RECONECT

Guidance document on integrating innovative NBS technologies into existing landscape, maintenance issues and long-term sustainability

Deliverable D1.4

Acknowledgement
This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 776866

Authors: TUHH

Contributors: IHE

Acknowledgement
This project has received funding from the European Union’s Horizon 2020 Research and Innovation Programme under grant agreement No 776866

Document Information

Project Number	776866	Acronym	RECONECT
Full Title	RECONECT- Regenarating ECOsystems with Nature-based solutions for hydrometeorological risk rEduCTion		
Project URL	http://www.reconect.eu/		
Document URL			
EU Project Officer	Laura Palomo Rios		

Deliverable	Number	D1.4	Title	D1.4 Guidance Document on Integrating Innovative NBS Technologies into Existing Landscape, Maintenance Issues and long-term Sustainability
Work Package	Number	WP1	Title	Framing science, policy and practice of NBS

Date of Delivery	Contractual	31.10.2021	Actual	31.12.2021
Status	version 1.0			
Deliverable type*	R			
Dissemination	PU			

*R – Report, P – Prototype, D – Demonstrator, O – Other.

**PU – Public, PP – Restricted to other programme participants (including the Commission Services), RE – Restricted to a group specified by the consortium (including the Commission Services), CO – Confidential, only for members of the consortium (including the Commission Services).

Authors (Partner)	Natasa Manojlovic (TUHH)			
Responsible Author	Name	Natasa Manojlovic	Partner	TUHH
Contributors	Bo-Syuan Wu (IHE), Zoran Vojinovic (IHE), Vytaute Dlugoborskyte (TUHH), Jannes Westermann (TUHH)			

Abstract	This report addresses some of the asset management aspects of NBS and as such represents an introduction to the lifecycle analysis of NBS within RECONECT. It aims to deliver a set of issues and findings, which are to be considered prior to the development of NBS, which are mainly related to the integration of NBS in the landscape with the focus on its dynamics and their maintenance in relation to hybrid solutions, taking into account the long-term sustainability.
Keywords	Nature-based solutions; NBS; maintenance issues, long-term sustainability, landscape dynamics

Version Log				
Issue Date	Rev. No.	Author	Change	Approved by
15.12.2021		NM (TUHH)		

Executive Summary

This report addresses some of the asset management aspects of NBS and as such represents an introduction to the lifecycle analysis of NBS within RECONECT. It aims to deliver a set of issues and findings, which are to be considered prior to the development of NBS, which are mainly related to the integration of NBS in the landscape with the focus on its dynamics and their maintenance in relation to hybrid solutions, taking into account the long-term sustainability.

The report provides some of the key lessons learned sourced from the scientific literature, projects and portals containing and addressing management aspects of NBS, and as such it also aims to provide an overview of the knowledge and experiences gained in the RECONECT so far.

The target audience for this deliverable can be divided in two groups. The first group is the RECONECT partners in particular Demonstrators and Collaborators. The second group involves practitioners dealing with asset management, NBS owners and to a certain extent researches supporting asset managers.

The Framework for implementation of large scale NBS has been developed and presented, highlighting the feedback loops ad interactions between different stages of the implementation process. The main findings and recommendations can be summarised to the following:

1. The scope of the planning should not be too narrow: the area beyond the project area that are affected by the NBS should be considered and if negative consequences from the NBS are to be expected;
2. The costing of the NBS or hybrid solutions should be performed for the while life span of the assets, not focusing on the short-term investment costs and the required efforts to adopt a new solution. The NBS are likely to decrease the overall costs, as the maintenance is often intended to be kept at the minimal effort level;
3. Innovation should be pursued when implementing NBS strategies. Underlined by the co-creation, the NBS related innovation in maintenance can improve the overall asset management by introducing new technologies; and
4. Long term sustainability is likely to be achieved by addressing the major pillars of sustainability and benefits of NBS in the long term perspective.

Executive Summary **5**

1 Introduction **7**

1.1. Background 7

1.2. Objectives and the structure of the report 9

1.3. Target audience 10

1.4. Links to other deliverables in RECONECT 10

2. The scope of Nature-based Solutions (NBS) addressed in this guidance document **11**

2.1. Definition and types of NBS addressed 11

2.1.1. Report D1.3 on Development of a database of existing knowledge and practice of NBS with the reference to the relevant policies and regulations” 11

2.1.2. RECONECT Database of measures 13

2.1.3. Measures identified within the Lead User Method (LUM) 18

2.2. Addressing the main enhancements and innovative technologies in RECONECT in this guidance document 19

3. Integrating NBS related Enhancements into Implementation Process of Large Scale NBS **22**

3.1 Integration into the existing landscape and its dynamics 25

3.2 Maintenance of NBS 30

3.2.1 Definition and scope of the maintenance activities of NBS/Hybrid solutions 30

3.2.2 Framework to analyse maintenance in the context of large scale NBS 32

3.3 Addressing long-term sustainability 46

4. Key Leassons Learned, Conclusions and Outlook **52**

4.1 Key lessons learned 52

4.2 Conclusions 53

4.3 Outlook 54

5. References **55**

6. APPENDIX - Lead User Measures **58**

1 Introduction

1.1. Background

Nature Based Solutions (NBS) are increasingly being acknowledged as the key to managing natural hydrological extremes in the future where climatic changes will increase the size and rate of occurrence for both droughts and floods. Already now, NBS is being implemented as functional responses to extreme, damage-causing events; e.g. the Dutch Room for the River project (Rijke et al., 2012) as a response to the Rhine River floods in 1993 and 1995 (Engel, 1997), the Copenhagen Cloudburst Management Plan as a direct response to the major pluvial floods of Copenhagen in 2010 and 2011 (City of Copenhagen, 2012) and the Dublin Climate Change Action Plans (Dublin City Council, 2019) that were created as a response to recurring severe pluvial flooding events in 2002, 2008, 2009 and 2011 (Dublin City Council et al., 2017).

Implementation of Nature-Based Solutions (NBS) for hydro-meteorological risk reduction offers the possibility to break away from traditional practices and enable to reconnect our land management practices and developments with nature in order to achieve multiple benefits to services and functions of ecosystems. According to Olsen and Bishop (2009) and van der Nat et al. (2016), such measures are potentially more cost-effective and adaptable than traditional hard engineering measures. However, cost-effective design and implementation of NBS is only part of the answer. Of equal importance is the ability to effectively place them in **diverse local and cultural contexts** and integrate them into broader land and risk management strategies. It is therefore of crucial importance **to understand the complexity of each case** and and to design them in such way that can minimise social and economic losses and environmental impacts, increase resilience to hydro-meteorological events and ensure the upscaling, business models and financial viability of any interventions. Examples of large scale NBS for hydro-meteorological risk reduction which can provide proof-of-concept for their upscaling and replication is currently lacking and there is a clear need to enhance their evidence base through demonstration within the European reference framework.

Project RECONECT H’2020-C5-08-2017-GA-776866 is an interdisciplinary international project that aims to contribute to European reference framework on Nature Based Solutions (NBS) by demonstrating, referencing and upscaling large scale NBS and by stimulating a new culture for 'land use planning' that links the reduction of risks with local and regional development objectives in a sustainable way.

In order to contribute effectively to the EU reference framework on NBS and to generate higher impacts across Europe, RECONECT draws upon a number of Demonstrator and Collaborator Sites. They have been carefully selected to cover a range of local criteria including climatic and geographic conditions (1.); type of hydro-meteorological events (floods, storm surges, droughts, landslides) (2.) and vulnerability to these events (3.). Besides from these criteria, the potential for collaboration and upscaling has also played a role in the selection process.

In order to capitalise on the existing knowledge and experiences on NBS within the RECONECT Consortium and initiate the knowledge sharing and upscaling process already in an early project stage, RECONECT bases its demonstration activities on two types of Demonstrators being A and B, which are at different stages in the NBS co-creation process. They further share this knowledge and experience with the Collaborators.

Both, Demonstrators and Collaborators form the RECONECT NBS network of cases. The geographic spread of the individual cases is presented Figure 1.

In **Demonstrators Type A** the large scale NBS will include the full co-creation (i.e., *co-assessment, co-design, co-implementation, co-monitoring and co-evaluation*) and validation process during the project lifetime either by requesting co-funding from the EC and/or by deploying their own funds and resources.

The **Demonstrators Type B** cases have a considerable track record in implementing large scale NBS in natural and rural areas and particularly those that are sensitive ones (e.g. mountainous and coastal areas, at watershed/landscape scale) with high local/national/international visibility. In order to capitalise on their experiences on already implemented NBS, RECONECT will demonstrate their NBS by co-monitoring, co-evaluating and validating their multiple benefits.

Collaborators are inspired and advised by RECONECT Demonstrators to uptake their experiences and produce **prefeasibility studies for implementation of NBS** (EU and International Collaborators). The prefeasibility studies will involve assessment of the following: potential sites for NBS implementation, applicable types of large-scale NBS, their potential benefits/co-benefits and the potential for mainstreaming NBS in land use planning

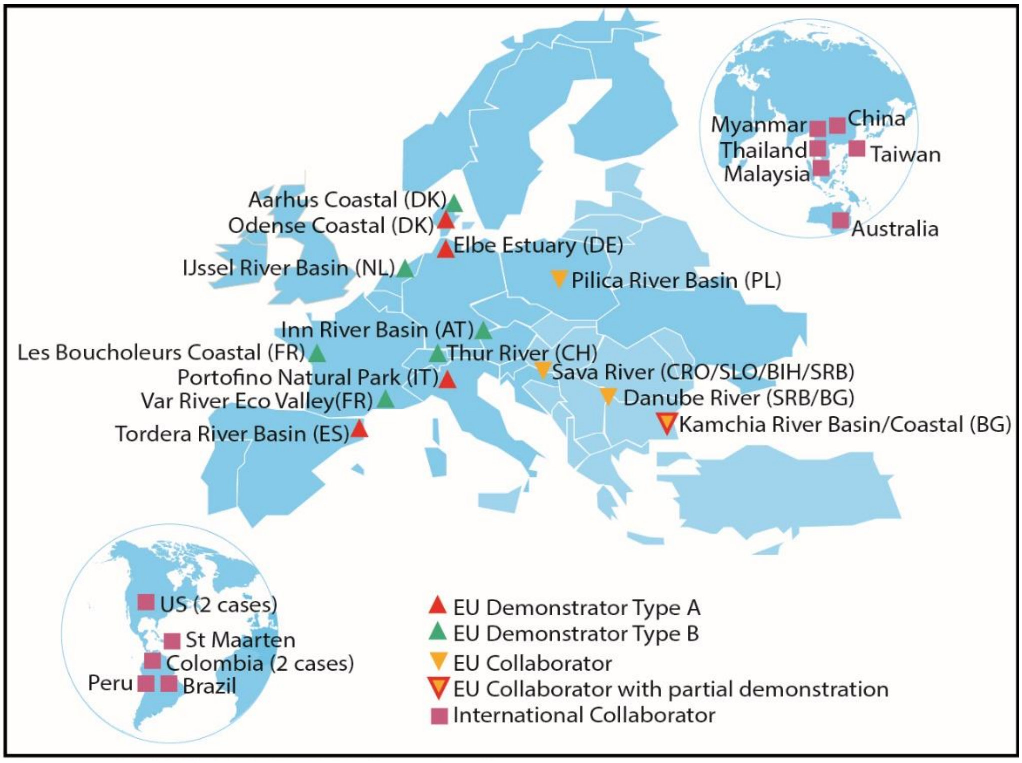


Figure 1 RECONECT Network of cases

WP1 on Framing science, policy and practice sets the scope of the project and delivers the frameworks, state of the art analyses and guidance documents and repositories of NBS enhancements, tools and methods to the RECONECT Network of Cases. The emerging relevant enhancements and developments in the field of NBS are analysed and addressed within the RECONECT network in order to make use of them for the demonstration and upscaling within the project and beyond.

Within WP1 the methods, tools and guidance documents are developed and made available to frame the activities within RECONECT or support their implementation. In that sense, WP1 delivers a set of tools to support those activities. Overview of the WP1 Products is given in Table 1. The guidance document presented in this report is given as P5 and is highlighted in Table 1.

Table 1 Overview of the WP1 Products

WP1 Product	Main Target audience (main beneficiaries)
P1- RECONECT Holistic ecosystem based framework	Academia,
P2- Geodatabase (overlay)	Practitioners, academia
P3- (Online) Portfolio of the existing and enhanced tools for NBS demonstration and upscaling	
P4- Lead user analysis	Practitioners, asset owners
P5- Guidance document on integration of innovative NBS into landscape and maintenance issues	Asset owners, practitioners,
P6- Complex adaptive systems (CAS) with the CLAIM framework tool for policy formulation	Academia, asset owners
P7- Guidance on the social innovation approach	Asset owners, practitioners

1.2. Objectives and the structure of the report

This report opens a series of RECONECT reports addressing the asset management of NBS and hybrid solutions and as such represents an introduction to the lifecycle considerations of the NBS. It is meant to deliver a set of issues and findings which are to be considered prior to the development of NBS, which are mainly related to the integration of NBS in the landscape and its dynamics so as the maintenance of NBS and hybrid solutions, taking into account the long-term sustainability.

This report provides extracted lessons learned on those topics sourced from the scientific finding, projects and portals containing and addressing the management of NBS, but more importantly, from the experiences gained in the RECONECT demonstrators so far. In this way, the report supports the exchange, twinning and transfer of knowledge towards other RECONECT demonstrators and collaborators, by delivering some practical recommendations on how to address NBS in the context of asset management, focusing on the above mentioned topics.

Mode detailed planning and design procedures so as the operation, decommissioning are given in reports D2.8 (*Guidelines for design, construction and maintenance of largescale NBS*) and their further exploitation and standardisation in D5.4 (*Draft standards for design, implementation, management and decommissioning of NBS)*.

How to read this guide:

This report is prepared in a form of a guidance document based on the available knowledge and experience within the RECONECT Consortium, but also including publicly available information. The topics addressed are given in stepwise procedures. Examples of a best practice experiences from RECONECT or other projects are given in a separate boxes, demonstrating and addressing some specific issues associated with the individual steps of the presented frameworks.

1.3. Target audience

The guidance document addresses two levels of end-users. The first group is the RECONECT partners in particular Demonstrators A and Collaborators.
The second level is related to the audience beyond RECONECT and in particular:

- Practitioners responsible for the management of assets that involve NBS
- Responsible agencies and asset owners
- Researches supporting asset owners to develop their asset management and NBS strategies

1.4. Links to other deliverables in RECONECT

This report building upon the previous project outcomes and in particular the following reports and activities:

- D1.3 "NBS for hydro-meteorological risk reduction: review of existing knowledge base, practices and policies"
- This report also draws upon the experiences and lessons learned by the RECONECT Network of Cases, in particular by the Demonstrators
- This report is cross-linked with the report D3.5 on co-creation strategy and tools
- D2.8 – "Guidelines for design, construction and maintenance of largescale NBS"
- D5.4 "*Draft standards for design, implementation, management and decommissioning of NBS*

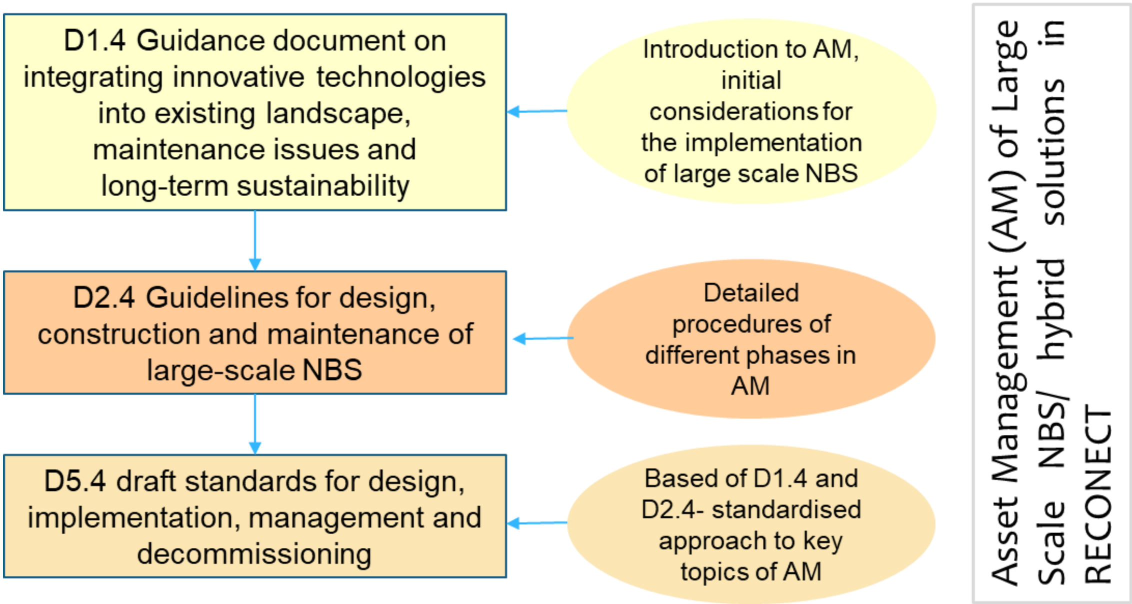


Figure 2 Asset Management of largescale NBS/ hybrid solutions in RECONECT; the key deliverables and their scope

2. The scope of Nature-based Solutions (NBS) addressed in this guidance document

2.1. Definition and types of NBS addressed

This report puts in the focus the management of nature-based solutions (NBS) defined by the European Commission 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.” [1]

Following this general definition of NBS, the key feature of NBS should be their ability to **deliver co-benefits** for nature and people in addition to their primary function.

A key characteristic that distinguishes NBS interventions from other ‘green solutions’ is that they are used to address key societal challenges. Societal challenges arise from a combination of natural and anthropogenic factors, and include climate change, disaster risk, economic and social development, human health or biodiversity loss (Cohen-Shacham et al. 2019).

In the context of RECONET the potential of **large scale NBS** to **mitigate hydrometeorological risks** is investigated, whereby the ***large scale*** **of NBS** refers to the actual geometry/size/area coverage of a single NBS or a network of NBS and/or their impacts on the hydro-meteorological risk reduction.
Generally, a large-scale NBS combines different NBSs within a larger system to achieve better long-term strategies. The most common large-scale NBSs are flood storage basins (De Risi et al., 2018) and preservation and regeneration of forests in flood-prone areas (Bhattacharjee and Behera, 2018), making more room for the river (Klijn et al., 2013), river restoration (Chou, 2016), wetlands (Thorslund et al., 2017) and mountain forestation (Castelleretal, 2018).

In RECONECT a number of sources have been used to develop understanding and create a pool of NBS. The main sources are given as:

2.1.1. Report D1.3 on Development of a database of existing knowledge and practice of NBS with the reference to the relevant policies and regulations”

In report D1.3 the state-of-the art of large scale NBS for hydrometeorological events has been analysed and brought to the context of RECONECT. Here, the existing NBS related body of literature together with the existing repositories of NBS have been analysed and used as one of the references for the definition of the NBS enhancements in this report: The summary of the key literature points is given in the review Ruangpan et al., 2020., The overview of the key identified repositories of NBS that are analysed within the RECONECT overlay geodatabase tool is given in Table 2.

[1] There is a considerable body of literature addressing and analysing the definitions of NBS and its relation to other sister concepts such as eco-engineering or BMPs, most of them concluding that the key distinguishing feature of NBS is the ability to deliver co-benefits for nature and people in addition to its main function. For more information and elaboration on NBS refer to D1.3 on “NBS for hydro-meteorological risk reduction: review of existing knowledge base, practices and policies” or Ruangpan et al., 2020)

Table 2 An overview of selected platforms/ repositories with some of their main features (see also report D1.3)

Name	References/ Website	Terminology used	Scale level	Funded by	Purpose
OPPLA	https://oppla.eu	Nature-Based Solution, Natural capital, Ecosystem services	Local to global	FP7 (EC)	A new knowledge marketplace - EU repository of NBS; a place where the latest thinking on ecosystem services, natural capital and NBS is brought together.
ClimateADAPT	https://climate-adapt.eea.europa.eu/	EbA, Nature-Based Solution, GI	Europe	EC, EEA	A platform that supports Europe in adapting to climate change by helping users to access and share data and information relevant for CCIVA.
Natural Water Retention Measures	http://nwrm.eu/	Natural water retention measures	Europe	EC	A platform that gathers information on NWRM at EU level.
Urban Nature Atlas	https://naturvation.eu/atlas	Nature-Based Solution	Europe	Horizon 2020 (EC)	A platform that contains around 1000 examples of NBS from across 100 European cities.
Natural Hazards – Nature Based Solutions	https://naturebasedsolutions.org	Nature-Based Solution	Global	The World Bank	Povides a list of nature-based projects that are sortable by implementing organisation, targeted hazard.
ClimateScan	https://climatescan.nl	Blue-Green Infrastructures	Global	EC	Global online tool which acts as a guide for projects and initiatives climate proofing

An example of a measure in the Natural Water Retention Measures platform is given in Figure 3.

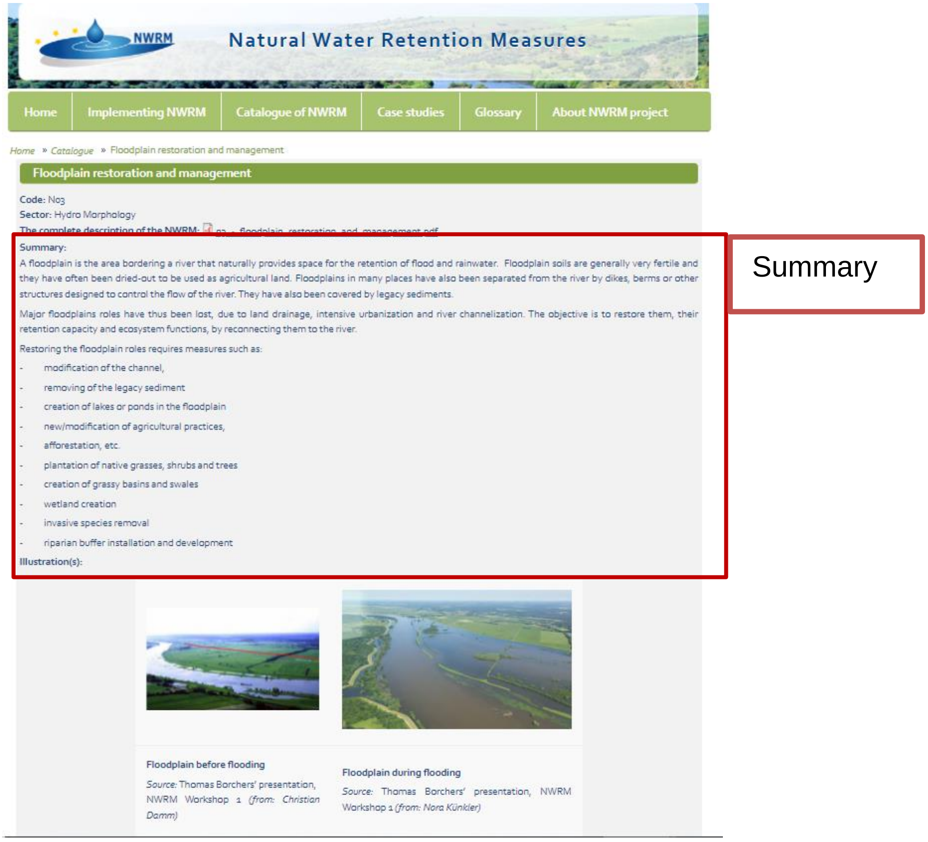


Figure 3 An example of a measure in the Natural Water Retention measures (http://nwrm.eu/measure/); here Floodplain Restoration and Management. In addition to a short description of the measure, a list of benefits is given together with link to the case studies

The solutions found in those platforms are given as real examples implemented in different contexts and conditions worldwide. They have been taken as a reference for this report, but they also contributed to the developed set of the generic measures within the RECONECT Database of measures.

2.1.2. RECONECT Database of measures

A set of generic measures has been developed and complied to form the RECONECT database of measures. Both, grey and NBS interventions are included, giving some basic information about different measures structured over three main topics: (1) Definition and the primary function; (2) Co-benefits; (3) Financial costs. An overview of the measures is given in Figure 4.

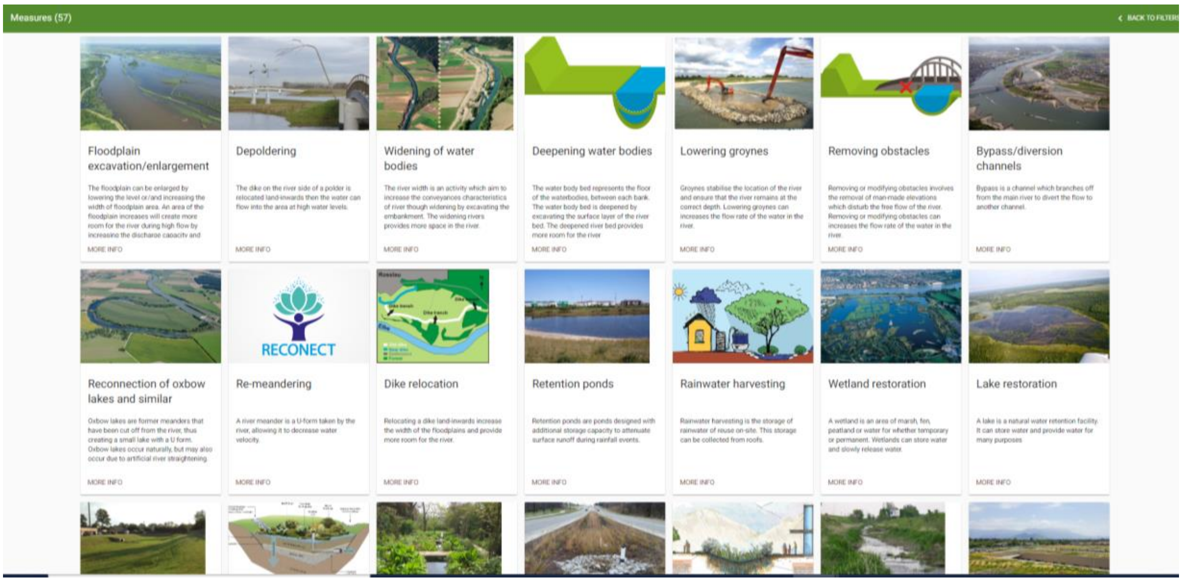


Figure 4 Examples of solutions given in the RECONECT Database of Measures (RECONECT measures selector (webscada.nl)) (Source: Ruangpan, 2021)

An example of a measure is given in Figure 5.

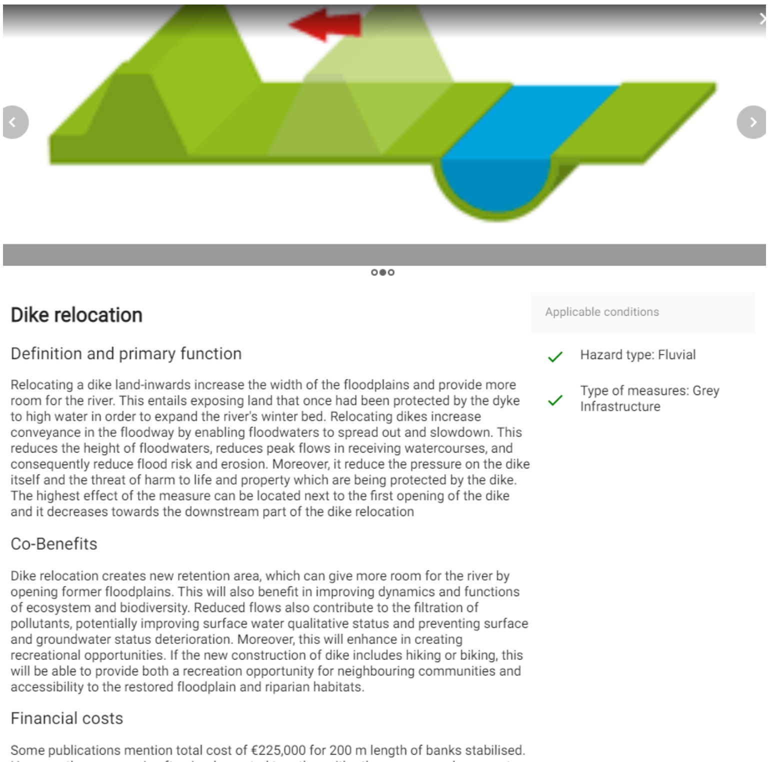


Figure 5 Example of a measure in the RECONECT Database of measures; here Dike relocation.

