sustainable irrigation methods, like watering with collected rainwater from surfaces and roofs, should be used for the maintenance of tree groups.

IV. Conditions for implementation

Species and sub species that are suitable for urban conditions should be planted (see factsheets 2.1 Single line street trees and 2.2 Boulevards). Selection of diverse, native species, especially in combination with understory vegetation, improves the likelihood of establishing more robust living conditions for urban wildlife, thereby supporting biodiversity. The group of trees may be planted on natural soils or in other locations, such as above underground buildings with sufficient soil depth and structural support.

V. Benefits and limitations

⊕ Potential benefits:

- Habitat provision (depending on species selection).
- Improved aesthetics.
- Meeting places.
- Public spaces for heat reduction.

⊖ Potential limitations / disservices:

- Allergic potential of pollen.
- Possible BVOC emissions, resulting in increased ozone emissions in warmer months.

VI. Performance

P1 Cooling service	
Transpiration	● ●
Shading	● ●
Evaporation	● ○
Building (Insulation)	○ ○
Reflection (Albedo)	● ●

P2 Water balance regulation service	
Water conveyance	○ ○
Water infiltration	● ○
Water retention	● ●
Water storage	○ ○
Water reuse	○ ○

P3 Water purification service	
Water filtering	○ ○
Water bio-remediation	○ ○

P4 Air purification service	
Deposition	● ○
Air biofiltration	● ○
Noise reduction	○ ○

P5 Biodiversity service	
Habitat provision	● ●
Connectivity	● ●

P6 Amenity value service	
Beauty / Appearance	● ●
Usability / Functionality	● ○
Social interaction	● ○
Education	○ ○

P7 Food / Energy / Material	
Food / Energy / Material	○ ○

P8 CO_2 Sequestration	
CO_2 Sequestration	○ ○

VII. References and further reading

Ferrini, F., van den Bosch, C. C. K., & Fini, A. (Eds.). (2019). Routledge handbook of urban forestry. Taylor & Francis. ISBN: 9780367352387.

Kowarik, I., Hiller, A., Planchuelo, G., Seitz, B., von der Lippe, M., & Buchholz, S. (2019). Emerging urban forests: Opportunities for promoting the wild side of the urban green infrastructure. Sustainability, 11(22), 6318. https://doi.org/10.3390/su11226318.

Kowarik, I., & Körner, S. (2005). Wild urban woodlands. New perspectives for urban forestry. Springer. ISBN: 978-3-540-26859-8.

Threlfall, C. G., Mata, L., Mackie, J. A., Hahs, A. K., Stork, N. E., Williams, N. S., & Livesley, S. J. (2017). Increasing biodiversity in urban green spaces through simple vegetation interventions. Journal of applied ecology, 54(6), 1874-1883. https://doi.org/10.1111/1365-2664.12876.

* See also: section VII. References and further reading of factsheets 2.1 Single line street trees and 2.2 Boulevards.

3. Soil conservation & quality management

Fig 3.0 Stream banks in Lübars, Germany.

Soil is an important natural resource in urban areas. Soils support above and below ground biodiversity, increase stormwater infiltration, improve water quality, and can help regulate the microclimate [15]. Additionally, soils mitigate climate change through carbon sequestration and the reduction of carbon dioxide (CO_2), methane (CH_4), and nitrogen nioxide (N_2O) emissions [4]. However, these benefits are reduced with common urban environmental stressors like pollution, erosion, compaction, and sealing [16,17]. As of 2015, it is estimated that about one-third of land is moderately to highly degraded due to stressors such as these [18,19]. Additionally, the formation of just one centimeter of fertile soil can take hundreds of years, making it a finite, non-renewable resource. Therefore, the protection of existing soils through soil conservation and quality management is essential. Examples of NBS and actions that involve soil conservation and quality management include slope revegetation, permaculture, organic matter enrichment, establishing windbreaks, using conservation-based tillage practices, and planting deep-rooted perennials [4]. Three examples of NBS that are used to stabilize soil and prevent erosion (i.e., living fascine, revetment with cuttings, and planted embankment mat) are described in more detail below.

3.1 Living fascine

Fig 3.1 Sketch of a living fascine at a stream bank.

Living fascines are used for the stabilization of riversides and hills. By using bundles of living wood, sometimes mixed with dead wood, living fascines can also provide habitat for plants and animals. For example, implementing living fascines, rather than their “hard” engineering counterparts, provides better structural connectivity of natural habitats, thereby supporting biodiversity. Additionally, when established near stream banks, fascines can provide food and shelter for aquatic organisms. In terms of stabilization, living fascines are superior in comparison to “dead” fascines, as plants readily develop from the living wood (vegetative growth) and developing roots provide soil protection. Additional species may also settle later into this new microhabitat.

I. Basic information

Synonyms: Live fascines

Addressed challenges:

II. Role of nature

Living fascines imitate and then stimulate natural vegetation layers with strong, branched root networks, with aboveground biomass that provides habitat structures.

III. Technical and design parameters

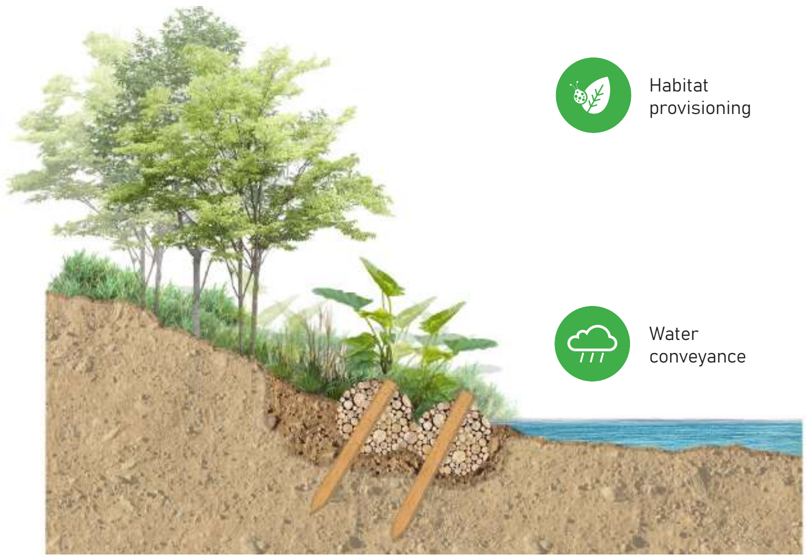


Fig 3.2 An example of a living fascine and its associated benefits.

Living fascines are traditional bioengineering elements that are mainly used outside of urban areas to restore riversides and hilly terrain. Living fascines consist of living tree branches and twigs, but may comprise up to 50% dead wood. The wood is bundled with steel cables or rope made from natural materials like jute; fast-rooting plants and cuttings should be used. Bundles usually have about a 15-20 cm diameter and are about 2-3 m long, depending on site conditions and purpose. The prepared bundles are then installed horizontally in trenches along the water bank or hillside using hardwood cuttings or dowels as fixation. Rooting fascines are covered with bushes or other plants to provide additional stabilisation and reduce the risk of erosion.

Willow is commonly used because of its favourable characteristics: Length, flexibility, elasticity and form, but species selection depends on the objective. For example, common bundle materials for hydraulic engineering are hazel and willow branches (e.g., *Salix viminalis*, *S. purpurea*), whereas for earthwork / hillside stabilization shrub branches from other species (e.g., *S. fragilis*, *S. alba*) are used. Choice of species may also depend on the local context, as species occurring on site may provide plant material for the fascines.

V. Conditions for implementation

Good timing for construction (e.g., low water flow, no rainfall) is needed, and vegetation material should be established during suitable weather and seasonal conditions to allow for vegetation development.

VI. Benefits and limitations

⊕ Potential benefits:

- Near-natural protection of hillsides and river banks.
- Benefits for biodiversity through habitat creation.

⊖ Potential limitations / disservices:

- Stability of the river bank is difficult to calculate and foresee.

VI. Performance

P1 Cooling service

Transpiration	● ○
Shading	○ ○
Evaporation	○ ○
Building (Insulation)	○ ○
Reflection (Albedo)	○ ○

P2 Water balance regulation service

Water conveyance	○ ○
Water infiltration	● ○
Water retention	● ○
Water storage	○ ○
Water reuse	○ ○

P3 Water purification service

Water filtering	● ○
Water bio-remediation	○ ○

P4 Air purification service

Deposition	○ ○
Air biofiltration	○ ○
Noise reduction	○ ○

P5 Biodiversity service

Habitat provision	● ●
Connectivity	● ○

P6 Amenity value service

Beauty / Appearance	● ○
Usability / Functionality	○ ○
Social interaction	○ ○
Education	○ ○

P7 Food / Energy / Material

Food / Energy / Material	○ ○

P8 CO_2 Sequestration

CO_2 Sequestration	● ○

VII. References and further reading

Graf, C., Böll, A., & Graf, F. (2003). Pflanzen im Einsatz gegen Erosion und oberflächennahe Rutschungen. Eid. Forschungsanstalt für Wald, Schnee und Landschaft.

Jany, A. & Geitz, P. (2013). Ingenieurbiologische Bauweisen an Fließgewässern, Teil 1. Leitfaden für die Praxis. Hg. V. WBW Fortbildungsgesellschaft für Gewässerentwicklung mbH.

Li, M. H., & Eddleman, K. E. (2002). Biotechnical engineering as an alternative to traditional engineering methods: A biotechnical streambank stabilization design approach. Landscape and Urban Planning, 60(4), 225-242. https://doi.org/10.1016/S0169-2046(02)00057-9.

Martin, F. M., Janssen, P., Bergès, L., Dupont, B., & Evette, A. (2021). Higher structural connectivity and resistance against invasions of soil bioengineering over hard-engineering for riverbank stabilisation. Wetlands Ecology and Management, 29(1), 27-39. https://doi.org/10.1007/s11273-020-09765-6.

Massachusetts clean water toolkit (n.d.). Live fascines. Retrieved from https://web.archive.org/web/20220812125353/https://megamanual.geosyntec.com/npsmanual/livefascines.aspx.

Riparian Habitat Restoration (n.d.). Live fascines. Retrieved from https://web.archive.org/web/20220812125526/http://riparianhabitatrestoration.ca/575/livefascines.htm.

Sotir, R.B. & Fischernich, C. (2001). Live and inert fascine streambank erosion control. Retrieved from https://web.archive.org/web/20220812125710/https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.694.3856&rep=rep1&type=pdf.

3.2 Revetment with cuttings

Fig 3.3 Sketch of a revetment with cuttings alongside a little stream.

A revetment with cuttings covers eroded riverbanks with, for example, willow (able to root) or brushwood (not able to root). This is a simple method using local material that stabilizes riverbanks against further erosion and leads to long-term stabilization by allowing plants to re-cultivate naturally. This method is often used in combination with other soil bioengineering techniques like living fascines to maximize stabilization potential.

I. Basic information

Synonyms: Spreitlage; Brush mattress; Brush and hedge layers; Dormant cuttings

Addressed challenges:

II. Role of nature

A revetment with cuttings imitates natural vegetation layers with strong and branched root networks, thereby offering natural production against erosion compared to bare hillsides that have a high risk of water, wind, and soil erosion. Eventually, as the revetment with cuttings matures, it should function more similarly to a restored riparian habitat.

III. Technical and design parameters

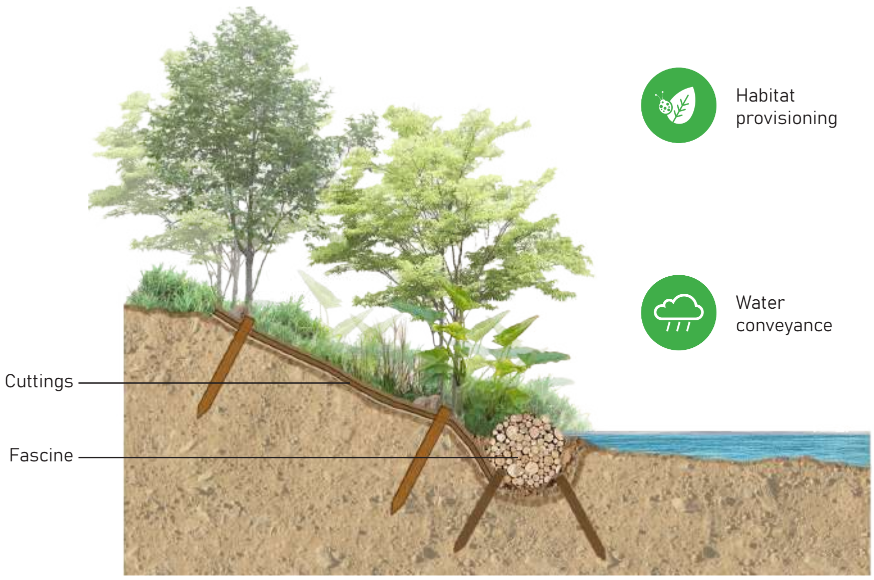


Fig 3.4 An example of a revetment with cuttings and its associated benefits, combined with a fascine.

Two to five year old shrub branches with a length of 1.5 m are typically used for construction. The stake length is usually 3-5 m, with a diameter of 4-8 cm. Native and typical plants for the specific location should be selected, both with regard to supporting local biodiversity and decreasing transportation costs.

IV. Conditions for implementation

Good timing for construction (e.g., low water flow, no rainfall) and planting is necessary.

V. Benefits and limitations

⊕ Potential benefits:

- Hillside stabilization.
- Protection against erosion.
- Riverbank protection.
- Habitat for wildlife.

⊖ Potential limitations / disservices:

- Stability of the river bank is difficult to calculate and foresee.

VI. Performance

P1 Cooling service

Transpiration	● ○
Shading	○ ○
Evaporation	○ ○
Building (Insulation)	○ ○
Reflection (Albedo)	○ ○

P2 Water balance regulation service

Water conveyance	● ○
Water infiltration	● ○
Water retention	● ○
Water storage	● ○
Water reuse	● ○

P3 Water purification service

Water filtering	● ○
Water bio-remediation	● ○

P4 Air purification service

Deposition	○ ○
Air biofiltration	○ ○
Noise reduction	○ ○

P5 Biodiversity service

Habitat provision	● ○
Connectivity	● ○

P6 Amenity value service

Beauty / Appearance	● ○
Usability / Functionality	○ ○
Social interaction	○ ○
Education	○ ○

P7 Food / Energy / Material

Food / Energy / Material	○ ○

P8 CO_2 Sequestration

CO_2 Sequestration	● ○

VII. References and further reading

Graf, C., Böll, A., & Graf, F. (2003). Pflanzen im Einsatz gegen Erosion und oberflächennahe Rutschungen. Eid. Forschungsanstalt für Wald, Schnee und Landschaft.

Jany, A. & Geitz, P. (2013). Ingenieurbiologische Bauweisen an Fließgewässern, Teil 1. Leitfaden für die Praxis. Hg. V. WBW Fortbildungsgesellschaft für Gewässerentwicklung mbH.

Li, M. H., & Eddleman, K. E. (2002). Biotechnical engineering as an alternative to traditional engineering methods: A biotechnical streambank stabilization design approach. Landscape and Urban Planning, 60(4), 225-242. https://doi.org/10.1016/S0169-2046(02)00057-9.

Soil bioengineering techniques (n.d.). Retrieved from https://web.archive.org/web/20220120062329/https://www.fs.fed.us/t-d/pubs/pdf/fs683/ch_05.pdf.

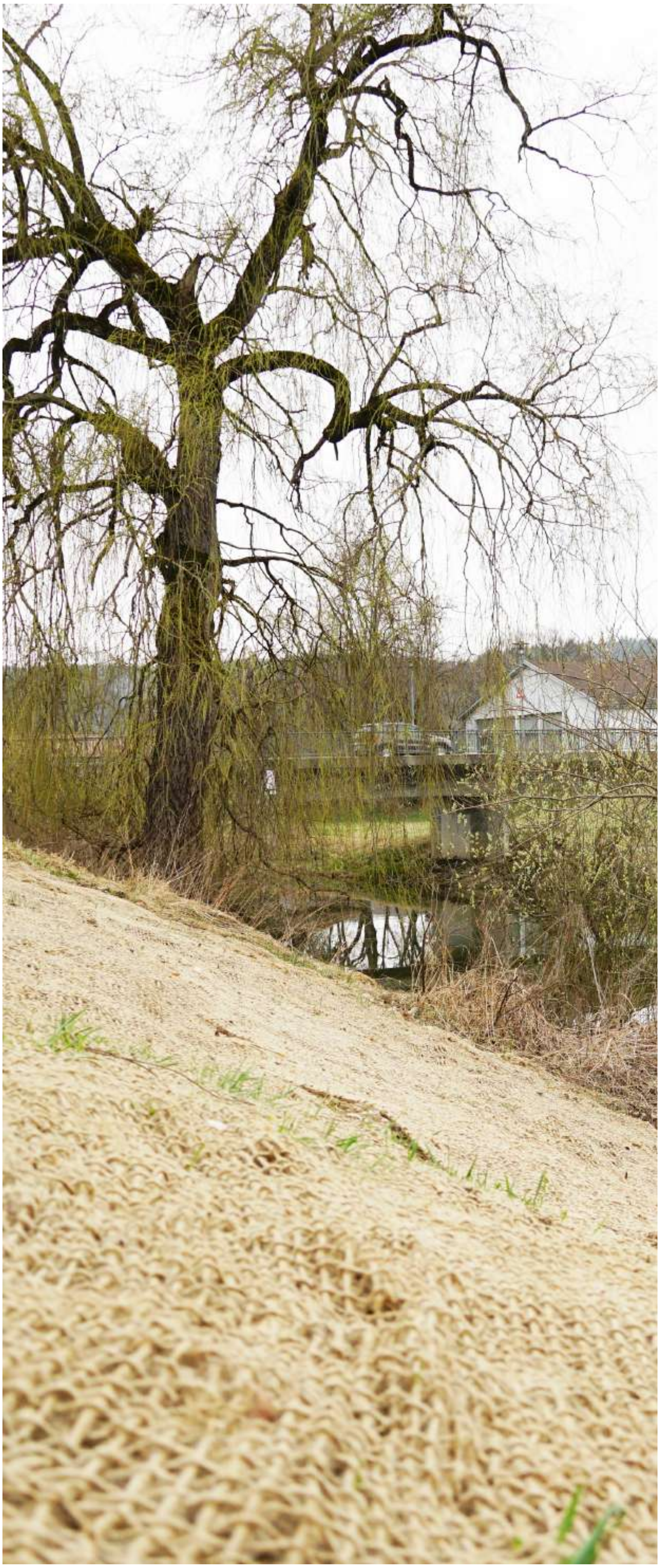


Fig 3.5 Planted embankment mat along the Danube river in Fridingen, Germany.

3.3 Planted embankment mat

Planted embankment mats are a combination of biodegradable mats with a vegetation layer. These mats are used to re-cultivate riverbanks and prevent erosion by reducing water velocity and promoting sedimentation. The biodegradable mats themselves provide temporary erosion control, while the vegetation develops and produces strong root networks, which then support longer-term erosion prevention. Using local vegetation can create or restore habitats and promote biodiversity. Construction is simple and fast, and combination with other soil bioengineering techniques like living fascines or live stakes is possible.

I. Basic information

Synonyms: Vegetated erosion-control mat; Vegetated erosion control blanket

Addressed challenges:

Water management

Air quality

Biodiversity

II. Role of nature

Planted embankment mats imitate natural vegetation layers with strong and branched root networks, thereby offering natural protection against erosion compared to bare hillsides that have a high risk of water, wind, and soil erosion. Eventually, as the vegetation on the planted embankment mat matures, it should function more similarly to a restored (e.g., riparian) habitat.

III. Technical and design parameters

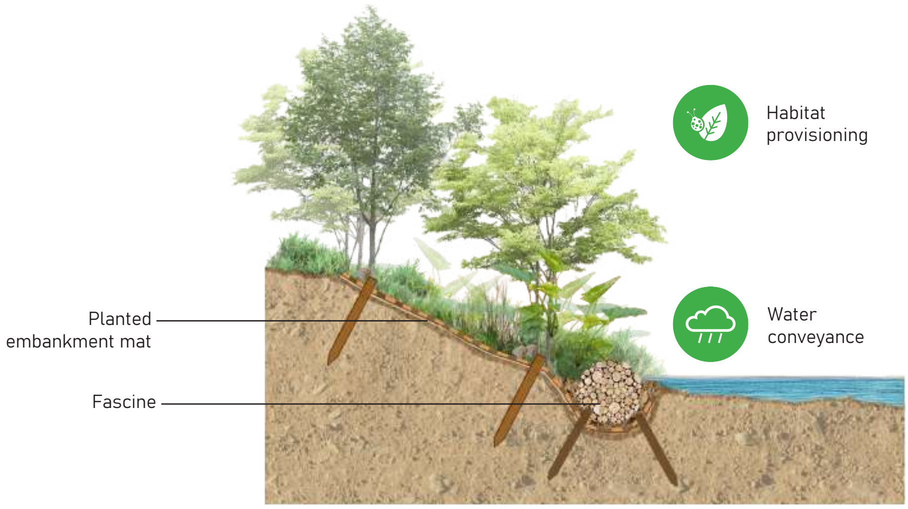


Fig 3.6 An example of a planted Embankment mat and its associated benefits, combined with a fascine.

The mats are simply constructed using biodegradable, plant-based materials such as coir (coconut fiber) or jute, and installation is simple and fast. Appropriate, steadfast species that develop strong rooting systems should be selected to best improve long-term erosion control potential. Addionally, local, native vegetation should be preferentially planted to support habitat restoration and biodiversity enhancement.

IV. Conditions for implementation

Good timing for construction (e.g., low water flow, no rainfall) and planting (e.g., suitable weather and seasonal conditions) is necessary.

V. Benefits and limitations

⊕ Potential benefits:

- Protection against erosion.
- Habitat for wildlife.

⊖ Potential limitations / disservices:

- Stability of the river bank is difficult to calculate and foresee.

VI. Performance

P1 Cooling service

Transpiration	● ○
Shading	○ ○
Evaporation	○ ○
Building (Insulation)	○ ○
Reflection (Albedo)	○ ○

P2 Water balance regulation service

Water conveyance	○ ○
Water infiltration	● ○
Water retention	● ○
Water storage	○ ○
Water reuse	○ ○

P3 Water purification service

Water filtering	● ○
Water bio-remediation	● ○

P4 Air purification service

Deposition	○ ○
Air biofiltration	○ ○
Noise reduction	○ ○

P5 Biodiversity service

Habitat provision	● ○
Connectivity	● ○

P6 Amenity value service

Beauty / Appearance	● ○
Usability / Functionality	○ ○
Social interaction	○ ○
Education	○ ○

P7 Food / Energy / Material

Food / Energy / Material	○ ○

P8 CO_2 Sequestration

CO_2 Sequestration	● ○

VII. References and further reading

Graf, C., Böll, A., & Graf, F. (2003). Pflanzen im Einsatz gegen Erosion und oberflächennahe Rutschungen. Eid. Forschungsanstalt für Wald, Schnee und Landschaft.

Jany, A. & Geitz, P. (2013). Ingenieurbiologische Bauweisen an Fließgewässern, Teil 1. Leitfaden für die Praxis. Hg. V. WBW Fortbildungsgesellschaft für Gewässerentwicklung mbH.

Li, M. H., & Eddleman, K. E. (2002). Biotechnical engineering as an alternative to traditional engineering methods: A biotechnical streambank stabilization design approach. Landscape and Urban Planning, 60(4), 225-242. https://doi.org/10.1016/S0169-2046(02)00057-9.

Swan River Trust (2009). Best management practices for foreshore stabilization. Retrieved March 20, 2021, from https://www.dpaw.wa.gov.au/images/documents/conservation-management/riverpark/Management.pdf.

Vishnudas, S., Savenije, H. H. G., Van der Zaag, P., Anil, K. R., & Balan, K. (2006). The protective and attractive covering of a vegetated embankment using coir geotextiles. Hydrology and Earth System Sciences, 10, 565–574. https://doi.org/10.5194/hess-10-565-2006.

4. Green built environment

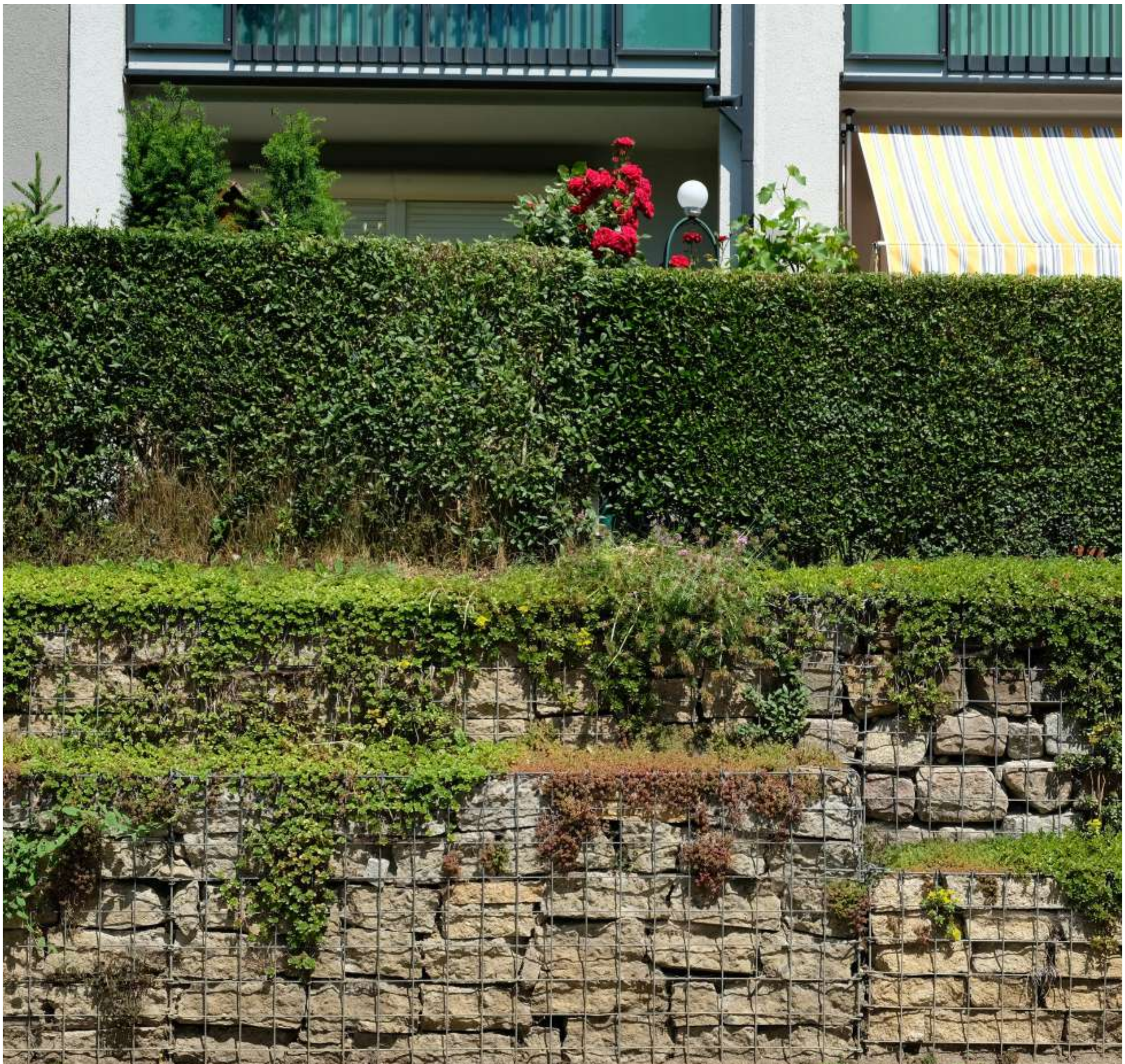


Fig 4.0 Planted stone gabions constructed using rubble from a demolished building in Berlin, Germany.

The green built environment includes structural elements of the urban environment that incorporate vegetation into their design [4]. This can include areas that were conventionally grey spaces like rooftops and façades.

NBS in this category are extremely diverse. Examples include green roofs, green walls and façades, green alleys and parking lots, and even small-scale or temporary structures like green living rooms. Additionally, elements of the same typology, for example green roofs, can be highly variable due to design, structural differences, selected species, and growing media [4]. Because of this diversity, there is a large range of benefits that can be supported by the green built environment including pollution mitigation, microclimate and stormwater regulation, biodiversity enhancement, as well as social and educational benefits. While smaller scale elements of the green built environment are beneficial on their own, potential benefits may be maximized when many of these NBS are integrated into a larger nature-based framework or masterplan focused on addressing urban challenges.

Examples of NBS as part of the green built environment (i.e., extensive and intensive green roofs, constructed wet roofs, smart roofs, green façades, free standing living walls, mobile green living rooms, and moss walls) are described in more detail below.

Fig 4.1 Extensive green roof on a mixed use building complex in Stuttgart, Germany.

4.1 Extensive green roof

Extensive green roofs are lightweight systems that consist of a thin substrate layer with shallow-rooted, low growing, and often rapidly spreading vegetation. Typical groups of vegetation for extensive green roofs include sedums, herbs, wildflowers, grasses, and mosses, since they are relatively hardy and can often survive in low-nutrient conditions. Once established, extensive green roofs are characterized by their minimal maintenance and management requirements. However, they are often only accessible for maintenance purposes and not open to the public.

Compared to typical grey roofs, extensive green roofs can offer benefits like localized air temperature and pollution reduction, and contribute to water management. These benefits, however, tend to be less extensive than those associated with their more complex and expensive counterparts – intensive green roofs.

I. Basic information

Synonyms: Low-Profile; Eco-Roofs; Extensive roof greening

Addressed challenges:

Climatic resilience | Water management | Natural & climatic hazards | Biodiversity | Public health & well-being

II. Role of nature

Through the establishment of green roofs on buildings, different services of natural vegetation layers are replicated. These include habitat creation (e.g., dry grassland types) or more generally, the establishment of stepping stone biotopes in an urban area.

III. Technical and design parameters

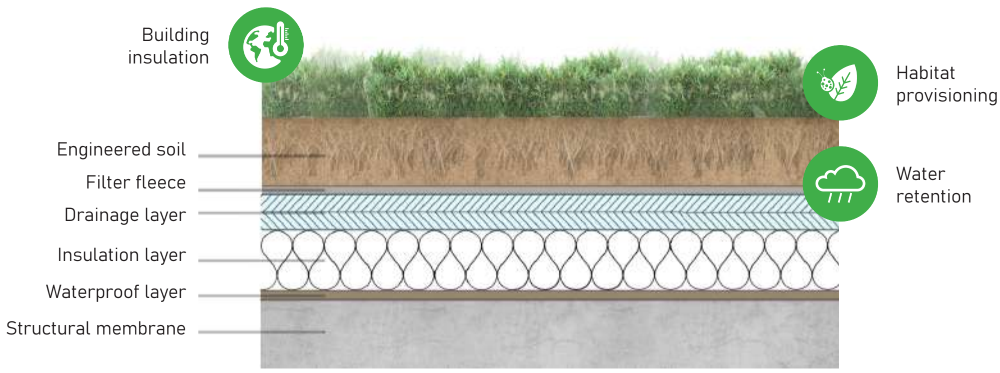


Fig 4.2 Typical layers of an extensive roof and its associated benefits.

There are many different systems for extensive green roofs, and therefore no uniform design exists. For example, vegetation can be planted directly on special “biological” concrete, established on a variety of substrate mixes, or on synthetic fiber mats, alone or in combination with an underlying substrate. If a substrate is included, then it is thin, typically under 20 cm. Despite this thin substrate, extensive green roofs should have a minimum water storage capacity of 25 L/m² and at least 95% vegetation coverage three years after implementation.

Although vegetation is usually restricted to non-woody plants (e.g., moss, sedum, herbs, grasses), there is still a great variety possible. Appropriate plants for extensive green roofs are low-growing, rapidly spreading, and shallow-rooting plants or hardy perennials including succulents that are able to survive with minimal nutrient uptake and without additional nutrient supply. The selected plants for extensive green roofs are generally well adapted to alpine or rocky environments and tolerate different climatic conditions like drought and temperature fluctuations.

Extensive green roofs typically bear less weight, require less water and investment, and can be planted on more steeply pitched surfaces (up to 85° possible with technical devices) than intensive green roofs. Therefore, existing buildings tend to be retrofitted with extensive, rather than intensive, green roofs. Regular maintenance (but less than for intensive green roofs) is necessary, and special care is needed to regularly remove spontaneous woody vegetation.

IV. Conditions for implementation

Site characteristics are often dependent on project objectives. For example, if the objective is to improve aesthetics, then high-density, visible sights are preferable. Regardless of location, solid, stable concrete buildings with a high bearing capacity, and flat or relatively flat rooftops with underground support structures are necessary.

V. Benefits and limitations

⊕ Potential benefits:

- Supports human health and good quality of life.
- Stormwater management and quality.
- Improved air quality.
- Aesthetic value
- Localized air temperature reduction (less than intensive green roofs).
- Energy reduction for buildings (less than intensive green roofs).
- Reduction of noise pollution.
- Habitat provision for urban wildlife.

⊖ Potential limitations / disservices:

- Limited development of undisturbed habitats because of human activities (if publically accessible).
- Limited space for roots.
- Often not publicly accessible.

VI. Performance

P1 Cooling service

Transpiration	○	○
Shading	●	○
Evaporation	●	○
Building (Insulation)	●	○
Reflection (Albedo)	●	○

P2 Water balance regulation service

Water conveyance	●	○
Water infiltration	○	○
Water retention	●	○
Water storage	○	○
Water reuse	○	○

P3 Water purification service

Water filtering	○	○
Water bio-remediation	○	○

P4 Air purification service

Deposition	○	○
Air biofiltration	○	○
Noise reduction	○	○

P5 Biodiversity service

Habitat provision	●	○
Connectivity	●	○

P6 Amenity value service

Beauty / Appearance	●	○
Usability / Functionality	●	○
Social interaction	○	○
Education	○	○

P7 Food / Energy / Material

Food / Energy / Material	○	○

P8 CO_2 Sequestration

CO_2 Sequestration	●	○

VII. References and further reading

Climate Adapt (2020). Green roofs in Basel, Switzerland: Combining mitigation and adaptation measures. Retrieved from https://web.archive.org/web/20220812131938/https://climate-adapt.eea.europa.eu/metadata/case-studies/green-roofs-in-basel-switzerland-combining-mitigation-and-adaptation-measures-1.

Climate Adapt (2020). Urban storm water management in Augustenborg, Malmö. Retrieved from https://web.archive.org/web/20220812132110/https://climate-adapt.eea.europa.eu/metadata/case-studies/urban-storm-water-management-in-augustenborg-malmo.

Elliott, R. M., Gibson, R. A., Carson, T. B., Marasco, D. E., Culligan, P. J., & McGillis, W. R. (2016). Green roof seasonal variation: Comparison of the hydrologic behavior of a thick and a thin extensive system in New York City. Environmental Research Letters, 11(7), 074020. https://doi.org/10.1088/1748-9326/11/7/074020.

Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V. (FLL, 2018). Green roof guidelines: Guidelines for the planning, construction and maintenance of green roofs. Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau, Bonn, Germany.

Lynch, A. J. (2019). Creating effective urban greenways and stepping-stones: Four critical gaps in habitat connectivity planning research. Journal of Planning Literature, 34(2), 131-155. https://doi.org/10.1177/0885412218798334.

Schröder, R., & Kiehl, K. (2020). Extensive roof greening with native sandy dry grassland species: Effects of different greening methods on vegetation development over four years. Ecological Engineering, 145, 105728. https://doi.org/10.1016/j.ecoleng.2020.105728.

Snodgrass, E. C., & McIntyre, L. (2010). The green roof manual: A professional guide to design, installation, and maintenance. Timber Press. ISBN-10: 1604690496.

U.S. Environmental Protection Agency (2008). Reducing urban heat islands: Compendium of strategies. Draft heat island reduction activities. Retrieved March 20, 2021, from https://www.epa.gov/heatislands/heat-island-compendium.

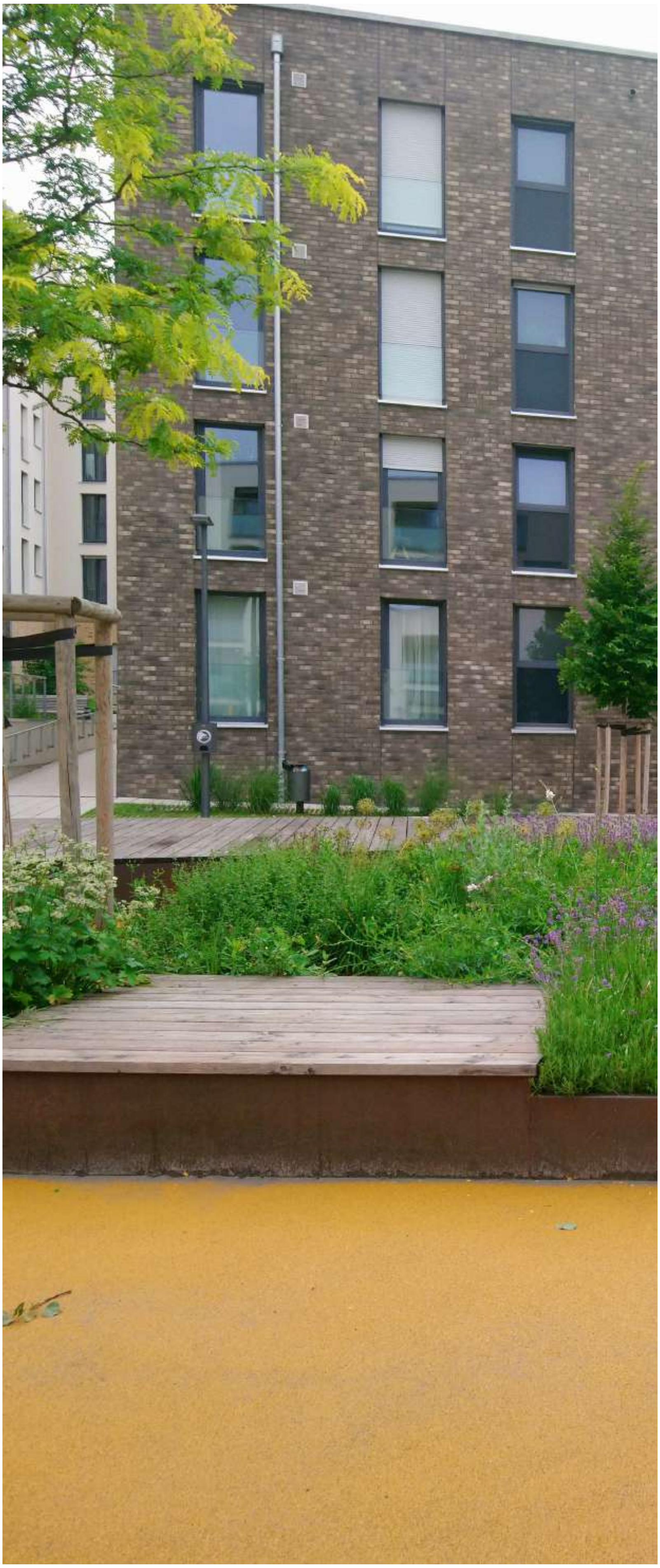


Fig 4.3 Intensive green roof used as a community courtyard in Stuttgart, Germany.