In total, there are more than 50 measures (both green and grey) that can be used at large scale for different hydrometeorological events, which can be found at [RECONECT measures selector (webscada.nl).](RECONECT measures selector (webscada.nl)) The measures that have been developed in the RECONECT Network of cases. They implement a range of different NBS, but are tailored to the specific contexts and conditions in the RECONECT demonstrators areas.

An important pool of knowledge and reference large scale NBS is being developed within the consortium, in particular with the RECONECT demonstrators (see also Section 1.1). Those solutions represent a combination of different NBS units or are combined with the grey infrastructure elements forming the hybrid solutions. They cover a range of local geomorphological and contexts, hydrometeorological events and the scale of interventions. An overview of the NBS/hybrid solutions developed in the RECONECT demonstration sites in given in Table 2.

Table 3 Overview of the NBS implemented in RECONECT Demonstrators site)

Demo Nr	Demonstrator Title/	Geogr. Context&scale	Hydrometeorological event	NBS Enhancements
DA1	**Greater Hamburg, Germany**	District (175km^2)	Fluvial floods, droughts	Hybrid; (1) smart control system operating a sluice gate (2) restoration of floodplains
DA2	**Seden Strand, Odense, Danmark**	Local (10-15 km^2)	Coastal floods	(1) Dike relocation (Removal of existing low coastal summer dikes and moving them inland to a higher location (2) Rehabilitation of floodplains (see and marine foreland→ salt meadows (3) Recreation of meanders of existing streams
DA3	**Tordera River Basin, Spain**	River Basin (900 km^2)	Fluvial floods	Hybrid; (1) Dike relocation (2) Heightening of the existing dikes (3) Widening, of the riverbed
DA4	**Portofino Natural Park, Italy**	Set of catchments (1000ha)	Fluvial and flash floods, Landslides, Droughts,	Hybrid; (1) Construction and repair of dry-stone walls and restoration of abandoned terraces, (2) Hydraulic-forestry arrangements on water courses; (3) Riverbed and tributary arrangements; (4) Natural engineering interventions along hiking paths; (5) Interventions of wood amelioration and re-forestation.

DB1	**Ijssel River Basin, The Netherlands**	River section (300ha)	Fluvial floods	Room for the river, (1) focusing on the vegetation management on floodplains and river channel
DB2	**Inn River Basin, Austria**	Catchment (around 10-15 km^2)	Fluvial and flash floods	Hybrid; (1) retention basins and (2) reforestation
DB3	**Greater Aarhus Denmark**	Local (Egå Engsø wetland, 1.6 km^2)	Floods	(1) Enhancement of the retention capacity of the area (establishment of artificial lakes) (2) wetlands
DB4	**Thur River basin**	Catchment (2.5 km^2)	Fluvial floods, droughts	(1)River restoration projects, (2) construction of retention areas for flood protection and artificial groundwater recharge
DB5	**Var River basin**	Catchment/Local (lower Var River, length of 22 km)	Floods, droughts	Hybrid; (1) green dikes, which combine the increase in retention capacity with the enhancement of habitats, (2) eco- urbanisation upstream
DB6	**Les Boucholeurs France**	Local, district (7 km^2)	Coastal floods	(1) Salt marshes, (2) creating space for the sea

A more detailed overview of the NBS in different Demonstrators is given in Report D2.7 or briefly described at the link: http://www.reconect.eu/network-of-cases/.

2.1.3. *Measures identified within the Lead User Method (LUM)*

Another pool of knowledge considered for the analysis results from ***the lead user method* (LUM),** performed with the objective to identify the solutions that have been not included in well-known repositories such as the ones given in Table 2 nor directly considered by any of the framed concepts of NBS (such as SUDS, BMPs) . The Lead User Method applied in RECONECT addresses this gap since it enables to find tested and proven Lead User innovations related to NBS. These have been developed by the people themselves while facing hydrometeorological risks. The method is a step-by-step process to identify user innovators, and, in the end, to find ways to up-scale the most valuable innovations and to make them generally available for those in need. The process of the Lead User Method is traditionally organized in the following four steps:

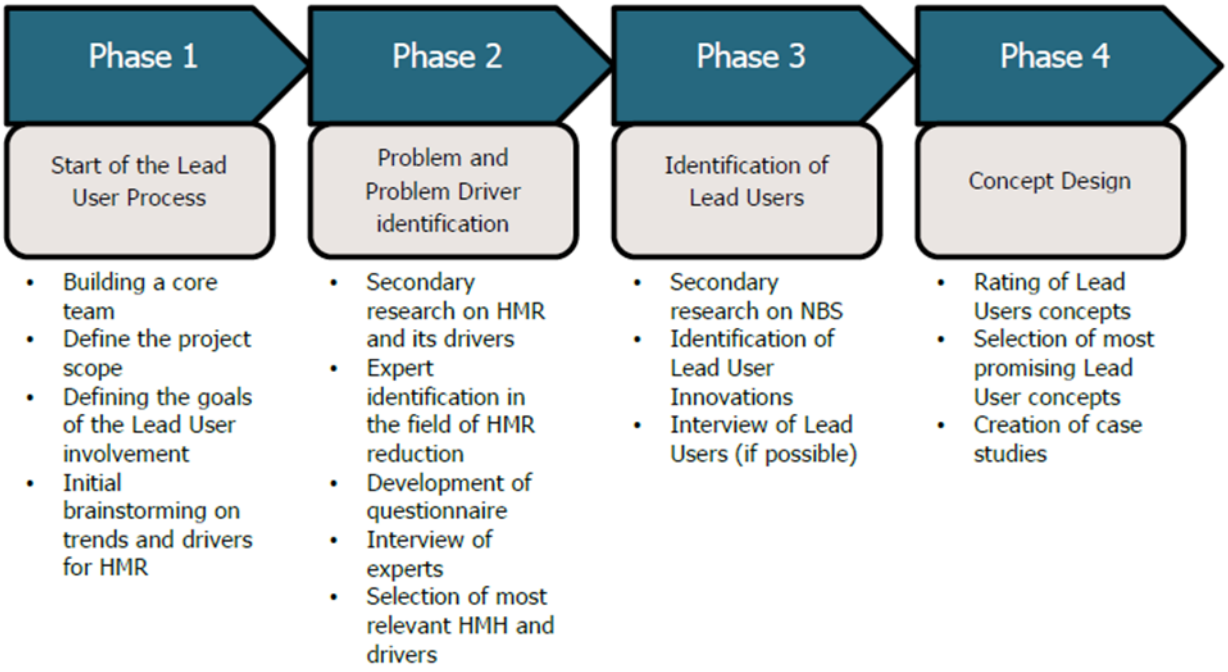


Figure 6 Lead user Method developed and applied in RECONECT to map the key lead users' NBS related innovation (the method is presented in detail in report D1.3)

The method is presented in detail in report D1.3. Through the application of the LUM to detect NBS for hydrometeorological risk mitigation, a total of 33 NBS have been derived. Those NBS are clustered into the categories of Green and Blue Infrastructure, Hybrid Solution, Digital Solution, and Governmental/Community Initiatives. During the research work, a total of 16 innovator and lead user interviews have been conducted and enabled the creation of mini case studies to gain an overview of each detected NBS. Additional desk research allowed data triangulation for a higher data robustness and helped to create additional 17 mini case studies. Each mini case study presents the NBS type, its functionality, which component of hydrometeorological risks it mitigates, the innovators motivation (if applicable), the development status and where they are implemented (if applicable). Those solutions range from devices for monitoring, which can be upscaled and used at a community/ regional level, up to the hydraulic constructions made of local materials, with all of them having in common a strong local perspective i.e. they did not exist in this form before and are developed to meet the acute need and a such are tailored to specific needs and use local materials and resources. Those case studies with the associated lead user innovations are presented in Appendix 2. An example is given in Figure 7.

NBS Type	Community Initiative	Motivation	Impact
HMH to be mitigated	Fluvial floods, droughts	To slow down the velocity of the river to increase the flood resilience of the local community.	This concept resulted not only in higher flood resilience but also in an increase in groundwater levels, a higher biodiversity and a sediment trap
Driver to be mitigated	Land degradation, loss in vegetation		
Who has the greatest benefit?	Local population		
Development Phase	Implemented		

Figure 7 An example of a lead user NBS related innovation Living Weir (Source: Worldwaterlife)

2.2. Addressing the main enhancements and innovative technologies in RECONECT in this guidance document

As given above, the RECONECT builds its pool of knowledge based on various main sources and repositories of large scale NBS knowledge and experiences. They range from the existing, already implemented measures that are in RECONECT systematically analysed, to the RECONECT specific interventions that are either being demonstrated (see Table 3) or have been identified beyond the existing repositories and pool of measures applying the RECONECT Lead User Method.

This inclusion and creating visibility for the NBS related lead user innovations, marks the distinguishing approach of RECONECT, which also explicitly address esthe role of innovation in the NBS sector.

Those solutions can *per se* be relevant for the end users but also can inspire them to innovate and develop own solutions that are tailored to their specific needs and using local resources.

Reflecting on the existing concept of innovation Granstrand and Holgersson, M, 2020, emphasise two defining characteristics when describing innovation: a degree of newness of a change and a degree of usefulness or success in application of something new. The concept of 'new' could mean new to world, new to a firm, etc.and new can be an idea or behaviour concerning a **product, service, device, system, policy or program** that has not been used before.

Put in simple terms, the innovation can be defined as the use of new ideas, products or methods where they have not been used. (https://ec.europa.eu/eurostat/statistics-explained/index.php).

In RECONECT the NBS related enhancements and their innovation potential are analysed at different stages, being:

1. Assessment of possible large scale NBS enhancements to mitigate the hydrometeorological risk
2. Evaluation of the innovation potential of the enhancements
3. Exploitation potential and management of the innovation

For the scope of this report, the enhancement has been understood as any alterations of the existing system that intend to improve the existing situation in terms of its main function at the same time aiming to deliver the envisaged co-benefits.

A detailed analysis of the exploitation potential and evaluation of the innovation readiness level of the solutions (steps 2 &3) will be delivered in the RECONECT tasks on exploitation contained in WP5 and are to be found in the corresponding reports (D5.3, D5.7).

The summary of the sources of knowledge and information on large scale NBS is presented in Figure 8

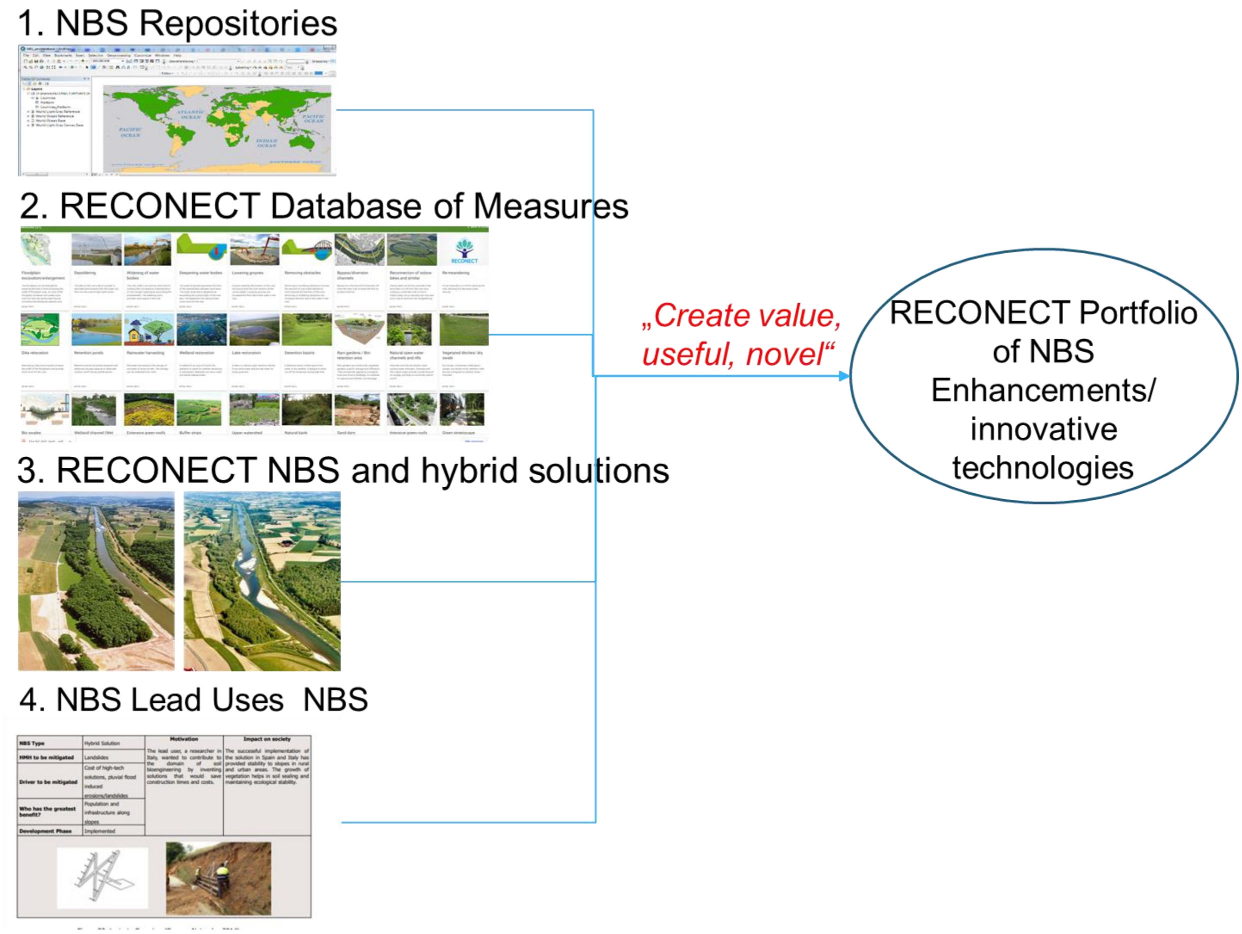


Figure 8 The sources of Knowledge and Practices for the RECONECT pool of large scale NBS/ hybrid solutions

Box 1: NBS in this report

The NBS addressed in this guidance document refer to the interventions that mitigate hydrometeorological risks such as storm surges, floods, droughts and landslides, implemented in natural and rural areas

Large scale refers to the actual geometry/size/are coverage of single NBS or a network of NBS and/or their impacts on the hydrometeorological risk reduction.
RECONECT specific contribution to the reference base of NBS is achieved in several ways:

- A detailed analysis of the existing extracting the generic measures that form the RECONECT database of measures,
- The portfolio of the RECONECT NBS/hybrid solutions demonstrated in RECONECT demonstration sites
- Identified innovation and enhancements performed by the Lead Users

The enhancement has been understood as any alteration of the existing system that intends to improve the existing situation in terms of its main function and co-benefits.

3. Integrating NBS related Enhancements into Implementation Process of Large Scale NBS

The integration of the NBS related enhancements in the implementation process is a challenging task, as it, as a rule, requires changes and adaptations of the existing asset management practices. The implementation of NBS requires involvement of a number of stakeholders, as not only the primary function of an asset, but also its co-benefits are to be delivered. It is also important to frame the NBS enhancements into the implementation procedure of NBS. The proposed RECONECT implementation framework is given in Figure 9. This framework was developed as a part of the RECONECT general framework for large-scale NBS. The individual phases of the framework are given as follows:

In the **inception phase** the context for planning of the large scale NBS is discussed and prepared for the co-creation process. The objectives for implementation are defined.

In the **situation analysis,** all relevant factors influencing the implementation procedures are assessed and quantified. Both, current situation and relevant future scenarios are analysed. As a result, hazard and risk maps for the relevant hydrometeorological risks are delivered. Based on the assessed current and future risks, the preliminary screening of the measures is performed. Here all relevant interventions from the RECONECT pool of large scale NBS/ hybrid solutions as summarised in Figure 8 are to be taken into account. At this point, the NBS enhancements are introduced in the large scale NBS implementation framework.

The **strategy building** is dedicated to the definition of the NBS/hybrid solutions alternatives, by performing an in-depth analysis of the pre-screened measures in the previous step. Such procedures are based on an understanding of the flood risks and the opportunities associated with alternative strategies, objectives and functional requirements and the performance of alternative adaptation measures necessary to achieve these. As a result, the preferred strategy is derived and used as an input for a more specific planning in phase IV.

In the **action planning** phase**,** the investment planning is undertaken balancing costs, risks and performance. In this phase a more specific planning of the adopted solution is performed. The aspects of the integration in the landscape dynamics are addressed. For the selected measures, the robust monitoring program is developed with the objective to monitor and evaluate the performance of the selected measures, but also of the co-benefits.

Actual I**mplementation** of NBS encompasses the activities of construction, placement of the required equipment and associated maintenance actions.

Monitoring and evaluation of performance and the benefits of the adopted NBS/hybrid solution is taking place throughout the implementation process with the objective to steadily assess the status of the adopted solution and compare it with the baseline i.e. the condition prior to the implementation.

Furthermore, the important aspect of the large scale NBS/hybrid implementation is the involvement of the key stakeholders within the co-creation process. Co-creation, as used in RECONECT is defined as [an approach to collaboratively generate new knowledge, with the aim to increase the social relevance of the knowledge produced for policy and practice applications, and to generate new research questions. Co-implementing the NBS solutions means involving people and stakeholders, especially local ones, in the provision and construction of the co-designed solution. Feeling to be part of the implementation phase is fundamental in order to initiate the following taking care of the solution in place]. More on the RECONECT co-creation approach can be found in the report D3.5.

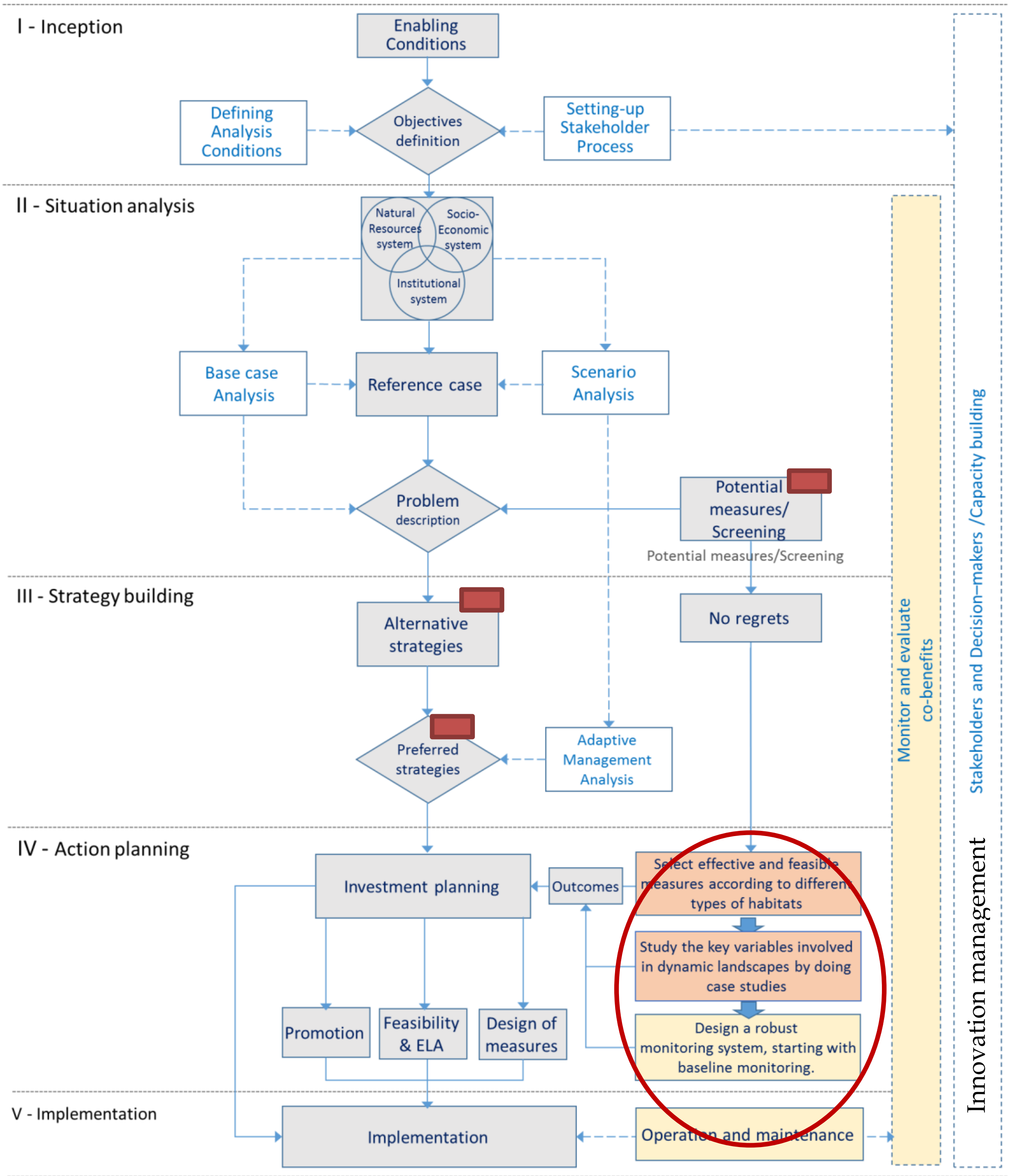


Figure 9 Framework for the implementation of large scale NBS; the red circled elements are in the focus of this report; the red rectangular indicates the steps in the implementation process where the NBS related enhancements are directly being addressed by including them or as a results of the selection process

As indicated in Figure 9, RECONECT foresees management of the NBS related innovation throughout the implementation process. It encompasses a sets of actions at different project and implementation stages ensuring that the enhancements are placed and integrated properly in each phase of the implementation framework. The overall RECONECT strategy to manage innovation is being developed in WP5 and given in the corresponding reports (D5.3 and D5.7).

What can be taken from the Implementation framework, presented in Figure 9, is that the issue of maintenance and the aspects of integration into the landscape planning and its dynamics are occurring in the later phases of the implementation process. However, their timely consideration is necessary in order to save costs and ensure better alignment of the expected co-benefits with the main objectives and features of NBS within the available resources.

Furthermore, maintenance aspects are often neglected or given little attention. But maintenance can have a considerable impact on the proper functioning of the assets and on the overall asset costs. The asset owners should be aware of those issues prior to the strategic planning and selection of measures (FAIR, 2020).

This report brings forward those issues that are placed in the last phases of the in the NBS implementation process and outlines the main challenges and items that are to be considered to address them in the implementation process. Also the conflicts between those two aspects are discussed and the recommendations outlined, based on the knowledge and experience gained so far.

For deriving this knowledge and best practices, a number of sources has been analysed. They are based on the available body of scientific literature, but also on the practical experiences and best practices from outside of RECONECT and from the RECONECT partnership as summarised in Figure 10.

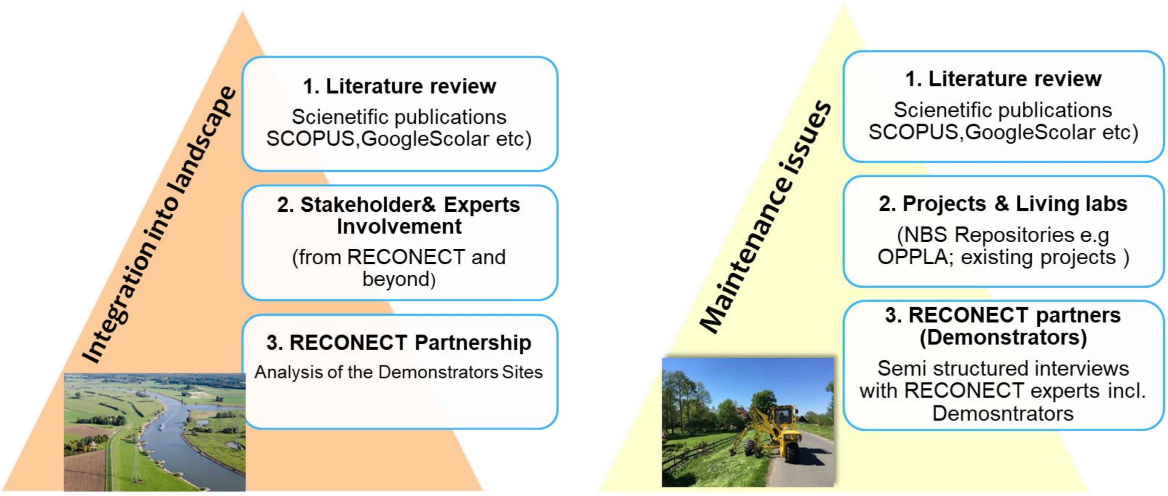


Figure 10. The sources of knowledge and experience for derivation of best practices and guidance points for the selected topics

The principles and actions to achieve the long term sustainability of large scale NBS have been derived based on the literature review and the existing best practices and concepts in RECONECT.

3.1 Integration into the existing landscape and its dynamics

Implementation of the large scale NBS triggers changes in large scale landscapes and ecosystems. However, the existing NBS related frameworks, such as the one developed by the International Union for Conservation of Nature (IUCN) framework for NBS and its principles does not necessarily address the temporal dynamics and ecosystem complexity, which are considered to be important factors for the successful implementation of NBS. Ecosystems have self-organizing abilities, e.g., hydrology and the propagation of disturbance can be highly self-reinforcing (Wu, 2021)

The implementation of NBS extends the landscape approaches in the sense that it seeks for consensus between the mitigation of hydrometeorological risks in the longterm perspective at the same time achieving societal and ecological co-benefits.

Landscape approaches" seek to provide tools and concepts for allocating and managing land to achieve social, economic, and environmental objectives in areas where different disciplines such as agriculture or compete with environmental and biodiversity goals. NBS can address the societal challenges of innovation, job creation and community development while at the same time create net positive effects on the environment by making a sustainable use of biodiversity and natural resources (Maes and Jacobs 2017).

There are different levels from which the integration of enhancements into existing landscapes can be analysed and implemented (e.g. Albert et., al, 2021). Here the question is how NBS principles translate into the local processes. The following perspectives and factors have been identified as the key to successfully implement NBS enhancements in the local context:

I) Governance perspective including funding arrangements and legal and administrative aspects (mainly addressed in reports D3.5 and D5.5)
II) Co-creation of solutions (mainly addressed in reports D3.5 and D5.5)
III) Technical implementation of solutions (mainly addressed in report D2.8 and D 5.4)
IV) Meeting the ecological objectives i.e. considering the landscape dynamics

The issues listed in I)- III) are addressed within other reports and guidance documents as indicated above.

Within this report some key issues in respect to the integration of NBS into the landscape dynamics will be delivered.

Meeting the ecological objectives i.e. considering the landscape dynamics
Since large-scale NBS usually contribute to changes in ecosystems and biodiversity, a variety of relationships between implementation interventions and changing factors should be studied in the design process to consider the key, yet representative, parameters/ variables that should be monitored in the environment.