4.2 Intensive green roof

Intensive green roofs are heavier greening systems characterized by a thicker growing medium with more varied vegetation types (compared to extensive green roofs). Common plants used for intensive green roofs include a variety of smaller trees, shrubs, and perennials. Depending on design, intensive green roofs provide many benefits like stormwater storage, reduction of air and water pollution, reduction of localized air temperature, and biodiversity enhancement. They are commonly found on residential buildings, hotels, and parking structures and are often multifunctional areas that can be used for many activites including gardening, relaxing, and socializing. To enable activities for people and the integration of larger plants, trees, and architectural elements on green roofs, suitable rooftops need to be relatively flat and fulfil more complex technical requirements e.g., regarding weight.

I. Basic information

Synonyms: High-Profile; Roof gardens; Roof greening

Addressed challenges:

Climatic resilience | Water management | Natural & climatic hazards | Air quality | Biodiversity | Public health & well-being | Social justice & cohesion

II. Role of nature

The model for a green roof is soil with its vegetation cover. Intensive green roofs on buildings provide services similar to natural vegetation layers, and can provide a variety of ecosystem services that benefit the surrounding environment. For example, retention of precipitation in the growing medium and mitigation of the urban heat island through vegetation shading and transpiration are fundamental services of intensive green roofs.

III. Technical and design parameters

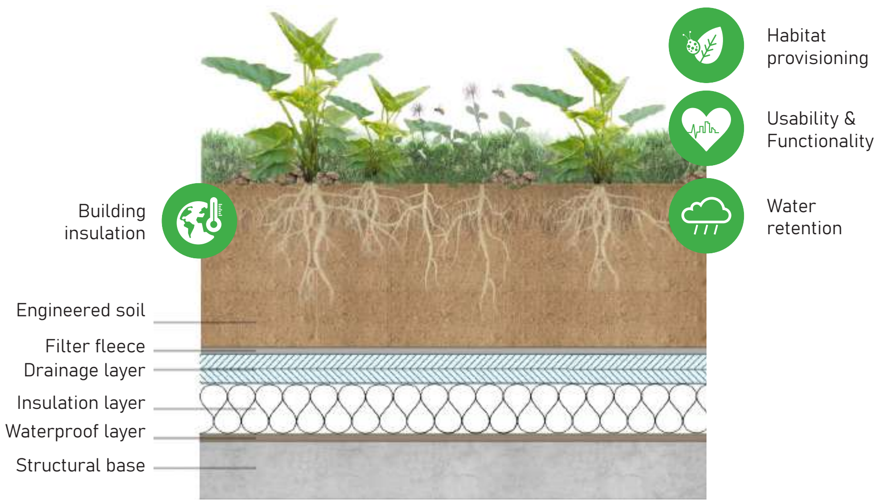


Fig 4.4 Typical layers of an intensive roof and its associated benefits.

There are many different greening systems for intensive green roofs, and therefore no uniform construction exists. The roof itself must be relatively flat (0-5°), and it is important to consider the weight load, irrigation system, growing medium, and maintenance. Because of their structural design, the choice of suitable plants is greater than for extensive green roofs. Appropriate plants for intensive green roofs include a variety of smaller trees, shrubs, and perennials. The growth media is relatively thick and notably deeper than for extensive systems with integrated low-growing plants (see Factsheet 5.1). The growth media of intensive green roofs needs to be relatively deep and nutrient rich to support the growth of plants such as trees.

Based on the technical construction itself and the choice growing media, intensive green roofs can be designed to temporarily store stormwater and wastewater, and reduce impurities. The thicker substrates used for intensive green roofs can increase the potential of services like building insulation and water filtration, storage, and retention. Additionally, using a biodiversity sensitive design (e.g., including a variety of substrate depths, incorporating local soils into the growing substrate, planting structurally diverse vegetation) may help improve the biodiversity enhancement potential of intensive green roofs.

IV. Conditions for implementation

Site characteristics are often dependent on project objectives. For example, if the objective is to improve aesthetics, then high-density, visible sights are preferable. Regardless of location, solid, stable concrete buildings with a high bearing capacity, and flat or relatively flat rooftops with underground support structures are necessary. Additionally, an artificial irrigation system or, preferably, rainwater irrigation facilities, are needed for dry periods. In some cases, special plates that distribute pressure on the rooftop are needed for planter-based intensive green roofs.

V. Benefits and limitations

⊕ Potential benefits:

- Supports human health and good quality of life.
- Stormwater management and quality.
- Improved air quality.
- Aesthetic and recreational value.
- Food production (e.g., through urban gardening).
- Additional (public) green space.
- Localized air temperature reduction.
- Energy reduction for buildings (heating / cooling).
- Reduction of noise pollution.
- Habitat provision for urban wildlife.

⊖ Potential limitations / disservices:

- Limited development of undisturbed habitats because of human activity.

VI. Performance

P1 Cooling service

Transpiration	●	●
Shading	●	○
Evaporation	●	○
Building (Insulation)	●	●
Reflection (Albedo)	●	○

P2 Water balance regulation service

Water conveyance	●	●
Water infiltration	○	○
Water retention	●	●
Water storage	●	○
Water reuse	○	○

P3 Water purification service

Water filtering	●	○
Water bio-remediation	○	○

P4 Air purification service

Deposition	●	○
Air biofiltration	○	○
Noise reduction	○	○

P5 Biodiversity service

Habitat provision	●	○
Connectivity	●	○

P6 Amenity value service

Beauty / Appearance	●	●
Usability / Functionality	●	○
Social interaction	●	○
Education	○	○

P7 Food / Energy / Material

Food / Energy / Material	○	○

P8 CO_2 Sequestration

CO_2 Sequestration	●	○

VII. References and further reading

ERSI Canada (n.d). Sustainable prosperity: Green Roof. Retrieved from https://web.archive.org/web/20220812133215/https://www.esri.ca/en-ca/about/sustainable-prosperity/green-roof.

Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V. (FLL, 2018). Green roof guidelines: Guidelines for the planning, construction and maintenance of green roofs. Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau, Bonn, Germany.

Grennroofs.com (n.d.). Chicago city hall. Retrieved from https://web.archive.org/web/20220812133550/https://www.greenroofs.com/projects/chicago-city-hall/.

Gonsalves, S., Starry, O., Szallies, A., & Brenneisen, S. (2022). The effect of urban green roof design on beetle biodiversity. Urban Ecosystems, 25(1), 205-219. https://doi.org/10.1007/s11252-021-01145-z.

Hui, S. C., & Chan, K. L. (2011). Biodiversity assessment of green roofs for green building design. In Proceedings of Joint Symposium 2011 on Integrated Building Design in the New Era of Sustainability.

International Green Roof Association e.V. (IGRA, 2018). IGRA guidelines for green roofs. Green roof policies. Manual for decision makers and green roof supporters. Nürtingen. Retrieved March 20, 2021, from https://www.scribd.com/document/384199777/IGRA-Green-Roof-Policy-Guideline.

Malmö stad (n.d.). Green roofs throughout the city. Retrieved March 20, 2021, from https://malmo.se/Nice-to-know-about-Malmo/Technical-visits/Theme-Sustainable-City/-Ecology-Energy-and-Climate/Green-roofs.html.

Perot Museum of Nature and Science (n.d.). Yes, it's an exhibit all by itself. Retrieved from https://web.archive.org/web/20220812134313/https://www.perotmuseum.org/exhibits/halls/the-building/.

Snodgrass, E. C., & McIntyre, L. (2010). The green roof manual: A professional guide to design, installation, and maintenance. Timber Press. ISBN-10: 1604690496.

U.S. Environmental Protection Agency (2008). Reducing urban heat islands: Compendium of strategies. Draft heat island reduction activities. Retrieved March 20, 2021, from https://www.epa.gov/heatislands/heat-island-compendium.

Fig 4.5 Sketch of a constructed wet roof.

4.3 Constructed wet roof

The idea of constructed wet roofs (CWR) is to combine extensive green roofs and constructed wetlands for domestic wastewater (i.e., grey water) treatment. Constructed wet roofs temporarily retain stormwater and gradually release it, thereby reducing peak runoff flow. CWRs offer many of the same benefits as extensive green roofs, but are more physiologically active than extensive green roofs, especially in hot, dry periods, contributing to stronger positive impacts on microclimate, air quality, and biodiversity. Additionally, the treated water from the CWR can be reused for irrigation or, for example, in toilets.

I. Basic information

Synonyms: Wetland roofs

Addressed challenges:

II. Role of nature

Constructed wet roofs are inspired by, and mimic the processes of natural wetlands, especially wetland soils. CWRs can provide a variety of benefits, with stormwater management often being the most targeted. CWRs collect and temporarily retain stormwater, thereby reducing flood risk during and shortly after a storm event. As in nature, the water then evaporates directly from the water surface and transpires from plant surfaces and stomata, decreasing the air temperature. Additionally, CWRs harness the ability of natural wetlands to reduce impurities in stormwater or potentially domestic or industrial grey water, as it filters through the system.

III. Technical and design parameters

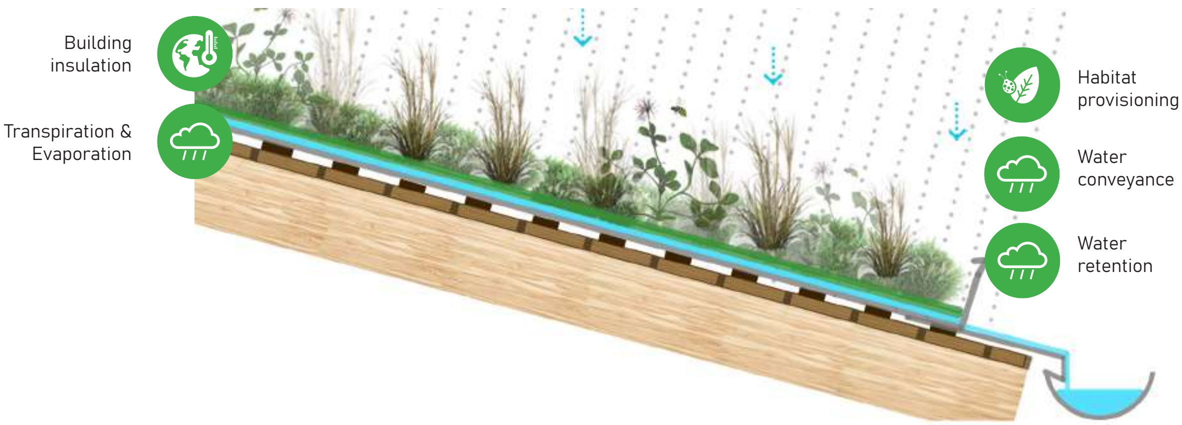


Fig 4.6 An example of a constructed wet roof and its associated benefits.

From the top down, a horizontal flow constructed wet roof typically consists of turf mats with sandy, fertilized soil, and vegetation rooting in stabilization plates on a substratum of sand, light expanded clay aggregates, and polyactic acid beads. The wetland-suitable plants are irrigated with storm and wastewater to ensure the surface remains moist and maintains the green space. Types of wastewater that can be used in CWRs include domestic wastewater, for example, from kitchen or bathroom sinks. CWRs are usually constructed on moderately to high-pitched roofs, with a waterproof (e.g., bituminous waterproofing) surface. Construction on flat roofs is also possible, in which case about 10 to 30 cm of water is retained with floating, vegetative mats.

Some of the technical devices that need to be considered in construction and maintenance include septic and inlet tanks, pumps for each bed, pressure pipes (influent and effluent pipe), and an infiltration pond.

IV. Conditions for implementation

Like with all green roofs, it is necessary that the roof is waterproofed and has a sufficient load-bearing capacity. The roof must also have a slope gradient to water outlets and emergency overflows.

V. Benefits and limitations

⊕ Potential benefits:

- Effect on microclimate: Cooling of air temperature.
- Reduced flood risk due to water retention.
- Habitat for wildlife.
- Improves water quality.
- Re-use of water (water can be used for different purposes after natural treatment).

⊖ Potential limitations / disservices:

- Greater maintenance effort and cost than traditional extensive green roofs.

VI. Performance

P1 Cooling service

Transpiration	●●
Shading	●○
Evaporation	●○
Building (Insulation)	●●
Reflection (Albedo)	●○

P2 Water balance regulation service

Water conveyance	●○
Water infiltration	○○
Water retention	●○
Water storage	●○
Water reuse	●○

P3 Water purification service

Water filtering	●○
Water bio-remediation	●○

P4 Air purification service

Deposition	●○
Air biofiltration	○○
Noise reduction	○○

P5 Biodiversity service

Habitat provision	●○
Connectivity	○○

P6 Amenity value service

Beauty / Appearance	●○
Usability / Functionality	●○
Social interaction	○○
Education	○○

P7 Food / Energy / Material

Food / Energy / Material	○○

P8 CO_2 Sequestration

CO_2 Sequestration	●○

VII. References and further reading

Oppla (n.d.). Multifunctional urban greening in Malmö, Sweden. Retrieved from https://web.archive.org/web/20220812134628/https://oppla.eu/casestudy/19011.

Ingenieurbüro Blumberg (n.d.). Wetland roofs. Retrieved from https://web.archive.org/web/20201205141838/https://www.blumberg-engineers.com/en/ecotechnologies/wetland-roofs.

Song, U., Kim, E., Bang, J. H., Son, D. J., Waldman, B., & Lee, E. J. (2013). Wetlands are an effective green roof system. Building and Environment, 66, 141-147. https://doi.org/10.1016/j.buildenv.2013.04.024.

William, R., Goodwell, A., Richardson, M., Le, P. V., Kumar, P., & Stillwell, A. S. (2016). An environmental cost-benefit analysis of alternative green roofing strategies. Ecological Engineering, 95, 1-9. https://doi.org/10.1016/j.ecoleng.2016.06.091.

Zapater-Pereyra, M., Lavrnić, S., Van Dien, F., Van Bruggen, J. J. A., & Lens, P. N. L. (2016). Constructed wetroofs: A novel approach for the treatment and reuse of domestic wastewater. Ecological Engineering, 94, 545-554. https://doi.org/10.1016/j.ecoleng.2016.05.052.

Zehnsdorf, A., Willebrand, K. C., Trabitzsch, R., Knechtel, S., Blumberg, M., & Müller, R. A. (2019). Wetland roofs as an attractive option for decentralized water management and air conditioning enhancement in growing cities: A review. Water, 11(9), 1845. https://doi.org/10.3390/w11091845.

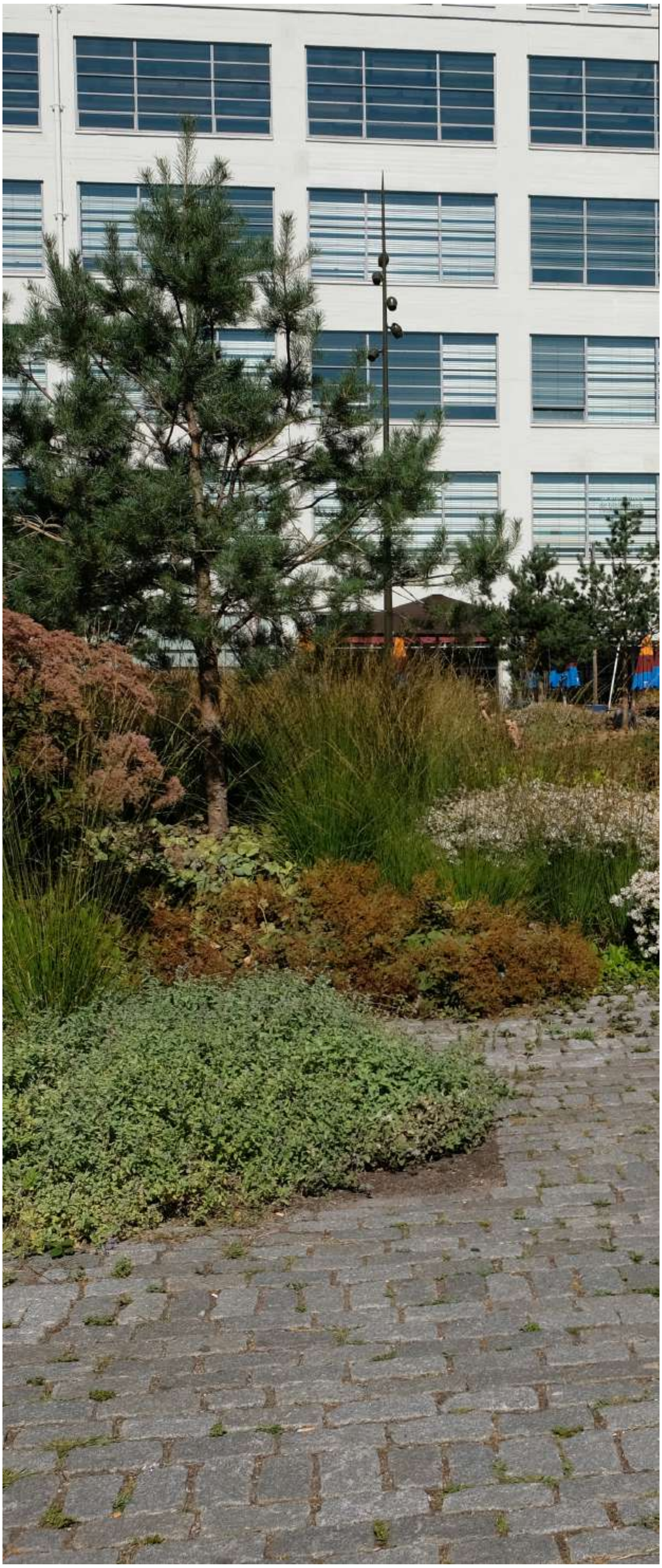


Fig 4.7 A complex roof greening design with capillary fibre cylinders at Clausplein in Eindhoven, Netherlands.

4.4 Smart roof

Smart roofs are a unique type of intensive or extensive green roof that provide several services to protect ecosystems in cities. Many of the benefits are similar to other green roofs (e.g., basic habitat provision, reduction of localized air temperature, stormwater management). However, capillary smart roofs represent an extension of conventional green roofs because the system is equipped with a drainage system under the vegetation layer. The drainage layer retains stormwater, thereby reducing flood risk more so than a typical green roof. Through capillary fiber cylinders, water is naturally returned to the vegetation layer during dry periods. Capillary smart roofs represent cyclic water management where additional plant irrigation is not needed (100% of the stormwater can be reused for irrigation).

I. Basic information

Synonyms: Capillary smart roof; Blue-green roof

Addressed challenges:

Climatic resilience | Water management | Natural & climatic hazards | Air quality | Biodiversity

II. Role of nature

The model for a green roof is natural soil with its vegetation cover. Through the establishment of green roofs on buildings, different services of natural vegetation layers are replicated. Capillary smart roofs use the process of capillary action (also the process plants use to move water from their roots and stems to the rest of the plant) to slowly transfer water from a storage layer to the soil layer, making it available for the vegetation.