Thus, the idea is to incorporate all the dynamic factors (such as spatial and temporal properties) into the NBS design and to reach biodiversity benefits on top of resolving the problem of natural disasters.

In order to integrate landscape dynamics into the overall design of NBS, RECONECT approach has been developed as a part of the general framework for large-scale NBS (Figure 9) and it follows the principles and implementation guidance for NBS recommended by The World Bank. For the design of large-scale NBS, it has been suggested to select measures of NBS and thereafter, design the intervention. The developed approach can be applied to large-scale NBS in order to support biodiversity, with a focus on incorporating dynamic landscapes into the design process. The developed approach is given in Figure 11 and is given as a step-wise procedure, which is described as follows.

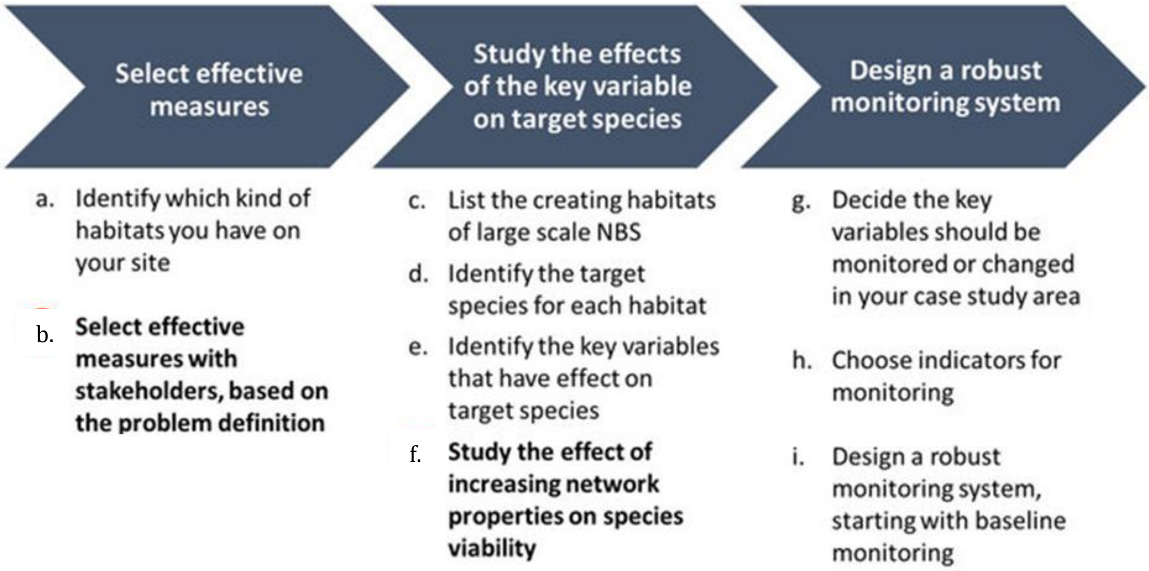


Figure 11 The RECONECT Approach to address the landscape dynamics when planning and designing NBS as a part of the Implementation Framework of the large scale NBS (Wu et., al, 2021)

Step 1: Selecting the Effective Measures

- Identifying the type of habitat at the site

Firstly, the different types of habitats are to be identified at the site in order to select effective measures for large-scale NBS.

- Selecting the effective measures with stakeholders, based on problem definition

In a general case, some NBS measures have positive effects on the habitats and can be identified by the user easily. For example, if we have multiple measures, we can discuss each measure with experts/stakeholders, based on the explanation of NBS measures. After that, the effective measures can be selected by discussing with various experts/stakeholders based on the problem definition.

Step 2: Studying the Effects of Key Variables on the Target Species

- Listing the creating habitats of large-scale NBS

During the design process, the intervention of the selected measures in dynamic landscapes in order to achieve the restoration and modification of habitat diversity should be studied in detail. After effective measures have been selected, the new habitats that are created by large-scale NBS are listed by doing a case study-based analysis with experts/stakeholders.

- Identifying the target species for each habitat

The target species for each habitat should be identified with experts/stakeholders afterwards. In general, the species groups should be clearly distinguished, including plants, arthropods, mammals, birds, amphibians, fish, aquatic microorganisms, and others as yet undefined

- Identifying the key variables that have a significant effect on the target species

A total of 10 key network variables were distinguished, including spatial (habitat) network properties and temporal (habitat) network properties. Nine key network properties were chosen based on the methodology proposed in the literature (e.g. Van Teeffelen, et al., 2012). Another variable, a habitat structural heterogeneity, was added, as it has a positive effect on the biodiversity (Zebisch, 2004), Table 4. Those 10 key network properties can be managed at the landscape scale. It is important for the users to identify which type of network properties were considered through empirical studies for the selected measures. For example, in the sand engine, an artificial sand bank in the coastal area was created, leading to increasing habitat network areas. The result showed that increasing habitat network areas leads to an increase in the vegetation. Thus, increasing the habitat network areas is one of the key network properties.

Table 4 The key variables and their definitions regarding network properties (Taken from Wu et., al, 2021)

No	Key variables	Short description/definitions
Spatial (habitat) network properties		
1/2	Habitat network area/connectivity	• The total area of the entire habitat is termed as the habitat network area. The functional connectivity relies on the distance between the nearby patches of habitats, leading to the permeability of the habitat networks between these units • Functional ecological network with target species relies on the habitat network connectivity, including sensitive ecosystems, areas of anthropogenic habitat fragmentation, gaps and corridors • However, connectivity is only a simplified interpretation of structural patterns, depending on a context-specific strategy on each ecological network
3	Habitat structural heterogeneity	• Heterogeneity is an estimation of the evenness and richness of the habitat pattern. The diversity of the habitat structure influences the interaction of species, organisms its distribution and adaptation • Ecological effects of habitat structural heterogeneity could be extremely dissimilar on different species groups • Increasing heterogeneous patch quality benefits the presence of different species and its distribution
4	Variation in patch size	• Changes in species variability is directly proportional to the patch size • A combination of small and large patches might be an effective strategy for reducing the risk of extinction from habitat turnover
5	Variation in patch quality	• Higher quality of patches is usually correlated to the increased species population. • If it is not possible to manage all the patches optimally; hence, it would be more advantageous and economical to include a few high-quality patches
Temporal (habitat) network properties		
6	Turnover proportion	• The proportion of habitat network can change at any given point of time • Turnover proportion can be measured using multiple and/or similar approaches • Increasing the turnover proportion/area will cut down the species viability
7	Spatial correlation in turnover	• At the network level, aggregation in the turnover pattern is important. Increasing the spatial correlation in turnover, such as a clustered turnover regime, will decrease the species population • The remaining population may be difficult to re-colonize empty or new patches because they could be placed at a further distance compared to a random turnover regime

8	Turnover rate	• It is the frequency of habitat turnover per patch. At the patch level, increasing the frequency of turnover has a negative effect on the species viability
9	Turnover intensity	• Turnover intensity indicates the fraction of a patch that is destroyed by a disturbed event. A disturbance event (e.g. extreme flood) can have a strong effect on the proportion of carrying capacity lost per patch. At the patch level, the effect of a change in the habitat can use turnover intensity as a parameter]
10	Temporal correlation in turnover	• It includes the variance in the turnover rate or the variance in the turnover proportion. The turnover rate could be continuous for the time frame or it can also be related to particular patch properties, such as time elapsed since the disturbance • The variance in the turnover rate means longer periods without turnover are alternated with shorter periods, which might damage species viability compared to a regime with a fixed turnover interval • The variance in turnover proportion means some years have more turnover proportion than others. Thus, the extinction risk could be higher than in a fixed turnover proportion

- Studying the effect of increasing network properties on species viability

Firstly, information from bio-monitoring reports and relevant research related to the area of concern areas should be gathered and classified. Secondly, the effect of changing spatial and temporal properties of habitat networks on the species viability at landscape units should be studied. After that, the results obtained should be discussed with the stakeholders to integrate/incorporate more current biota conditions, features, and management strategies from the stakeholders. The results should reveal information about which network properties would have strong positive or negative effects. It can help the users to decide which network properties should be changed or managed in the target habitat(s).

Step 3: Design a Robust Monitoring System

- Decide the key variables that should be monitored or changed in your case study area

After finishing Steps 1 and 2, users will understand the key variables in dynamic landscapes that have an effect on the target species, and thereafter, users can decide which key variables should be monitored or changed in their area.

- Choose an indicator for monitoring

Stakeholder/expert involvement is very crucial during this step. They can help point out or bespeak which indicators should be monitored for biodiversity.

- Design a robust monitoring system, starting with baseline monitoring and previous data

The data needed for monitoring programs should be listed (for example: it can be data at different levels—environmental, climatological, floristic/faunistic, taxonomic, morphological, genomic, phylogenetic, ecological). After that, a robust monitoring system can be designed by considering the baseline situation and the local conditions.

For all steps, it is important to involve key experts/stakeholders (e.g., local “wise” people) who have relevant knowledge and experience in biodiversity. In any general case, for Step 1 (selecting the effective measures), all stakeholder groups can be involved to receive different opinions from different site conditions and situations. Step 2 (the effects of key variables on the target species) is implemented with experts, such as environmental consultants, environmental scientists, or biologists, to identify the target species for each habitat in the identified study areas. Finally, for Step 3, the decision-makers should follow up on the next step of actions. The decision makers should be aware f both, positive and negative effects of

the NBS. It means that also the negative effects could be incurred in original habitats before the implementation of NBS projects. For instance, original habitats (such as vegetated land) could be replaced by new habitats (such as wetlands) after depoldering. Some original trees died after the Room for River project because these trees could not adapt to the higher water level after depoldering. If decision-makers are aware of this condition, i.e., during the planning phase and before construction, they can relocate original trees in advance to reduce the negative effects. Also the interplay and dependences between maintenance issues and biodiversity are to be taken into account (will be addressed in the following session.
Currently the Odense, Denmark Demonstration site is implementing this framework by involving all relevant stakeholders in Steps 1 and 2 and setting up and implementing a robust bio-monitoring plan.

Box 2 Integration of NBS and the existing landscape and its dynamics- Some Lessons learned within RECOENCT

- There are different levels from which the integration of enhancements into existing landscapes can be analysed and implemented:
  - Governance perspective including funding arrangements and legal and administrative aspects (mainly addressed in reports D3.5 and D5.5)
  - Co-creation of solutions (mainly addressed in reports D3.5 and D5.5)
  - Technical implementation of solutions (mainly addressed in report D2.8 and D 5.4)
  - **Meeting the ecological objectives i.e. considering the landscape dynamics (mainly addressed in this document)**
- The proposed framework contains 3 main steps:
  - Selecting the Effective Measures
  - Studying the Effects of Key Variables on the Target Species
  - Design a Robust Monitoring System
- Raising awareness and involvement of key stakeholders including the landscape architects and planners is crucial to achieve sound integration of the NBS and the landscape dynamics. The tools and methods for co-creation can be made use of (as presented in Report D3.5).
- The management strategies in dynamic landscapes might be necessary for the habitats created by humans, especially large-scale NBS. A robust monitoring system can not only ensure the performance of the intervention, but also regulate or reduce the negative effects by natural and human activities.
- The recommendation is that bio-monitoring programs should be included at the early stages because biodiversity situations need a long-term monitoring program of at least 10 years.

3.2 Maintenance of NBS

3.2.1 Definition and scope of the maintenance activities of NBS/Hybrid solutions

The main goal of maintenance is to preserve (maintain) or improve a defined target state of the asset in order to ensure desired functionality (here to mitigate hydrometeorological risks) over the complete operating life of the asset.

“Maintenance encompass the combination of all[2]

- technical
- administrative and
- managerial

actions during the lifecycle of a unit, which serves to restore or maintain its’ functioning condition so that it can perform the required function.”

This comprises four basic measures:

a) servicing - measures that extend or maintain the desired lifespan;
b) inspection – measures to assess the actual status of an asset to derive necessary consequences;
c) repairs – measures to restore the functioning of a failed asset;
d) upgrade – measures to increase the reliability/maintainability/safety of an asset without altering the original function.

Independent of the type of asset/solution there are three main general approaches to a maintenance strategy in (Glimm et al. 2009; DIN EN 13306, 2018) being

1. Corrective
2. Predictive
3. Condition based maintenance

In the corrective maintenance approach, an asset or a unit is being replaced when there is a failure of the unit.

When following the predictive maintenance approach, depending on the expected wear and tear, maintenance measures are planned and initiated in a timely intervention before a failure occurs.

The condition-based maintenance approach schedules regular inspection to gather information about the condition of single units of an asset. Further, a risk based inspection approach requires a detailed analysis of the probability and consequences of failure, both

---

[2] A Europe-wide accepted maintenance standard, where basic steps and approaches of maintenance are defined, has not yet been implemented. However, there are initiatives to develop an EN on Maintenance Engineering, such as the initiative of the Standards Norway to be led by CEN/TC 319, and the working group WG 14 Maintenance engineering (Working Programme, CENELEC, 201929). Several international as well as national standards of relevance are available for maintenance applicable to AM for FRM. For example, ISO 16646:2014 Maintenance–Maintenance within Physical Asset Management, supports ISO 55001:2014 (Asset Management) in ensuring asset management requirements are met (Nagyova & Pacaiova, 2018). ISO 9001:2015 Quality Management Systems sets out the need for and essentials of a risk-based approach.

quantitatively and qualitatively. The focus is therefore on the critical assets that carry the most risk to fail. Thus the objective of this strategy is to determine the most economic use of maintenance resources to minimise the risk to failure, or to lower it to an acceptable level.

A combination of the advantages of these maintenance strategies is required to organise maintenance efforts for assets as economically as possible.

The key advantages and disadvantages of different maintenance strategies are given in Table 5.

Table 5 Maintenance strategies, advantages and disadvantages (modified after Jordan, Manojlovic, Fröhle,2019, adapted from Glimm et al., 2009 and DIN EN 13306, 2018)

Strategy	Advantages	Disadvantages
Corrective maintenance	• Optimum use of life span of the asset or element of asset • no costs for preventive planning low administrative effort	• Only possible if the asset does not always have to be available • Looming damages are not detected • Possible high follow costs from damage
Predictive maintenance	Avoidance of high follow-up costs from damages	• Severe planning effort (extensive data collection) • Technical life span rarely fully utilised
Condition-based maintenance (risk included)	• Flexible adaption of inspection intervals • Optimised use of the life span of an object • Collection of data and information on degree of wear • Plannable costs in the long term	• Often considerable costs for inspection

Various European countries have general maintenance guidelines or norms of their own assets. They are often related to the grey infrastructure and focused on specific hydrometeorological risks e.g. floods (in Germany DIN EN 13306, 2018). However, many structural flood protection assets, for example, grassed dikes, rely on vegetation to function effectively and therefore require the management of vegetation as part of maintenance. Furthermore, following the increasing demand to develop and deploy NBS as a part of the flood risk management strategies, the maintenance strategies should be adapted in the future to support the needs of those NBS and hybrid systems (Fröhle& Manojlovic in FAIR final report, 2020).

The Natural Water Retention Measures (NWRM http://nwrm.eu/), specifies the definition of the NBS related maintenance as [the set of actions or processes that are performed to keep an already existing natural process functioning in the best possible manner. Maintenance can include physical activities, the planning process and communication].

Following the underlying idea of NBS, which emphasises the importance and relevance of the co-benefits and keeping an already existing natural process functioning, the general objective of maintenance would be to minimise the interventions wherever possible, aiming at the enhancements of the biodiversity and organic developments. In that sense, "less is more" principle is governing the definition of the overall maintenance strategy for the NBS projects. The feasibility of such approach for the given case is to be assessed, anticipating the adverse consequences of the "low maintenance strategy" on the proper functioning of the solution. Furthermore, the natural features, if not maintained correctly, can cause damage to the grey infrastructure even outside the NBS area. Therefore the scope and scale of the risk assessment is not to be set to narrow.

In order to define and implement a maintenance strategy for large scale NBS and hybrid solutions, a comprehensive analysis of relevant factors, requirements, issues, challenges and opportunities should be performed.

3.2.2 Framework to analyse maintenance in the context of large scale NBS

Following the implementation framework, given in Figure 9, the maintenance is directly related to the implementation of NBS and is connected to the monitoring actions.
In order to understand better the role and the required actions in respect to the maintenance, a framework for the analysis of maintenance in the context of large scale NBS has been developed as given in Figure 12. It is composed of three main steps referred to as:

a) Scoping of the maintenance activities with the objective to define and adopt a maintenance strategy
b) Implementation of the adopted maintenance strategy
c) Derivation of the lessons learned and providing the feedback to the steps of the implementation framework

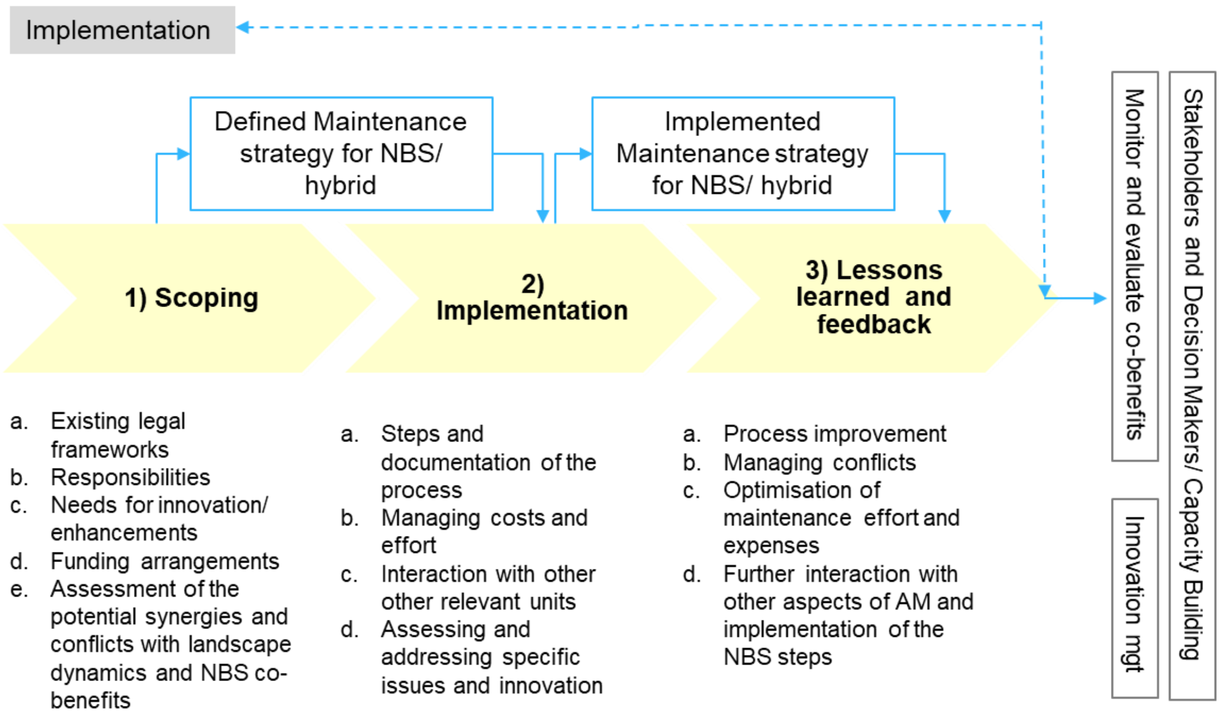


Figure 12 The RECONECT approach to address the NBS Maintenance issues

In the following text, those steps are described, addressing the key aspects to consider, supported by the examples and experiences from RECONECT and beyond.

Scoping the maintenance activities

In the first step, the scope of the maintenance action in terms of its technical, administrative and managerial aspects is to be assessed. This encompasses the following activities:

1. Assessment of the existing legal frameworks

The existing legal frameworks that might be relevant for maintenance are scoped and the key requirements assessed. Often they are not explicitly related to the maintenance of NBS but are to be searched in different contexts and domains in which the elements of the NBS/hybrid solutions are to be found, with some examples being:

a) Asset management of flood protection infrastructure- in the case of the hybrid solution including the grey hydraulic structures and assets
b) Coastal zone management- for NBS solutions in coastal areas
c) Management of water courses- e.g. implementation of the EC Water Framework Directive anchored in the national or local policy

For example, in the state of Hamburg, Germany, the information about maintenance of NBS in water courses can be found in the local legal documents addressing the implementation of the EC Water Framework Directive, which is here very advanced. The responsible authority has developed a set of guidance documents, which are obligatory for management and maintenance of all public watercourses. Those documents are available at: https://www.hamburg.de/gewaesserunterhaltung/. Apart from the general guidelines on which actions to undertake it postulates the minimal invasive strategy formulated as *"as much as necessary, as little as possible*" (Volume 2 Appendix 2 Guideline for Maintenance of Hamburg Waters and Volume 1 - Measure: Pg. 20)

Furthermore, the internationally available guidance documents that may be relevant for the own case (type of hydro meteorological event, geographical location or type of NBS) should be investigated. For example, when addressing flood protection assets including some hybrid solutions (such as vegetated dikes), the Condition Assessment Manual (CAM) of the UK Environment Agency, 2012 can provide some initial criteria for the assessment of the conditions of the assets. Those recommendations, although they provide some specific insights and descriptions of the actions to be undertaken, should be taken as a reference and adapted to the own conditions and needs.

2. Defining responsibilities

One of the crucial tasks in the preparatory phase is the clarity in terms of roles and responsibilities in the maintenance process. In case of the implementation of NBS or conversion of the existing grey infrastructure into the hybrid one, can happen that the responsibilities change or some additional know-how and consequently, the parties that are to be involved.
In the course of this process it is necessary to identify the units and institutions that are to be involved with a brief definition of the scope of the actions. It is often the case that the responsible agencies outsource certain actions, especially when it comes to some specific activities such as vegetation management that has not been the part of the previous maintenance activities of the merely ‘grey’ assets.

In the Var catchment, France demonstration site, where the measures in the river Var (upstream) are combined with the redevelopment of a suburban area (downstream), the responsibilities had to be reassigned due to substantial changes of the landscape settings in the area. Moreover, a comprehensive monitoring programme has been initiated to monitor the performance of the implemented measures and sediment transport, mapping the changes in the biodiversity, but also the changes in the liveability of the area.

3. Definition of the maintenance strategy

Based on the type of NBS/hybrid solutions and the given local conditions, the overall strategy for maintenance together with the individual steps are defined see also Table 5).

The undertaken maintenance approaches with the experiences of the RECONECT demonstration sites are summarised in Box 3.

Box 3 Scoping the maintenance activities- The RECONECT experience

The RECONECT demonstrators (Table 3) addressed their maintenance strategies at the beginning of the NBS implementation process i.e. coordinated them with the planning and design actions. The roles are clarified and defined prior to the implementation. Both approaches to assign roles and responsibilities are at place- to outsource specific tasks to the specialised companies and to perform the maintenance on its own.

In the *Thur, Switzerland demonstration area,* with a large natural catchments with low rate of urbanisation, *no maintenance* approach has been initially adopted for the restored river section and the created flood plains. This was enabled through the land acquisition and compensations by the Canton. Still, this approach had to be corrected, as the generated debris during the river re-meandering process caused damage to the areas and farms downstream, outside of the project area. By establishing the monitoring procedures of the conditions in the river and in the flood plains, more efficient “on demand” maintenance actions will be enabled.

In the *Greater Aarhus, Denmark demonstration area,* the responsibilities have been defined at the very beginning of the planning process. This project encompasses two different sub projects (the artificial lake Egå Engsø and the associated wetland and eleven different smaller projects in the suburb of Lystrup) with two different maintenance plans. The both concepts have in common the envisaged minimal maintenance activities. Still, the Climate Adaptation Act, which came into force in 2020, stipulates that before a new project is started, agreements must be made to ensure that the planned solutions will work in the future, which also includes planning of the maintenance actions. Consequently, Aarhus Water has developed and implemented special maintenance plans for the NBS projects. In terms of costs, the preliminary analyses show that the average costs decrease as the personnel costs are reduced (for example, the meadows are no longer mown).

In the *Portofino Park, Italy demonstration area*, the major maintenance activities are related to the removal of obstacles (in the catchments) and cleaning of sediment traps and terraced elements.
The current maintenance strategy combines the corrective and preventive maintenance. The culverts are cleaned after a heavy rainfall event (corrective). However, within RECONECT a comprehensive monitoring plan has been developed and implemented to monitor the conditions of the implemented NBS to determine if and where the repairs need to be made (preventive).

In the *Inn, Austria demonstration area,* the responsibilities for maintenance of torrents and avalanches are defined and documented in various guidance documents at the national or local level which are publicly available (https://sp.tirol.gv.at/tirol.gv.at/dvtwiki/display/WBB/Wildbachbetreuung+Tirol). The budgets are planned and allocated accordingly. In the guidance documents it is defined what kind of maintenance activities and in which way are to be undertaken by the local authorities and how to document them. Those activities encompass both, engineering structures and NBS:

4. Identification of the needs for innovation

As indicated in the Figure 9, the management of innovation is taking place throughout the implementation framework, including the ones during the maintenance. By introducing the new elements (NBS) in the existing infrastructure, the changes and adaptations of the maintenance strategy and procedures are often required. Those changes can also cause the demand to adopt *new* methods and tools to perform such a maintenance. Within this step it is to prove whether the existing methods, tools and know-how is sufficient to perform the planned maintenance actions.

The innovation may be required to

1. Improve organisational arrangements including outsourcing of specific tasks or developing the community maintenance approach
2. Develop new tools and devices or features for conducting the maintenance process
3. Identify new funding schemes

For the NBS related lead users solutions, which were not existing in that form before, it may be necessary to develop a new approach to maintenance.

Also the experiences from the RECONECT demonstrators indicate the need for innovating in order to adjust to the existing conditions or to improve the existing practices.

In the Odense demonstration area, as a part of the NBS solution, the dikes have been redesigned to enable maintenance of the grass sod by cattle and not as usually practiced using sheep. The reason for the change is that the sheep are not available in the area and redesign of the dike enabled the use of the available animals for maintenance which is in this case cattle. It is also a good example on how planning& design and maintenance can work comprehensively for the benefit of the overall NBS management.

In the ECODIKE Project (see also Box 5) to monitor and maintain the ecologically enhanced dikes ("Ecodikes") the demand has been identifies to have a portable tool that can support the risk based maintenance strategy. A device to assess the erosion stability of the dike cover, without destroying it, a so called "dike elephant", has been developed and deployed as shown in Figure 13.

The grass sod section that is to be assessed, is flooded with water and the amount of water together with the amount of sediment which has been mobilised in this way is assessed and analysed. In this way, it is possible to assess the erosion rate of the dike slope.

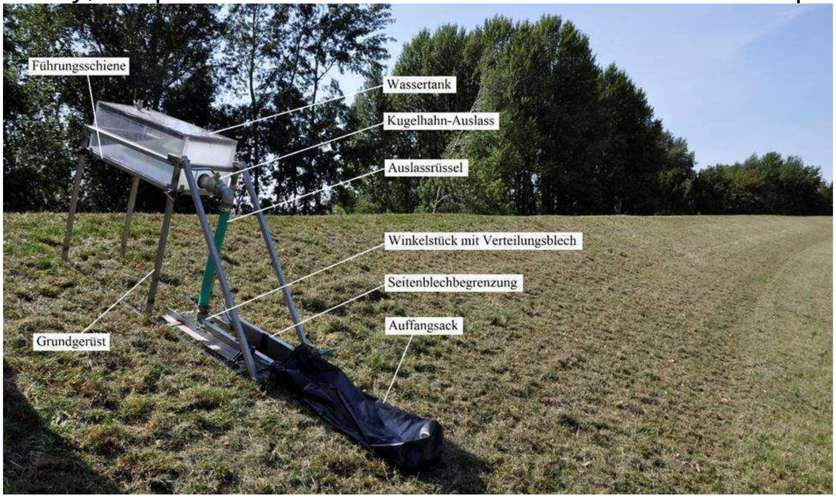


Figure 13 A innovative portable device "dike elephant" to assess the erosion stability of the green dikes as a part of the risk based maintenance strategy, developed at TUHH

Automated (smart) analysis of asset condition assessment is evolving rapidly across Europe, where attempts have been made to analyse the individual asset condition from sensor based measurement networks, including loads and behaviour of the infrastructure. These technical approaches are being tested within the projects EarlyDike[3] and LiveDjik[4].