III. Technical and design parameters

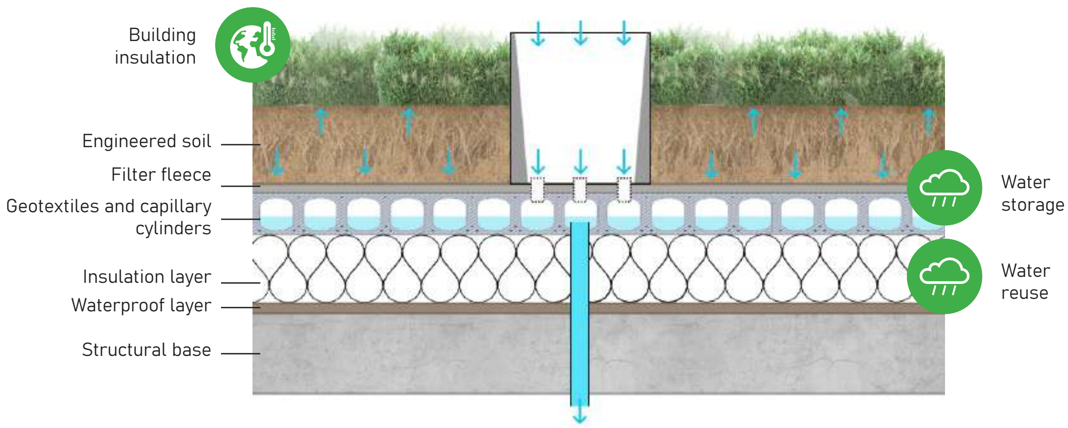


Fig 4.8 Typical layers of a smart roof and its associated benefits.

Capillary smart roofs have a layered construction. The basic construction starting from the bottom up begins with a protective layer and waterproof membrane, followed by drainage and storage layers of capillary geotextiles and capillary cylinders, and topped off with a lightweight substrate and vegetation. An emergency overflow system should be included, but in general, additional technical devices like pumps, tanks, and valves are unnecessary.

IV. Conditions for implementation

The roof or surface must have sufficient load-bearing capacity and waterproofing.

V. Benefits and limitations

⊕ Potential benefits:

- Reduced flood risk.
- Re-use of water.
- Habitat for wildlife.

VI. Performance

P1 Cooling service

Transpiration	● ○
Shading	● ○
Evaporation	● ○
Building (Insulation)	● ●
Reflection (Albedo)	● ○

P2 Water balance regulation service

Water conveyance	● ●
Water infiltration	○ ○
Water retention	● ●
Water storage	● ●
Water reuse	● ○

P3 Water purification service

Water filtering	● ○
Water bio-remediation	○ ○

Deposition	● ○
Air biofiltration	○ ○
Noise reduction	○ ○

P5 Biodiversity service

Habitat provision	○ ○
Connectivity	○ ○

P6 Amenity value service

Beauty / Appearance	● ○
Usability / Functionality	○ ○
Social interaction	○ ○
Education	○ ○

P7 Food / Energy / Material

Food / Energy / Material	○ ○

P8 CO_2 Sequestration

CO_2 Sequestration	● ○

VII. References and further reading

ABG (2020). AGB blueroof and green extensive roof, Huddersfield, UK. Retrieved from https://web.archive.org/web/20220812140658/https://www.abg-geosynthetics.com/case-studies/green-roofs-blue-roofs-and-podium-decks/blueroof-green-extensive-roof-huddersfield/.

Amsterdam Rainproof (2017). Project smart roof 2.0. Retrieved from https://web.archive.org/web/20220812141308/https://www.rainproof.nl/project-smartroof-20.

Marineterrein Amsterdam (n.d.). From blazing hot to cool and green. Retrieved from https://web.archive.org/web/20220211131810/https://www.marineterrein.nl/en/project/project-smartroof-2-0/.

Fig 4.9 Green façade with a façade-bound greening in Reutlingen, Germany.

4.5 Green façades

Planted façades with controlled cultivation are called green façades. Green façades offer many benefits including reduction of air pollution, thermal insulation for buildings, and biodiversity support via habitat provision and connectivity improvement. Façade greenings are divided into two types: façade-bound greening and ground-based greening.

Façade-bound greening uses panels or containers that are fixed to the façade or is part of the façade itself. Vegetation is usually planted directly in the thin substrate of the panel and then elevated. Therefore, façade-bound greening systems do not rely on climbing plants, and can be removed during winter.

Ground-based green façades are established using climbing plants. The climbing vegetation is planted in the ground and therefore extracts water and nutrients directly from the soil. The vegetation grows directly on the wall, or climbs on a frame that is connected to, but keeps a small distance from the wall.

I. Basic information

Synonyms: Façade-Bound greening; Ground-Based greening; Green wall; Living wall; Vertical greening systems

Addressed challenges:

II. Role of nature

Façade-bound greening provides services similar to a very thin natural soil, which is used to support vegetation. Depending on the type and level of engineering for irrigation, nutrient supply, and substrate, façade-bound greening can perform highly. Integrated vegetation can range from plants of rather wet environments to very dry environments.

Climbing plants used in ground-based greening grow from rather small areas of natural soil and often need supporting vertical elements or a porous surface the plant can attach to (species dependent). A comparable natural situation may be bright areas of forests and their fringes (e.g., *Clematis* species).

III. Technical and design parameters

Façade-bound greening

In most cases, façade-bound greening intensively uses technology for irrigation and special substrates for reducing the weight of the green façade. Pre-cultivated panels or special plant pot systems are most frequently used. For lightweight structures, special tissues are used. Because of the thinness of the soil or substrate layer, temperatures below 0°C may be a problem. Therefore, some greening systems have panels that can be removed during winter. Façade-bound greening does not usually rely on climbing plants, as vegetation is usually first planted in the panel and then elevated.

Options depend highly on the character of the building (new construction, refurbishment, restoration) and on structural engineering. For new constructions, integrated façade systems can be used with vegetation panels (0.5 m²-1 m²).

For regeneration projects, a separate scaffolding is often needed. Typical specifications include:
- Panel: 0.5-1.0 m²
- Selection of 10-15 (usually small) plant species, mainly perennial species.
- Regular irrigation and special substrate is necessary

Fig 4.10 Two types of façade-bound greening. Planter-based with climbers (left) and a modular greening system (right).

Ground-based greening

It is important to differentiate between self-climbing plants and climbers that need a support system. A façade without gaps is necessary for self-climbers to avoid intrusion of roots into the façade, whereas a supporting frame is needed for climbers. Climbing plants can grow up to 25 meters high, however plant selection depends on environmental factors, and usually only few of species can be combined. Depending on the desired outcomes (e.g., shading in the summer with light in the winter, or year-round insulation), evergreen or deciduous vegetation may be selected.

Fig 4.11 Two types of ground-based greening with an external support system (left) and without a support system (right).

IV. Conditions for implementation

While all surfaces are potentially usable for a green façade, areas with plenty of sun exposure and with mild climatic conditions (e.g., not very dry, hot, or cold) tend to perform best. For façade-bound greening, mosses and small perennial plants are appropriate, but other suitable vegetation can also be selected. For ground-based greening, good soil or substrate, and a strong façade without gaps is necessary. It takes about 5-20 years for ground-based greening to fully cover a medium-sized house façade.

It is important to use material that can withstand high temperatures, and if the substrate or vegetation dries out there is a risk of fire. Special care of professional gardeners (particularly for façade-bound greening) is usually needed for maintenance.

V. Benefits and limitations

⊕ Potential benefits:

- Air pollution is reduced by plants, they bind high proportions of the particulate matter and polluting gases.
- Reduction of façade surface temperature via shading, evapotranspiration, and reflection.
- Reduction of local air temperature via evapotranspiration.
- Building insulation.
- Water retention.
- Biodiversity support through increased habitat connectivity and provision: For example, habitat for nesting and breeding for birds and potentially for bats.
- Natural noise protection.
- Improved aesthetics.
- Ground-based green façades that are irrigated by surface water runoff replace a part of the surface water regulation service of a natural soil.

⊖ Potential limitations / disservices:

- High dependency on irrigation system (façade-bound types).
- Fire risk – especially if vegetation is dry.
- Frost risk.
- Relatively long time span before walls are fully covered for ground-based greening.

VI. Performance

P1 Cooling service

Transpiration	●	●
Shading	○	○
Evaporation	○	○
Building (Insulation)	●	●
Reflection (Albedo)	○	○

P2 Water balance regulation service

Water conveyance	○	○
Water infiltration	○	○
Water retention	○	○
Water storage	○	○
Water reuse	○	○

P3 Water purification service

Water filtering	○	○
Water bio-remediation	○	○

P4 Air purification service

Deposition	●	●
Air biofiltration	●	●
Noise reduction	○	○

P5 Biodiversity service

Habitat provision	●	○
Connectivity	●	○

P6 Amenity value service

Beauty / Appearance	●	●
Usability / Functionality	●	○
Social interaction	○	○
Education	○	○

P7 Food / Energy / Material

Food / Energy / Material	○	○

P8 CO_2 Sequestration

CO_2 Sequestration	●	○

VII. References and further reading

Gandy, M. (2010). The ecological façades of Patrick Blanc. Architectural Design, 80(3), 28-33. https://doi.org/10.1002/ad.1071.

Greenroofs.com (2018). GPW: Musée du quai Branly. Retrieved March 20, 2021, from https://www.greenroofs.com/2011/09/26/gpw-musee-du-quai-branly/.

Hancvencl, G. (2013). Fassadengebundene Vertikalbegrünung. Untersuchungen des Mikroklimas fassadengebundener Begrünungssystem. Masterabeit. Universität für Bodenkultur Wien, Wien. Retrieved March 20, 2021, from https://abstracts.boku.ac.at/oe_list.php?paID=3&paLIST=0&paSID=10671.

Humbolt-Universität Berlin (n.d). Das Lise-Meitner-Haus (Institut für Physik). Retrieved March 20, 2021, from https://www.physik.hu-berlin.de/de/institut/ueber/lise-meitner-haus/das-institutsgebaeude.

Hien, W. N., & Jusuf, S. K. (2010). Air temperature distribution and the influence of sky view factor in a green Singapore estate. Journal of urban planning and development, 136(3), 261-272. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000014.

Köhler, M. (2008). Green façades: A view back and some visions. Urban Ecosystems, 11(4), 423. https://doi.org/10.1007/s11252-008-0063-x.

Köhler, M. & Nistor, C.R. (2015). Wandgebundene Begrünunugen. Quantifizierungen einer neuen Bauweise in der Klima architektur. Endbericht. Bundesinstitut für Bau-, Stadt-, und Raumordung im Bundesamt für Bauwesen und Raumordung. Bonn.

Paull, N. J., Krix, D., Irga, P. J., & Torpy, F. R. (2020). Airborne particulate matter accumulation on common green wall plants. International Journal of Phytoremediation, 22(6), 594-606. https://doi.org/10.1080/15226514.2019.1696744.

Pfoser, N. (2016). Fassade und Pflanze. Potenziale einer neuen Fassadengestaltung (Doctoral dissertation, Technische Universität Darmstadt). Retrieved March 20, 2021, from https://tuprints.ulb.tu-darmstadt.de/5587/.

Schmidt, M. (2018). Cooling Urban Heat. In: Hortitecture. Jovis Verlag GmbH Berlin, Germany. ISBN: 978-3-86859-547-5.

Stadt Zürich Tiefbau- und Entsorgungsdepartement (n.d.). MFO-Park. Retrieved from https://web.archive.org/web/20220812142720/https://www.stadt-
zuerich.ch/ted/de/index/gsz/planung-und-bau/abgeschlossene-projekte/mfo-park.html.

Wong, N. H., Tan, A. Y. K., Chen, Y., Sekar, K., Tan, P. Y., Chan, D., Chiang, K., & Wong, N. C. (2010). Thermal evaluation of vertical greenery systems for building walls. Building and environment, 45(3), 663-672. https://doi.org/10.1016/j.buildenv.2009.08.005.

Fig 4.12 Free standing living wall in Ludwigsburg, Germany.

4.6 Free standing living wall

Verticalization of green spaces is a method to increase vegetated surfaces with many ecological services in urban environments. Free standing living walls serve as adaptation measures for the urban heat island effect. Furthermore, they create space with high amenity value and potentially high biodiversity. Free standing living walls can also be used as noise barriers along highly frequented roads. They are suitable to re-use stormwater runoff water and have a high rate of evapotranspiration.

I. Basic information

Synonyms: Living wall; Green wall; Green noise barrier

Addressed challenges:

II. Role of nature

Natural soil with vegetation cover (perennials, shrubs, and trees) is the model for living walls. They consist of vertical layering of soil with plants growing on a vertical surface as well as on top of the wall. Depending on the construction, thickness (typically at least 40 cm), and height of the living wall, functions of natural soils like water filtration may develop. While dependent on plant selection, exposition, and level of irrigation, evaporation from the vertical soil and vegetative transpiration are also key natural processes that can help reduce the surrounding air temperature.

III. Technical and design parameters

Fig 4.13 An example of free standing living wall and its associated benefits.

Free standing living walls are constructed by the vertical layering of soil or substrate that is contained in hollow cubes constructed using metal wire with supporting elements to create walls of up to four meters in height. Fabric (organic or inorganic) is used to prevent the erosion of substrate or soil from the cubes. It is a fairly heavy construction that rests on a simple strip foundation. Living walls tend to be at least 40 cm wide and need to be constructed with a minimum of two segments that form a right angle for stabilization (e.g., L-shaped).

Living walls are very flexible with regard to plant selection as long as they are properly maintained. Therefore, living walls can help support biodiversity with proper species selection and a biodiversity-sensitive design. An irrigation system is necessary and should preferentially use collected rainwater or run-off from nearby surfaces.

IV. Conditions for implementation

Because of the thickness of the living wall, there are few issues with central European frost periods. The ground and underground space needs to be sufficiently loadable to support the living wall. An irrigation system should also be implemented, as regular irrigation supports the vegetation and reduces fire risk.

V. Benefits and limitations

⊕ Potential benefits:

- Provides direct shelter from the sun, and depending on the vegetation indirect shelter (e.g., living wall with trees).
- Evapotranspiration of vegetation helps to mitigate the heat island effect.
- Can help support biodiversity with proper species selection and biodiversity-sensitive design.
- Noise reduction.
- Surface water can be used for irrigation of living wall (re-use of rainwater or run-off).
- Can be used for way-finding in public space.

⊖ Potential limitations / disservices:

- Irrigation is needed (summer and winter), but should not rely on drinking water.
- Underground support is needed.
- Free standing living walls may act as a barrier for pedestrian movement.

VI. Performance

P1 Cooling service

Transpiration	● ●
Shading	● ●
Evaporation	● ○
Building (Insulation)	○ ○
Reflection (Albedo)	● ●

P2 Water balance regulation service

Water conveyance	○ ○
Water infiltration	○ ○
Water retention	○ ○
Water storage	○ ○
Water reuse	○ ○

P3 Water purification service

Water filtering	○ ○
Water bio-remediation	○ ○

P4 Air purification service

Deposition	● ○
Air biofiltration	● ○
Noise reduction	○ ○

P5 Biodiversity service

Habitat provision	● ●
Connectivity	● ○

P6 Amenity value service

Beauty / Appearance	● ●
Usability / Functionality	● ○
Social interaction	● ○
Education	○ ○

P7 Food / Energy / Material

Food / Energy / Material	○ ○

P8 CO_2 Sequestration

CO_2 Sequestration	● ○

VII. References and further reading

Eisenberg, B., Gölsdorf, K., Weidenbacher, S., & Schwarz-von Raumer, H. G. (2016). Report on Urban Climate Comfort Zones and the Green Living Room Ludwigsburg.

Lacasta, A. M., Penaranda, A., Cantalapiedra, I. R., Auguet, C., Bures, S., & Urrestarazu, M. (2016). Acoustic evaluation of modular greenery noise barriers. Urban Forestry & Urban Greening, 20, 172-179. https://doi.org/10.1016/j.ufug.2016.08.010.

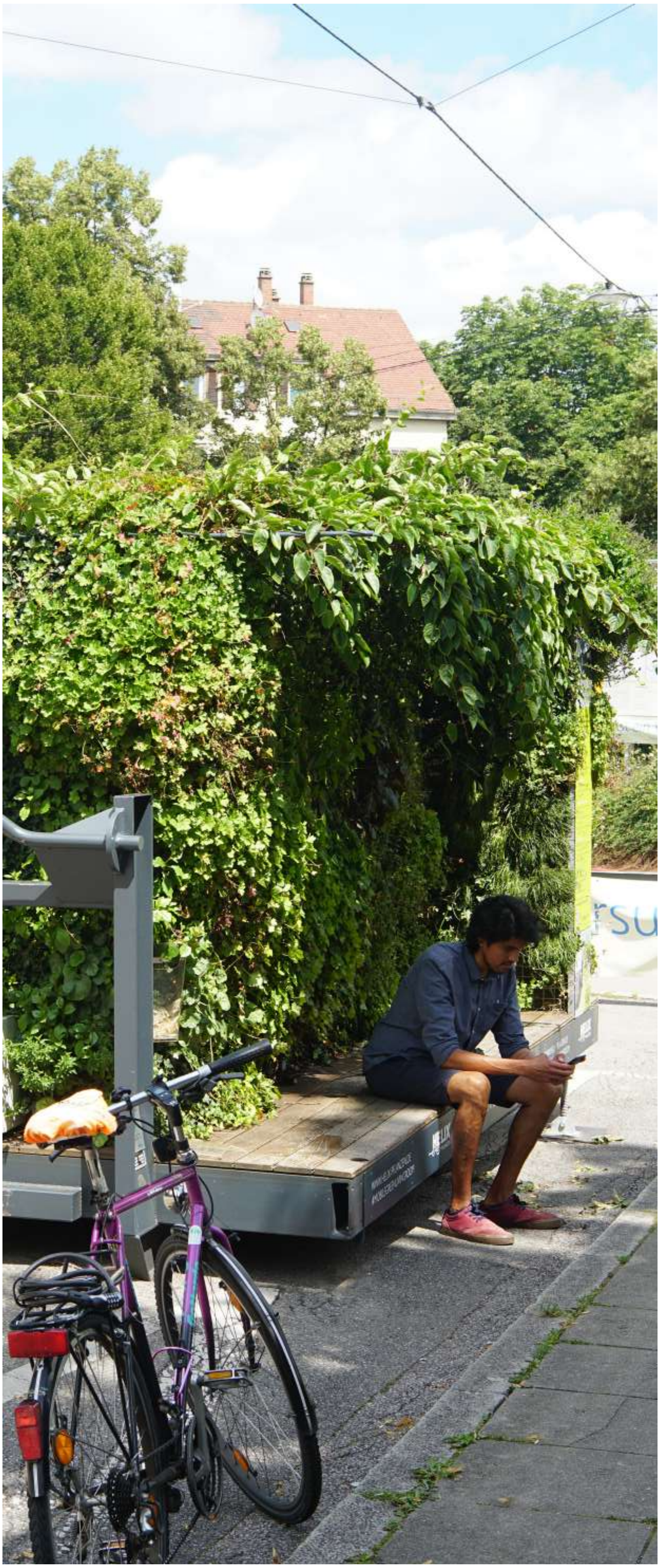


Fig 4.14 Mobile Green Living Room in Stuttgart, Germany.

4.7 Mobile vertical greening

Mobile vertical greening such as the Mobile Green Living Room consists of living wall modules (Factsheet 5.6 Free standing living wall) that are fixed to a hook lift container platform. The vegetation cover is very diverse in order to illustrate the high potential of living walls to increase amenity value and stimulate biodiversity. A light, open roof structure partly covered with vegetation provides shade. Mobile vertical greening instantly provides services for clean air provision, cooling and shading, and habitat for urban biodiversity. It can be used for educational purposes, as a mobile demonstration for green infrastructure, a test feature, a temporary green installation, or as an open green office for information and communication purposes.

I. Basic information

Synonyms: Mobile Green Living Room; Vertical mobile garden

Addressed challenges:

II. Role of nature

Natural soil with vegetation cover (perennials and shrubs or trees) is the model for living walls. However, there is not an adequate example from nature for the loading and unloading of "mobile vegetation."

III. Technical and design parameters

Fig 4.15 Detail of a typical mobile vertical greening unit and its associated benefits.

Mobile vertical greening such as the Mobile Green Living Room can be moved to any location that has truck access. The actual module itself is constructed using substrate filled wire cubes, similar to a free standing living wall (see Factsheet 5.6). It acts as a semi-autonomous unit with an on-board water tank that lasts for up to a week and an irrigation system that needs a temporary energy supply.

IV. Conditions for implementation

Space for loading and unloading is needed, the surface has to be flat (<3°), and permission is needed before installation.

V. Benefits and limitations

⊕ Potential benefits:

- Mobile vertical elements serve as models for large scale interventions by testing the suitability of a location for permanent vertical greening and in participatory processes.
- In combination with additional green elements, the performance increases significantly.
- Raises awareness and offers educational opportunities for NBS use in urban areas.

⊖ Potential limitations / disservices:

- The requirements for transporting mobile elements eclipse the environmental benefits of vertical greening.
- The average performance of vertical greening, such as heat reduction, cannot be replicated completely in mobile elements due to the limited space.
- Size is limited.

VI. Performance

P1 Cooling service

Transpiration	● ○
Shading	● ●
Evaporation	○ ○
Building (Insulation)	○ ○
Reflection (Albedo)	● ○

P2 Water balance regulation service

Water conveyance	○ ○
Water infiltration	○ ○
Water retention	○ ○
Water storage	○ ○
Water reuse	○ ○

P3 Water purification service

Water filtering	○ ○
Water bio-remediation	○ ○

P4 Air purification service

Deposition	● ○
Air biofiltration	○ ○
Noise reduction	● ○

P5 Biodiversity service

Habitat provision	● ○
Connectivity	● ○

P6 Amenity value service

Beauty / Appearance	● ○
Usability / Functionality	● ●
Social interaction	● ○
Education	● ●

P7 Food / Energy / Material

Food / Energy / Material	○ ○

P8 CO_2 Sequestration

CO_2 Sequestration	● ○

VII. References and further reading

Climate Alliance (2016). The mobile green living room roadshow – A feast for the senses. Retrieved from https://web.archive.org/web/20220812143626/http://www.climatealliance.org/newsroom/news/news-detail/the-mobile-green-living-room-roadshow-a-feast-for-the-senses.html.

Urban Green UP (n.d.) Vertical mobile garden. Retrieved from https://web.archive.org/web/20220812143745/https://www.urbangreenup.eu/solutions/vertical-mobile-garden.kl.

4.8 Moss wall

Fig 4.16 Sketch of a moss wall.

Constructed moss walls use the natural capacities of mosses to reduce air pollution. There is a range of test sites with open-air experiments in order to test the effectiveness for fine dust reduction and air quality improvement using moss walls. Additionally, because mosses can store a relatively large amount of water and a have a large surface area for transpiration, they also contribute to the local reduction of air temperature.

A variety of products based on different concepts are available on the market, but here, the "City Tree" is described to exemplify this NBS. The "City Tree" is a compact and mobile construction, vertically planted with different species of mosses on both its front and backside, with the primary aim to reduce air pollution, especially at the pedestrian level.

I. Basic information

Synonyms: City tree

Addressed challenges:

Climatic resilience | Air quality | Social justice & cohesion

II. Role of nature

Mosses, compared to other plants, have a large bioactive surface, transpire more, and actively reduce some pollutants. The “City Tree” and moss walls in general, maximize the ecological function of natural mosses, by utilizing their large surface area to filter air pollutants and cool the surrounding area via transpiration.

III. Technical and design parameters

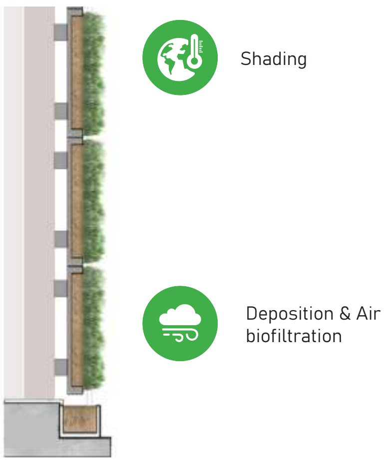


Fig 4.17 An example of moss wall and its associated benefits.

The “City Tree” is a compact, vertical greening element that combines multiple moss species on both sides of a mobile module. “City Trees” are also equipped with additional technical solutions. For example, externally controllable ventilators inside the vertical construction and underneath the moss surface strengthen the airflow through the installation, thereby increasing air filtering and water transpiration capacity.

They are also equipped with a device that provides real-time information about the “City Tree” and the surrounding environmental conditions. Depending on local climate conditions, the “City Tree” may need an additional irrigation system. Solar panels can supply electricity or it may be connected to the main power line.

IV. Conditions for implementation

Flat surfaces for installation and enough space for loading and unloading is needed for the mobile “City Tree”.

V. Benefits and limitations

⊕ Potential benefits:

- Local reduction of air pollution.
- Local reduction of air temperature: Mitigation against heat stress.
- Relaxation.

⊖ Potential limitations / disservices:

- Non-experimental performance is still under discussion; further independent studies needed.
- Transportation and production produce emissions.

VI. Performance

P1 Cooling service		
Transpiration	●	●
Shading	●	○
Evaporation	●	○
Building (Insulation)	○	○
Reflection (Albedo)	○	○

P2 Water balance regulation service		
Water conveyance	○	○
Water infiltration	○	○
Water retention	○	○
Water storage	○	○
Water reuse	○	○

P3 Water purification service		
Water filtering	○	○
Water bio-remediation	○	○

P4 Air purification service		
Deposition	●	○
Air biofiltration	●	○
Noise reduction	●	○

P5 Biodiversity service		
Habitat provision	○	○
Connectivity	○	○

P6 Amenity value service		
Beauty / Appearance	●	○
Usability / Functionality	●	○
Social interaction	●	○
Education	●	○

P7 Food / Energy / Material		
Food / Energy / Material	○	○

P8 CO_2 Sequestration		
CO_2 Sequestration	○	○

VII. References and further reading

Enercity. (2017). Der "City Tree" eine multifunktionale Grünfläche. Retrieved March 20, 2021, from https://e-government.hannover-stadt.de/.

Greencity solutions (n.d.). Der City Tree- der weltweit erste Bio-Tech-Filter zur nachweisbaren Verbesserung der Luftqualität. Retrieved from https://web.archive.org/web/20220812144005/https://greencitysolutions.de/en/.

Haynes, A., Popek, R., Boles, M., Paton-Walsh, C., & Robinson, S. A. (2019). Roadside moss turfs in South East Australia capture more particulate matter along an urban gradient than a common native tree species. Atmosphere, 10(4), 224. https://doi.org/10.3390/atmos10040224.

5. Natural and semi-natural water storage and transport structure

Fig 5.0 Renatured segment of the Lura river in Arese, Italy.

It is projected that many areas of Europe will experience both intensifying rainfall events and longer dry periods due to the effects of climate change [20]. Indeed these trends have already been observed with the frequency and total amount of extreme rainfall increasing in Europe since 1950. Additionally, projections suggest large future increases of extreme rainfall in parts of Europe [21]. The negative consequences of these climate trends include not only increased risk of flooding, including the associated risks of erosion and water pollution, but also drought. Traditional urban areas dominated by grey infrastructure may experience these challenges more intensely, for example with increased flood risk due to heavy runoff from sealed surfaces. Natural and semi-natural water storage and transport structures are natural or constructed waterbodies that help mitigate these challenges by reducing runoff flow, increasing retention capacity, and reducing pollution by facilitating particulate settling [4]. Additionally, these structures may provide a range of recreational opportunities for people and natural habitat for wildlife thereby enhancing biodiversity. Examples of NBS that are natural and semi-natural water storage and transport structures include surface wetlands, floodplains and floodplain reconnection with rivers, restoration of degraded waterbodies and waterways, and retention ponds. Four examples (i.e., constructed wetlands, retention / detention ponds, daylighting, and underground water storage) are described in more detail below.

Fig 5.1 Urban wetland on the University of Stuttgart's Vaihingen campus in Stuttgart, Germany.

5.1 Constructed wetland

Constructed wetlands are artificial wetlands with the main objective to harvest, treat, and store grey water or stormwater run-off in urban areas. Constructed wetlands are a cost-effective alternative, as they are often less expensive than conventional wastewater treatment options. Processes and services of natural wetlands are adapted to constructed wetlands focusing on water purification and storage. Wetlands are complex systems where vegetation, soil, microbiological activity, and their interactions, play an important role in their filtering performance. Constructed wetlands can also enhance urban biodiversity, for example, by including design elements such as diverse vegetation and barrier-free shores.

I. Basic information

Synonyms:

Addressed challenges:

II. Role of nature

Wetlands are complex systems with their vegetation, soil, microbiological activity, and their interactions, playing an important role for their functionality. Processes and services of natural wetlands are adapted to constructed wetlands focusing on water purification and storage. The main processes in a constructed wetland are: Settling of particles, filtration, chemical transformation, adsorption, positive ion exchange, and the uptake / breakdown / transformation of pollutants and nutrients. Additionally, natural wetlands are among the most biodiverse ecosystems, and therefore constructed wetlands should use an intentional biodiversity-senstive design (e.g., diverse vegetation, native species selection, potential water level fluctuations, and barrier-free shores) to support urban nature as well as water management.

III. Technical and design parameters

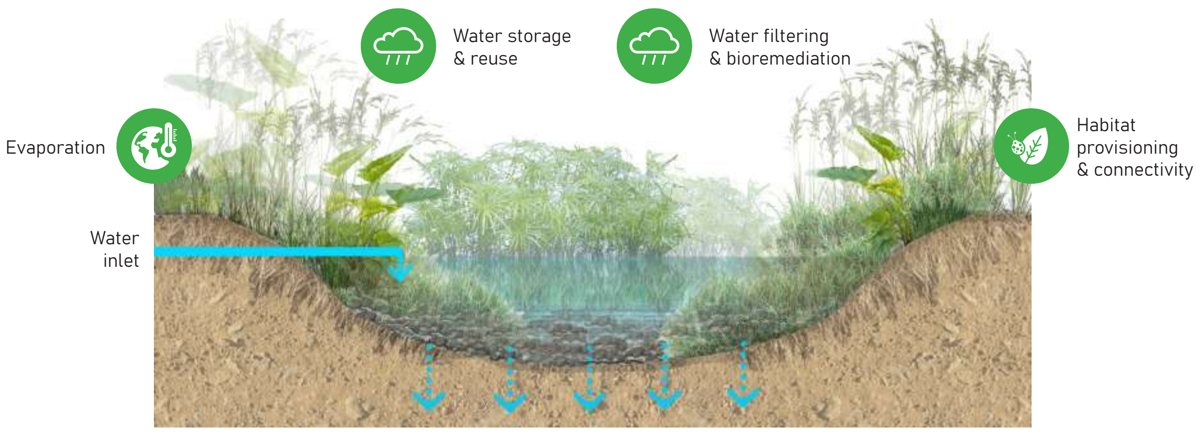


Fig 5.2 An example of a constructed wetland and its associated natural processes and benefits.

Constructed wetlands are shallow basins that are filled with substrate. There are various substrate options, but usually constructed wetlands are filled with sand or gravel. The substrate layer is planted with aquatic or semi-aquatic vegetation. Constructed wetlands have an inlet pipe for grey water or stormwater run-off. The untreated water can then flow over or through the substrate layer and vegetation while it is naturally filtered and cleaned. The constructed wetland is equipped with an outlet (pipe, weir) for controlled water discharge. Often, the treated water flows into another pond where it is stored. The treated stormwater can be used for different purposes (e.g., for green space irrigation). Depending on the type of constructed wetland, wastewater flows 1) horizontally over the ground surface, 2) horizontally under the ground surface and through the substrate layer, or 3) vertically through the constructed wetland (hybrid systems).

IV. Conditions for implementation

Suitable locations must be selected for constructed wetlands. There needs to be enough accessible land with compact soils to minimize infiltration into groundwater and they should be located upland, near a wastewater source, and outside floodplains. They should also be built on a gentle slope, as water flows by gravity through constructed wetlands. They can also be included in green spaces as landscaping elements. Installation of water control measures, and regular inspections, monitoring, and maintenance are necessary. Furthermore, the protection of biodiversity should be considered, and therefore construction should not displace endangered or threatened species or disturb archaeological or historic resources.

V. Benefits and limitations

⊕ Potential benefits:

- Water supply regulation.
- Water temperature control.
- Improve water quality.
- Provide water for different purposes (e.g., irrigation).
- Flood control / mitigation.
- Habitat for wildlife supports wetland biodiversity.

⊖ Potential limitations / disservices:

- Traditional constructed wetlands require relatively large areas.

VI. Performance

P1 Cooling service	
Transpiration	● ○
Shading	○ ○
Evaporation	● ●
Building (Insulation)	○ ○
Reflection (Albedo)	○ ○

P2 Water balance regulation service	
Water conveyance	● ○
Water infiltration	● ○
Water retention	● ○
Water storage	● ○
Water reuse	● ●

P3 Water purification service	
Water filtering	● ○
Water bio-remediation	● ●

P4 Air purification service	
Deposition	○ ○
Air biofiltration	○ ○
Noise reduction	○ ○

P5 Biodiversity service	
Habitat provision	● ●
Connectivity	● ●

P6 Amenity value service	
Beauty / Appearance	● ●
Usability / Functionality	● ○
Social interaction	● ●
Education	● ○

P7 Food / Energy / Material	
Food / Energy / Material	● ○

P8 CO_2 Sequestration	
CO_2 Sequestration	○ ○

VII. References and further reading

Andreo-Martínez, P., García-Martínez, N., Quesada-Medina, J., & Almela, L. (2017). Domestic wastewaters reuse reclaimed by an improved horizontal subsurface-flow constructed wetland: A case study in the southeast of Spain. Bioresource Technology, 233, 236-246. https://doi.org/10.1016/j.biortech.2017.02.123.

City of Melbourne (2015). Urban water: Discover how water creates a liveable city, a case study. Trin Warren Tam-boore wetlands. Retrieved March 20, 2021, from https://urbanwater.melbourne.vic.gov.au/wp-content/uploads/2015/02/COM-UW-Trin-Warren-Tam-boore-wetlands.pdf.

City of Melbourne (n.d.). Urban Water: constructed wetlands. Retrieved from https://web.archive.org/web/20220812145842/https://urbanwater.melbourne.vic.gov.au/industry/treatment-types/constructed-wetlands/.

Davis, L. (1995). A handbook of constructed wetlands: A guide to creating wetlands for agricultural wastewater, domestic wastewater, coal mine drainage, stormwater. In the Mid-Atlantic Region. Volume 1: General considerations. USDA-Natural Resources Conservation Service.

GreenWorks (n.d). Tanner Springs Park. Retrieved from https://web.archive.org/web/20220812150131/https://greenworkspc.com/ourwork/tanner-springs-park.

Jácome, J. A., Molina, J., Suárez, J., Mosqueira, G., & Torres, D. (2016). Performance of constructed wetland applied for domestic wastewater treatment: Case study at Boimorto (Galicia, Spain). Ecological Engineering, 95, 324-329. https://doi.org/10.1016/j.ecoleng.2016.06.049.

Kilian Water (2020). Types of constructed wetlands. Retrieved from https://web.archive.org/web/20220812150410/http://www.kilianwater.nl/en/constructed-wetlands/solar-powered-water-treatment.html.

Knapp, S., Schmauck, S., & Zehnsdorf, A. (2019). Biodiversity impact of green roofs and constructed wetlands as progressive eco-technologies in urban areas. Sustainability, 11(20), 5846. https://doi.org/10.3390/su11205846.

Moinier, S. (2013). Constructed Wetlands Redefined as Functional Wetlands. Retrieved August 23, 2022, from https://publications.deltares.nl/1202415_047.pdf.

Sample, D., Wang, C. Y., & Fox, L. (2013). Innovative best management fact sheet no. 1, floating treatment wetlands. Virginia Cooperative Extension. Retrieved March 20, 2021, from: https://vtechworks.lib.vt.edu/bitstream/handle/10919/70627/BSE-76.pdf?sequence=1&isAllowed=y.

Wiegleb, G., Dahms, H. U., Byeon, W. I., & Choi, G. (2017). To what extent can constructed wetlands enhance biodiversity. International Journal of Environmental Science and Development, 8(8), 561-569. DOI: 10.18178/ijesd.2017.8.8.1016.

Zhang, C., Wen, L., Wang, Y., Liu, C., Zhou, Y., & Lei, G. (2020). Can constructed wetlands be wildlife refuges? A review of their potential biodiversity conservation value. Sustainability, 12(4), 1442. https://doi.org/10.3390/su12041442.

Fig 5.3 Wet retention pond in Tampere, Finland.

5.2 Retention / detention pond

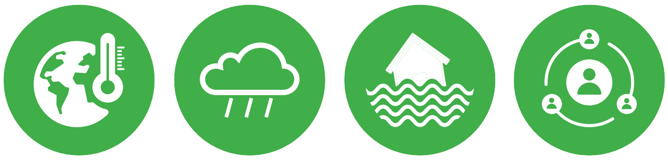
Dry detention ponds are surface storage basins that retain stormwater. During periods of heavy rain, the area gets flooded and could fill the detention pond for several days in cases of heavier or longer rainfall events. After the rain ends, the water flows in the sewer system or, ideally, infiltrates through the soil and recharges the groundwater. If there is no heavy rainfall event, the detention ponds are dry and could be used as a green area.

Retention ponds retain stormwater continuously, holding water also in dry periods. They can also improve the water quality, for example, with downstream infiltration and sedimentation and provide habitat for aquatic and semi-aquatic species.

I. Basic information

Synonyms: Detention pond: Dry detention pond; Dry detention basin
Retention pond: Wet retention pond; Wet retention basin

Addressed challenges:



Climatic resilience | Water management | Natural & climatic hazards | Social justice & cohesion

II. Role of nature

Detention ponds mimic a natural landscape that contains a heterogeneous surface with slightly elevated areas and lower areas in close proximity, forming a mosaic of micro conditions. Water remains in the lower parts for some time until it infiltrates or evaporates. Wet retention ponds, however, mimic natural ponds that have standing water (although at various levels) year round. Similar to natural ponds, wet retention ponds store stormwater and run-off and provide habitat for aquatic and semi aquatic species.

III. Technical and design parameters

Detention and retention ponds can be incorporated into public areas like parks and sports fields, but must always be at the lowest part of the green space. Additionally, traditional dry detention ponds can be used as green areas in times without heavy rainfall events. Both dry detention ponds and wet retention ponds can improve biodiversity enhancement potential if designed to have, for example, greater structural diversity (e.g., larger transition zones between aquatic and terrestrial conditions for wet retention ponds, or the inclusion of various substrates in dry detention ponds).

IV. Conditions for implementation

There needs to be appropriate available area (enough space to flood) with proper soil and rainfall conditions. While there are limited design options, they could be considered in park planning.