5. Funding arrangements

The selection of the maintenance strategy can have a considerable impact on the overall costs of solutions and therefore should be included into the analysis from the beginning of the implementation process. In order to get a real representation of the costs of measures/assets, it is required to perform the lifecycle cost assessment i.e. assessing costs for planning, design, construction, maintenance and decommissioning rather than focusing on the mere investment costs.

This is very often a challenge as the benefits of maintenance and consequently the associated costs are difficult to visualise in comparison to the investment costs, when drafting the budges for the asset management. However, the experiences from the implemented large scale, such as the one from Portofino RECONECT demonstrator case, indicate that it is better to "spend 10 today not to spend 100 tomorrow", meaning that investing in proper maintenance to keep the assets in a good condition, can save costs for their replacement.

Box 4 Room for the River Programme (https://www.dutchwatersector.com/news/room-for-the-river-programme) , Netherlands- Managing maintenance in a complex project and funding arrangements

The complexity of the Room for the River Programme created the need to find and deploy flexible funding arrangements, addressing the whole span of the lifecycle of the deployed solutions, also including the maintenance.

The projects implemented under the umbrella of the Room for the River had a steering group composed of authorities, utilities and water boards, the same ones that are responsible for the maintenance at different scales. In this way it was ensured that maintenance has been included from the very beginning of the planning process. Important was the role of the landscape planning agencies and State Forestry, who were invited to develop plans of NBS that can also be maintained easily and cost effectively.

At the beginning of all projects the key players such as nature conservation agencies, design, planning, or maintenance units, were invited to take part in the overall planning, so that the efforts, resources including budgets can be properly estimated. Water boards, who have a special taxation system, included those cost in their annual budgets to be charged and in such way could fund the project.

Also, as the implementation of innovative or new solutions can add effort and complexity for the maintenance units, they were compensated for this additional work. Based on the experience gained during the Room for the River Project, the current maintenance of the Dutch watercourses deploy the following resources:

- Approx. 20 full time staff for asset management/monitoring/real estate/monitoring, including management of lease contracts and contracts with nature conservation organisations
- Approx. 6-8 full time staff for contract management (5 contracts, each ca. 4-5 million/year)
- Budget approx. 30 million/year (vegetation, sediment, constructions management)
- Maintenance work is usually outsourced: lease, owners, contractors

[3] https://mdi-de.baw.de/earlydike/
[4] https://www.ijkdijk.nl/

Referring to the coastal systems Sutton-Grier et al, 2018 concluded that [Investing in maintenance and repair of aging infrastructure must continue to be a priority but investment in the removal of outdated and vulnerable infrastructure, as well as investment in new infrastructure, is also necessary.] Also benefits of NbS have been found to outweigh the costs of implementation and maintenance in a range of contexts, including disaster (mainly flood) risk reduction along coasts and in river catchments (Sutton-Grier et al, 2018).

6. Assessment of the potential synergies and conflicts with the NBS requirements including the benefits for the ecology (NATURE) and liveability of the areas (PEOPLE)

This step addresses one of the most critical aspects of the NBS maintenance and needs thorough analysis. The requirements on maintenance of assets to perform their primary function, here to mitigate the hydrometeorological risks, can conflict with the holistic objectives of the NBS/hybrid solutions, which is to provide the co-benefits for ecology and societies.

The experiences from the implemented NBS projects such as natural restoration of rivers or restoration of wetlands confirms this type of conflicts. For example, referring to the benefits of the NBS solutions for flood risk management[It has been observed and reported that the excessive widening or deepening of natural watercourses can initiate channel instabilities resulting in erosion and sedimentation, requiring maintenance work to preserve the design capacity of the scheme] (Dadson et al., 2017).

In the Room for the River projects, the re-establishment of the natural regime in the rivers after the restoration projects of water courses attracted the beavers which became a threat for the stability and functioning of hydraulic structures in restored water courses and had to be removed.

On the other hand the cultivation and maintenance of bankside and river channel vegetation, which is often of value for biodiversity, can induce a small decrease in water flow and hence reduce downstream flood risk in their immediate vicinity in narrow rivers where the width is less than 16 times the depth (Dadson et al., 2017).

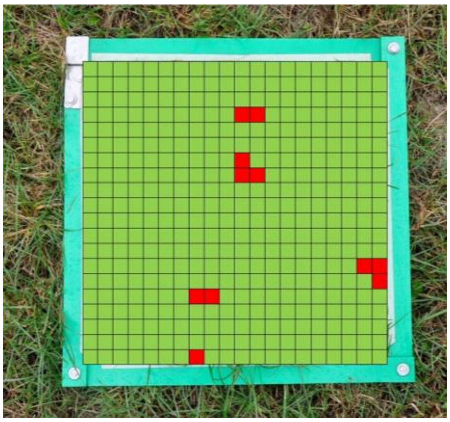
In the Les Boucholeurs, France demonstration rea, the established oyster farms are minimising the effort for maintenance of the shoreline at the same time creating economic benefits for the local population, creating synergies with the maintenance effort.

Those examples demonstrates even more the necessity to holistically approach the objectives and implementation goals of the solutions already in the II phase of the Implementation framework for large scale NBS as presented in Figure 9. In this way, the link between maintenance and the integration of NBS into the landscape dynamics can be established, managing priorities and agreeing on them prior to the selection of the final strategy.

Box 5 A maintenance approach for ecologically enhanced coastal dikes ('ecodikes') in Northern Germany- does enhancement of the ecological value of dikes create conflict with maintenance?

In order to enhance the ecological value of the coastal dikes in northern Germany, the ECODIKE project (https://deutsche-kuestenforschung.de/ecodike-367.html) systematically analysed the possibilities to enhance the ecosystem services of dikes and revetments while preserving or possibly enhancing the existing safety standards. Options for ecological enhancement of sea dikes were created by (i) supporting natural or nature-based solutions in the foreshore and (ii) enhancing the dike structure itself, e.g. with ecologically more valuable sea dike vegetation. For that purpose, specific mixtures of vegetation/ grass have been developed, tested and compared to the reference condition i.e. the standard blend used for the conventional coastal dikes.
As these interactions between the co-benefits and safety requirements on dikes may substantially change over the anticipated lifetime of the structure, a risk-based monitoring and maintenance strategy has been developed. This risk-based approaches to maintenance and inspection take a qualitative and/or quantitative risk assessment focusing on the critical elements and processes related to the asset performance (such as dikes) and operation. For coastal dikes in this case, the following elements have been assessed as critical: (1) gaps and cracks in structures; (2) condition of the grass sod and; (3) susceptibility to erosion of a dike (Jordan et al., 2020). Quantitative criteria have been further developed to assess the criticality of a dike condition for these elements. Figures below illustrate methods to analyse the shear stress within a dike and how this is related to the dike condition. Further, a raster to analyse the quality of the dike sod as a part of the quantitative method is shown (still being developed and tested between the academic partners and the asset owners). As a result, it will be possible to deliver information whether such new, ecologically more valuable mixtures compromise the stability of a dike and lead to higher maintenance costs.
This project is also an example on how to integrate "easy to use" devices to support the maintenance units in quantitative assessments of the asset conditions.

Assessment of sheer stress using the pocket device (left) and the scheme for assessment (right) as a part of the risk based maintenance strategy of green dikes



Implementation of the maintenance strategy

The maintenance process is composed of a set of individual steps and the associated activities with the objective to fulfil the requirements of the adopted maintenance strategy.

1. Stepwise implementation of the adopted strategy

Although the overarching idea of maintenance of NBS is to minimise the interventions and allow for natural, organic development of the area, wherever this is feasible, still the frequency and intensity of the maintenance process is to be assessed and defined. This is especially important for the hybrid solutions, where different type of maintenance activities are to be implemented.

Some of the typical maintenance actions are given in Table 6, Figure 14 and Figure 15. The maintenance procedures for different types of large scale NBS assets is given in report D2.8.

Table 6 Some typical maintenance activities. The activity *) is potentially conflicting with the ecological co-benefits of NBS

Location/Assets or infrastructure affected	Maintenance action
Water course (including torrents)	Removing debris and other obstacles generated by the additional “greening” of the water course and the flood plains
Water course (including torrents)	Removing any interfering invasive species*)
Water course; floodplain	Trimming tree branches, vegetation management
Water course, flood plain, (including torrents)	Sediment management
Water courses (including torrents)	Repair of cracks and gaps along the water course and revetments using stones or (other) natural materials
Dikes	Grass sod maintenance on dikes using animals (sheep or others)
Dikes	Grass sod maintenance on dikes using machinery
Terraces/ landslide protection measures	cleaning of areas (of soil elements, replacement of suitable plant species), maintenance of sediment traps
Wetlands	Vegetation management

Figure 14 left: Maintenance of green dikes in Northern Germany using machinery; right: Maintenance of green dikes by animals (source: TUHH)

Figure 15 Managing vegetation in the Room for the River Project (removing trees to create more space for the river (left) and after a regular maintenance (right), source: Room for the River).

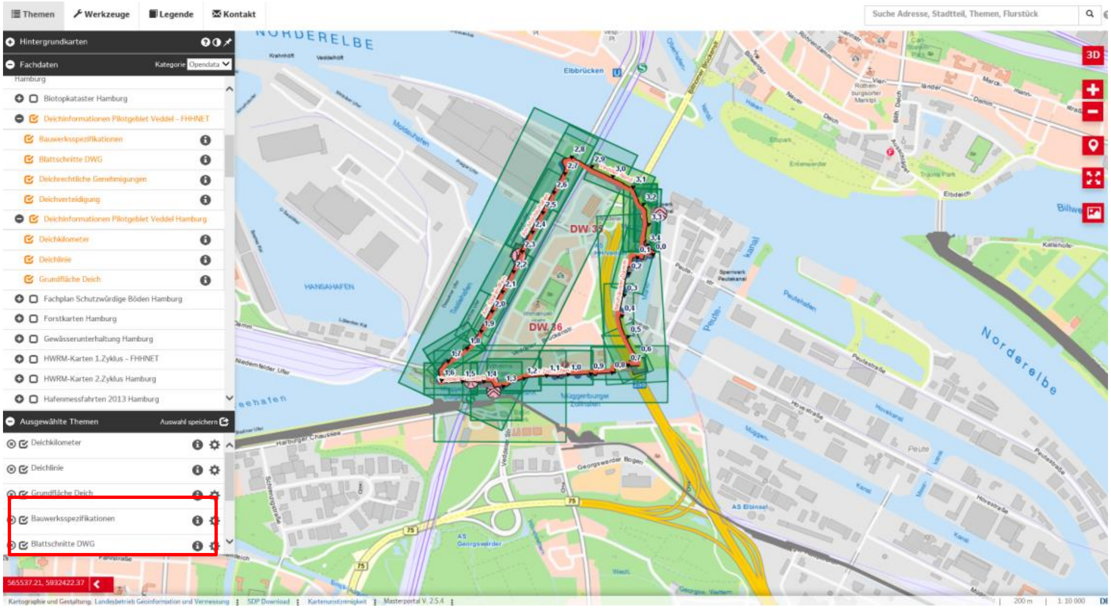
It is also to mention that the co-maintenance approach as a part of the co-creation strategy should be taken into consideration. This can be realised by e.g. shared responsibilities of the restored river section among the private owners and residents living in the area. Those activities can be combined with the co-monitoring actions e.g. by encouraging the resident to monitor, document and report the conditions of the developed measures either in a digital form (using smart phones) or using other communication channels with the responsible agencies.
A list of different co-maintenance and co-monitoring actions is given in the RECONECT co-creation manual presented in the report D3.5.

d) Documentation of the process

Within this step, all relevant information that is to be monitored or reported to other phases of the implementation framework presented in Figure 9 are to be documented. It includes the actions, responsibilities, but also the actual costs associated with the maintenance. Although often neglected or underestimated, adequate documentation of the process can help identifying and tracking problems or actions to be improved.
With the increase in the demand on the interoperability and on developing digital documentation in projects, this task can be seen in a broader context, by addressing data and information management in this step. An example of a digital webbased geo tool to support and document the maintenance actions is presented in Box 6.

Box 6 The Hamburg Experience- Documentation and data& information management for maintenance of hybrid solutions

In order to manage and visualise all relevant data and information related to the maintenance of the flood protection facilities, the Hamburg Agency responsible for maintenance developed Dike Information System (DIS) within the INTERRG Vb Project FAIR, with the key aim to provide the official supervisory authorities, planners and maintenance staff with a tool that allows them to work comprehensively. It is a webbased application providing the Information in the office but also on the dike, out in the field or at any other location. The information available also addresses the green i.e. vegetated elements of the dike and the associated maintenance procedures. In the future, if the vegetation type is to be changed to additionally enhance biodiversity, this can be easily integrated into the existing platform.



An example of a view in the Dike Information System (DIS); a dike located in Hamburg with all relevant documents including maintenance is depicted. The red rectangular marks the information about the vegetated parts of the dike (source: LSBG, Hamburg)

2. Managing costs

As given in the introduction of the section 3.2 the budget for maintenance is to be allocated at the beginning of the planning process of NBS. Overall costs of asset should contain realistic estimation of the maintenance efforts.

During the implementation of the maintenance strategy, the costs are monitored with the objective to obtain a more realistic representation of the costs and consequently adjust the budgets to be allocated for those purposes. Here, it is important to assess the costs for personnel, energy, equipment costs or the costs for contracting/leasing is applicable.

Finally the analysis of the overall costs of NBS or hybrid assets and the mere grey ones can be performed.

[Some reported observations by the National Park Service in the US based on real projects show that the installation of engineering infrastructures (e.g. seawalls, dikes, breakwaters...) cost usually from 6 500 to 9 800 $/m, while nature-based projects (natural living shorelines) usually have a cost of installation ranging from 0 (ecosystems already present) to 6 600 $ per meter (Beavers et al., 2016; Sutton-Grier et al., 2018)]. The nature-based projects are also assessed to be cost-efficient in terms of maintenance and reparation, with observations of 0 to 328 $ per meter, in comparison to the maintenance and repair costs of the engineering infrastructures ranging from 0 to 1.710 $ per meter (Beavers et al., 2016). Maintenance and repair costs were converted to annual costs assuming a 50-year lifespan and do not include projects that involved complete structure replacement. Furthermore, natural ecosystems are expected to provide additional societal co- benefits through ecosystem services.

Infrastructure Type[a]	Installation Cost[b]	Annual Maintenance/ Repair Cost[b]	Annual Water Quality & Fish Production Value[c]
Built (seawall/bulkhead)	\$6,500 - \$9,800 m^{-1}	\$0 - \$1,710 $m^{-1} yr^{-1}$	\$0 $m^{-2} yr^{-2}$
NNBI (natural/living shoreline)	\$0 - \$6,562 m^{-1}	\$0 - \$328 $m^{-1} yr^{-1}$	\$1 - \$7 $m^{-2} yr^{-2}$

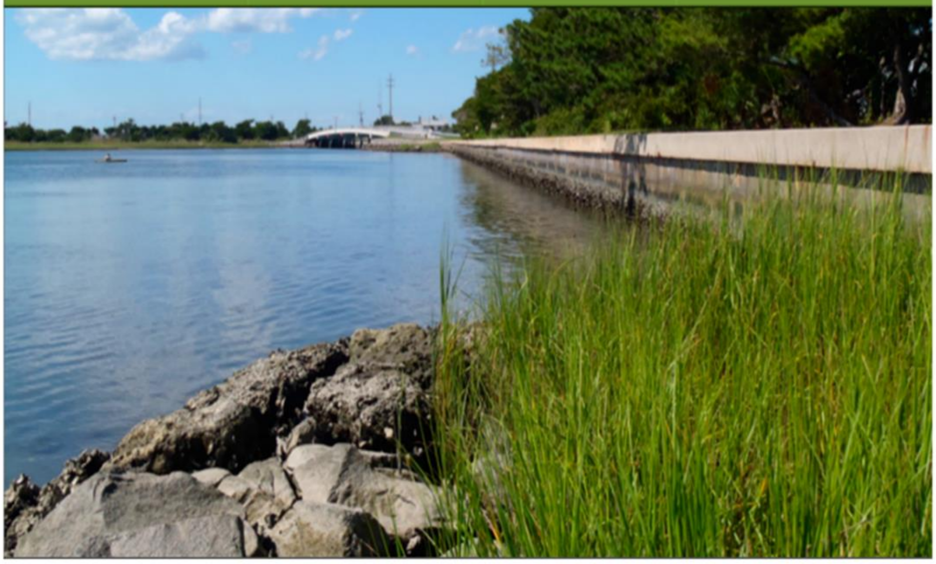


Figure 16 An example of the grey and NBS solution for coastal protection in USA; The installation and actual maintenance costs are given in the table on top of the picture (Source: Sutton-Grier et., al, 2018)

The web platform Natural Water Retention Measures (NWRM http://nwrm.eu/) delivers a rough estimation of the maintenance costs for a set of NBS (small and large scale). It is based on the literature or on the experiential values from the real cases. This information can be taken as a reference.

3. Interaction or experience exchange with other maintenance departments or other relevant units

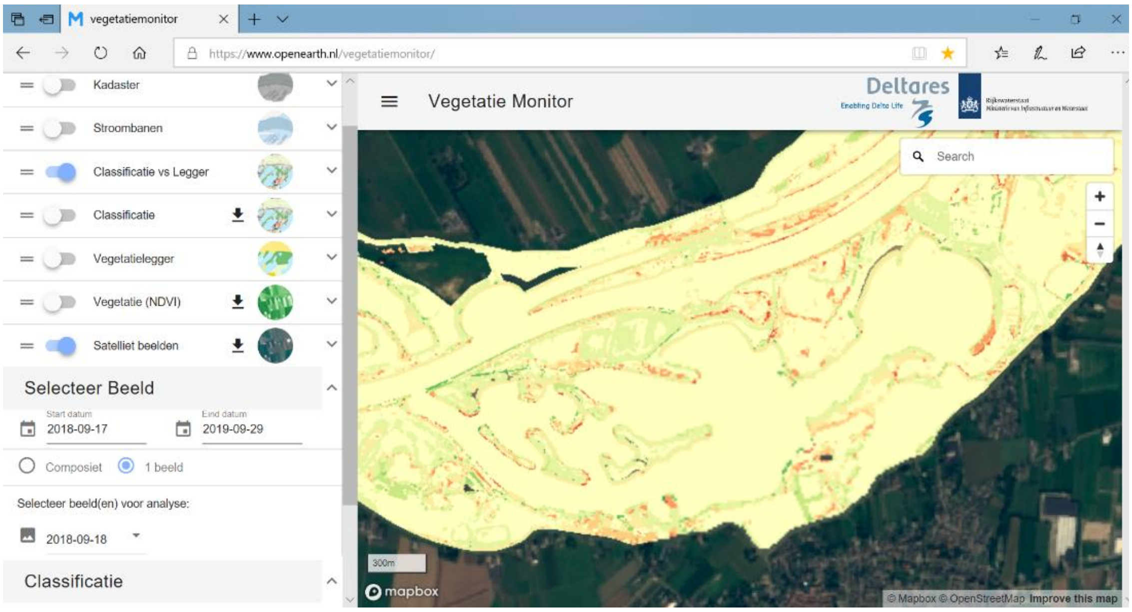
A holistic view, encompassing all steps of the implementation process by creating relations between different phases is an essential aspect for the development of the maintenance strategy. The RECONECT holistic approach foresees and emphasises the interaction between different types of expertise and units. Moreover, the RECONECT co-creation approach envisages joint development of solutions throughout the NBS implementation process.
In respect to the lifecycle management of assets including NBS, the existing literature and projects deliver experience that the constant exchange and communication between different contexts has to take place throughout the project (e.g. FAIR Final Report, 2020).

In the Var catchment, France demonstration site, the substantial redesign of the whole area required an intensive communication of all relevant units, including the maintenance ones.

In the Odense, Denmark demonstration site, the maintenance has been addressed already during the planning phase, adjusting and adapting the design with the objective to create a solution that is easy and cost effective to maintain.
A special relation and interdependences occurs between the monitoring and maintenance strategies and a comprehensive monitoring concept should be developed that links the outcomes to the actions need for repair. An example of this link is given in Box 7.

Box 7 Combining monitoring and maintenance activities- the experience from the “Room for the River” Project

As a follow up from the Room for the River Project, an online tool has been developed and deployed to map the monitored condition of different types of vegetation in the implemented projects. The provided information utilising the remote sensing is amongst other used to assess the need for the maintenance actions.



(Source: Room for the River)

4. Assessing and addressing specific issues and innovation

Here, any other relevant case specific issue is to be addressed and discussed. Also the feedback on the innovative features related to maintenance that have been deployed are to be assessed and prepared for the feedback.

Review and lessons learned

The asset owners and operators are in process of modifying individual operation and maintenance strategies and concepts to ensure that these include adaptive planning, and effective functional links between operation and the strategy building context.
Important feedback from the maintenance organisation is gathered for future NBS/hybrid solutions design in order to contribute to sustainable planning. The permanent improvement process is based on the goal of providing optimised and application-oriented systems (FAIR final report).

During the implementation of the maintenance concept, the improvements regarding the following aspects are collected and analysed:

1. Execution of the individual steps
2. Documentation of the process
3. Improvement of the legal framework
4. Optimisation of maintenance effort and expenses
5. Better interaction with other phases of the implementation framework of large scale NBS and co-benefits

In the RECONECT demonstration sites, there are examples that the feedback has led to the improved management of implemented NBS.

In the case of Thur river, “the less is more” the maintenance approach that has originally been adopted (see also Box 3) had to be corrected, as the generated debris caused damage to the adjacent areas downstream. More maintenance actions have been agreed upon to prevent uncontrolled debris flow.

In the Room for the River Programme, the optimisation of the maintenance actions took about 2 years, supported by intensive discussion of the asset owners, operators and maintenance units.

Following the Implementation framework of large scale NBS presented in Figure 9 operation and maintenance should feed back into the strategy building phase through the monitoring activities.
Also, the performance, longevity, operation and maintenance of NBS and hybrid solutions should be systematically compared with traditional engineering solutions.

Stakeholders/ Decision makers, Capacity building

The implementation framework of large scape NBS presented in section 3.1 and Figure 9 foresees the involvement of stakeholders and decision makers and the capacity building actions throughout the implementation process. One of the key problems in defining and implementing maintenance strategies is the awareness of the key players about the relevance and activities of the maintenance actions. The capacity building in this case should be directed to raise awareness of the key parties involved so as of the decision makers.
Also, by following the co-monitoring strategy, it is possible to increase the ownership of the solutions
Different measures for co maintenance and co-monitoring are presented in report D3.5 on co-creation approach.

The experiences from the RECONECT partnership in respect to the awareness and capacity building for maintenance are given in Box 8 and Figure 17.

Box 8 Awareness about the maintenance issues – The RECONECT experience

In the Portofino Park, Italy, demonstration site, the major problem is with the awareness of the decision makers about the NBS relevance, who traditionally prefer the engineering solutions, which are considered to be 'visible'. Therefore, the budgets allocated for maintenance of NBS are not always corresponding to the real needs of the site. The Local Authority (The Park Portofino) is well aware of the efforts needed, however, some areas of the park are privately owned and it is needed to make the owners aware that they should also undertake the maintenance measures.

In the Thur river, Switzerland, demonstration site, some conflicts with farmers and the removal of trees from the water by the companies could not be avoided. Conflicts between water providers and ecologists were also reported. In addition regular monitoring and inspection take place, ensuring that the adopted NBS solution is fulfilling its role and not affecting the adjacent areas.

One advantage of the Danish projects in general, but also of the RECONECT Demonstrators Aarhus and Odense is that public opinion and decision-makers have moved strongly in the direction in favour of NBS in the last 3 to 5 years and these are being promoted intensively wherever possible. Currently, the co-maintenance approach is being tested, with the idea to create stronger connections between people and NBS and make them aware of the NBS co-benefits, but also of the responsibilities to maintain the main functions of the developed solution.

In the Dove/Gose Elbe, Hamburg, Germany demonstration site, for each NBS introduced, the budgets are allocated for maintenance and planning, means that the key parties are aware and involved from the beginning of the implementation process. Although the NBS proved to be less expensive than conservative solutions, they always had to be maintained, which should be clearly communicated to the professionals, but also to the residents, who can also take an active role in the co-maintenance procedures.

Figure 17 Combining WATER-NATURE-PEOPLE benefits of large scale NBS in the Room for the River Projects. To make it functioning properly, all responsible parties (planning, design, operation and maintenance) at different levels have to be aware of the overall context and objectives, but also of their roles and responsibilities (Photo: room for the River)

3.3 Addressing long-term sustainability

At the core of NBS is the ability to create co-benefits, while addressing key societal challenges, arising from a combination of natural and anthropogenic factors, including climate change or disaster risk reduction (Cohen-Shacham et al. 2019). In that sense, the implementation of NBS has on objective to set up longterm sustainable solutions by balancing equity, economic and environmental benefits (Purvis et al., 2019). This is also in line with the definition of sustainability of different agencies such as the US Environment Protection Agency (EPA), which states that [To pursue sustainability is to create and maintain the conditions under which humans and nature can exist in productive harmony to support present and future generations]. https://www.epa.gov/sustainability/learn-about-sustainability#what
Ensuring the long-term achievement of the relevant UN Sustainable Development Goals (SDGs) becomes an imperative for all developed solutions for disaster risk reduction (UN, https://sustainabledevelopment.un.org/topics/disasterriskreduction). The key contributions to meet the SDGs are given in Table 7.

Table 7 NBS and their role in achievement of SDGs (EEA, 2021)

Relevant SDG	**Relevance of NbS and related concepts for hydrometeorological risk reduction**
SDG 13 Climate Action: Take urgent action to combact climate change and its impacts	Increases resilience to natural hazards and slow-onset events including heat waves, heavy precipitation, droughts, flooding, sea level rise, wildfires, landslides and avalanches, windstorms and storm surges
SDG 15 Life on Land: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	Protects, restores and promotes sustainable use of terrestrial ecosystems including sustainable management of forests, combats desertification, halts and reverses land degradation and loss of biodiversity
SDG11 Sustainable Cities and Communities: Make cities and human settlements inclusive, safe, resilient and sustainable	Regenerates urban and rural areas; promotes sustainable land use and liveable urban development, including urban green and blue spaces and urban agriculture
SDG 8 Decent Work and Economic Growth	Promote inclusive and sustainable economic growth (potential for new economic opportunities) through full and productive employment and decent work for all (potential for green jobs)

[Any long-term economic competitiveness and security depends on the extent to which natural resources are used sustainably] (Maes& Jacobs, 2016).

The RECONECT sees the NBS in the light of their long-term competitiveness by taking a holistic view of the NBS and their interrelations and interdependences with the social, technical and natural environment so as with the drivers of future developments i.e. climate change and social and economic development as summarised in the RECONECT holistic ecosystem based framework presented in report D1.7.

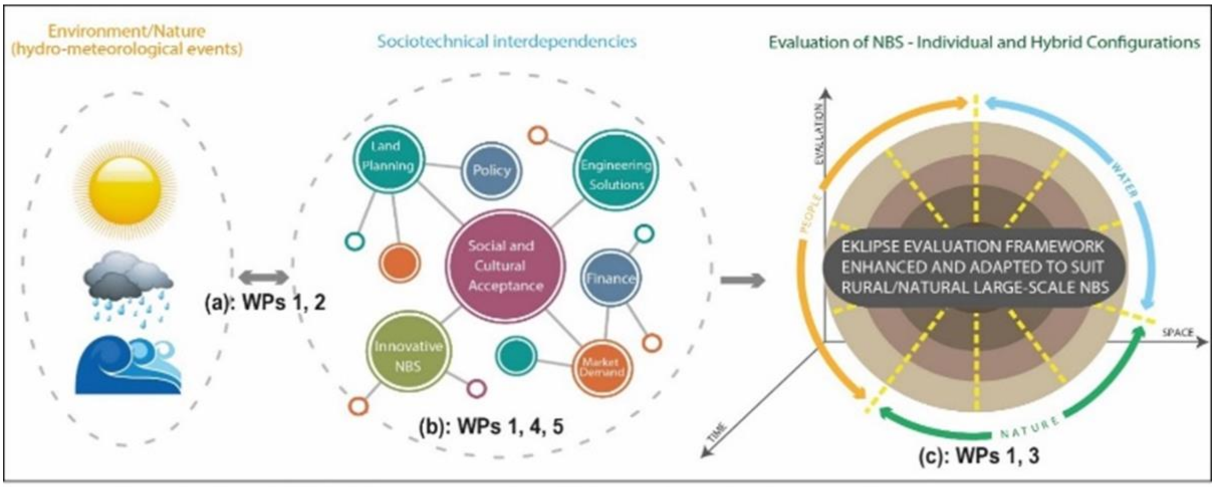


Figure 18 The overview of the RECONECT holistic ecosystem based framework. The time axis in the evaluation framework indicates the importance of long-term achievements of the benefits and co-benefits of NBS.

Figure 18 depicts the main components of the framework. The NBS are regarded as an element of the sociotechnical environment with defined interdependences with other elements such as social and cultural acceptance, market demand but also with the environmental factors such as climate change or hydrometeorological phenomena. The evaluation of the NBS potential to mitigate the hydrometeorological risks at the same time providing the co-benefits for the ecology and people is taking place over different dimensions- space and time. The time axis in the framework indicates the importance of long-term achievements of the benefits and co-benefits of NBS.

Based on the available experience so far and the available resources in RECOENCT and beyond, a set of lessons learned has been derived that can serve as a guidance for establishing the context for NBS. In order to ensure the longterm perspective of the NBS, RECOENCT develops and implements a set of actions that are given below.

How to ensure long-term sustainability of large scale NBS and how RECONECT can contribute to it:

1. **Ensuring functionality of the NBS/hybrid assets for different future projections – adaptability of solutions**

One of the anticipated advantages of the NBS solutions is the ability to cope with a range of possible futures, addressing a range of cases, embracing the uncertainty. Therefore, it is crucial to demonstrate the adaptability of the developed NBS/hybrid solutions. The implementation framework presented in Figure 9 foresees the scenario analysis, taking into account different development pathways and climate change scenarios.

The possible tools enhanced or developed in RECONECT that can support the scenario analysis are presented in the report D1.5. They range from individual hydrologic and hydrodynamic models to decision support systems or commercial and open source software platforms.

The RECONECT Demonstrators and Collaborators have developed or are developing scenarios that take into account climate change and possible future developments, when deciding upon the NBS or hybrid solutions. The selected solutions are the ones that have a potential to perform under a range of possible futures.

2. **Unlocking the NBS related innovation potential**

As NBS is *new* to many decision makers and asset owners, the reluctance to implement something *unknown* is a challenge and one of the key barriers to NBS implementation. Innovation or any kind of enhancement of the existing system is often seen as a risk rather than as an opportunity. Also, a number of ideas or products for NBS remain unexploited due to lack of mechanisms to identify those and adequately convey them to the potential users.
RECONECT contributes to unlocking this potential in different ways. Firstly, by identifying the lead users for NBS as presented in section 2.1.3 and further guiding them towards the market by developing business models and integrating them in the overall exploitation strategy.
Furthermore, the RECONECT has developed a strategy on how to deal with innovation from the idea, over the enhancement to a strategy to its exploitaiton (as presented in D5.3). A system based on the innovation readiness level approach is used as metrics to assess the status of the innovation delivered, assisting in the decisions on how to develop it further with the final objective to place it
In general the mechanisms should be developed to enhance the innovation by incentivising it and developing the mechanisms and infrastructure (physical, administrative and business) to place it and exploit in an adequate manner. The unlocking of NBS related innovation should go in line with the social innovation (see also point 7).

3. **Establishing adequate framework conditions for effective governance and for NBS assets at every stage in their life-cycle**

Adaptive asset management is taking into account the needs for adaptation and incorporates it into the planning procedures and strategy building.
In that sense, the loops and feedbacks of the RECONECT implementation framework as presented in Figure 9 are to be emphasised shifting towards stronger exchange between the strategic and operational level. This has already been emphasised in the discussion on the landscape dynamics and maintenance issues in sections 3.1 and 3.2 and the need to create a feedback loop between them and the both of them with the strategic planning.

One example of such an approach, which has been developed for the flood protection assets within the INTERREG FAIR Project, is presented in Figure 19.

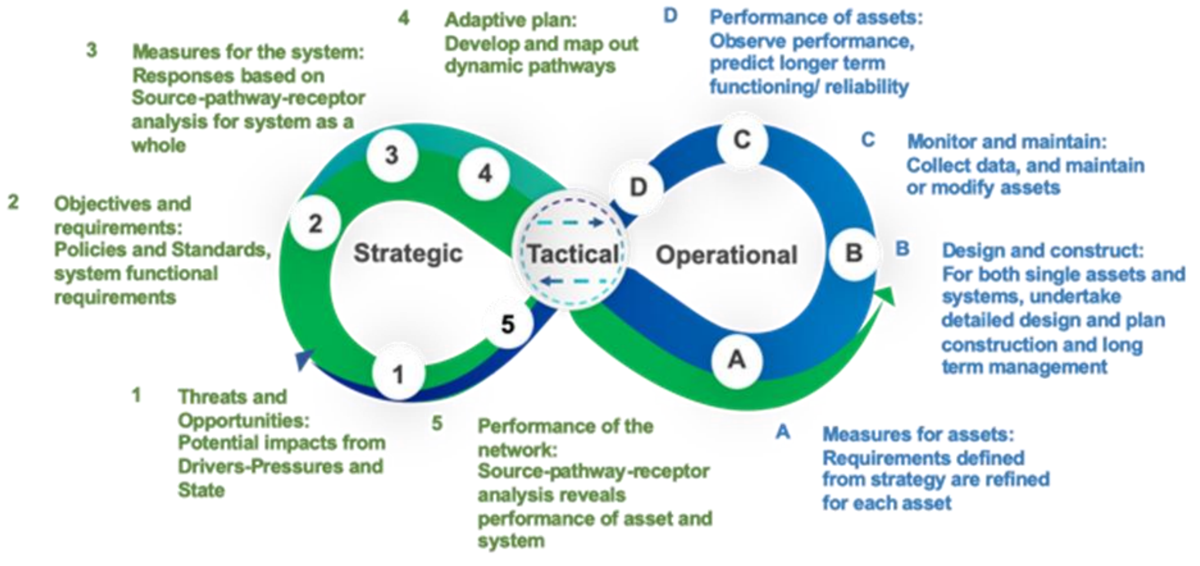


Figure 19 Levels and loops for effective governance in developing longterm strategies- emphasising feedback loops (FAIR Project, 2020)

The Strategic level takes a long-term overall system perspective based on understanding drivers, threats, policy or interactions with systems beyond this flood risk domain. Long term planning processes are used to decide on priorities that aim to balance cost, risk and performance at high, usually national level. Those adaptive plans are developed taking into account various dynamic pathways, objectives and functional requirements and the performance of alternative adaptation measures necessary to achieve these.

Operational level assesses the performance (reliability) of existing assets by monitoring and maintaining the required performance based on the knowledge gained from information collected. Where and when necessary, design and construct adaptations are undertaken, based on the inputs from the overall strategic planning level.

An additional level between those two has been introduced to maintain their interconnectivity. This Tactical (handshake) level provides a feedback loop for information and knowledge transfer between those two level, especially about individual asset performance in the context of overall system performance and how best to create or modify assets so that these are adaptable and reliable. This ensures that the developed strategic objectives are transferred into local conditions. At the same time the design and construction of the assets are modified to adapt to the longterm requirements defined at the strategic level.

4. Unlocking investments for NBS- Establish sustainable long-term funding arrangements achieving the financial sustainability→ Strategic roadmaps

Although the financing is crucial for realising NBS, it is rarely given much consideration in the frameworks (e.g. in Cohen-Shacham et al. (2019). One of the possibilities to unlock investments for NBS is to put an emphasis on the [potential role of experiments (e.g. showcases, flagship projects) for innovation and learning, and consequently the use of targeted project funds for financing NBS] (Wickelberg et., al, 2021).

Still, in a general case the questions around long term financing schemes for NBS are considered as emergence. As major challenges for the NBS investment is the need for long-term collaboration, coordination and knowledge integration. Here as the key issue appears the awareness of the different stakeholders on how they a benefit from NBS and to which extent it becomes the motivation to be part of the exploitation strategies of NBS including business models (Wickenberg et. al, 2021). It means that the developed exploitations strategies for NBS have to be innovative and inclusive to take into account all relevant players, which at the same time have to build capacity to understand the multiple benefits and values of NBS.

The role of public-private partnerships is in that respect often highlighted as crucial where the financing of NBS implementation depends on matching public funding with several private land owners and their engagement and in-kind contributions in implementing measures on their own land.

It is also to mention that the complexity of decision making on NBS becomes more difficult when the longterm choices (that take account of future uncertainties in climate and socioeconomic context) clash with short-term political realities and varying perceptions of risk (FAIR, 2020).

RECONECT is developing strategy and strategic roadmaps to unlock investments in a long-term run, which are expected to deliver results towards the end of the project and beyond. An important role is seen in deploying the RECONECT social innovation strategy by involving all relevant actors, but also providing them with tools to assess and analyse the multiple benefits of NBS and providing assistance to become involved in the exploitation strategy.

5. Ensuring that the monitoring of co-benefits feeds into the adaptation strategies development

Based on the experience presented in sections 3.1 and as illustrated in Figure 9, the feedback between monitoring of co-benefits and strategy development plays an important role in adjusting the further planning activities of NBS, making them compatible and competitive also for the future conditions at the same time constantly delivering the co-benefits.

As presented in Figure 18, the RECONECT holistic ecosystem based framework foresees a longterm monitoring of co-benefits, playing a pivotal role in delivering the necessary evidence on how NBS can fulfil their roles in the longterm perspective.

6. Pay attention to the long-term benefits in addition to the short-term costs

The overall cost of assets should be taken into account, rather than concentrating on the investment costs and on the initial efforts for rearrangements of the existing structures new roles assignment. The benefits of NBS solutions are to expect in the long run,
This experience has been reported and highlighted by the RECONECT demonstrators B, who already implemented NBS measures and are now in the monitoring and evaluation phases (e.g. Room for the River).

7. Co-create and build capacity → Shift towards polycentric governance

Co-creation and collaboration are considered as major factors for creating a solid foundations for the implementation of NBS and their longterm effects.
There are two suggested key issues in respect to the co-creation process:

1. Co-creation of knowledge relevant for undertaking own role or informed decision-making in a long term
2. Embeddedness of the created knowledge and solutions in the wider governance structures (e.g. Cohen-Shacham et al., 2019)

The EU identified polycentric governance as a driver for successful NBS implementation (EC 2003) and provided clear guidance encouraging collaborative planning through different policies, e.g., the Flood Directive or the Water Framework Directive. Still, the ways to successfully implement the collaborative planning processes to co-design NBS is an emergence.
The longterm sustainability of NBS appears still to be an emergence. Although the notion and idea is clear and accepted by the wider NBS community, the experiences and evidence of the benefits of NBS in a long run are still scattered or uncomplete as the monitoring periods of the implemented solutions to date are s a rule too short.
In RECONECT we developed and presented a set of postulates based on the available literature and experiences from other related domains (such as small scale blue green infrastructure) that are to be followed to enable the longterm perspective of the NBS or hybrid solutions to be implemented. The current related activities in RECONECT will deliver the lessons learned beyond the project lifetime.

Box 9 Longterm sustainability of NBS- The RECONECT view

- Longterm sustainability of NBS describes their ability to perform and create co-benefits in a long run, while addressing key societal challenges, arising from a combination of natural and anthropogenic factors, including climate change or disaster risk reduction.
- They aim to balance equity, economic and environmental benefits in a long run
- Longterm sustainability is likely to be achieved by addressing the major pillars of sustainability and benefits of NBS in the longterm perspective as follows:
    - Technical
        - Ensuring functioning of the NBS for a range of possible futures
        - Unlocking the innovation potential
    - Economic
        - Unlocking investments for NBS
        - Paying attention to the long-term benefits in addition to the short-term costs
    - Societal
        - Raising awareness and capacity building as a part of the co-creation process
        - Creating embeddedness of the developed solutions and the co- created knowledge into the wider governance structures shifting towards the polycentric governance
    - Environmental
        - Ensuring constant monitoring of co-benefits and its feedback to the strategy development

4. Key Leassons Learned, Conclusions and Outlook

4.1 Key lessons learned

The following key outcomes and lesson learned could be identified and should be considered by the end users when developing NBS related strategies:

Integration into the Landscape dynamics

1. The strategies for integrating large scale NBS into the landscape dynamics are emergence in both, research and practice.
2. Based on the experiences gained so far, it is possible to recommend suitable guidelines for the planning and design step of large-scale NBS. In the immediate future, many large-scale NBS cases are going to be monitored in the RECONECT project or beyond.
3. Raising awareness and involvement of key stakeholders including the landscape architects and planners is crucial to achieve sound integration of the NBS and the landscape dynamics. The tools and methods for co-creation can be made use of (as presented in Report D3.5).
4. The management strategies in dynamic landscapes might be necessary for the habitats created by humans, especially large-scale NBS. A robust monitoring system can not only ensure the performance of the intervention, but also regulate or reduce the negative effects by natural and human activities.
5. The recommendation is that bio-monitoring programs should be included at the early stages because biodiversity situations need a long-term monitoring program of at least 10 years. Those bio-monitoring data can be used for further studies with the objective to produce qualitative guidelines for planning and designing large-scale NBS.

Maintenance

Scope:

1. Don't set the scope too narrow: the area beyond the project area that are affected by the NBS should be considered and if negative consequences from the NBS are to be expected (e.g. due to debris flow) they have to be compensated or given assistance for the maintenance
2. Integrate the maintenance issues from the very beginning and align the planning efforts and the expectations with the required maintenance efforts in the case of both, NBS and hybrid solutions.
3. Do a proper sourcing of the available legal documents or recommendations relevant for your case. They are not necessarily available but can be found e.g. in international documents such as the Asset performance tool by the UK Environment Agency.
4. The costing of the NBS or hybrid solutions should be performed for the whole life span of the assets, not focusing on the short-term investment costs and the required initial efforts to adopt a new solution. The NBS are likely to decrease the overall costs, as the maintenance is often intended to be kept at the minimal effort level.
5. Don't be afraid of innovation when developing maintenance strategies. Underlined by the co-creation, the NBS related innovation in maintenance can improve the overall asset management by introducing new technologies.

Implementation

6. Monitoring activities should support maintenance, by delivering the information about the status of the assets, which can considerably increase the efficiency of the maintenance efforts.
7. Raising awareness on the importance and scope of the NBS maintenance among the decision makers and people in order to obtain appropriate resources, funding and support from the parties to be involved

Feedback and Review:

8. The outcomes and lessons learned from the maintenance should feedback into the strategy building level with the objective to optimise the design and reduce the overall costs of the NBS assets
9. Life cycle management is the key- regard the NBS/hybrid assets in a holistic manner; involving all relevant organisations and units from the beginning

Long term sustainability

Longterm sustainability is likely to be achieved by addressing the major pillars of sustainability and benefits of NBS in the longterm perspective:

Performance:

- Ensuring functioning of the NBS for a range of possible futures
- Unlocking the innovation potential

Economic

- Unlocking investments for NBS
- Paying attention to the long-term benefits in addition to the short-term costs

Societal

- Raising awareness and capacity building as a part of the co-creation process
- Creating embeddedness of the developed solutions and the co- created knowledge into the wider governance structures shifting towards the polycentric governance

Environmental

- Ensuring constant monitoring of co-benefits and its feedback to the strategy development

4.2 Conclusions

The NBS addressed in this guidance document refer to the interventions that mitigate hydrometeorological risks such as storm surges, floods, droughts and landslides, implemented in natural and rural areas. RECONECT builds upon different sources to analyse the NBS enhancements ranging from the already available solutions in different repositories (such as OPPLA), but also the solutions developed or sourced within the project in the Demonstration Sites or identified utilising the Lead User Method. The NBS enhancement has been understood as any alteration of the existing system that intends to improve the existing situation in terms of its main function and co-benefits.

A Framework for implementation of large scale NBS has been developed and proposed which addressed all relevant implementation steps from the inception analysis to operation and maintenance and incorporates the maintenance and landscape dynamics issues. We emphasise the importance of the feedback loops within the implementation framework especially of the landscape dynamics and maintenance issues into the strategy building and between each other. Capacity building and co-creation process by timely involving relevant stakeholder should underline both of those phases.
The lessons learned and guidance principles could be develop to different extents for the selected topics. It is particular related to the time frames of those issues. Whilst the

maintenance issues have already been addressed and considered for the implemented NBS, the knowledge and experiences with the efficiency of the integration of the landscape dynamics and design of NBS and of the longterm sustainability are not available to that extent as those activities need time to be evaluated.
It is not possible to make a steadfast conclusion about the effect of changing temporal network properties at this stage as there are only few large-scale NBS cases that have long-term biota and abiotic data to support. Due to the limits of relevant cases and monitoring data, it is also not possible (at this stage) to provide a qualitative/quantitative guideline for the entire design process based on the available data.
The systematised or evaluated knowledge in available body of literature and material on maintenance is rather scarce and the main source of information has been the RECOENCT consortium i.e. experienced researchers, practitioners and asset owners and operators.

Still, this guidance document extracted the knowledge available to date and framed it providing hints about the specific actions to be undertaken or taken care of when implementing the developed frameworks.

4.3 Outlook

This report is the first one of the RECONECT asset management series of reports with the key objective to tackle upon selected issues and reflects the current knowledge, experiences and lessons learned from RECONECT. Further updates and more elaborated guidance documents will be delivered towards the end of the project in particular in the following deliverables:

Report D2.8 on *Guidelines for design, construction and maintenance of largescale NBS*, will provide detailed guidelines including the integration of NBS into the landscape in the planning and design process and specific maintenance actions for different types of NBS

Report D5.4 on *Draft standards for design, implementation, management and decommissioning of NBS,* which will include standardised approach to asset management of NBS also building upon the experiences and lessons learned presented in this report.

The outcomes of the lead user method have been incorporated into the RECONECT exploitation strategy and will be used to develop business models which will be presented in reports D5.7 and D5.9 on *Business models and sustainability plans (preliminary and final).*
The longterm sustainability issues will be updated based on the RECONECT findings and will also feed into the reports D5.7 and D5.9.

5. References

Albert, C., Hack, J., Schmidt, S. et al. (2021): Planning and governing nature-based solutions in river landscapes: Concepts, cases, and insights. Ambio 50, 1405–1413 (2021) https://doi.org/10.1007/s13280-021-01569-z

Beavers, R.L.; Babson, A.L.; Schupp, C.A. (2016): Coastal Adaptation Strategies Handbook; National Park Service: Washington, DC, USA, 2016; pp. 1–160.

Bhattacharjee, K. and Behera, B.: Does forest cover help prevent flood damage? Empirical evidence from India, Global Environ. Change, 53, 78–89, https://doi.org/10.1016/j.gloenvcha.2018.09.004, 2018

Casteller, A., Häfelfinger, T., Cortés Donoso, E., Podvin, K., Kulakowski, D., and Bebi, P.: Assessing the interaction between mountain forests and snow avalanches at Nevados de Chillán, Chile and its implications for ecosystem-based disaster risk reduction, Nat. Hazards Earth Syst. Sci., 18, 1173–1186, https://doi.org/10.5194/nhess-18-1173-2018, 2018

Chou, R.-J., 2016. Achieving Successful River Restoration in Dense Urban Areas: Lessons from Taiwan. Sustainability 8, 1159. https://doi.org/10.3390/su8111159

Cohen-Shacham, E., Andrade, A., Dalton, J., Dudley, N., Jones, M., Kumar, C., Maginnis, S., Maynard, S., Nelson, C.R., Renaud, F.G., Welling, R., Walters, G., (2019). Core principles for successfully implementing and upscaling Nature-based Solutions. Environ. Sci. Policy. https://doi.org/10.1016/j.envsci.2019.04.014

Dadson, S.J, Hall J. W., Murgatroyd, A., Acreman, M., Bates, P., Beven, K., Heathwaite, L., Holden, J., Holman, I. P., Lane, S., O'Connell, E., Penning-Rowsell, E., Reynard, N., Sear, D., Thorne, C., and Wilby, R., (2017): A restatement of the natural science evidence concerning catchment-based 'natural' flood management in the UK, https://doi.org/10.1098/rspa.2016.0706

De Risi, R., De Paola, F., Turpie, J., Kroeger, T., 2018. Life Cycle Cost and Return on Investment as complementary decision variables for urban flood risk management in developing countries. Int. J. Disaster Risk Reduct. 28, 88–106. https://doi.org/10.1016/j.ijdrr.2018.02.026

DIN EN 13306, 2018

Dublin City Council, 2019. Climate change action plan 2019 - 2024.

Dublin City Council, Dún Laoghaire-Rathdown County Council, Fingal County Council, South Dublin County Council, 2017. A STRATEGY TOWARDS CLIMATE CHANGE ACTION PLANS FOR THE DUBLIN LOCAL AUTHORITIES

European Environment Agency (EEA) (2021): Nature-based solutions in Europe: Policy, knowledge and practice for climate change adaptation and disaster risk reduction, available at : https://www.eea.europa.eu/publications/nature-based-solutions-in-europe/file

Engel, H., 1997. The flood events of 1993/1994 and 1995 in the Rhine River basin. IAHS-AISH Publ. 21–32

European Commission, 2021. https://ec.europa.eu/info/research-and-innovation/research-area/environment/nature-based-solutions_en (accessed Dec 2021)

FAIR Consortium (2020): Adaptive asset management for flood protection FAIR end report

Glimm et al., 2009. Integrierte Konzepte, Modelle und Techniken für bestehende und neue Bauwerke. Unsere Gewässer – Forschungsbedarf aus Sicht der Praxis, Eine Dokumentation von HTG und DGGT, Hafentechnische Gesellschaft e.V. und Gesellschaft für Geotechnik e.V., Schifffahrtsverlag Hansa C. Schroedter & Co., Hamburg, 128-133.

Granstrand, M., Holgersson, M, (2020): Innovation ecosystems: A conceptual review and a new definition, https://doi.org/10.1016/j.technovation.2019.102098

Jordan, Ph., Manojlovic N., Fröhle, P. (2020): Unterhaltung ökologisch aufgewerteter Seedeiche, in Ökologische Aufwertung von Seedeichsystemen (Maintenance of ecologically enhanced sea dikes), Hsg. Schuttrumpf, Scheres, Book, DOI doi.org/10.1007/978-3-658-31507-8, Springer Vieweg, Wiesbaden

Klijn, F., de Bruin, D., de Hoog, M. C., Jansen, S., and Sijmons, D. F.: Design quality of room-for-the-river measures in the Netherlands: role and assessment of the quality team (Q-team), Int. J. River Basin Manage., 11, 287–299, https://doi.org/10.1080/15715124.2013.811418, 2013

Maes, J., Jacobs, S., (2016): Nature-Based Solutions for Europe's Sustainable Development, DOI: 10.1111/conl.12216

Morris RL, Konlechner TM, Ghisalberti, M., Swearer, SE., (2018): From grey to green: efficacy of eco-engineering solutions for nature-based coastal defence**.** Glob. Change Biol. **24,** 1827-1842. (doi:10.1111/gcb.14063)

Nagyova, A., Pacaiova, H., (2018): Maintenance evaluation based on the EFQM model excellence, IOP Conference Series Materials Science and Engineering 393(1):012005, DOI:10.1088/1757-899X/393/1/01200

Olsen, N., Bishop, J., 2009b. Ecosystem-based adaptation: A natural response to climate change. Gland, Switzerland.

Purvis, B., Mao, Y. & Robinson, D. (2019): Three pillars of sustainability: in search of conceptual origins. Sustain Sci 14, 681–695 (2019). https://doi.org/10.1007/s11625-018-0627-5

Rijke, J., van Herk, S., Zevenbergen, C., Ashley, R., (2012): Room for the river: Delivering integrated river basin management in the netherlands. Int. J. River Basin Manag. 10, 369–382. https://doi.org/10.1080/15715124.2012.739173

Ruangpan, L., Vojinovic, Z., Di Sabatino, S., Leo, L.S., Capobianco, V., Oen, A.M.P., 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. Nat. Hazards Earth Syst. Sci. 20, 243–270. https://doi.org/10.5194/nhess-20-243-2020

Sayer, J., Sunderland, T., Ghazoul, J., Pfund, J-L., Sheil, D., Meijaard, E., Venter, M., Klintuni Boedhihartono, A., Day, M., Garcia, C., van Oosten, C., E. Buck, L., (2012): Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses, PNAS May 21, 2013 110 (21) 8349-8356; https://doi.org/10.1073/pnas.1210595110

Seddon, N., Chausson, A., Berry, P., Girardin, C., Smith A., Turner, B (2020): Understanding the value and limits of nature-based solutions to climate change and other global challenges, The Royal Society Publishing, https://doi.org/10.1098/rstb.2019.0120

Sutton-Grier, A. E., Gittman, K. Arkema, R., O. Bennett, J.Benoit, Seth, Blitch, Kelly A. Burks-Copes, Colden, A., Dausman, A., M. De Angelis, B., Hughes, A. R., Scyphen, S. B., Grabowski, J. H (2018): Investing in Natural and Nature-Based Infrastructure: Building Better Along Our Coasts, Sustainability 2018 https://www.mdpi.com/2071-1050/10/2/523/htm

Thorslund, J., Jarsjo, J., Jaramillo, F., Jawitz, J. W., Manzoni, S., Basu, N. B., Chalov, S. R., Cohen, M. J., Creed, I. F., Goldenberg, R., Hylin, A., Kalantari, Z., Koussis, A. D., Lyon, S. W., Mazi, K., Mard, J., Persson, K., Pietro, J., Prieto, C., Quin, A., Van Meter, K., and Destouni, G.: (2017): Wetlands as large-scale nature-based solutions: Status and challenges for research, engineering and management, Ecol. Eng., 108, 489–497, https://doi.org/10.1016/j.ecoleng.2017.07.012, 2017

UK Environment Agency, (2012): Condition Assessment Manual

van der Nat, A., Vellinga, P., Leemans, R., van Slobbe, E., (2016): Ranking coastal flood protection designs from engineered to nature-based. Ecol. Eng. 87, 80–90. https://doi.org/10.1016/j.ecoleng.2015.11.007

Van Teeffelen, A.J.A.; Vos, C.C.; Opdam, P. (2012): Species in a dynamic world: Consequences of habitat network dynamics on conser-vation planning. Biol. Conserv. 2012, 153, 239–253.