V. Benefits and limitations

⊕ Potential benefits:

- Reduces flood risk from heavy rain events.
- Multifunctional use of detention pond is possible.
- Retention of stormwater.
- Potential reuse of water for irrigation.
- Recreation and aesthetic value.

⊖ Potential limitations / disservices:

- Usually requires a relatively large area.

VI. Performance

P1 Cooling service

Transpiration	○	○
Shading	○	○
Evaporation	●	○
Building (Insulation)	○	○
Reflection (Albedo)	○	○

P2 Water balance regulation service

Water conveyance	○	○
Water infiltration	○	○
Water retention	●	●
Water storage	●	○
Water reuse	●	○

P3 Water purification service

Water filtering	●	○
Water bio-remediation	○	○

P4 Air purification service

Deposition	○	○
Air biofiltration	○	○
Noise reduction	○	○

P5 Biodiversity service

Habitat provision	○	○
Connectivity	○	○

P6 Amenity value service

Beauty / Appearance	●	○
Usability / Functionality	●	○
Social interaction	●	○
Education	●	○

P7 Food / Energy / Material

Food / Energy / Material	○	○

P8 CO_2 Sequestration

CO_2 Sequestration	○	○

VII. References and further reading

Monberg, R. J., Howe, A. G., Ravn, H. P., & Jensen, M. B. (2018). Exploring structural habitat heterogeneity in sustainable urban drainage systems (SUDS) for urban biodiversity support. Urban Ecosystems, 21(6), 1159-1170. https://doi.org/10.1007/s11252-018-0790-6.

Schifman, L. A., Kasaraneni, V. K., & Oyanedel-Craver, V. (2018). Contaminant Accumulation in Stormwater Retention and Detention Pond Sediments: Implications for Maintenance and Ecological Health. In Integrated and Sustainable Environmental Remediation. American Chemical Society. ISBN13: 9780841233676.

Stormwater Equipment Manufactures Association (n.d.). Detention / Retention ponds. Retrieved from https://web.archive.org/web/20220812151539/https://www.stormwaterassociation.com/detention-retention-ponds.

Susdrain (n.d.). Component: Retention ponds. Retrieved August 12, 2022, from https://www.susdrain.org/delivering-suds/.

5.3 Daylighting

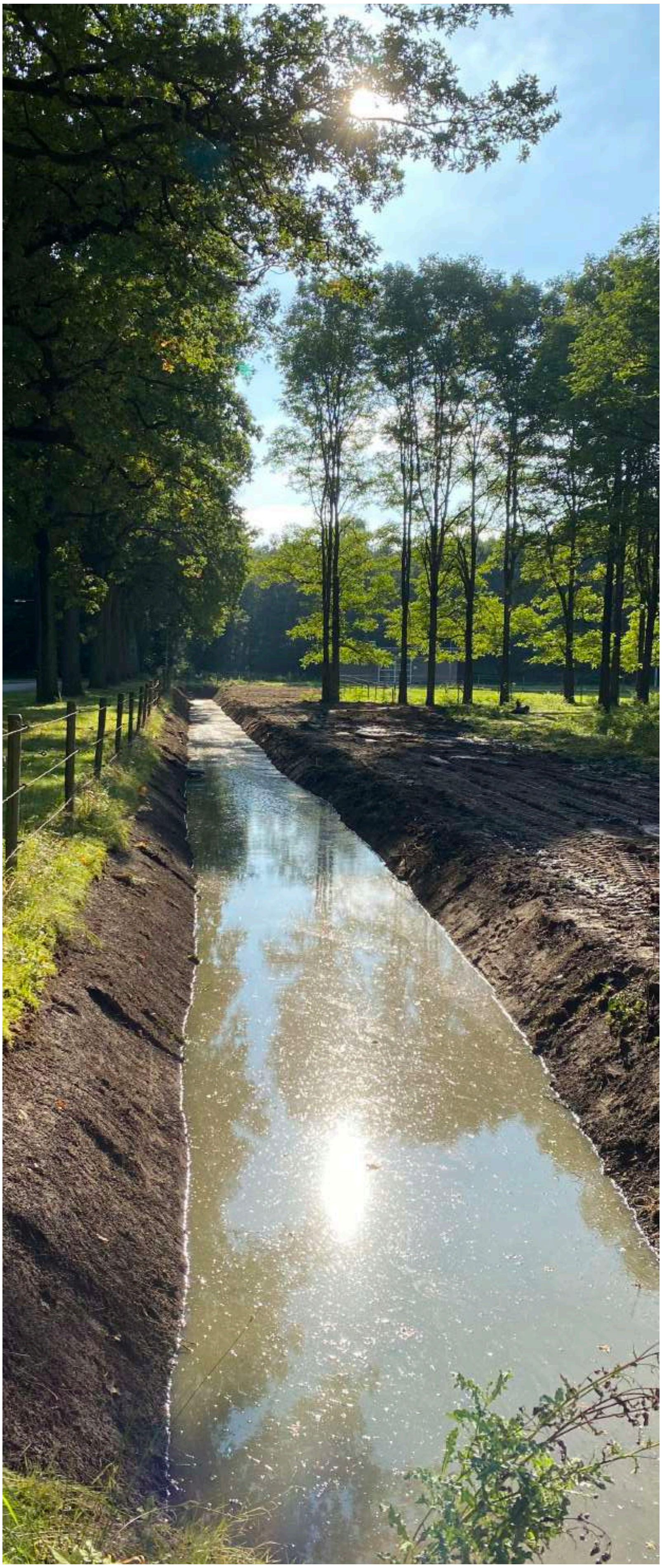


Fig 5.4 Daylighted segment of De grote beek, Eindhoven, Netherlands.

Daylighting describes the opening of buried or covered watercourses, such as rivers and drainage systems, by removing concrete layers. This creates more space for the river, which allows for increased storage capacity of the channel, thus decreasing flood risk. Daylighting also results in a more natural development of the riverbed and riparian zone, thereby enhancing aesthetics and supporting biodiversity through improved habitat quality or habitat creation. Both natural and architectural restoration can be considered when daylighting. Natural restoration refers to the daylighting of channels followed by a natural development of the riverbed and riparian zone, whereas architectural restoration describes the daylighting of a watercourse that still follows a concrete or constructed channel.

I. Basic information

Synonyms: River daylighting; Stream daylighting; Culvert removal

Addressed challenges:

Climatic resilience | Water management | Natural & climatic hazards | Biodiversity | Social justice & cohesion

II. Role of nature

Daylighting allows the natural development of a water channel that fulfils services of a natural stream. For example, it provides habitat for aquatic or semi-aquatic wildlife and vegetation, and increases the regulation and uptake of stormwater run-off. Natural restoration typically offers benefits more similar to those of a natural stream than architectural restoration. For example, natural channels enable the water to flow and expand to its riverbanks, and vegetation contributes to reducing water velocity.

III. Technical and design parameters

There are a variety of designs and levels of intervention possible that are dependent upon the intention of the planned project. For example, the completely culverted structure, or parts of it like as the top layer, may be completely removed or gaps created. Natural restoration is associated with more effort than only removing the top layer of a culvert that results in an open constructed channel. However, with natural restoration the water channel is shaped by nature leading to a dynamic water channel and a riparian zone with a natural shape that includes plants and rocks.

IV. Conditions for implementation

There may be restrictions or limited possibilities in dense and highly built areas because of high costs for shifting or removing infrastructure. Additionally, there needs to be enough space and a sufficient channel width to deculvert the watercourse. Furthermore, information about soil types under and surrounding the channel need to be collected to guarantee the performance of the daylighting measure.

V. Benefits and limitations

Potential benefits:

- Stormwater management.
- Benefits for many aquatic organisms (light plays a role for population movement).
- Habitat provision for riparian flora and fauna.
- Improving physical habitat conditions of the watercourse, habitat niches arise from structural diversity.
- Natural bank development; creating natural watercourses.
- Enables natural processes (e.g., erosion, deposition).
- Aesthetic and recreational value.
- Educational resource.

Potential limitations / disservices:

- Architectural restoration is less near natural than the natural restoration. As a result the development and establishment of flora and fauna may be limited.

VI. Performance

P1 Cooling service	
Transpiration	●○
Shading	○○
Evaporation	●○
Building (Insulation)	○○
Reflection (Albedo)	○○

P2 Water balance regulation service	
Water conveyance	●○
Water infiltration	●○
Water retention	●○
Water storage	○○
Water reuse	○○

P3 Water purification service	
Water filtering	●○
Water bio-remediation	●○

P4 Air purification service	
Deposition	○○
Air biofiltration	○○
Noise reduction	○○

P5 Biodiversity service	
Habitat provision	●●
Connectivity	●○

P6 Amenity value service	
Beauty / Appearance	●●
Usability / Functionality	●○
Social interaction	●○
Education	●○

P7 Food / Energy / Material	
Food / Energy / Material	○○

P8 CO_2 Sequestration	
CO_2 Sequestration	●○

VII. References and further reading

Addy, S., Cooksley, S., Dodd, N., Waylen, K., Stockan, J., Byg, A., & Holstead, K. (2016). River Restoration and Biodiversity. IUCN. Retrieved August 12, 2022, from https://portals.iucn.org/library/sites/library/files/documents/2016-064.pdf.

Boffa Miskell (2017). Stream daylighting: Identifying opportunities for central Auckland. Retrieved from https://web.archive.org/web/20220812152132/https://www.boffamiskell.co.nz/project.php?v=stream-daylighting.

Baho, D. L., Arnott, D., Myrstad, K. D., Schneider, S. C., & Moe, T. F. (2021). Rapid colonization of aquatic communities in an urban stream after daylighting. Restoration Ecology, 29(5), 73394. https://doi.org/10.1111/rec.13394.

European Center for River Restoration (ECRR, 2019). Remove culverts. Retrieved March 20, 2021, from http://www.ecrr.org/River-Restoration/Flood-risk-management/Healthy-Catchments-managing-for-flood-risk-WFD/Environmental-improvements-case-studies/Remove-culverts.

European Centre for River Restoration (ECRR, n.d.). Allow the river to flood its floodplain. Retrieved from https://web.archive.org/web/20220812152747/https://www.ecrr.org/River-Restoration/Flood-risk-management/Healthy-Catchments-managing-for-flood-risk-WFD/ Environmental-improvements-case-studies/Allow-the-river-to-flood-its-floodplain.

The River Restoration Centre (2020). Manual of river restoration techniques. Retrieved August 12, 2022, from https://www.therrc.co.uk/manual-river-restoration-techniques.

Fig 5.5 Public square with an Underground water retention basin in Freiburg, Germany.

5.4 Underground water storage

Underground water retention systems are typically composed of modular elements to retain stormwater from heavy precipitation events and store that water for nearby irrigation purposes. They can be constructed below open spaces such as parks, sports fields, or public squares, and are usually topped with permeable pavements or soil substrates with vegetation that allow water to enter the system. Underground water retention systems can be incorporated into a multifunctional design while simultaneously supporting water management (e.g., flood risk reduction, re-use of water for irrigation).

I. Basic information

Synonyms: Underground water retention basin

Addressed challenges:

Water management

Natural & climatic hazards

Biodiversity

II. Role of nature

Depending on the geology of an area, underground storage systems retain and store water after heavy precipitation events. Examples from Peru show that already in pre-Inca times, people made use of these qualities and directed water in channels to storage areas or to feed artificial ponds or springs.

III. Technical and design parameters

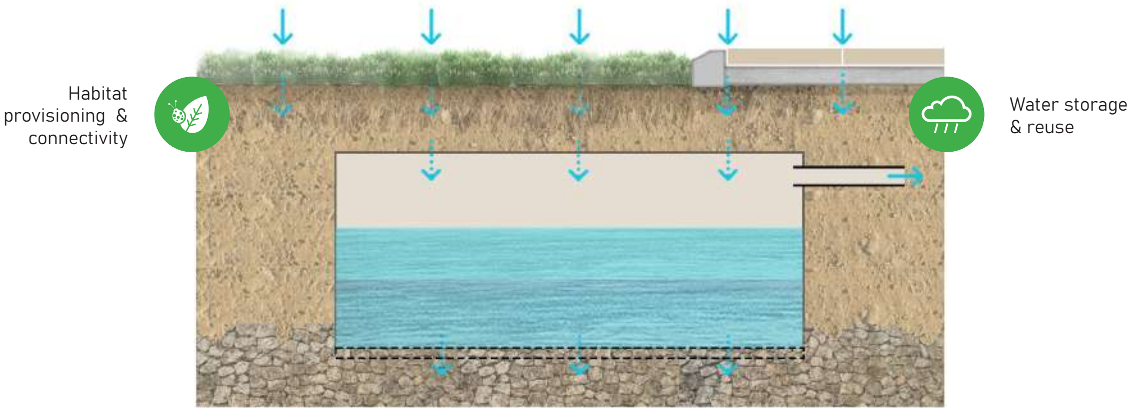


Fig 5.6 An example of an underground water retention basin and its associated and benefits.

Underground water storage can be incorporated into larger water management projects as long as it is disconnected from the sewage system. Above the water storage tanks, there is a top layer consisting of vegetation or a permeable pavement, followed by a load-bearing substrate layer. Underneath the tanks, the lower substrate acts as a filtration layer. Other aspects should also be considered such as the drainage gradient and overflow pipes and systems.

IV. Conditions for implementation

Space for underground storage needs to be excavated. Therefore, they are relatively difficult to incorporate into already existing infrastructure.

V. Benefits and limitations

⊕ Potential benefits:

- On-site storage of water helps minimize flood risk by reducing run-off and delaying water flow.
- Reuse of water on site can be used for irrigation during hot, dry seasons.
- Multifunctional use of open space.

⊖ Potential limitations / disservices:

- Minimum water quality needed for storage.
- Space for underground storage required.
- They can be relatively difficult to incorporate into already existing infrastructure.

VI. Performance

P1 Cooling service

Transpiration	○	○
Shading	○	○
Evaporation	○	○
Building (Insulation)	○	○
Reflection (Albedo)	○	○

P2 Water balance regulation service

Water conveyance	○	○
Water infiltration	●	●
Water retention	●	○
Water storage	●	○
Water reuse	●	●

P3 Water purification service

Water filtering	●	○
Water bio-remediation	○	○

P4 Air purification service

Deposition	○	○
Air biofiltration	○	○
Noise reduction	○	○

P5 Biodiversity service

Habitat provision	●	○
Connectivity	●	○

P6 Amenity value service

Beauty / Appearance	○	○
Usability / Functionality	●	○
Social interaction	○	○
Education	○	○

P7 Food / Energy / Material

Food / Energy / Material	○	○

P8 CO_2 Sequestration

CO_2 Sequestration	○	○

VII. References and further reading

UrabnNext (n.d.). Zollhallen Plaza: A climate adaptation tool. Retrieved from https://web.archive.org/web/20220812153514/https://urbannext.net/zollhallen-plaza/.

WLA (2012). Zollhallen Plaza. Retrieved from https://web.archive.org/web/20220812153630/https://worldlandscapearchitect.com/zollhallen-plaza-freiburg-germany-atelier-dreiseitl/.

6. Infiltration, filtration and biofiltration structures

Fig 6.0 Dry bioretention basin near University of Stuttgart's Vaihingen campus, Germany.

The urban water cycle differs greatly from the natural water cycle with regard to evapotranspiration, water run-off, and infiltration. This has severe consequences for the urban climate, groundwater recharge, and risk management [22]. These challenges are likely to increase as Europe is projected to experience more intense precipitation events in the future [20]. Infiltration, filtration, and biofiltration structures as part of a water sensitive urban design or sustainable drainage system, can help mitigate these challenges. These green infrastructures are often areas that are usually dry (excluding during or after precipitation events) and that reduce peak flows by slowing surface runoff, increasing infiltration, and providing water storage [4]. They can also reduce pollutants in run-off water through natural physical, biological, and chemical processes, allowing cleaner water to be discharged, collected, or recharge groundwater [23]. Depending on design, these structures may also support biodiversity by providing habitat for wildlife. Examples of NBS that are infiltration, filtration, and biofiltration structures include infiltration basins, bioretention basins, rain gardens, bioswales, infiltration planters, and subsurface constructed wetlands or filtration systems. Selected examples (i.e. bioswales, raingardens, infiltration basins, permeable paving systems, and biofilters) are described in more detail below.

6.1 Bioswale

Fig 6.1 Bioswale in Gartz (Oder), Germany.

A bioswale is a vegetated, linear, and low-sloped structure often established in urban areas, near or between roads, with the objective to reduce flood risk during or after heavy rain events. The intention of bioswales is comparable to rain gardens (see Factsheet 6.2). Bioswales absorb, store, and convey surface water runoff, and also remove pollutants and sediments as the water trickles through the vegetation and substrate layers. If properly planned and planted with native vegetation, a bioswale can contribute to local stormwater management and can help support biodiversity.

I. Basic information

Synonyms: Swale; Grassed swale; Vegetated filter strip; Stripswale

Addressed challenges:

Water management

Natural & climatic hazards

Biodiversity

II. Role of nature

There are several processes in bioswales that are inspired by nature. For example, the vegetation and soil within the bioswale can retain and store water, allowing it to slowly infiltrate through the layers as organic pollutants, sediments, and other substances are filtered out of the water. The physical and chemical characteristics of the soil substrate and selected vegetation will have an effect on each of these processes. Other natural processes in bioswales include evapotranspiration as the vegetation takes up and transpires water, and water conveyance that is similar to that of a riverbed.

III. Technical and design parameters

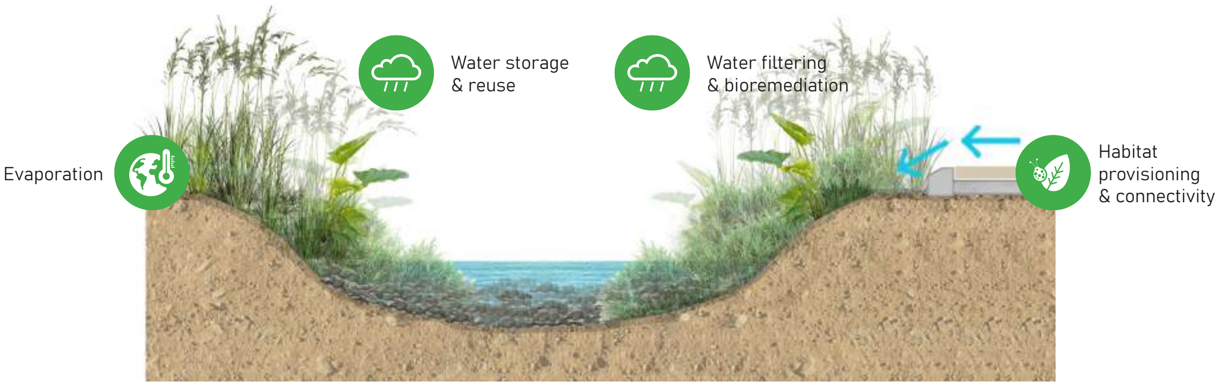


Fig 6.2 An example of a bioswale and its associated natural processes and benefits.

While similar to raingardens, bioswales are usually medium to larger scale installations. Bioswales are often linear, with a gentle downward slope that facilitates water flow into the base of the bioswale and positively affects infiltration. They must have relatively dense vegetation to slow water flow, without being so dense as to negatively affect water conveyance. It is best to select native, deep-rooted vegetation that can withstand occasional flooding, which is often a mixture of grasses and other vegetative plants. Vegetation should be selected specifically for each zone of the bioswale, with the most water tolerant species being located at the base of the swale. To improve water storage capacity, infiltration or pollutant removal, engineered soils and other substrates could be considered in construction. Access for maintenance (e.g., mowing the grass, leaf litter, and sediment removal), inspection, and management is also necessary. Bioswales can be combined with other sustainable drainage system (SUDS) elements such as rainwater harvesting measures and permeable paving. Trampling or any other soil compaction within bioswales should be avoided to ensure water infiltration capacity.