Vonk, B., Klerk, W. J., Fröhle, P., Gersonius, B., den Heijer, F., Jordan, Ph., Ciocan, U.R., Rijke, J., Sayers, P., Ashley R., (2020): Adaptive Asset Management for Flood Protection: The FAIR Framework in Action, Infrastructures 2020, 5(12), 109;**doi:10.3390/infrastructures5120109**

Wildbach- und Lawinenverbau-Wildbachbetreuung Tirol (last update 2021) https://sp.tirol.gv.at/tirol.gv.at/dvtwiki/pages/viewpage.action?pageId=3965014

Wickenberg, B., Cormick, K., Alkan Olsson., J. (2021): Advancing the implementation of nature-based solutions in cities: A review of frameworks, Environmental Science and Policy, 2021 https://doi.org/10.1016/j.envsci.2021.08.016

World Bank. World Bank Implementing Nature-Based Flood Protection (2017): Principles and Implementation Guidance; World Bank: Washington, DC, USA, 2017

Wu, S-S., Ruangpan, L., Sanchez Torres, A., Vojinovic, Z., Rasmussen, M., Rene, E. (2021): Environmental Design Features for Large-Scale Nature-Based Solutions: Development of a Framework That Incorporates Landscape Dynamics into the Design of Nature-Based Solutions, Sustainability 13(11):6123, DOI: 10.3390/su13116123

Zebisch,M. (2004): Modellierung der Auswirkungen von Landnutzungs Anderungen auf Landschaftsmuster und Biodiversit. Ph.D. Thesis,TUBerlin,Berlin, Germany, 2004.(PDF)

6. APPENDIX - Lead User Measures

Through the application of the LUM to detect NBS for HMR mitigation the research team detected a total of 33 NBS. Those NBS are clustered into the categories of Green and Blue Infrastructure, Hybrid Solution, Digital Solution, and Governmental/Community Initiatives. During the research work, a total of 16 innovator and lead user interviews have been conducted and enabled the creation of mini case studies to gain an overview of each detected NBS. Additional desk research allowed data triangulation for a higher data robustness and helped to create additional 17 mini case studies. Each mini case study presents the NBS type, its functionality, which component of HMR it mitigates, the innovators motivation (if applicable), the development status and where they are implemented (if applicable).

Blue and Green Infrastructures

6.1.1 Billion Tree Tsunami

Billion tree tsunami is an initiative by Imran Khan, Chairman of Pakistan's Tehreek-e-Insaf party. Initiative was launched in 2014 to plant 1 billion trees across the Khyber-Pakhtunkhwa province. It’s a green NBS solution. To better cope with climate change and land degradation, 350,000 hectares of land have been covered by trees. Over years of fleeing and natural disasters the forest area has been significantly reduced. Pakistan has been hit hard by climate change and its geographical location makes it vulnerable to natural disasters such as floods. It has experienced severe natural hazards in the last two decades, for example earthquakes in 2005, Indus river flooding in 2010, glacier avalanche in 2012, etc. These recuring disasters, especially floods, have resulted in migration. Moreover, as an agricultural economy, Pakistan has been heavily harmed by destruction of crops due to flooding.

The provincial government of Khyber Pakhtunkhwa is the first local entity from any country in the world to register itself with the bonn challenge and astonishingly complete it in half the planned time. “The Bonn Challenge is a global effort to bring 150 million hectares of the world’s deforested and degraded land into restoration by 2020, and 350 million hectares by 2030”.

A network of private nurseries has been established. Along with benefiting the environment, they create green jobs and lift up the communities (World Economic Forum, 2018). The project has been declared a social and environmental success by IUCN.

After the completion of first project in 2017 the government has started another initiative to plant 10 Billion trees across the country until 2023. This project proved beneficial even during the Corona-19 pandemic and the government offered people to plant trees and get paid.

Billion tree tsunami improves human health, increases biodiversity and contributes to economy by mitigating the natural hazards. The project can be followed by other governments across the globe.

NBS Type	Government initiative	**Motivation**	**Impact on society**
HMH to be mitigated	Floods, Droughts, Mudslides, Heatwaves	To cope with the recuring natural hazards as a result of changing climate the Pakistani provincial government volunteered for the Bonn challenge and has planted 1 billion trees in one province and is expanding the project to 10 billion trees across the country.	The project improves human health, increases biodiversity and contributes to economy by creating green jobs and mitigating the natural hazards. The project can be followed by other governments across the globe.
Driver to be mitigated	Deforestation, Land degradation		
Who has the greatest benefit?	Humans, Wildlife		
Development Phase	Implemented		

Figure 20: Billion Tree Tsunami (Source: Redd-monitor)

6.1.2 Bioshoreline

Bioshoreline is a research project to develop biodegradable geotextiles as a temporary filter on inland waterways for technical and biological bank protection. The need for such an innovation arose with the introduction of the European Water Framework Directive (WFD). The WFD imposes riverbanks to be secured by vegetation, but ships and coastal floods lead to changing hydraulic loads on the riverbanks and quickly destroy newly planted vegetation due to the lack of root stability.

Bioshoreline is a geotextile fleece that retains the soil and holds the plants' roots until they are strong enough to withstand the hydraulic loads themselves (see Figure 8). During the growth process of the plants, the geotextile filters the water. Over a period of three years the geotextile fleece gradually degrades (Fraunhofer Institute for Environmental, Safety, and Energy Technology UMSICHT n.d.). The biodegradable geotextile fleece is made out of a mixture of natural fibers and bio-based synthetic fibers. The current prototypes are tested for their filter stability, soil retention capability, permeability to roots, and biodegradability. Once the functionality of the geotextiles is proven, natural riverbank protection can be implemented on a large scale (Fraunhofer Institute for Environmental, Safety, and Energy Technology UMSICHT n.d.).

By implementing Bioshoreline along the inland waterways, new green areas can be realized and simultaneously mitigate the risk of floods. The impact on the society can be aesthetic, as well as a decrease of CO2 concentration in the air, along waterways.

<table>
<tr><td>NBS Type</td><td>Green Infrastructure</td><td rowspan="6">Innovator Motivation

On inland waterways, shipping traffic leads to changing hydraulic loads on the banks. With the introduction of the European Water Framework Directive (WFD), the banks, which up to now have been mainly secured by grey infrastructures, are to be made more natural in the long term through the use of plants.</td><td rowspan="6">Impact on society

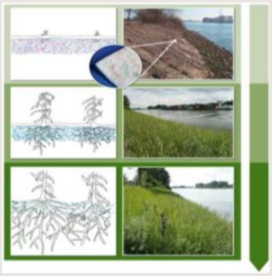
By implementing Bioshoreline along the inland waterways, new green areas can be realized and simultaneously mitigate the risk of floods. The impact on the society can be aesthetic, as well as a decrease of CO_2 concentration in the air, along waterways.</td></tr>
<tr><td>HMH to be mitigated</td><td>Coastal floods</td></tr>
<tr><td>Driver to be mitigated</td><td>Coastal flood induced erosions/landslides, rising sea levels, soil sealing</td></tr>
<tr><td>Who has the greatest benefit?</td><td>Flora along rivers</td></tr>
<tr><td>Development Phase</td><td>Prototyping</td></tr>
<tr></tr>
<tr><td colspan="4"> </td></tr>
</table>

Figure 21: Bioshoreline overview (Source: Federal ministry of food and agriculture)

6.1.3 Climate Trees

Climate trees support the urban green to withstand newly arising circumstances generated by climate change. The combined urban green can mitigate rising temperatures and droughts. In Germany, local tree species suffer from rising temperatures, droughts and soil sealing, and rising temperatures have also brought new plant diseases to Germany, causing tree nurseries to suffer substantial economic damages. The innovator of the Climate Trees described that *"the average age of a tree, in the nursery, is 25 years. If a disease comes and attacks the ash tree, it's a disaster. We have produced many thousands of ash trees that are no longer saleable because they have a problem created by climate change."* As a solution, the innovator searched for tree species that are already used to the new diseases, to the rising temperatures, and to convective events. The result is a climate tree grove with 61 different tree species, mostly from Northern America and the Middle East, that can withstand the changing hostile urban circumstances. Figure 9 on the right-hand side shows the climate tree grove. To preserve Germany's biodiversity, the climate trees are only used in urban area and not in suburban or countryside forests.

Climate trees are implemented in multiple climate zones from western to eastern Europe. First pilot projects are in place for the city of Hamburg (see Figure 9 left hand side), but in Hamburg it is problematic to implement the idea of climate trees on a large scale. The reason for this is that each district acts on its own and there is no city-wide approach.

NBS Type	Green Infrastructure	**Motivation**	**Impact on society**
HMH to be mitigated	Droughts, heat waves, pluvial floods	A lead user from Germany had suffered from great economic damage in his tree nursery and wanted to sell solutions to customers and not problems, because local trees are being destroyed by new diseases that are arriving in Germany because of the climate change.	By implementing climate trees the urban biodiversity increases, which then increases the urban life quality and greater resilience of urban nature towards natural hazards.
Driver to be mitigated	Soil sealing, loss in urban green, rising temperatures		
Who has the greatest benefit?	Urban population, urban green and wildlife		
Development Phase	Implemented		

Figure 22: Climate Tree overview (Source: Baumschule Lorenz von Ehren 2021a (left), 2021b(right))

6.1.4 Cribwall Krainer

Cribwall Krainer is a NBS that was developed by a growing bioengineering firm in Spain. The firm was inspired by the NBS measures available in other countries to safeguard local ecosystems and has the goal to provide NBS techniques to the masses. This particular NBS is a highly resistant technique for rapid stabilization of the riverbank and can be particularly useful in increasing the resilience to landslides and floods. It can be used for stabilization of slopes until gradients of 60°. The company is driven by the notion of making simple but effective NBS techniques available to everyone. The founder of the company described the creation of Cribwall Krainer and other concepts in the following words- *“I was inspired by what I had seen in other countries and wanted to do the same in my country. All the money that we get, we use it for improving the quality of the work, teach people about new techniques but also to do research. We are involved with several Universities as well. We try to find common points between what is needed and what can be done.”*

In simple terms, the Cribwall Krainer is a gravity wall made of a cellular structure with logs and plants in containers. Trunks, preferably of slowly degrading trees (chestnut), are placed in many layers that are perpendicular to each other. The logs are secured with nails. The space between the trunks is filled with soil and sown with plants in containers. The plants serve the purpose of providing stability by substituting the degraded log structure at a later stage. It is necessary to allow a soft slope towards the inside part of the cribwall (Naturalea 2019). Figure 10 shows one such Cribwall Krainer arrangement implemented along a slope in rural Spain. The NBS has been successfully implemented in Europe with rural areas particularly in focus.

NBS Type	Green Infrastructure	Motivation	Impact on society
HMH to be mitigated	Landslides, floods	The lead user was inspired by the NBS measures available in other countries to safeguard local ecosystems and decided to start his own company to do the same in Spain. The firm wishes to make simple NBS techniques available to the masses.	Cribwall Krainer enables a rapid stabilization of the riverbank and slopes thus increasing the resilience to floods and landslides respectively.
Driver to be mitigated	Coastal flood induced erosions/landslides, rising sea levels, soil sealing		
Who has the greatest benefit?	Population and infrastructure along slopes, flora along rivers		
Development Phase	Implemented		

Figure 23: Cribwall Krainer Overview (Source: Naturalea 2019)

6.1.5 Elevated Houses

A Pakistani village elevated their houses after a wheat farmer had to rebuild his house for several times due to recurring inundation. At one point, after losing his house again, he decided to adapt and rebuilt it on a raised dirt platform, surrounded by eucalyptus trees (see Figure 11). It’s a green NBS type solution and a response to the recurring floods. This new housing concept did not take long to be adopted by locals and transfuse to nearby villages. As a result, less people have to migrate from the area as a consequence of a flood. change. It addresses the improper infrastructure practices and stops climate migration. Safe, sustainable houses can cut the spending in refugee tents arranged for flood affected people. The most vulnerable people of the society become the victim of floods and lose their livelihood and house. This is all mostly they own. The adaptation of a house roughly costs $1000, which is way higher than the average monthly income of people in the developing world. This concept of elevated houses can easily be implemented with the government support and funding in other flood prone regions across the globe.

NBS Type	Green Infrastructure	Motivation	Impact
HMH to be mitigated	Pluvial floods	A wheat farmer after losing his multiple times in recuring floods adapted and rebuilt the house on a raised dirt platform, surrounded by eucalyptus trees.	Elevated house was able to withstand the floods in upcoming years. This new housing concept did not take long to be adopted by locals and transfuse to nearby villages. Climate migration stopped.
Driver to be mitigated	Improper infrastructure planning		
Who has the greatest benefit?	Population in flood prone areas		
Development Phase	Implemented		

Figure 24: Elevated Houses (Source: Braced)

6.1.6 Favela Green Roof

Favela Green Roof is green roof project to reduce the temperature and filter the rainwater at the dense Aara slum in Rio de Janerio. It's a green NBS solution. A doctoral candidate carried out the project and observed it for two years for his PhD thesis. The aim was to find ways to reduce the inhouse temperature in densely populated area of Aara slum in Rio di Janerio. Native species of bromeliads and orchids were used in 2 years long project (Oppla, 2010).

The project was implemented in 2016. The results of the green roof were astonishing. The temperature monitoring indicated that in comparison with the bare neighboring roof, house interior with the greenery on the roof had up to twenty-degree temperature drops. Storm-water runoff was also reduced because of the green roof.

Temporary settlements and especially urban slums are extremely vulnerable to climate change and heatwaves could be catastrophic because of lack of resources to maintain a reasonable temperature during the hot summer weather. Green roofs can be introduced in slums in developing countries, e.g., India and Bangladesh. It's a low-cost and low maintenance solution to lower the inhouse temperature (Oppla, 2010). Figure 12 shows the project implemented.

NBS Type	Green Infrastructure	Motivation	Impact on society
HMH to be mitigated	Heatwaves	Project was implemented to reduce the temperature and filter the rainwater at the dense Aara slum in Rio de Janerio	Favela green roof project lowered the inhouse temperature by 20°C in comparison with neighboring houses.
Driver to be mitigated	Rising temperature		
Who has the greatest benefit?	Slum dwellers		
Development Phase	Implemented		

Figure 25: Favela Green Roof Overview (Source: Oppla)

6.1.7 Floating Agriculture

Floating agriculture is a technique of crop cultivation wherein floating rafts or platforms are created on flooded low-lying areas for the cultivation of crops without soil. Such a system decreases the impact of HMHs such as floods and cyclones in agriculture by reducing the dependency on soil/land for growing the produce and thus strengthening food security. The concept of floating agriculture emerged in Bangladesh where farmers were severely affected by HMHs that threatened their livelihoods (FAO 2017). Figure 13 displays one such floating agriculture field in Bangladesh.

Floating agriculture involves growing crops that derive nutrients from a floating substrata of water hyacinth and other aquatic weeds on flooded water. The deeper regions of the flooded water are suitable for the production of fish. Water hyacinths are stacked in 2 - 4 layers. The first layer serves as the base of the floating bed maintaining stability and buoyancy whereas the subsequent layers act as compost. Upon decomposition of the aquatic bed, seeds are sown. As the bed is rich in nitrogen, potassium, and phosphorous, there is very little need for fertilizers. The floating beds vary in size with lengths ranging from 10 - 60 m and breadth ranging from 1.25 - 4 m. When the flood water recedes, the floating beds settle on the ground which forms the compost for cultivation in winter.

Such a system of cultivation has been implemented successfully in Southeast Asian countries such as Bangladesh and Indonesia wherein large areas of land are susceptible to flooding from cyclones and sea level rise.

NBS Type	Green Infrastructure	Motivation	Impact on society
HMH to be mitigated	Coastal and pluvial floods, cyclones	To cope with recurring seasonal floods and cyclones that threatened their livelihoods, farmers of Southeast Asia devised this technique of soil-less farming.	Floating agriculture technique reduced the impact of HMHs on the agriculture industry, thus strengthening food security and securing livelihoods of farmers
Driver to be mitigated	Rising temperature		
Who has the greatest benefit?	Agriculture Industry		
Development Phase	Implemented		

Figure 26: Floating Agriculture Overview (Source: FAO 2017)

6.1.8 Flood Planting using Coir Logs

This green infrastructure innovation is based on the alternative method of laying coir logs (natural fiber found in ripe coconut husks) and planting vegetation along riverbanks which are susceptible to erosion and flooding. The application of coir logs made it possible to improve the flood conditions and ensure the protection of areas along the riverbed. It also maintains the ecological continuity and stability by supporting the growth of locally available plant species. The innovator of this solution was exploring the nature-based alternatives to traditional practices of flood protection. In her own words, *"nature based solutions need minimum human intervention. Nature itself generates stability. This is my focus and reason that I use biodegradable materials and vegetation. Whatever project I do, I want it to be a nature based solution".* As a solution, the innovator came up with the idea of using biodegradable coir logs to prevent inundation of riverbeds.

After a thorough analysis of the water and soil characteristics, coir logs were placed in 3 - 4 layers in areas with loose soils. Sticks were placed 1m apart and were connected with ropes to provide stability to the coir logs. Three layers of vegetation were planted in between the subsequent coir log arrangements. Poplar, reed and willow trees were chosen for planting. The advantage of using coir logs is that the fiber allows vegetation to grow within it. It takes 2 - 5 years for the coir to degrade after which it becomes a part of the soil matrix. At this stage, the roots of the vegetation provide long-term stability to the soil, thus preventing erosion and inundation.

This NBS has been successfully implemented along the bed of Erzeni river in Albania as shown in Figure 14.

<table>
<tr><td>NBS Type</td><td>Green Infrastructure</td><td rowspan="6">Motivation

The innovator of this solution wanted to employ nature based alternatives to protect the riverbed along the Erzeni River in Albania.</td><td rowspan="6">Impact on society

Coir logs successfully ensured the protection of areas along the riverbed. Locally available plant species were also supported through the implementation of this technique, thereby maintain the ecological stability of the region</td></tr>
<tr><td>HMH to be mitigated</td><td>Landslides, floods</td></tr>
<tr><td>Driver to be mitigated</td><td>Coastal flood induced erosions/landslides, rising sea levels, soil sealing</td></tr>
<tr><td>Who has the greatest benefit?</td><td>Flora along rivers</td></tr>
<tr><td>Development Phase</td><td>Implemented</td></tr>
</table>

Figure 27: Flood Planting using Coir Logs Overview (Source: Photos from Enkelejda Kucaj)

6.1.9 Managed Aquifer Recharge

Managed Aquifer Recharge is a water management measure introduced to counter longer periods of drought and high temperatures in summer and shorter but intense precipitation in winter which contribute to shortage of freshwater resources for agro- and natural systems. This solution emerged from an Environmental Science group of a University that grew up connected to the local territory and community in a town in Italy. In the words of one of the innovators, *"We started to make a list of the problems that are common here such as water management and topography. We realized that drainage was one of the main factors in saltwater intrusion. How could we improve freshwater availability and prevent saltwater intrusion? We realized that sectorial approach is not good anymore. A transdisciplinary involvement of different expertise is needed."*

This NBS involves digging or excavation of an infiltration trench which stores comparatively good quality drainage water from the pumping stations. This water would in other cases be discharged to the sea without being used. The stored water can be later used for irrigation purposes or aquifer recharge through natural infiltration. The water level in the trench is kept 0.5-1 m above the surrounding water table, thereby facilitating the aquifer recharge. Such an infiltration trench should be ideally located in close proximity to the pumping station and agricultural lands. This particular Managed Aquifer Recharge technique implemented in Italy was found to provide 120 days of good quality drainage water through infiltration and storage into the coastal aquifer. Furthermore, it allowed irrigation of over 1500 hectares of land and thus increased agricultural production by 50 percent. Globally, over 1200 case studies of Managed Aquifer Recharge (and its variations) in over 50 countries exist.

<table>
<tr><td rowspan="2">NBS Type</td><td rowspan="2">Blue Infrastructure</td><td>Motivation</td><td>Impact on society</td></tr>
<tr><td rowspan="5">The Environment Sciences group of a University developed this nature-based technique of water management to help the local community cope with reduced water availability in summer and salt water intrusion</td><td rowspan="5">The solution provided enough water to irrigate 1500 hectares of land and thus increased agricultural production by 50%. Moreover, the load on the drainage systems was also reduced.</td></tr>
<tr><td>HMH to be mitigated</td><td>Droughts</td></tr>
<tr><td>Driver to be mitigated</td><td>Water scarcity</td></tr>
<tr><td>Who has the greatest benefit?</td><td>Agriculture Industry</td></tr>
<tr><td>Development Phase</td><td>Implemented</td></tr>
</table>

Figure 28: Managed Aquifer Recharge Overview (Source: Own depiction)

6.1.10 The Cocoon

The Cocoon is a biodegradable cardboard solution in the shape of a doughnut that enables plants (or saplings) to grow in particularly arid regions. This innovative planting technology can be especially useful for regions facing drought conditions, thus revitalizing ecosystems and communities. Generally, the survival rate of manually planted saplings in arid regions is only 10% but with the use of the Cocoon, it ranges between 80% and 95%. According to the inventor of The Cocoon, *"Two billion hectares of land is degraded globally, which is the size of the United States and China combined. This is a result of fires, or intense deforestation and abandoned agricultural land. Very few resources are going into bringing that nature back. Our mission is to help restore these two billion hectares of land"* (Besnainou 2019).

The concept of the Cocoon firstly requires a shallow pit to be dug to plant the seedling. The sapling is surrounded by the biodegradable cocoon made out of recycled paper pulp, grass or other crop residuals. The cocoon is filled with water and then covered by a lid to prevent loss of water from evaporation. Small channels or wicks within the cocoon sparsely transport the water to the root of the saplings. With time, the cocoon degrades and enriches the soil while the empty shallow pit serves as a catchment to collect water in case of rainfall. A cylindrical shelter is placed over the cocoon's opening in order to protect the young sapling from excessive sun exposure, winds and smaller animals. In some cases, Mycorrhizal fungi is added to the soil to enhance the plant's ability to absorb soil moisture and nutrients (see Figure 17).

This NBS brings other co-benefits related to reforestation such as carbon sequestration, reduction of surface runoff and prevention of soil erosion. Moreover, as the Cocoon requires only 1-10% of water compared to a drip-irrigated tree, it reduces stress on natural resources making it available in times of need (Land Life Company 2020). The company behind this innovation has worked with government authorities in Australia, US and Europe to undertake reforestation projects and plans to plant over 1 million trees in the coming year.

<table>
<tr><td>NBS Type</td><td>Green Infrastructure</td><td rowspan="5">Motivation

The innovator of this solution aims to restore the increasing amounts of vegetation that are lost to forest fires, deforestation and infertile land.</td><td rowspan="5">Impact on society

The developed solution reduces the load on natural resources such as water for irrigating trees. Moreover, other co-benefits such as carbon sequestration, surface runoff reduction and prevention of soil erosion follow.</td></tr>
<tr><td>HMH to be mitigated</td><td>Droughts, heat waves</td></tr>
<tr><td>Driver to be mitigated</td><td>Cost of high-tech solutions, rising temperatures, water scarcity</td></tr>
<tr><td>Who has the greatest benefit?</td><td>Agriculture Industry</td></tr>
<tr><td>Development Phase</td><td>Implemented</td></tr>
</table>

Figure 29: The Cocoon Overview (Source: Reset 2020)

6.1.11 Vegetative Sediment Trapping

Vegetative sediment trapping is a NBS primarily aimed at land and soil conservation to prevent soil erosion and manage runoff. These measures include grass strips and stone bunds in slopes to trap water and sediment from upstream. The need for this NBS originated in Ethiopia whereby farmers were looking to make use of the soil and land resources in a sustainable manner.

Grass strips are bands of grass that are planted along contours at specified vertical intervals whereas stone bunds employ the same concept but use stones instead of grass. This results in the formation of micro-terraces in the downstream path of the water and sediments. However, these NBS measures alone have been ineffective in conserving the soil in the fields as evidenced by the accumulation of sediments in reservoirs downstream. This calls for a need to catch the sediments on their transport path. This can be done by NBS such as grassed waterways. These are channels that are planted with grasses to reduce runoff, enhance infiltration and prevent sediment downflow by decreasing flow velocity. Such an integrated soil management solution that incorporates various NBS was found to solve the degradation problem and decrease the sediment yield in reservoirs downstream (Mekonnen et al. 2015). This innovation can be extremely beneficial in rural and agricultural landscapes where soil erosion is a major hindrance to optimizing agricultural productivity. Figure 18 shows grassed strips and waterways used to conserve the soil in a rural landscape in Ethiopia.

<table>
<tr><td>NBS Type</td><td>Green Infrastructure</td><td rowspan="5">Motivation

Farmers in Ethiopia devised this NBS to use the available soil and land resources in a sustainable manner and to keep soil erosion in check.</td><td rowspan="5">Impact on society

The farmers were able to keep their soil fertile and increase their agricultural productivity by preventing soil degradation through erosion.</td></tr>
<tr><td>HMH to be mitigated</td><td>Landslides, erosion</td></tr>
<tr><td>Driver to be mitigated</td><td>Soil degradation</td></tr>
<tr><td>Who has the greatest benefit?</td><td>Agriculture Industry</td></tr>
<tr><td>Development Phase</td><td>Implemented</td></tr>
<tr><td colspan="4"> </td></tr>
</table>

Figure 30: Vegetative Sediment Trapping Overview (Source: Mekonnen et al. 2015)

6.1.12 Vetiver planting to prevent landslides and floods

A fragrant root plant (Vetiveria zizanioides) commonly known as vetiver can be used in mudslide prone regions. It is a green infrastructure NBS type solution to mitigate floods and landslides due to the soil erosion. It has deep strong roots, which grow up to three to four meters deep in the first year and very effectively grip the soil to prevent mudslides. It can stabilize steep slopes, prevents erosion and rehabilitates degraded land. Suitable regions are tropical and temperate (Vetiver grass, 2020). Vetiver plants have great potential for water and soil conservation. The combination of its deep roots and thick growth of the hedges protects the banks of rivers and streams under flood conditions. The deeply penetrated roots hinder the vetiver to be washed away in flood conditions and the thick dense top part of the plant reduces the flow velocity of landslides. If properly designed and planted, the hedges can direct the water flow in a certain direction. It can also tolerate metals and could also be used as biological pest control. It can mitigate environmental and agricultural problems. Additionally, oil is extracted from its roots and is used in cosmetics industry. Vetiver's fiber properties also make it useful in the handicraft industry. It is already been used in Malaysia, Philippines and Australia for steam bank and riverbank stabilization. It could be used in Northwestern Europe in urban setups to strengthen the flood resilience of the city's ecosystem. Figure 19 shows the implementation.

NBS Type	Green Infrastructure	Motivation	Impact on society
HMH to be mitigated	Floods and mudslides	To increase the flood resilience and soil strength to mitigate landslides. vetiver grass is used as a nature bases solution.	It is already been used in Malaysia, Philippines and Australia for steam bank and riverbank stabilization. Additionally, its roots are used in cosmetics industry. Vetiver's fiber properties also make it useful in the handicraft industry.
Driver to be mitigated	Mudslides, soil erosion		
Who has the greatest benefit?	Urban and rural management authorities		
Development Phase	Implemented		

Figure 31: Vetiver planting to prevent landslides and floods Overview (Source: Vetiver grass)

Digital Solutions

6.1.13 Arduino Setup for water parameters

This Digital Solution is aimed at collecting data on important water parameters that are vital for studying sediment dynamics and inundation patterns. Typical devices that measure water salinity, turbidity, velocity, and water depth are costly. The innovator created a device that is 10 times cheaper than the commercially available alternatives. In his own words, *"I realized straightaway the lack of data, especially for sediment concentration. The price that was quoted for such a device blew my mind. Then, I thought how can I make it cheaper and make it work remotely?"*

Tides can cause an influx of sediments in short and regular periods. This creates a need to collect sediment concentration data in intervals of 1-3 hours. This device consists of an Arduino and GSM module which is connected to a turbidity sensor. With the GSM module, sediment concentration data can be easily uploaded to a remote server/website. To make it operable for longer, the device is powered by a power bank which can be recharged with a small solar panel if necessary. This would enable a minimum runtime of 6 months. Further enhancements to the device were made by integrating an EC meter for salinity measurements and proximity sensors for checking the water level. Such devices will enable the identification of zones in a polder that are more susceptible to sedimentation. Moreover, real time water level checks can serve as a warning system for floods in case water level rises above a certain threshold. Finally, the salinity measurements can help monitor the ecosystem. With further improvements to the device, it will be able to measure the moisture in the soil which can help prevent subsidence of dikes and eventual flooding. This device has been used extensively to study sediment dynamics in polders in Netherlands and Bangladesh.

		Motivation	Impact on society
NBS Type	Digital Solution	The lead user wanted to support his own PhD project that was hindered by lack of data on sediment dynamics and high cost of measurement devices to record this information.	The low cost device can help in alerting communities along river banks when water level in the river rises, thus saving lives. Moreover, salinity measurements will enable actions to be taken that can preserve the aquatic biodiversity.
HMH to be mitigated	Coastal floods		
Driver to be mitigated	Data insufficiency, cost of high-tech solutions, rising sea level		
Who has the greatest benefit?	Inhabitants of polders		
Development Phase	Implemented		

Figure 32: Arduino Setup for water parameters Overview (Source: Own depiction)

6.1.14 Data driven rescue operations

A Stanford graduate during his visit to India got stranded in a flood and waited for weeks for assistance. During the week he came back in California an earthquake occurred. Out of frustration of late assistance in India and curiosity how rescue operations work in USA, he investigated the rescue priorities and realized that its first some first base but the problem is often the telecommunication services get disrupted in most affected areas. This lead user combined his knowledge of machine learning and earthquake and trained a program to predict the impact of an earthquake. One concern is a startup started by Stanford's graduates, which uses artificial intelligence to predict the impact of a disaster in an area. It's a digital-solution to help disaster management teams to provide assistance to the most affected people in case of a disastrous event like earthquake. One concern's prediction tool can save lives by providing valuable information to the emergency responders. The goal of one concern is to make natural disaster less disastrous by predicting their affects and the regions which will be affected the most (One Concern, 2020).

Several cities are already using the services of the startup and now the first oversea city is from Japan. After testing the tool for earthquakes, the startup has expanded to incorporate floods and cyclones and is aiming to cover wildfires in the near future, as the company is based in California, which frequently encounter wildfires. This technology can be applied all over the world to provide valuable information to the rescue and disastrous management teams.

Figure 20 shows the prediction about the impact of an earthquake in Northern California, block by block, areas of severe (red) and moderate (yellow) damage.

<table>
<tr><td>NBS Type</td><td>Digital Solution</td><td rowspan="5">Motivation
A lead user, a Stanford graduate got stranded in a flood in India and waited for assistance for weeks. He wondered why? Soon after an earthquake occurred in California, USA and he investigated the priorities of rescue teams and realized that at the time of crisis most affected people often aren't provided assistance because of disruption of communication services.</td><td rowspan="5">Impact
One concern's model predicts the impact of earthquakes in 15 minutes after the event and provides authorities with the information which areas got most affected and where highest assistance is needed. The model has been adapted by several cities in USA and now overseas in Japan as well.</td></tr>
<tr><td>HMH to be mitigated</td><td>Earthquake, Storms</td></tr>
<tr><td>Driver to be mitigated</td><td>Data insufficiency</td></tr>
<tr><td>Who has the greatest benefit?</td><td>Disaster response teams,
Insurance companies</td></tr>
<tr><td>Development Phase</td><td>Implemented</td></tr>
</table>

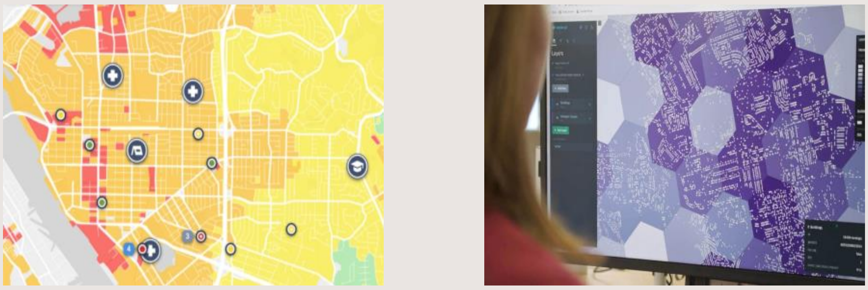


Figure 33: Data driven rescue operations Overview (Source: One Concern)

6.1.15 The German Drought Monitor

The German drought monitor monitors soil water availability on a daily basis on a regional and national level, and it enables effective water management for drought risk mitigation. It is mainly used by farmers to optimize their crop irrigation during drought periods to prevent crop failure caused by water scarcity (see figure 13).

The innovator saw a personal need for a drought monitor, because he experienced great infrastructure mismanaged based on the lack of data. *"This southern province of Ecuador, where I come from, had already in the 1970s a huge drought […]. A consequence of this was the creation of a long-term program for creating these [irrigation] channels […]. Everything was nonsense […]. You can't monitor and you can't design and if you do a design, it's probably overestimated."* The solution the innovator created is a data driven model that is updated daily and follows the following four steps: (1) Update of meteorological data provided by the German Weather Service; (2) estimation of soil status using a mesoscale hydrological model; (3) calculation of soil moisture index (SMI); (4) index classification into five drought classes (abnormally dry, moderate drought, severe drought, extreme drought, exceptional drought) (Zink et al. 2016). The German drought monitor is running not only on a national scale but is the base model for other drought monitoring approaches in Egypt and South Asia (see http://ufzchs.pythonanywhere.com). For an even more effective drought mitigation, it is the innovator's goal to add short and medium range forecasting functions into the drought monitor as well as a smartphone application.

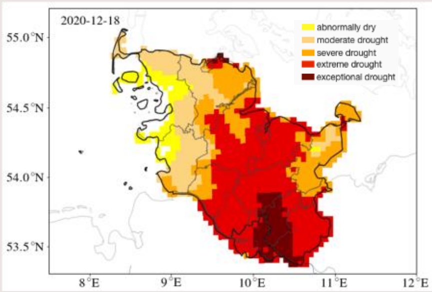
NBS Type	Digital Solution	**Motivation**	**Impact on society**
HMH to be mitigated	Droughts, heat waves	A lead user, a civil engineer from South America, experienced extreme over dimensioning of grey infrastructures to mitigate the risk of droughts. The reason for this was the lack in knowledge about true precipitation amounts. In order to design more appropriate infrastructures, he wanted to created a drought monitor.	Through the implementation of the German Drought Monitor the society started to realize that droughts do not only exist in Africa or South America, but also in Germany. Farmers see the potentials in this solution to adapt their irrigation and mitigate crop loss during droughts. The German Drought Monitor is the base for other drought monitors in Egypt and India.
Driver to be mitigated	Data insufficiency, risk neglection		
Who has the greatest benefit?	Agricultural industry / insurance industry		
Development Phase	Implemented		
			

Figure 34: The German Drought Monitor overview (Source: Helmholz Center for Environmental Reseaech 2020)

6.1.16 The Hail Damage Model HSCM

The Hail Damage Model HSCM is a model to quantify the possible damage of a “once in 200” years hailstorm event or of an ongoing hailstorm. The Hail Damage Model is used primarily by an insurance companies to estimate their damage portfolio, which is the possible damage of a one in 200 years hailstorm event (see Figure 23). By using this model, the insurance company was capable to recalculate the risks and costs of hail damages for their customers. As a result, insurance policies decreased.

The innovator created the Hail Damage Model to *“[…] really understand what the driver is of the hailstorms, why in several regions hail occurs more frequently compared to other regions and this is more less basic research. As a meteorologist I'm actually interested in the basic research.”* The model contains a module that calculates the possible exposure of hailstorm trajectories and a second module to calculate the vulnerability of buildings within the hailstorm trajectory. The model’s vulnerability calculation depends mostly on the size and speed of hailstones and the building types. By transferring hailstorm trajectories to different regions, the Hail Damage Model can re-evaluate the vulnerability for each individual building (Schmidberger 2018).

The Hail Damage Model has been implemented in the German State of Baden-Württemberg and was the base for a European and Australian Model. Those models include only the hail exposure module.

<table>
<tr><td>NBS Type</td><td>Digital Solution</td><td rowspan="5">Motivation

A scientist had the desire to better understand the phenomena of hail storms and their consequences. A collaboration with a local insurance company was created to fund the research and the created model was used in return by the insurance company.</td><td rowspan="5">Impact on society

By using this model, a local insurance company was capable to recalculate the risks and costs of hail damages for their customers. As a result, insurance policies decreased.
The Hail Damage Model HSCM was the base for a European and Australian model.</td></tr>
<tr><td>HMH to be mitigated</td><td>Convective hailstorms</td></tr>
<tr><td>Driver to be mitigated</td><td>Data insufficiency, modern infrastructure, risk neglection</td></tr>
<tr><td>Who has the greatest benefit?</td><td>Insurance industry</td></tr>
<tr><td>Development Phase</td><td>Implemented</td></tr>
</table>

Figure 35: Hail Damage Model HSCM overview (Source: Own depiction)

6.1.17 Monitoring of rivers with video surveillance cameras

Two researchers from France with background in water management put 10 years of their research into industrial use and enter into Alp-Water-Scarce-Project in 2010 with their IMAGINE project. Their technological project becomes a reality and shapes into a company named Tenevia. Tenevia, a startup founded in 2012 in Grenoble, France mitigates the threat of floods by monitoring water levels using image sensors. It’s a digital-solution which uses digital surveillance cameras deployed along the rivers to assess water levels, the flow and surface speed. Unlike the gauges, the traditional water monitoring systems, the cameras are not below the water line. Tenevia’s solutions use computer vision and numerical modelling to predict flooding threats and gather data over longer periods to help planners make risk-sensitive decisions at the time of flooding, when the information is most needed (Tenevia, 2020).

The technology is already now being used in several cities across France and has also reached overseas in Morocco. This technology has huge potential to provide real time data and allows authorities to take precautionary measure and proactively take initiatives to mitigate the impacts of floods. Figure 23 shows flood monitoring cameras in action.

<table>
<tr><td>NBS Type</td><td>Digital solution</td><td rowspan="5">Motivation

Two researchers with background in Geology and hydrology put their 10 years of research into industrial use by entering into Alp-Water-Scarce project. Company came out of this project to make an operational water measurement solution using technology</td><td rowspan="5">Impact

Tenevia's technology has won several prizes and is deployed in various cities in France and overseas in Morocco as well. The technology increases flood resilience of city authorities and allows them to take preventive measures by providing real time data.</td></tr>
<tr><td>HMH to be mitigated</td><td>Floods</td></tr>
<tr><td>Driver to be mitigated</td><td>Flash floods</td></tr>
<tr><td>Who has the greatest benefit?</td><td>Flood control management, Decision makers</td></tr>
<tr><td>Development Phase</td><td>Implemented</td></tr>
</table>

Figure 36: Monitoring of rivers with video surveillance cameras Overview (Source: Tenevia)

6.1.18 PlantBest

PlantBest is a decision support tool for selecting the most appropriate plant species for slope protection. Additionally, it can be used to detect regions that are at maximum risk of landslide occurrence within a study site. It also helps in identifying the most sensitive plant traits that one must consider for landslide hazard mitigation. The inventor of this digital-solution described his motivation in the following words- *"I was looking into how trees and vegetation perform to stop landslides. I could not find a tool to select plants. Plants can be simplified into a number of traits: how thick the bark is? How wide is the canopy? How the branches are arranged? With these kind of factors, I was introducing or setting the bases for creating a plant selection tool."*

To operate the computer-based tool, a list of parameters pertaining to the candidate plant species, soil conditions and the climatic variables are entered. The output generated by the tool provides a detailed evaluation of the long-term effects of the plant cover on slopes and recommends the most ideal plant species against rainfall induced shallow landslides (Gonzalez-Ollauri and Mickovski 2017).

It can help geotechnical engineers, foresters, ecologists, and landscape architects in plant selection decisions. Other benefits include soil loss estimations, support in land use planning, ecosystem services and risk assessment of landslide prone zones. However, it must be noted that a certain level of understanding of concepts of GIS and soil bioengineering is needed to operate the tool. The tool has been successfully implemented in Catterline, UK whereby inhabitants were able to choose appropriate plant species to reduce impact of landslides.

<table>
<tr><td>NBS Type</td><td>Digital solution</td><td rowspan="5">Motivation

The lead user, a researcher in UK, was frustrated by the lack of research that could help in identifying important traits and thus selecting appropriate plant species to increase resilience of slopes to landslides.</td><td rowspan="5">Impact

The resulting solution was employed in Catterline, UK to select the most suitable plant species which helped in reducing the vulnerability of these slopes to landslides.</td></tr>
<tr><td>HMH to be mitigated</td><td>Landslides</td></tr>
<tr><td>Driver to be mitigated</td><td>Data insufficiency</td></tr>
<tr><td>Who has the greatest benefit?</td><td>Population and infrastructure along slopes</td></tr>
<tr><td>Development Phase</td><td>Implemented</td></tr>
</table>

Figure 37: PlantBest Overview (Source: Own depiction)

Hybrid Solutions

6.1.19 Airdrop

Airdrop is a device developed by a university student touched by the consequences that one of the worst droughts in Australia had on orange farmers, who for years were suffering from mounting debts and failing crops. Airdrop is a hybrid solution, which harvests water from air by condensation process. The self-powering device delivers moisture to the soil by feeding the humid air from the atmosphere back underground to the nearby plants. By employing a system that enabled to provide regular moisture to plants, being grown in even the driest places, Airdrop ensured a worldwide attention and had received several awards. Airdrop design was inspired by rooftop turbines. Its wind turbines could be powered by solar energy. The lead user, the university graduate wanted the design to be simple and easy to use. As he explains, *“A lo-tech solution is perfect for rural farmers. Something that they can install. Something that they can maintain themselves.”* During the prototype phase, with much smaller device was able to produce one litter of water per day. Figure 25 shows the device.

The device is in prototyping phase but shows huge potential to mitigate the droughts and has won several prizes. With proper funding and guidance, the prototype could be developed into a business case and device could be deployed in different droughts prone regions.

<table>
<tr><td>NBS Type</td><td>Hybrid Solution</td><td rowspan="5">Motivation

Airdrop is a device developed by a university student touched by the consequences that one of the worst droughts in Australia had on orange farmers, who for years were suffering from mounting debts and failing crops.</td><td rowspan="5">Impact

Airdrop is a low-tech and affordable solution to harvest water from air using condensation process. Prototype has harnesses one litter water per day. The simple to use device has won several prizes and has attracted attention of many researchers.</td></tr>
<tr><td>HMH to be mitigated</td><td>Droughts, heat waves</td></tr>
<tr><td>Driver to be mitigated</td><td>Water scarcity, cost of high-tech technology</td></tr>
<tr><td>Who has the greatest benefit?</td><td>Rural farmers</td></tr>
<tr><td>Development Phase</td><td>Prototyping</td></tr>
<tr><td colspan="4"></td></tr>
</table>

Figure 38: Airdrop Overview (Source: Coolhunting)

6.1.20 Aqua Trap

The Aqua Trap is a method to create a “false water table” to hold water, temperature and important nutrients on a steady level for crops to grow.

During a trip through Africa the innovator became sensibilized for the lack and poor quality of water on the African continent and *“started to think about ways to safe water and also the whole thing of growing vegetables sustainably was an appeal to me.”* One, of many solutions created by the innovator, is the Aqua Trap. The Aqua Trap is assembled from the sidewalls of rubber tires and an inner tube glued into the center of the tire sidewalls. Those are then buried about 400 mm to 500 mm under the surface and filled up with compost and soil. Lastly, crop seedlings are planted on top of the Aqua Trap. Figure 15 shows the design and installation of the Aqua Trap. To provide water and nutrients for large plants such as trees a whole rubber tire can be used with one missing sidewall to create a tub like shape. Aqua Trap decreases water irrigation amounts by 50% with an increasing crop growth rate of 30% to 40%. The Aqua Trap can be implemented in almost any type of soil. Tests have even shown its effectiveness on beach sand. Further tests were made in cooperation with the Cape Town University to show that the rubber is not leaching poisonous material and the crops growing on the Aqua Trap are healthy.

Users are mainly schools in South Africa for personal food gardens; however, the idea spread to Ghana, Kongo, Mozambique and Canada as well and the users are generally very happy with the results. The next step is to test the Aqua Trap on large scale projects like parks or soccer fields.

<table>
<tr><td>NBS Type</td><td>Hybrid Solution</td><td rowspan="5">Motivation

During a road trip through Africa, the innovator saw the poor conditions and quality of the water and ultimately created the desire to find a solution for clean water.</td><td rowspan="5">Impact on society

The Aqua Trap generates local food gardens in the townships of Cape Town and helps to mitigate food scarcity by sustainably using the scarce resource of water. The Aqua Trap was implemented at local schools as well and helped to educate children on sustainable water management in the agriculture.</td></tr>
<tr><td>HMH to be mitigated</td><td>Droughts, heat waves</td></tr>
<tr><td>Driver to be mitigated</td><td>Cost of high-tech technology, rising temperatures</td></tr>
<tr><td>Who has the greatest benefit?</td><td>Small size farming</td></tr>
<tr><td>Development Phase</td><td>Implemented</td></tr>
</table>

Figure 39: Aqua Trap overview (Source: Picture from Mark Algra)

6.1.21 Bio-based building

The bio-based building is a construction that includes a series of solutions that complement each other for climate adaption. This solution particularly tackles the problem of water scarcity and hot temperatures in peak summer. The inventor of this solution used his knowledge as a construction worker to devise this NBS. In his own words, *“I try to live very basic and as natural as possible. I see that there are a lot of problems with respect to changing climate. In Netherlands, it is getting dry in summers and in winters, we do not have very cold temperatures. That makes me worried. With my experience as a construction worker, I was looking for solutions to tackle climate adaption. I found that most solutions are expensive which demotivates people.”*

Firstly, to prevent the use of drinkable water in the toilet, a system of rainwater harvesting was implemented. Two IBC tanks are installed, each of 1000 liters capacity on his roof. The collected rainwater is diverted to the toilets in the house with a sufficient pressure of 0.3 bar. A pump connected to a solar panel provides ample power to spray the garden when it is dry. Extreme rainfall and droughts can be tackled by this innovative method of water storage. Secondly, to reduce damping and heat buildup indoors, the interiors of the walls are lined with clay. With its outstanding thermal insulation properties, clay lining ensures a relatively constant indoor temperature. The bio-based building reduces the temperature within the house by up to 5 degrees Celsius. Finally, a third solution involved planting a green roof with a layer of hemp insulation. In addition to providing a cooling effect for the house, the hemp insulation also provided strength to withstand the weight of the massive IBC tanks. The success of this particular case inspired other people in the locality of the innovator to implement similar measures in their own houses.

		Motivation	Impact on society
NBS Type	Hybrid Solution	The lead user, a construction worker in Netherlands, was driven by the motivation to implement cheap solutions in his own house that would help combat climate change.	The series of measures helped in reducing temperature within the house by 5 degree Celsius and reduced water consumption through ways of rainwater harvesting.
HMH to be mitigated	Droughts, pluvial floods		
Driver to be mitigated	Water scarcity, rising temperatures		
Who has the greatest benefit?	Housing sector		
Development Phase	Implemented		

Figure 40: Bio-based building Overview (Source: Own depiction)

6.1.22 Converting CO2 into building materials

An Australian company, Mineral Carbonation International (MCi) hopes to lock away 1 Billion tons of CO2 per annum by 2040 through an accelerated natural process called mineral carbonation. It is a hybrid solution and an alternative approach towards climate change. Where everyone considers CO2 bad and corporations and countries are striving to get carbon neutral by 2050, MCi thinks CO2 could be used to make useful materials. For example, building materials. The company has a pilot plant in Newcastle, Australia where they transform CO2 into building material by the process of mineral carbonation (Mineral Carbonation, 2020). Company follows the model of circular economy, using waste and converting it into new products. By using industrial wastes like steels slags, incinerator bottom ash, other minerals and reacting them with CO2 or any gas out coming out of stack pipe produces useful materials, like cement brick and plaster board (Mineral Carbonation, 2020). It’s a novel technology and it will be easier to implement it in industrialized countries, which fall in developed category. Additionally, developed countries emit most CO2, as they are industrialized so it makes sense to apply this method in developed countries.

NBS Type	Community Initiative	**Motivation**	**Impact**
HMH to be mitigated	Droughts	Instead of just being eco-efficient and finding the ways to reduce the CO2 emissions, how can we act eco-effectively was the thought to explore ways to use CO2 which will contribute to the reduced greenhouse gases and result in useful materials.	Company follows the model of circular economy, using waste and converting it into new products. By using industrial wastes like steels slags, incinerator bottom ash, other minerals and reacting them with CO2 or any gas out coming out of stack pipe produces useful materials, like cement brick and plaster board
Driver to be mitigated	Climate change, outdated water management		
Who has the greatest benefit?	Drought affected communities		
Development Phase	Prototype		

Figure 41: Converting CO2 into building materials Overview (Source: own depiction)

6.1.23 Dripper System

The Dripper System is frugal drip irrigation system and is especially useful in dry and windy regions. The innovator is the same innovator as for the Aqua Trap and he realized that *“in Khayelitsha they used a hosepipe in Summer, temperature 30 degrees Celsius plus, and a strong dry summer wind 60 km/h. Most of the water gets blown away by the strong wind, the gardener is holding the pipe 700mm of the ground, the wind blows it all over.”*

The dripper system is based on the idea of high-tech drip irrigation systems from Israel. The system consists of multiple 44-gallon tanks standing 800 mm of the ground, and special irrigation pipes fixed onto the ground. Each valve is 300 mm apart. The 44-gallon tanks are filled with rainwater or well water, and gravity feeds the water into the irrigation pipes. Each valve distributes 450 to 500 ml of water to the seedlings (see Figure 29). Clean rainwater is the best water to use, but this is not always available; to purify water from wells and other water sources there is a settling tank with a filter for the water to stand for 24 hours. The filters require regular cleaning. One 44-gallon tank supplies 350 to 400 seedlings with water and nutrients per day within 60 minutes. The dripper system recycles and saves large amounts of water, it improves the growth rate of crops, and it is inexpensive compared high-tech irrigation systems used in industrial countries.
This frugal drip irrigation system is mainly used in connection to the Aqua Trap food gardens in Cape Town.

<table>
<tr><td>NBS Type</td><td>Hybrid Solution</td><td rowspan="5">Motivation

During a road trip through Africa, the innovator saw the poor conditions and quality of the water and ultimately created the desire to find a solution for clean water.</td><td rowspan="5">Impact on society

The Dripper System supports the Aqua Trap food gardens to supply townships of Cape Town with food and educate children on sustainable water management in the agriculture, by having school food gardens.</td></tr>
<tr><td>HMH to be mitigated</td><td>Droughts, heat waves, strong wind</td></tr>
<tr><td>Driver to be mitigated</td><td>Cost of high-tech technology, rising temperatures</td></tr>
<tr><td>Who has the greatest benefit?</td><td>Small size farming</td></tr>
<tr><td>Development Phase</td><td>Implemented</td></tr>
</table>

Figure 42: Dripper System overview (Source: Picture from Mark Algra)

6.1.24 Integrated Floating Cage Aquageoponics System (IFCAS)

This particular solution was developed through a participatory research of farmers and researchers in Bangladesh. The solution is a simple technology for growing vegetables and farming fish in shaded ponds. Additionally, it can also be used in shaded dikes not suitable for vegetable cultivation as well as ponds inundated during floods. This NBS helps in increasing the resilience to floods by ensuring continuous agricultural productivity in flooded waters. The inventor of this solution described the drive to help the poor farmers as his motivation. In his words, *"World Fish Center was looking for alternatives on how to produce fish and vegetables to provide nutrition to poor households. I thought I can develop something for this. If I can do something for the people, definitely it is a benefit for me."*

The system consists of a rectangular iron-bar made structure with grooves at its corners for holding floats of plastic drums. The structure is surrounded by a nylon net cage at its bottom for the farming of fish. Also, the net ensures free flow of water in and out of the system. The nets retain a rectangular shape under water on account of half-brick weights which are hung under the corners and the center of the net. Dried pond mud and cow dung is placed in pits and serves a growth and holding medium for the plants. Nutrients from that medium and from waste excreted by the fish are supplied to the plants through the pond water. The plants in turn, purify the water. Finally, a scaffold made out of bamboo is placed on top of the rectangular structure for the vegetables to support the growth. Farmers also elevated the height of the scaffold to grow long vegetables and harvest fish easily (Haque et al. 2015).

This NBS can prove effective in strengthening food security and adapting to climate change. Moreover, it had a positive societal impact in the rural settings of villages as women were happy to be involved in the maintenance of the IFCAS. This solution is a variant of Floating

Agriculture which is widespread in Southeast Asian countries such as Indonesia and Bangladesh. Figure 30 shows the physical structure of an IFCAS system.

NBS Type	Hybrid Solution	**Motivation**	**Impact on society**
HMH to be mitigated	Reoccurring floods	The lead user, a researcher in Bangladesh, was driven by his altruistic nature to help local farmers in safeguarding their agricultural production during floods.	The developed solution strengthened food security thus helping in adapting to climate change. Social cohesion was also promoted amongst the women in the villages who were involved in maintenance of the system.
Driver to be mitigated	Rising sea level		
Who has the greatest benefit?	Small size farming and fishing		
Development Phase	Implemented		

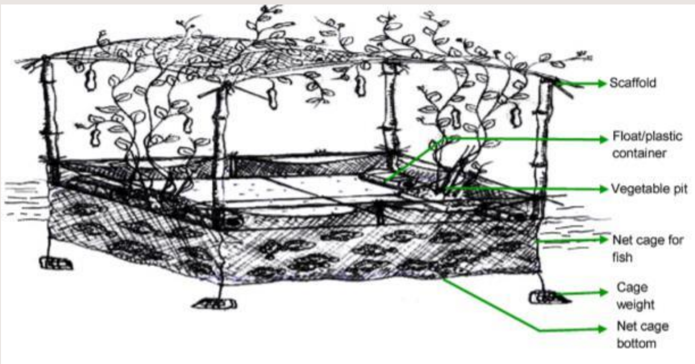


Figure 43: Integrated Floating Cage Aquageoponics System Overview (Source: Haque et al. 2015)

6.1.25 Grey Water Chambers

This water management solution enables reuse of water through natural filtration processes and is particularly useful in times of extreme events such as heavy rain or lack of precipitation. According to the inventor of this NBS, "in India, per capita requirement of water is 135L per day out of which grey water is 65 percent and black water is 35 percent. The 65% grey water is mixed with the 35% black water and is treated in the treatment plants. In a way, you are treating 100 percent of the black water. That puts an enormous pressure on the water treatment plant."

The solution needs a complete rerouting of the drainage system at the site (e.g. household) to separate out the grey water which is then collected in 4-5 inspection chambers of 1m x 1m size. The chambers are made out of brick walls and are tightly plastered to prevent leakage. The chambers have different layers of materials- sand, charcoal, and gravel, to purify the water through filtration and adsorption of particles. After this treatment, most pathogens are removed from the grey water and the water can be reused or further purified in additional treatment. In this particular case, the grey water collected in the chambers was supplied to a separate water tank for subsequent use in firefighting. When the tank is filled to the brim, the excess water is infiltrated into the ground. When the filtered water reaches the sources at shallow depth, it maintains the groundwater level.