IV. Conditions for implementation

A large enough area is necessary so that bioswales can be an effective part of a stormwater management system. To maximize efficiency, stormwater from roofs or paved areas can be collected and intentionally led into a bioswale.

V. Benefits and limitations

⊕ Potential benefits:

- Stormwater management and control.
- Reduced flood risk.
- Improvement of water quality.
- Habitat provision for wildlife.
- Improvement of amenity value.

⊖ Potential limitations / disservices:

- Trees need to be managed or limited to allow water conveyance.
- The performance and acceptance of bioswales are dependent on regular and appropriate maintenance.

VI. Performance

P1 Cooling service

Transpiration	○	○
Shading	○	○
Evaporation	●	○
Building (Insulation)	○	○
Reflection (Albedo)	○	○

P2 Water balance regulation service

Water conveyance	●	○
Water infiltration	●	●
Water retention	●	○
Water storage	●	○
Water reuse	○	○

P3 Water purification service

Water filtering	●	○
Water bio-remediation	●	○

P4 Air purification service

Deposition	○	○
Air biofiltration	○	○
Noise reduction	○	○

P5 Biodiversity service

Habitat provision	●	○
Connectivity	●	○

P6 Amenity value service

Beauty / Appearance	●	●
Usability / Functionality	○	○
Social interaction	○	○
Education	○	○

P7 Food / Energy / Material

Food / Energy / Material	○	○

P8 CO_2 Sequestration

CO_2 Sequestration	○	○

VII. References and further reading

Anderson, B. S., Phillips, B. M., Voorhees, J. P., Siegler, K., & Tjeerdema, R. (2016). Bioswales reduce contaminants associated with toxicity in urban storm water. Environmental toxicology and chemistry, 35(12), 3124-3134. https://doi.org/10.1002/etc.3472.

Bray, B., Gedge, D., Grant, G., & Leuthvilay, L. (2018). Rain garden guide. Reset Development. Retrieved August 12, 2022, from www.raingardens.info.

Ekka, S. A., Rujner, H., Leonhardt, G., Blecken, G. T., Viklander, M., & Hunt, W. F. (2021). Next generation swale design for stormwater runoff treatment: A comprehensive approach. Journal of Environmental Management, 279, 111756. https://doi.org/10.1016/j.jenvman.2020.111756.

European Commission (EC, n.d.). Individual NWRM swales. Retrieved August 12, 2022 from http://nwrm.eu/sites/default/files/nwrm_ressources/u4-swales.pdf.

Everett, G., Lamond, J. E., Morzillo, A. T., Matsler, A. M., & Chan, F. K. S. (2018). Delivering green streets: An exploration of changing perceptions and behaviours over time around bioswales in Portland, Oregon. Journal of Flood Risk Management, 11, S973-S985. https://doi.org/10.1111/jfr3.12225.

Kazemi, F., Beecham, S., & Gibbs, J. (2011). Streetscape biodiversity and the role of bioretention swales in an Australian urban environment. Landscape and Urban Planning, 101(2), 139-148. https://doi.org/10.1016/j.landurbplan.2011.02.006.

Susdrain (n.d.). Component: Swales. Retrieved from https://web.archive.org/web/20220812154242/https://www.susdrain.org/delivering-suds/using-suds/suds-components/swales-and-conveyance-channels/swales.html.

Susdrain (n.d.). Houndsden road rain gardens, London. Retrieved from https://web.archive.org/web/20220812154409/https://www.susdrain.org/case-studies/case_studies/houndsden_road_rain_gardens_london.html.

United States Department of Agriculture (USDA, n.d.). Bioswales. Retrieved from https://web.archive.org/web/20220812154609/https://www.nrcs.usda.gov/wps/portal/nrcs/detail/?cid=nrcs142p2_008505.

Fig 6.3 Sketch of a rain garden close to the road.

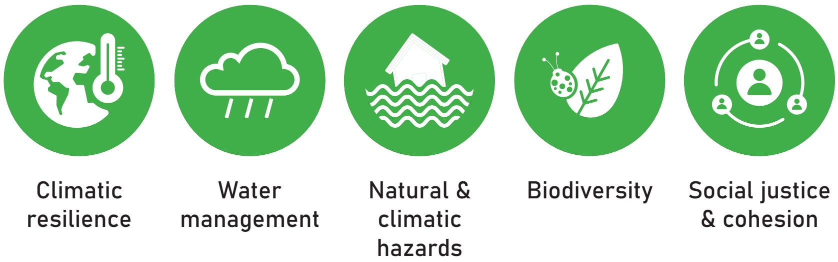
6.2 Rain garden

A rain garden primarily serves as an area for small-scale water management (e.g. storage, infiltration, pollution removal), especially in urban areas. Rain gardens are often established within the built environment and collect water runoff from roofs, roads, and other sealed surfaces. Stormwater runoff is drained into rain gardens, where it is temporarily stored, and then infiltrates through the soil or flows into the sewage system. Rain gardens are not restricted to certain climate conditions and can be found in many countries. However, the selected vegetation should be native and well adapted to local climate conditions.

I. Basic information

Synonyms: Bioretention area; Biorentention swale

Addressed challenges:



II. Role of nature

There are several processes in rain gardens that are inspired by nature. For example, the vegetation and soil within the rain garden can retain and store water, allowing it to slowly infiltrate through the layers as organic pollutants, sediments, and other substances are filtered out of the water. The physical and chemical characteristics of the soil substrate and selected vegetation will have an effect on each of these processes. Other natural processes in rain gardens include evapotranspiration as the vegetation takes up and transpires water, and water conveyance that is similar to that of a river (in larger installations).

III. Technical and design parameters

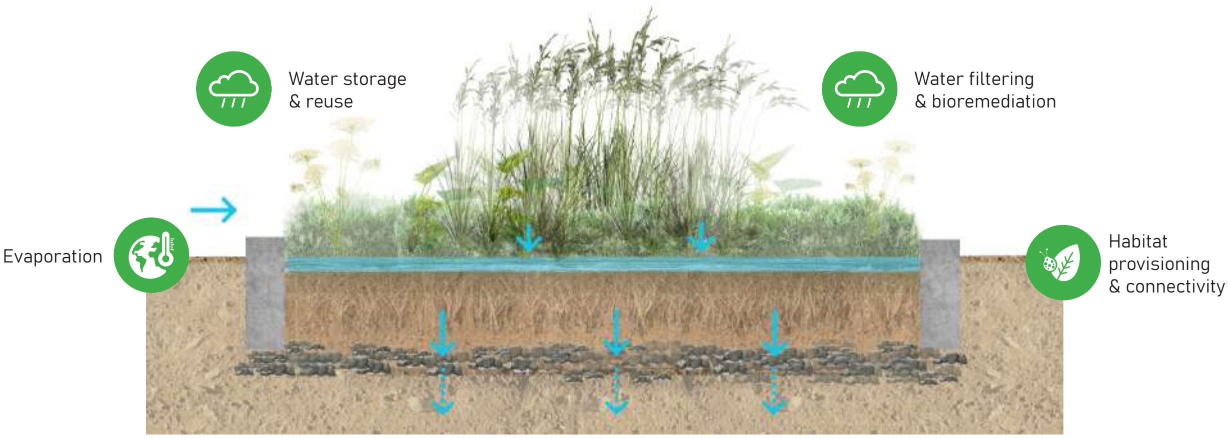


Fig 6.4 An example of a rain garden and its associated natural processes and benefits.

Rain gardens are small-scale, private or public, installations. There are many established designs and arrangements of rain gardens and a variety of elements can be incorporated into their design including grass filter strips, water ponds, mulch areas, soil or other substrates, vegetation, and sand beds. Each of these elements has a particular function (e.g., to slow down, reduce, filter, and store water run-off or increase evapotranspiration), and should therefore be selected according to the local stormwater challenges. Additionally, a gentle downward slope facilitates water flow into the base of the rain garden and positively affects infiltration. In general, rain gardens should be planted with relatively dense, native vegetation that can withstand occasional flooding. Vegetation should be selected specifically for each zone of the rain garden, with the most water tolerant species being located at the base of the garden. Access for regular maintenance, management, and inspection is necessary. Rain gardens can also be combined with other water management solutions like permeable paving and rainwater harvesting.

IV. Conditions for implementation

The amount of available space, selection of adapted plant species, and maintenance need to be considered for implementation.

V. Benefits and limitations

⊕ Potential benefits:

- Stormwater management and control.
- Reduced flood risk.
- Improvement of water quality.
- Habitat provision for wildlife.
- Aesthetic value and improvement of amenity value.

⊖ Potential limitations / disservices:

- The performance and acceptance of rain gardens are dependent on regular and appropriate maintenance.

VI. Performance

P1 Cooling service

Transpiration	● ○
Shading	○ ○
Evaporation	● ○
Building (Insulation)	○ ○
Reflection (Albedo)	○ ○

P2 Water balance regulation service

Water conveyance	○ ○
Water infiltration	● ○
Water retention	● ○
Water storage	● ○
Water reuse	● ●

P3 Water purification service

Water filtering	● ○
Water bio-remediation	● ○

P4 Air purification service

Deposition	○ ○
Air biofiltration	○ ○
Noise reduction	○ ○

P5 Biodiversity service

Habitat provision	● ●
Connectivity	● ○

P6 Amenity value service

Beauty / Appearance	● ●
Usability / Functionality	● ○
Social interaction	● ○
Education	○ ○

P7 Food / Energy / Material

Food / Energy / Material	○ ○

P8 CO_2 Sequestration

CO_2 Sequestration	○ ○

VII. References and further reading

Bray, B., Gedge, D., Grant, G., & Leuthvilay, L. (2018). Rain garden guide. Reset Development. Retrieved August 12, 2022, from www.raingardens.info.

European Commission (EC, n.d.). Individual NWRM swales. Retrieved August 12, 2022 from http://nwrm.eu/sites/default/files/nwrm_ressources/u4-swales.pdf.

Everett, G., Lamond, J. E., Morzillo, A. T., Matsler, A. M., & Chan, F. K. S. (2018). Delivering green streets: An exploration of changing perceptions and behaviours over time around bioswales in Portland, Oregon. Journal of Flood Risk Management, 11, S973-S985. https://doi.org/10.1111/jfr3.12225.

National Association of City Transportation Officials (NACTO, 2017). Case study: Barton CSO control with roadside rain gardens retrofit, Seattle. Retrieved from https://web.archive.org/web/20220812155148/https://nacto.org/case-study/barton-cso-control-seattle/.

Sharma, R., & Malaviya, P. (2021). Management of stormwater pollution using green infrastructure: The role of rain gardens. Wiley Interdisciplinary Reviews: Water, 8(2), e1507. https://doi.org/10.1002/wat2.1507.

Shuster, W. D., Darner, R. A., Schifman, L. A., & Herrmann, D. L. (2017). Factors contributing to the hydrologic effectiveness of a rain garden network (Cincinnati OH USA). Infrastructures, 2(3), 11. https://doi.org/10.3390/infrastructures2030011.

Susdrain (n.d.). Ashby grove residential retrofit rain garden, London. Retrieved from https://web.archive.org/web/20220812155250/https://www.susdrain.org/case-studies/case_studies/ashby_grove_residential_retrofit_rain_garden_london.html.

Susdrain (n.d.). Component: Rain gardens. Retrieved from https://web.archive.org/web/20220812155347/https://www.susdrain.org/delivering-suds/using-suds/suds-components/infiltration/rain-gardens.html.

Susdrain (n.d.). Greening streets, retrofit rain gardens, Nottingham. Retrieved from https://web.archive.org/web/20220812155509/https://www.susdrain.org/case-studies/case_studies/greening_streets_retrofit_rain_gardens_nottingham.html.

Yuan, J., Dunnett, N., & Stovin, V. (2017). The influence of vegetation on rain garden hydrological performance. Urban Water Journal, 14(10), 1083-1089. https://doi.org/10.1080/1573062X.2017.1363251.

Fig 6.5 Infiltration basin in Berlin - Adlershof, Germany.

6.3 Infiltration basin

Infiltration basins are flat, vegetated areas that are usually dry. After heavy rainfall, the water fills up the basin and soaks into the ground. Infiltration basins are usually built with the additional goal to recharge the water table, which differentiates them from retention basins in general. While often planted with grass, additional vegetation types can be integrated into infiltration basins, creating habitats for wildlife, thereby supporting biodiversity and improving aesthetic appeal.

I. Basic information

Synonyms: Infiltration planter (see also Factsheet 6.2); Infiltration pond; Recharge basin

Addressed challenges:

Water management | Natural & climatic hazards | Biodiversity

II. Role of nature

Infiltration basins, similar to dry detention ponds, mimic a natural landscape that contains a heterogeneous surface with slightly elevated and lower areas in close proximity, forming a mosaic of micro conditions. Water is temporarily stored in the lower areas of the basin until it evaporates or infiltrates through the soil, eventually recharging the ground water. Infiltration basins also take advantage of the natural properties of vegetation and soil layers to reduce pollution levels before the stormwater joins the ground water.

III. Technical and design parameters

Infiltration basins are simple to construct. They must be lower than ground level, should be relatively flat, and grass and other vegetation should be taller than 7.5 cm in order to survive flooding. Infiltration basins should have the capacity to infiltrate 50% of their storage volume within 24 hours of filling.

Some maintenance is required including removal of litter and debris, mowing, and annual removal of sediment from inlets and outlets.

IV. Conditions for implementation

Local soil conditions (e.g., permeability and infiltration capacity), available space, and highly specific rainwater intensities must be considered when implementing infiltration basins. They can be integrated into private gardens, public green space, and driveways, but should not be directly connected to aquifers (even if there is a permeable layer in between). Trampling or any other soil compaction within infiltration basins should be avoided to ensure water infiltration capacity.

V. Benefits and limitations

⊕ Potential benefits:

- Temporarily stores stormwater and run-off, thereby reducing peak flows and flood risk.
- Reduces pollution from stormwater.

⊖ Potential limitations / disservices:

- Performance is dependent on regular and appropriate maintenance.

VI. Performance

P1 Cooling service

Transpiration	○	○
Shading	○	○
Evaporation	●	○
Building (Insulation)	○	○
Reflection (Albedo)	○	○

P2 Water balance regulation service

Water conveyance	○	○
Water infiltration	●	●
Water retention	●	○
Water storage	○	○
Water reuse	○	○

P3 Water purification service

Water filtering	●	○
Water bio-remediation	○	○

P4 Air purification service

Deposition	○	○
Air biofiltration	○	○
Noise reduction	○	○

P5 Biodiversity service

Habitat provision	●	○
Connectivity	●	○

P6 Amenity value service

Beauty / Appearance	●	○
Usability / Functionality	○	○
Social interaction	○	○
Education	○	○

P7 Food / Energy / Material

Food / Energy / Material	○	○

P8 CO_2 Sequestration

CO_2 Sequestration	○	○

VII. References and further reading

Bean, E. Z., & Dukes, M. D. (2016). Evaluation of infiltration basin performance on coarse soils. Journal of Hydrologic Engineering, 21(1), 04015050. doi: 10.1061/(ASCE)HE.1943-5584.0001258.

European Commission (n.d). Natural water retention measures: Individual NWRM, infiltration basins. Retrieved August 12, 2022, from http://nwrm.eu/sites/default/files/nwrm_ressources/u12infiltration_basins.pdf.

Natural Water Retention Measures (NWRM, 2015). Leidsche Rijn sustainable urban development, Netherlands. Retrieved from https://web.archive.org/web/20220812160211/http://nwrm.eu/case-study/leidsche-rijn-sustainable-urban-development-netherlands.

Susdrain (n.d.). Component: Infiltration basins. Retrieved from https://web.archive.org/web/20220812160339/https://www.susdrain.org/delivering-suds/using-suds/suds-components/infiltration/infiltration-basin.html.

Fig 6.6 Permeable paving system in Stuttgart, Germany.

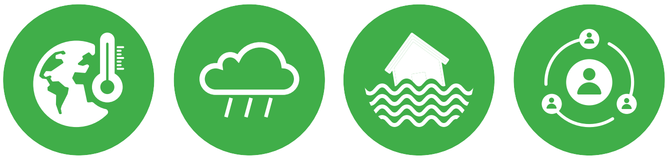
6.4 Permeable paving system

Permeable paving systems are surfaces that are able to absorb stormwater, thereby minimizing and delaying surface water run-off, while reducing the amount of some pollutants. After storm events, the water either trickles through the permeable surface itself, or through gaps or funnels between pavers. Water is then temporarily stored in the underlying stone layer and infiltrates into the soil or to an additional drainage layer that conveys water into the sewage system (subsurface drain). They are commonly installed in parking lots, residential streets, and sidewalks. There are many different systems of permeable pavements. For example, porous asphalt and permeable concrete improve infiltration of homogeneous surfaces. Other solutions such as vegetated grid pavers increase the share of substrate or vegetation cover for better infiltration and allow for water uptake by plants. Solutions such as permeable stone carpets provide macropores for gravity-driven percolation.

I. Basic information

Synonyms: Permeable pavement; Draining pavements

Addressed challenges:



Climatic resilience | Water management | Natural & climatic hazards | Social justice & cohesion

II. Role of nature

Permeable paving systems imitate the permeability and drainage effect of natural soils. Soil permeability depends on soil type and degree of water saturation, which affects infiltration potential. Soil with large pores absorbs more water compared to sealed surfaces, and filling material between bricks enables a high level of water infiltration.

III. Technical and design parameters

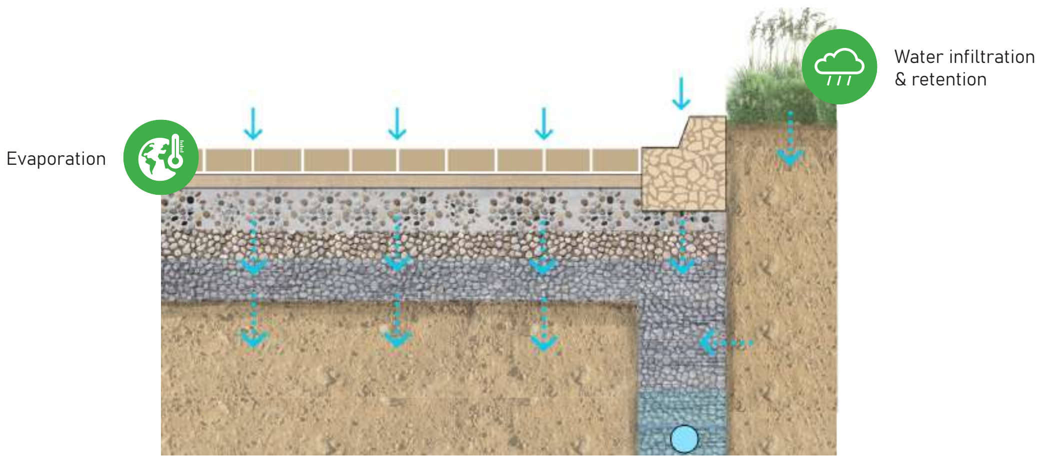


Fig 6.7 An example of a permeable paving system and its associated natural processes and benefits.

Technical and design parameters are dependant upon the specific implemented solution. For example, permeable pavers have a relatively simple construction consisting of a single layer of bricks or stones, followed by an underlying gravel layer, a drainage layer, and filling material that consists of gravel or sand (Fig 6.7). While technical and design parameters differ among permeable paving systems, all require regular maintenance to avoid clogging and maintain functionalitiy.