The solution can incorporate natural elements by utilizing water filtering plants such as hyacinth, reed plants. Such grey water chambers can reduce the load on drainage systems and help in tackling urban floods when implemented on a larger scale. This solution was successfully implemented in a newly constructed house in India. High costs in construction, however, were a downside to the widespread application of this concept.

<table>
<tr><td>NBS Type</td><td>Hybrid Solution</td><td rowspan="5">Motivation
The innovator of this solution combined his passion for architectural solutions with the need to reduce the stress on drainage systems in urban landscapes.</td><td rowspan="5">Impact on society
Water scarcity in urban areas can be reduced through this water management solution. This additionally helps in reducing the load on urban drainage infrastructure and providing water for irrigation/firefighting.</td></tr>
<tr><td>HMH to be mitigated</td><td>Pluvial floods, droughts</td></tr>
<tr><td>Driver to be mitigated</td><td>Water Scarcity</td></tr>
<tr><td>Who has the greatest benefit?</td><td>Urban population</td></tr>
<tr><td>Development Phase</td><td>Implemented</td></tr>
</table>

Figure 44: Grey Water Chambers Overview (Source: Own depiction)

6.1.26 Loricata

Loricata is a constructive technique which is based on the creation of a log structure that maintains its configuration over a long period of time. This NBS is useful in preserving the slope against landslides and subsidence. The drive to contribute to the field of soil bioengineering inspired the inventor to create this NBS. He describes Loricata as a "naturalistic soil bioengineering technique aimed at saving materials, construction times and costs. No economic benefits were obtained since the solution has not been patented."

It makes use of a steel frame which is anchored to the ground and holds the wooden logs on its frontal end. Vegetation such as native shrubs are planted in the space between the wooden logs. The vegetation provides stability to the soil once it has consolidated. The NBS shows effects immediately and has been proven to be cheap and easily installable. It also offers the possibility to replace the wooden logs if needed, making the work effective for decades (Naturalea 2014). This solution has been implemented across Italy and Spain by many companies. The analysis carried out in these sites indicate the robustness of Loricata and the success of the intervention even after many years.

NBS Type	Hybrid Solution	Motivation	Impact on society
HMH to be mitigated	Landslides	The lead user, a researcher in Italy, wanted to contribute to the domain of soil bioengineering by inventing solutions that would save construction times and costs.	The successful implementation of the solution in Spain and Italy has provided stability to slopes in rural and urban areas. The growth of vegetation helps in soil sealing and maintaining ecological stability.
Driver to be mitigated	Cost of high-tech solutions, pluvial flood induced erosions/landslides		
Who has the greatest benefit?	Population and infrastructure along slopes		
Development Phase	Implemented		

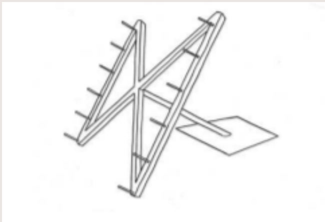


Figure 45: Loricata Overview (Source: Naturalea 2014)

6.1.27 Resilient homes to withstand storms

Constructing resilient homes using natural ingredients such as mud and rice straw could enhance the resilience of internally displaced people against natural hazards such as windstorms and heatwaves. It's a hybrid NBS type solution, which mitigates the risk of suffering due to poor construction practices. Internally displaced people because of conflict or economic migrants making temporary settlements in both rural areas and urban slums are extremely vulnerable to storms and heatwaves because of poor construction practices.

In addition to providing protection and stability against storms, mud construction also lowers the inside temperature of house in comparison to construction done using flimsy rags, recycled wood and plastic and corrugated iron sheeting, all of which are unsuited to the natural environment. These houses can better cope with the environmental extremes in form of storms and extreme temperatures (Openideo, 2020). Fig. 33 depicts the current situation of houses (left) and the presented idea of using mud and other natural ingredients for temperature control and resilience against storms (right). The presented solution has already been implemented in Somalia, and houses withstood the windstorms and maintain cooler temperature. The idea could be used in developing countries, where internal migration often happens because of conflicts or natural hazards such as floods. This will reduce the vulnerability of migrants against windstorms and extreme weather.

NBS Type	Hybrid Solution	Motivation	Impact on society
HMH to be mitigated	Storms	Temporary settlements often become victim to strong windstorms and are vulnerable to heatwaves. Using ancient knowledge of house construction by using natural ingredients could enhance hazard resistance.	These resilient homes have withstood the environmental extremes such as storms and maintain cooler temperature in Somalia.
Driver to be mitigated	Improper infrastructure planning		
Who has the greatest benefit?	Migrants, slum dwellers		
Development Phase	Implemented		

Figure 46: Resilient homes to withstand storms Overview (Source: Openideo)

6.1.28 Sipendil

Sipendil is a low-cost rain gauging device that acts as an early warning system for landslides. It is a monitoring device for hydro-meteorological risk reduction. It's a hybrid solution developed by a researcher from UGM Yogyakarta after he witnessed a landslide. The system works on precipitation threshold. The system consists of two simple components, a rainwater container and a box controller. The box contains threshold container, a led light and a spillway tap. If the water container has more water than the threshold, an alarm warns people. Additionally, a led light is placed so that even people with hearing disabilities could see the warning light.

The device is already used in several villages to warn inhabitants about massive rainfall. The device has been transformed into a business case and has been produced in mass, the researcher's team also provide services to assist people

Spendil reduces the vulnerability of the people and increases hazard resistance by an early warning system. People can take precautionary measures and city authorities can provide assistance to the vulnerable people. The device could be used all over the world in landslide prone areas.

<table>
<tr><td>NBS Type</td><td>Hybrid Solution</td><td rowspan="5">Motivation

Sipendil is a low-cost rain gauging device that was developed by a researcher from UGM Yogyakarta after he witnessed a landslide.</td><td rowspan="5">Impact

The device is deployed in various landslide vulnerable villages to warn inhabitants about massive rainfall.</td></tr>
<tr><td>HMH to be mitigated</td><td>Landslides induced by pluvial rain</td></tr>
<tr><td>Driver to be mitigated</td><td>Cost of high-tech technology</td></tr>
<tr><td>Who has the greatest benefit?</td><td>Rural population</td></tr>
<tr><td>Development Phase</td><td>Implemented</td></tr>
</table>

Figure 47: Sipendil Overview (Source: Picture from Department of Technology and Innovation Management, TUHH.)

6.1.29 Natural waste management by using black soldier flies

Black soldier flies can consume organic waste in large quantities and therefore help municipalities to naturally manage organic waste. It's a hybrid NBS solution. On daily basis black solider flies can consume waste almost equivalent to 70% of their body weight (Caruso et al., 2013). A lead user an environmental health graduate from Gunung Kangin, Bali was frustrated from improper waste management practices in his town which caused recurring flooding in case of heavy rains. He wanted to change the situation and observed that sometimes nature itself could be a solution. He explored the potential of nature and used an insect, now called black soldier flies to sustainably degrade the organic waste.

Additionally, on consumption of waste they produce protein which could be used for feeding livestock, e.g., chicken feeding. For every 1 kg consumption of waste, they produce 50 grams of protein. This could be a sustainable waste management technique, cut operational costs and also show potential to inactivate transmission diseases, such as Salmonella spp (Caruso et al., 2013). Figure 35 shows black soldier flies and how they could be used. For optimal use of black soldier flies the most suitable temperature range is 24 - 30°C. Larvae avoid light and prefer shaded environment. Moist food source helps larvae to ingest. Carbohydrates are good for larval growth. Waste can be better consumed by them if it has already been through some bacterial decomposition process (Caruso et al., 2013).

This lead user now has some helpers, they collect waste, put their soldiers to work, degrade waste and use the larva to feed farm animals. By making this a business case, he wants to start a business selling animal food and fertilizers.

Researchers from all over the world has shown great interest in black soldier flies and pilot projects on a larger scale are now underway. There are several papers and books to guide people to use black soldier flies to make a business case and earn money by helping the environment by degrading the organic waste. These insects have huge potential to solve the waste management problem.

<table>
<tr><td>NBS Type</td><td>Green Infrastructure</td><td rowspan="6">Motivation

A lead user, an environmental health graduate from Gunung Kangin, Bali, being frustrated by floods due to improper waste management decided to explore nature and started using black soldier flies to sustainably degrade the organic waste.</td><td rowspan="6">Impact on society

In addition to degrading the organic waste, the leftover is used to feed animals. The project has become an interest for several researchers and a business case for people to produce animal feed.</td></tr>
<tr><td>HMH to be mitigated</td><td>Heatwaves</td></tr>
<tr><td>Driver to be mitigated</td><td>Rising temperature</td></tr>
<tr><td>Who has the greatest benefit?</td><td>Slum dwellers</td></tr>
<tr><td>Development Phase</td><td>Implemented</td></tr>
</table>

Figure 48 Natural waste management by using black soldier flies Overview (Source: Openideo)

Governmental and Community Initiatives

6.1.30 Façade gardens of Rotterdam

Façade gardens of Rotterdam was a campaign aimed at planting 1000 façade gardens which are simple gardens that are planted adjacent to the façade of the buildings. Although the motivation behind this NBS was its aesthetic appeal, a large number of such gardens can help in reducing heat stress by making the streets cooler and adding to interest its biodiversity. The initiator of this campaign described his motivation as “I am really enthusiastic about green cities with lots of biodiversity, plants and nature. Cities are a very difficult place in general for nature because there isn't enough money available for maintaining the greens. I am really enthusiastic about green cities with lots of biodiversity. Grey infrastructure makes me feel sad. I am a natural being and I would like to have nature around me.”

The response to the campaign was overwhelming with 959 of such façade gardens being made. In order to plant such façade garden, the front rows of the paving stones from the sidewalk are removed and replaced with green and flowery plants. The total length of these façade gardens exceeded 4kms with over 18400 impervious tiles being replaced. Moreover, in times of heavy rainfall, they help in infiltration of rainwater and thus help against waterlogging. They also attract bees and insects thereby having a positive impact on biodiversity. Finally, such gardens can promote general well-being of the residents and boost social contact. Figure 33 shows the gardens grown as part of the Campaign in Rotterdam.

NBS Type	Community Initiative	**Motivation**	**Impact on society**
HMH to be mitigated	Pluvial floods, heat waves	The initiator of this social media campaign aimed to reduce the presence of grey infrastructure in his surroundings by encouraging other people to take part in the campaign.	Over 1000 façade gardens were planted that spanned 4kms. Over 18400 impervious tiles were removed to accommodate plants that can help in infiltration of rainwater. Moreover, social harmony was improved through this campaign bringing a sense of togetherness.
Driver to be mitigated	Rising temperatures, soil sealing		
Who has the greatest benefit?	Urban population and biodiversity		
Development Phase	Implemented		

Figure 49: Façade gardens of Rotterdam Overview (Source: Indebuurt 2020 (left) and Hetkanwel 2020 (right))

6.1.31 From drought to prosperity

Paani foundation is a non-profit organization founded in 2016 who conducts a unique competition, called water cup, between different villages to do the maximum work for water shed management. It's a community initiative or movement. The founder of paani foundation is a famous actor who learned about the devastating impacts of drought in Maharashtra state during a reality TV show. He decided to act using his position and involved local government and drought experts. His focus was not just to donate and help rather raise awareness about the issue and make it a people's movement.

Paani foundation provides training for a group of people from each village on water shed management and rainwater harvesting structures. The organization believed if the locals could recognize the problem and if they could be inspired to change the situation, it will be a sustainable model instead of just spending some money on projects which the local community wouldn't own. The organization has inspired villagers to get the training, do the voluntary work and harvest their own water and increase the water storage capacity of their villages (Paani Foundation, 2020). The competition organized by Paani Foundation will last for 45 days and Villages will be judged on the most water conservation work done and will be awarded accordingly, first prize of 50 Lakhs 2nd prize of 30 Lakhs and 3rd prize of 20 Lakhs. Figure 34 shows some of the transformed villages. By using different watershed management techniques, the rainwater is plough able fields as ground water table has been recharged. Natural habitat is restored. Within 5 years, 51 thousand people have been trained and the project has resulted in 145 Billion gallons (550 billion liters) of water storage capacity, worth US$4.5 Billion (Paani Foundation, 2020). Along with the countless advantage of turning drought affected areas into green and plough able fields the economic situation of the villagers improved and the economic migration towards major cities stopped (Paani Foundation, 2020). This is one of the biggest and most successful permaculture projects. It can be effectively implemented in drought affected regions in developing countries. Of course, it can also be implemented in developed countries, but volunteer labor might be replaced by machines and state funding.

<table>
<tr><td>NBS Type</td><td>Community Initiative</td><td>Motivation</td><td>Impact on society</td></tr>
<tr><td>HMH to be mitigated</td><td>Droughts</td><td rowspan="4">After learning about the devastating impacts of droughts in an Indian province during a reality TV show, a famous actor decided to change the situation by empowering people with watershed techniques knowledge and training</td><td rowspan="4">By using different watershed management techniques, the rainwater is used to plough fields and ground water table has been recharged. Natural habitat is restored. Within 5 years, 51 thousand people have been trained and the project has resulted in 145 Billion gallons (550 billion liters) of water storage capacity, worth US$4.5 Billion.</td></tr>
<tr><td>Driver to be mitigated</td><td>Climate change, outdated water management</td></tr>
<tr><td>Who has the greatest benefit?</td><td>Drought affected communities</td></tr>
<tr><td>Development Phase</td><td>Implemented</td></tr>
<tr><td colspan="4"> </td></tr>
</table>

Figure 50: From drought to prosperity Overview (Source: Paani Foundation)

6.1.32 Living Weir

A living weir is a nature-based structure made out of sandbags, bamboo and banyan trees designed to change the velocity of a river. It is community nature-based solution for HMR reduction. Weirs have been in use around rivers for a long time to control the flow of rivers and streams. Living weir concept is from local knowledge base on the king's sufficient economy theory. Community actors such as local people and government execute the concept using available natural materials.

This result not only in higher flood resilience but also in an increase in groundwater levels, a higher biodiversity such as increasing in fish habitat, variety of plants etc. Additionally, it unified the local community as they were working side by side towards a common goal. The concept was introduced by a local community in Thailand and is a NBS that was built on local knowledge and with local materials.

The concept can be easily transferred to other flood prone regions to have a control over the flow of rivers and streams.

NBS Type	Community Initiative	**Motivation**	**Impact**
HMH to be mitigated	Fluvial floods, droughts	To slow down the velocity of the river to increase the flood resilience of the local community.	This concept resulted not only in higher flood resilience but also in an increase in groundwater levels, a higher biodiversity and a sediment trap
Driver to be mitigated	Land degradation, loss in vegetation		
Who has the greatest benefit?	Local population		
Development Phase	Implemented		

Figure 51: Living Weir Overview (Source: Worldwaterlife)

6.1.33 Natürlich Hamburg! – (Urban) nature conservation program

Natürlich Hamburg! is a large-scale urban nature conservation program, located in Hamburg, and can be translated as “naturally Hamburg”. It is the first large-scale urban nature conservation project in Germany. The project is funded and driven by the Federal Ministry for the Environment and the Hamburg Senate with 22 million Euros and they want to *“show that here [in Hamburg] in the city something is happening in the area for more nature, nature-oriented design and also for more nature awareness.”* The main goal of this project is to reconcile the needs of humans and nature, by supporting biodiversity, bringing the wilderness into urban parks, experiencing wildlife in the urban setting, and to develop an understanding for nature’s needs within urban areas. Positive side effects can be drought, heat wave and urban flood mitigation, but this is not the central goal of the project and is not planned to further evaluate those effects. The project area of 62 km2 is distributed over 19 nature reserves, 20 parks and greenspaces, three biotope networks, and roadside greenery along four highways leading in and out of the city (see figure 18).

The project is currently in the first phase, out of two phases, which involves collecting data on the urban inventory and the development of nature development and maintenance plans. Those plans include measures to reverse soil sealing, develop water retention areas and to increase the urban green with local vegetation. The second phase will proceed between 2022 and 2031 and will implement the development and maintenance plans (Behörde für Umwelt, Klima, Energie und Agrarwirtschaft 2017).

Natürlich Hamburg has caught national attention and other cities have applied for similar funding from the federal government.

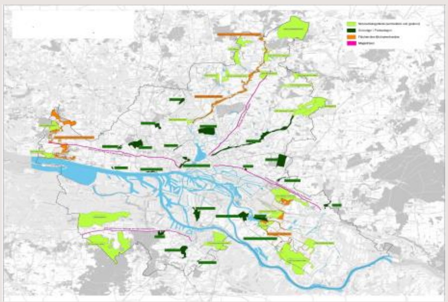
NBS Type	Governmental Initiative	**Motivation**	**Impact on society**
HMH to be mitigated	Droughts, heat waves, pluvial floods	Natürlich Hamburg! gives wild vegetation more importance in the urban life. Green spaces in parks are to be enriched with wildflowers to attract bees and insects.	Natürlich Hamburg! allows the urban population to experience nature and at the same time remain habitats for endangered species. Both people and nature will benefit.
Driver to be mitigated	Soil sealing, loss in urban green, data insufficiency		
Who has the greatest benefit?	Urban population, flora and wildlife		
Development Phase	Phase I: Inventory and planning		
 			

Figure 52: Natürlich Hamburg! Overview (Source: Pictures from https://www.hamburg.de/)

REFERENCES

Alfieri, L.; Burek, P.; Feyen, L.; Forzieri, G. (2015): Global warming increases the frequency of river floods in Europe.
Almar, Rafael; Kestenare, Elodie; Boucharel, Julien (2019): On the key influence of remote climate variability from Tropical Cyclones, North and South Atlantic mid-latitude storms on the Senegalese coast (West Africa). In Environ. Res. Commun. 1 (7), p. 71001. DOI: 10.1088/2515-7620/ab2ec6.
Baumschule Lorenz von Ehren (2021a): JUNGFERNSTIEG, HAMBURG. In Lorenz von Ehren, Die Baumschule seit 1865. Available online at https://www.lve-baumschule.de/projekte/jungfernstieg-hamburg/, checked on 7/1/2021.
Baumschule Lorenz von Ehren (2021b): Klimabäume: Geeignete Bäume für die Stadt. In Lorenz von Ehren, Die Baumschule seit 1865. Available online at https://www.lve-baumschule.de/pflanzen/klimabaeume/, checked on 7/1/2021.
Behörde für Umwelt, Klima, Energie und Agrarwirtschaft (2017): Mehr Natur für die Metropole, „Natürlich Hamburg!", Naturschutzgroßprojekt für mehr Artenvielfalt in der Stadt startet. Available online at https://www.hamburg.de/bukea/9941644/2017-11-28-bue-naturschutz-grossprojekt/, checked on 1/7/2021.
Besnainou, Jules (2019): Is Profitable Reforestation Possible? Land Life Company Makes the New 50 to Watch List. Cleantech. London. Available online at https://www.cleantech.com/is-profitable-reforestation-possible-land-life-company-makes-the-new-50-to-watch-list/, checked on 8/5/2020.
Braced: https://www.braced.org/.
Chapman, Sarah; Watson, James E. M.; Salazar, Alvaro; Thatcher, Marcus; McAlpine, Clive A. (2017): The impact of urbanization and climate change on urban temperatures: a systematic review. In Landscape Ecol 32 (10), pp. 1921–1935. DOI: 10.1007/s10980-017-0561-4.
Churchill, Joan; Hippel, Eric von; Sonnack, Mary (2009): Lead User Project Handbook: A practical guide for lead user projekt teams. Available online at https://evhippel.files.wordpress.com/2013/08/lead-user-project-handbook-full-version.pdf.
Coolhunting: https://coolhunting.com/tech/airdrop/. Accessed on 06 April 2021.
CRED (2019): Human cost of disasters: An overview of last 20 years; Centre for Research on the Epidemiology of Disaster (CRED): Brussels, Belgium.
Debele, Sisay E.; Kumar, Prashant; Sahani, Jeetendra; Marti-Cardona, Belen; Mickovski, Slobodan B.; Leo, Laura S. et al. (2019): Nature-based solutions for hydro-meteorological hazards: Revised concepts, classification schemes and databases. In Environmental research 179, p. 108799. DOI: 10.1016/j.envres.2019.108799.
Department of Technology and Innovation Management, TUHH.: https://cgi.tu-harburg.de/~timab/tim/en.
European Commission: Nature-Based Solutions. In European Commission. Available online at https://ec.europa.eu/research/environment/index.cfm?pg=nbs, checked on 5/15/2020.
FAO (2017): Floating Garden Agricultural Practices in Bangladesh. A Proposal for Globally Important Agricultural Heritage Systems (GIAHS). Food and Agriculture Organization of the United Nations. Rome, Italy.
Federal ministry of food and agriculture: https://www.bmel.de/.
Fraunhofer Institute for Environmental, Safety; Energy Technology UMSICHT (2021): Bioshoreline: Biodegradable geotextiles for bank protection. In Fraunhofer UMSICHT. Available online at https://www.umsicht.fraunhofer.de/en/references/bioshoreline.html, checked on 1/7/2021.
Gonzalez-Ollauri, Alejandro; Mickovski, Slobodan B. (2017): Plant-Best: A novel plant selection tool for slope protection. In Ecological Engineering 106, pp. 154–173. DOI: 10.1016/j.ecoleng.2017.04.066.
Haque, Mohammad Mahfujul; Alam, Md. Rushna; Alam, Md. Mehedi; Basak, Biplob; Sumi, Kanij Rukshana; Belton, Ben; Jahan, Khondker Murshed-E (2015): Integrated floating cage

aquageoponics system (IFCAS): An innovation in fish and vegetable production for shaded ponds in Bangladesh. In Aquaculture Reports 2, pp. 1–9. DOI: 10.1016/j.aqrep.2015.04.002.
Helmholz Center for Environmental Reseaech (2020): German Drought Monitor, checked on 12/18/2020.
Herstatt, Cornelius; Lüthje, Christian; Lettl, Christopher (2001): Innovation search fields with Lead Users. In Hamburg University of Technology(TUHH), Institute for Technology and Innovation Management (TIM), p. 11.
Hetkanwel (2020). Available online at hetkanwel.nl, checked on 2/2/2021.
Hippel, Eric von (1986): Lead Users: A Source of Novel Product Concepts. In Management Science 32 (7).
Indebuurt (2020): Indebuurt. Available online at indebuurt.nl, checked on 2/2/2021.
IPCC (Ed.) (2012): Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press. Available online at http://ebooks.cambridge.org/ref/id/CBO9781139177245, checked on 7/23/2020.
Kruse, Daniel J.; Goeldner, Moritz; Eling, Katrin; Herstatt, Cornelius (2019): Looking for a Needle in a Haystack: How to Search for Bottom-Up Social Innovations that Solve Complex Humanitarian Problems. In J Prod Innov Manag 36 (6), pp. 671–694. DOI: 10.1111/jpim.12507.
Land Life Company (2020): A new way to fix the planet - Land Life Company. Available online at https://landlifecompany.com/technology/, updated on 8/5/2020, checked on 8/5/2020.
Liu, Jie; Niyogi, Dev (2019): Meta-analysis of urbanization impact on rainfall modification. In Scientific reports 9 (1), p. 7301. DOI: 10.1038/s41598-019-42494-2.
Mekonnen, Mulatie; Keesstra, Saskia D.; Stroosnijder, Leo; Baartman, Jantiene E. M.; Maroulis, Jerry (2015): Soil Conservation Through Sediment Trapping: A Review. In Land Degrad Dev 26 (6), pp. 544–556. DOI: 10.1002/ldr.2308.
Muis, Sanne; Güneralp, Burak; Jongman, Brenden; Aerts, Jeroen C. J. H.; Ward, Philip J. (2015): Flood risk and adaptation strategies under climate change and urban expansion: A probabilistic analysis using global data. In The Science of the total environment 538, pp. 445–457. DOI: 10.1016/j.scitotenv.2015.08.068.
Mukherjee, Sourav; Mishra, Ashok; Trenberth, Kevin E. (2018): Climate Change and Drought: a Perspective on Drought Indices. In Curr Clim Change Rep 4 (2), pp. 145–163. DOI: 10.1007/s40641-018-0098-x.
Naturalea (2014): Loricata. Naturalea. Spain. Available online at https://www.naturalea.eu/Ntr/wp-content/uploads/2018/05/entramat_loricata.ca_.pdf, checked on 10/19/2020.
Naturalea (2019): Cribwall Krainer. Naturalea. Spain. Available online at https://www.naturalea.eu/Ntr/wp-content/uploads/2019/02/Cribwall_Krainer_en.pdf, checked on 10/2/2020.
Nobre, G. Guimarães; Jongman, B.; Aerts, J.; Ward, P. J. (2017): The role of climate variability in extreme floods in Europe. In Environ. Res. Lett. 12 (8), p. 84012. DOI: 10.1088/1748-9326/aa7c22.
One Concern.: https://oneconcern.com/. Accessed on 09 Dec 2020.
Openideo: https://challenges.openideo.com/challenge/urban-resilience/expert-feedback/harness-local-building-culture-and-innovation-for-resilient-homes. Accessed on 15 Nov 2020.
Openideo: https://challenges.openideo.com/challenge/urban-resilience/wining-ideas/maggots-nature-based-solutions. Accessed on 15 Nov 2020.
Oppla: https://oppla.eu/casestudy/20119. Accessed on 05 Dec 2020.
Paani Foundation.: https://www.paanifoundation.in/. Accessed on 09 Dec 2020.
Redd-monitor: https://redd-monitor.org/2020/06/02/pakistans-tree-planting-programmes-corruption-exclusion-and-marginalisation/ Accessed on 06 April 2021.

Reset (2020): Cocoon: a Paper Pulp Doughnut for Planting Trees in the Desert | Biodiversity. Available online at https://en.reset.org/blog/cocoon-paper-pulp-doughnut-planting-trees-desert-03272018, updated on 8/15/2020, checked on 8/15/2020.
Rogger, M.; Agnoletti, M.; Alaoui, A.; Bathurst, J. C.; Bodner, G.; Borga, M. et al. (2017): Land use change impacts on floods at the catchment scale: Challenges and opportunities for future research. In Water resources research 53 (7), pp. 5209–5219. DOI: 10.1002/2017WR020723.
Russo, Simone; Dosio, Alessandro; Graversen, Rune G.; Sillmann, Jana; Carrao, Hugo; Dunbar, Martha B. et al. (2014): Magnitude of extreme heat waves in present climate and their projection in a warming world. In J. Geophys. Res. Atmos. 119 (22), 12,500-12,512. DOI: 10.1002/2014JD022098.
Sabine, L. Perch-Nielsen; Michèle, B. Bättig; Dieter, Imboden (2008): Exploring the link between climate change and migration. In Climatic Change 91, pp. 375–393.
Schmidberger, Manuel (2018): Hagelgefährdung und Hagelrisiko in Deutschland basierend auf einer Kombination von Radardaten und Versicherungsdaten: KIT Scientific Publishing.
Sørup, H.J.D.; Asmussen, Maria Faccin; Boogaard, Floris; Dickin, Sarah; Dlugoborskyte, Vytaute; Kuhlicke, Christian et al. (2019): NBS for hydro-meteorological risk reduction: review of existing knowledge base, practices and policies - RECONECT Deliverable D1.3.
Tenevia: https://www.tenevia.com/en/. Accessed on 09 Dec 2020.
Vetiver grass.: https://www.vetivergrassuk.com/. Accessed on 07 Dec 2020.
Worldwaterlife: https://worldwaterlife.com.
Zink, Matthias; Samaniego, Luis; Kumar, Rohini; Thober, Stephan; Mai, Juliane; Schäfer, David; Marx, Andreas (2016): The German drought monitor. In Environmental Research Letters 11 (7), p. 74002. DOI: 10.1088/1748-9326/11/7/074002.