IV. Conditions for implementation

Permeable pavements can be implemented on new or previously existing building sites. Prior analysis of the soil is necessary, and compatibility with all kinds of street usage should be considered.

V. Benefits and limitations

⊕ Potential benefits:

- Water quality protection.
- Stormwater management.
- Reduced surface run-off.
- Controlled infiltration.
- Temporary water storage.
- Water filtering.

⊖ Potential limitations / disservices:

- Limited load on paved area - often not applicable for high speed or highly trafficked roads.
- Prone to clogging without regular maintenance.

VI. Performance

P1 Cooling service

Transpiration	●	○
Shading	○	○
Evaporation	●	○
Building (Insulation)	○	○
Reflection (Albedo)	●	○

P2 Water balance regulation service

Water conveyance	○	○
Water infiltration	●	○
Water retention	●	○
Water storage	○	○
Water reuse	○	○

P3 Water purification service

Water filtering	●	○
Water bio-remediation	○	○

P4 Air purification service

Deposition	○	○
Air biofiltration	○	○
Noise reduction	○	○

P5 Biodiversity service

Habitat provision	○	○
Connectivity	○	○

P6 Amenity value service

Beauty / Appearance	○	○
Usability / Functionality	●	○
Social interaction	●	○
Education	○	○

P7 Food / Energy / Material

Food / Energy / Material	○	○

P8 CO_2 Sequestration

CO_2 Sequestration	○	○

VII. References and further reading

City of Portland (n.d.). Environmental services: Pervious pavement projects. Retrieved from https://web.archive.org/web/20220812160845/https://www.portlandoregon.gov/bes/article/77074.

City of Portland (n.d.). Westmoreland pervious pavers, Portland, Oregon: Project summary. Retrieved August 12, 2022, from https://www.portlandoregon.gov/shared/cfm/image.cfm?id=174662.

Eisenberg, B., Lindow, K. C., & Smith, D. R. (Eds., 2015). Permeable pavements. American Society of Civil Engineers. https://doi org/10.1061/9780784413784.

Hein, D. K., & Eng, P. (2014). Permeable pavement design and construction case studies in North America. In Transportation 2014: Past, Present,

Future-2014 Conference and Exhibition of the Transportation Association of Canada//Transport 2014: Du passé vers l'avenir-2014 Congrès et Exposition de'Association des transports du Canada.

Kuruppu, U., Rahman, A., & Rahman, M. A. (2019). Permeable pavement as a stormwater best management practice: A review and discussion. Environmental Earth Sciences, 78(10), 1-20. https://doi.org/10.1007/s12665-019-8312-2.

Sambito, M., Severino, A., Freni, G., & Neduzha, L. (2021). A systematic review of the hydrological, environmental and durability performance of permeable pavement systems. Sustainability, 13(8), 4509. https://doi.org/10.3390/su13084509.

Watershed Council (2019). Permeable Pavers. Retrieved from https://web.archive.org/web/20220812161536/https://www.watershedcouncil.org/permeable-pavers.html.

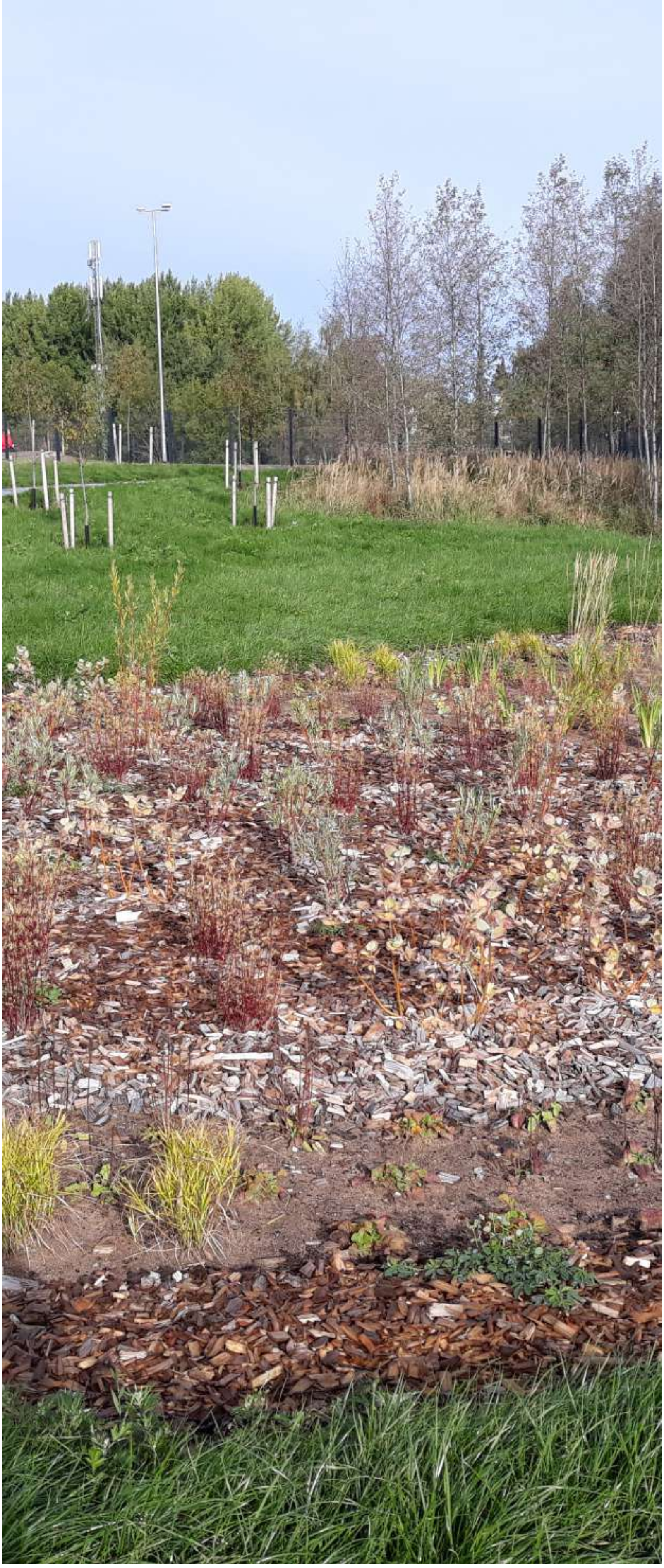


Fig 6.8 Heidanranta biofilter, Finland.

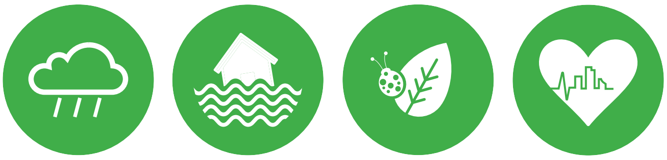
6.5 Biofilter (water purification)

Biofilters are developed to collect and treat storm- and wastewater and represent a promising system for grey water treatment. Bacteria and microorganisms are located on a filter medium (biofilm), which often consists of sand or granular activated carbon. The biofilm degrades nutrients and contaminants in the wastewater (influent) that is pumped through the filter material. The term “filter,” however, can be misleading. Biofilters separate and remove nutrients and organic carbons from storm- and wastewater through biodegradation. As a result, biofiltration improves the quality of storm- and wastewater (e.g., the reduction of nutrients, metals, sediments) while temporarily storing stormwater, which can help reduce peak flows.

I. Basic information

Synonyms:

Addressed challenges:



Water management

Natural & climatic hazards

Biodiversity

Public health & well-being

II. Role of nature

Biodegradation is a natural process in soils. This natural degradation is used for different processes, for example, in anaerobic digestion (biogas production). Microorganisms and bacteria degrade and therefore remove excess nutrients and contaminants.

III. Technical and design parameters

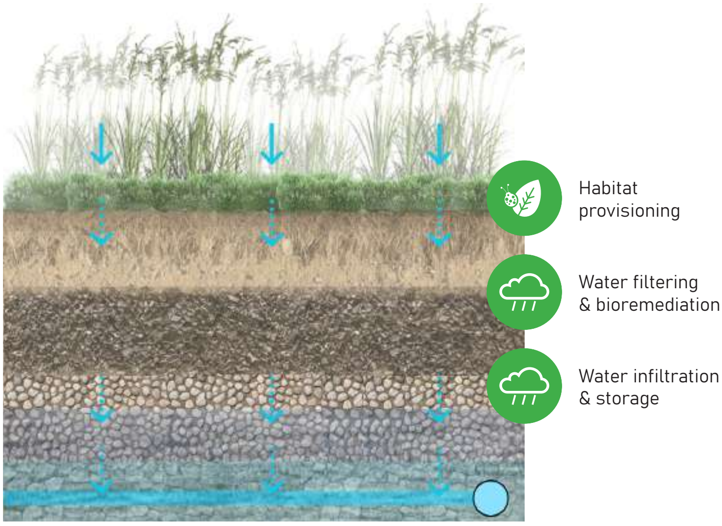


Fig 6.9 An example of a biofilter and its associated natural processes and benefits.

Biofilters consist of layers of different soil types or substrates (e.g., sand, activated carbon) with a biofilm of bacteria and other microorganisms that degrade and remove pollutants (e.g., nitrogen, phosphorus, heavy metals). Typically, anaerobic conditions are necessary for this biodegradation, so the biofilter should be continuously saturated with water. To maintain the proper level of saturation without overwhelming the system, stormwater run-off can be stored in an ornamental pond and slowly guided (or pumped) to the biofilter. Filtered water can then be re-used after treatment.

On top of the biofilter, a vegetation layer should be established. Depending on the design of the filter, suitable species (e.g., water and pollution tolerant) should be selected. Proper selection of native and condition-tolerant species can help support small-scale biodiversity enhancement through habitat establishment.

IV. Conditions for implementation

Adequate space for construction and flat terrain are needed.

V. Benefits and limitations

⊕ Potential benefits:

- Water treatment.
- Improves quality of storm- and wastewater.
- Stormwater regulation and management.
- Improve quality of life (e.g., reduction of odours).
- Small-scale habitat establishment.
- Smaller than solutions with similar benefits, e.g., constructed wetlands.

⊖ Potential limitations / disservices:

- High level of maintenance and monitoring necessary to ensure effectiveness.

VI. Performance

P1 Cooling service

Transpiration	○○
Shading	○○
Evaporation	○○
Building (Insulation)	○○
Reflection (Albedo)	○○

P2 Water balance regulation service

Water conveyance	●○
Water infiltration	●●
Water retention	●○
Water storage	●●
Water reuse	●○

P3 Water purification service

Water filtering	●●
Water bio-remediation	●●

P4 Air purification service

Deposition	○○
Air biofiltration	○○
Noise reduction	○○

P5 Biodiversity service

Habitat provision	●○
Connectivity	○○

P6 Amenity value service

Beauty / Appearance	●○
Usability / Functionality	○○
Social interaction	○○
Education	○○

P7 Food / Energy / Material

Food / Energy / Material	○○

P8 CO_2 Sequestration

CO_2 Sequestration	○○

VII. References and further reading

Deletic, A., McCarthy, D., Chandrasena, G., Yali, L., Hatt, B., Payne, E., Zhang, K., Rebekah, H., Kolotelo, P., Randjelovic, A., Meng, Z., Glaister, B., Pham, T., & Ellerton, J. (2014). Biofilters and wetlands for stormwater treatment and harvesting. Cooperative Research Centre for Water Sensitive Cities, Monash University, Melbourne. ISBN: 9781921912221.

Feng, W., Hatt, B. E., McCarthy, D. T., Fletcher, T. D., & Deletic, A. (2012). Biofilters for stormwater harvesting: Understanding the treatment performance of key metals that pose a risk for water use. Environmental science & technology, 46(9), 5100-5108. https://doi.org/10.1021/es203396f.

Hatt, B. E., Fletcher, T. D., & Deletic, A. (2009). Pollutant removal performance of field-scale stormwater biofiltration systems. Water science and technology, 59(8), 1567-1576. https://doi.org/10.2166/wst.2009.173.

Payne, E. G. I., Pham, T., Cook, P., Fletcher, T., Hatt, B. E., & Deletic, A. (2014). Biofilter design for effective nitrogen removal from stormwater: Influence of plant species, inflow hydrology and use of a saturated zone. Water Science and Technology, 69(6), 1312 - 1319. https://doi.org/10.2166/wst.2014.013.

Shen, P., Deletic, A., Urich, C., Chandrasena, G. I., & McCarthy, D. T. (2018). Stormwater biofilter treatment model for faecal microorganisms. Science of the Total Environment, 630, 992-1002. https://doi.org/10.1016/j.scitotenv.2018.02.193.

7. References

1. Eisenberg, B., & Polcher, V. (2018). Nature-based solutions technical handbook. UNaLab project deliverable D 5.1.

2. European Commission (EC, n.d.). Research and innovation: Nature-based solutions. Retrieved from https://web.archive.org/web/20220209093103/https://ec.europa.eu/info/research-and-innovation/research-area/environment/nature-based-solutions_en.

3. Eggermont, H., Balian, E., Azevedo, J. M. N., Beumer, V., Brodin, T., Claudet, J., Fady, B., Grube, M., Keune, H., Lamarque, P., Reuter, K., Smith, M., van Ham, C., Weisser, W. W., & Le Roux, X. (2015). Nature-based solutions: New influence for environmental management and research in Europe. GAIA-Ecological Perspectives for Science and Society, 24(4), 243-248. https://doi.org/10.14512/gaia.24.4.9.

4. Wendling, L., Rinta-Hiiro, V., Jermakka, J., Fatima, Z., zu-Castell Rüdenhausen, M., Ascenso, A., Miranda, A. I., Roebeling, P., Martins, R. & Mendonca, R. (2019). Performance and impact monitoring of nature-based solutions. UnaLab project deliverable D 3.1.

5. Thompson, C. W. (2011). Linking landscape and health: The recurring theme. Landscape and urban planning, 99(3-4), 187-195. https://doi.org/10.1016/j.landurbplan.2010.10.006.

6. Jones, K. R. (2018). "The lungs of the city": Green space, public health and bodily metaphor in the landscape of urban park history. Environment and History, 24(1), 39-58. https://doi.org/10.3197/096734018X15137949591837.

7. Strohbach, M. W., Lerman, S. B., & Warren, P. S. (2013). Are small greening areas enhancing bird diversity? Insights from community-driven greening projects in Boston. Landscape and Urban Planning, 114, 69-79. https://doi.org/10.1016/j.landurbplan.2013.02.007.

8. Berland, A., Shiflett, S. A., Shuster, W. D., Garmestani, A. S., Goddard, H. C., Herrmann, D. L., & Hopton, M. E. (2017). The role of trees in urban stormwater management. Landscape and urban planning, 162, 167-177. https://doi.org/10.1016/j.landurbplan.2017.02.017.

9. Ko, Y. (2018). Trees and vegetation for residential energy conservation: A critical review for evidence-based urban greening in North America. Urban Forestry & Urban Greening, 34, 318-335. https://doi.org/10.1016/j.ufug.2018.07.021.

10. Abhijith, K. V., Kumar, P., Gallagher, J., McNabola, A., Baldauf, R., Pilla, F., Broderick, B., Di Sabatino., S., & Pulvirenti, B. (2017). Air pollution abatement performances of green infrastructure in open road and built-up street canyon environments: A review. Atmospheric Environment, 162, 71-86. https://doi.org/10.1016/j.atmosenv.2017.05.014.

11. Wolf, K. L., Lam, S. T., McKeen, J. K., Richardson, G. R., van den Bosch, M., & Bardekjian, A. C. (2020). Urban trees and human health: A scoping review. International journal of environmental research and public health, 17(12), 4371. https://doi.org/10.3390/ijerph17124371.

12. Pretzsch, H., Moser-Reischl, A., Rahman, M. A., Pauleit, S., & Rötzer, T. (2021). Towards sustainable management of the stock and ecosystem services of urban trees. From theory to model and application. Trees, 1-20. https://doi.org/10.1007/s00468-021-02100-3.

13. New York City Department of Parks and Recreation (n.d.). Million Trees NYC. Retrieved from https://web.archive.org/web/20220209152153/https://www.nycgovparks.org/trees/milliontreesnyc.

14. Gromke, C., & Blocken, B. (2015). Influence of avenue-trees on air quality at the urban neighborhood scale. Part II: Traffic pollutant concentrations at pedestrian level. Environmental Pollution, 196, 176-184. https://doi.org/10.1016/j.envpol.2014.10.015.

15. Anne, B., Geoffroy, S., Cherel, J., Warot, G., Marie, S., Noël, C. J., Louis, M.J., & Christophe, S. (2018). Towards an operational methodology to optimize ecosystem services provided by urban soils. Landscape and urban planning, 176, 1-9. https://doi.org/10.1016/j.landurbplan.2018.03.019.

16. Federal Ministry for the Environment, Nature Conservation, Nuclear Safety, and Consumer Protection (2020). What is soil conservation about? Retrieved from https://web.archive.org/web/20220210083258/https://www.bmuv.de/en/topics/water-resources-waste/soil-conservation/what-is-soil-conservation-about.

17. European Commission (2020). Global soil erosion projected to be worse than previously expected. Retrieved from https://web.archive.org/web/20220210092924/https://ec.europa.eu/jrc/en/news/global-soil-erosion-projected-be-worse-previously-expected.

18. Lu, C., Kotze, D. J., & Setälä, H. M. (2020). Soil sealing causes substantial losses in C and N storage in urban soils under cool climate. Science of the Total Environment, 725, 138369. https://doi.org/10.1016/j.scitotenv.2020.138369.

19. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2018). Summary for policymakers of the assessment report on land degradation and restoration of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services [Scholes, R., Montanarella, L., Brainich, A., Barger, N., ten Brink, B., Cantele, M., Erasmus, B., Fisher, J., Gardner, T., Holland, T. G., Kohler, F., Kotiaho, J. S., von Maltitz, G., Nangendo, G., Pandit, R., Parrotta, J., Potts, M. D., Prince, S., Sankaran, M., and Willemen L. (eds.)]. IPBES secretariat, Bonn, Germany. Retrieved March 20, 2021, https://ipbes.net/assessment-reports/ldr.

20. The Intergovernmental Panel on Climate Change (IPCC, 2021). Climate change 2021: The physical science basis. Contribution of working group I to the sixth assessment report of the intergovernmental panel on climate change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press. ISBN: 978-92-9169-158-6.

21. European Environment Agency (EAA, n.d.). Indicator assessment: Heavy precipitation in Europe. Retrieved February 14, 2022, from https://www.eea.europa.eu/publications/europes-changing-climate-hazards-1/wet-and-dry-1/wet-and-dry-heavy.

22. Kabisch, N., Korn, H., Stadler, J., & Bonn, A. (2017). Nature-based solutions to climate change adaptation in urban areas: Linkages between science, policy and practice. Springer Nature. ISBN: 978-3-319-53750-4.

23. Ruangpan, L., Vojinovic, Z., Di Sabatino, S., Leo, L. S., Capobianco, V., Oen, A. M., McClain, M.E., & Lopez-Gunn, E. (2020). Nature-based solutions for hydro-meteorological risk reduction: A state-of-the-art review of the research area. Natural Hazards and Earth System Sciences, 20(1), 243-270. https://doi.org/10.5194/nhess-20-243-2020.

8. List of Figures

UNaLab URBAN NATURE LABS

ILPÖ INSTITUT FÜR LANDSCHAFTSPLANUNG UND ÖKOLOGIE

Universität Stuttgart