"NATURE BASED SOLUTIONS FOR FLUVIAL FLOOD MITIGATION: AN INTEGRATED ASSESSMENT FRAMEWORK"

TU Delft

Interreg
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Nature Based Solutions (NBS) for fluvial flood mitigation: An integrated assessment framework

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By

Tatiana Andrikopoulou

Student number: 4850777

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Graduation committee

Chairperson:	Prof. Dr.Ir. Astrid Blom, Hydraulic Engineering, TU Delft
Daily supervisor:	Dr. Ralph Schielen, Hydraulic Engineering, TU Delft & Rijkswaterstaat
Supervisor:	Dr. Erik Mostert, Water Management, TU Delft
Company Supervisor:	Dr. Cor Schipper, Rijkswaterstaat

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Sources of the cover photos from top left to bottom right:

- Volunteer revegetation work on Fish Creek improvements project in Estes Park. [Colorado Watershed Flood Recovery 2013-2018]
- Lake Wood re-meandering, Eddleston Water Project [from a presentation]
- Surface water attenuated by leaky dam, Belford UK [Photo by Mark Wilkinson, Newcastle University]
- Flooded Noordwaard polder, Netherlands [Retrieved from: https://www.rijkswaterstaat.nl/nieuws/2020/02/ondergelopen-noordwaard-dat-is-best-uniek.aspx]

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Executive Summary

Inland flooding along with its casualties is expected to increase. Climate change, urban expansion on floodplains, degraded ecosystems due to human interventions, lack of effective emergency flood risk management plans contribute to flood intensification and risk exposure. The heretofore flood mitigation practices seem to stop short of both mitigating flood risk and providing further economic, social, and environmental benefits. Instead, practices co-working with nature and its physical processes are constantly gaining ground.

Nature-based solutions (NBS) are measures encompassing the ‘co-operation with nature’ approach; mitigating fluvial flood risk while being cost-effective, resource-efficient, and providing numerous environmental, social, and economic benefits. Current progress is working on strengthening the evidence-base of NBS projects through multiple on-going projects. Such evidence would lay the foundation for the mainstreaming and transferability of the NBS practice that will, eventually, lead to its upscaling.

To this end, there is need for holistic and coherent organisation of all the NBS information and approaches acquired in practice. Therefore, several frameworks have been developed in an attempt to map the NBS design and implementation and/or evaluate them using indicators. Contribution of NBS to sustainable development has also been established since the social, economic and environmental sectors, on which NBS have an impact, constitute the so-called “triple bottom line” of the sustainability concept.

Given the unequivocal link between NBS and sustainability, a growing interest recognizes the need to explore a NBS connection to the Sustainable Development Goals (SDGs), as set by the United Nations Organization. Additionally, since NBS seek to complement conventional infrastructure, their engineering characteristics should also be assessed.

Therefore, this research project develops a framework for assessing the NBS performance for fluvial flood mitigation. The framework adopts an integrated approach, using indicators for evaluative and benchmarking purposes. Novel aspects of the framework are the direct link between the NBS for fluvial flood mitigation and the SDGs and the introduction of technical assessment indicators. Ultimately, the NBS framework is meant to assist experts in providing guidance for similar projects and contributing to the mainstreaming and transferability of the NBS practice.

The framework was guided by a review of existing NBS assessment frameworks and methodologies, already realized NBS projects, and the UN 2030 Agenda. The assessment frameworks and methodologies worked as a starting point both for the structure and the components of the deliverable framework. Already realized NBS projects were treated as case studies calibrating the literature findings with what was applied in practice. The UN 2030 Agenda was used for developing indicators that address contribution to the SDGs. Finally, the framework was tested by applying it to an already realized NBS project, the Eddleston Water Project (different from the calibration ones), by giving the project metadata as input to the framework indicators.

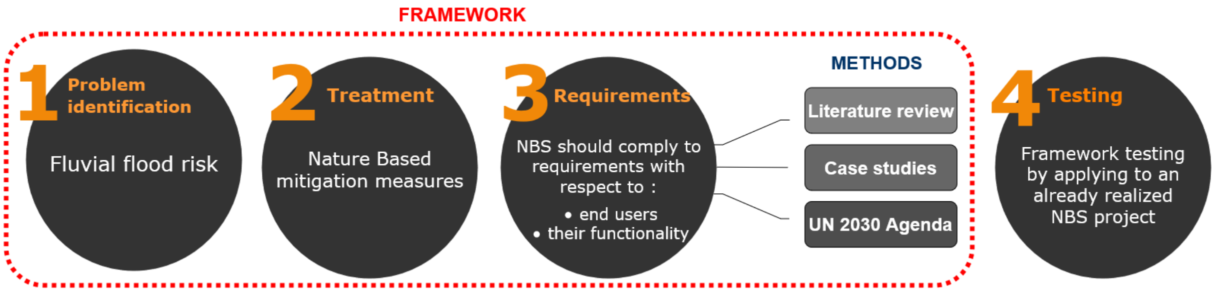

Figure 1: Overview of the research approach and methodologies of the research project

Overall, the framework performed well as most of its indicators are having indicative data that were found in publicly available references. Expert consultation was needed for acquiring some of the data but was kept to a limited extent as much as possible. Additionally, some overlaps between the needed data per framework indicator were observed that can probably be attributed to the scope and current state of the Eddleston project. Regarding the Eddleston project it was found that meets its initial objectives, contributes to SDGs 1, 6, 8, 9, 11, 12, 13, 15, and 17 while enhances several provisioning, regulating, cultural, and supporting ecosystem services of the Eddleston Water.

To the downsides of the framework, its testing with only one case study due to the time frame of the project. Furthermore, it was developed and tested focusing on the developed world. Additionally, the link between NBS and SDGs is based on the author's self-explanation and gained insights throughout the project. Hence, a more experienced person might create different links.

In line with the aforementioned limitations, future recommendations suggest further testing with ranging, both in scale and in location, case studies. Expert judgment could also be used as another testing way by examining experts' suggestions and willingness to use the framework. Finally, the inclusion of the SDGs in the indicators offer several opportunities: (i) re-evaluating potential NBS-SDG links and (ii) examining framework changes in case of considering the developing world.

Acknowledgments

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I would also like to express my gratitude for the opportunity that I was given to conduct my thesis at Rijkswaterstaat. Although I did not have the chance to work physically from their offices due to the coronavirus pandemic, they provided me with all the contacts that I needed. Additionally, they introduced me to the Interreg North Sea Region Program, which actively works on the evidence base of the Building with Nature (BwN) practice and inspired even more my thesis work.

Special thanks also to Professor Chris Spray, from University of Dundee. His valuable contribution to the testing stage of the framework made it possible to have a complete overview of the performance of the framework. He was very detailed in whatever I was asking and always available to help in every way he could.

Finally, I cannot skip mentioning my family and friends that were companions in this journey. Especially my flatmates that were de-stressing me while keeping my mood up during these odd times. Lastly, my parents for supporting me both financially and mentally throughout my whole studying journey.

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Tatiana Andrikopoulou

Delft, October 2020

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1. INTRODUCTION

1.1 Importance of flood management in river ecosystems

Rivers are a vital part of both natural and human ecosystems as they provide various intrinsic functions (habitat for species, conveyance of nutrients, sediments), as well as ecosystem services (flood attenuation, navigation, recreation). However, natural and anthropogenic drivers of change cause river ecosystem degradation, limiting its valuable functions and services, thereby threatening its sustainability. For instance, projected precipitation patterns as well as urban expansion trends will affect the flood conveyance capacity, a regulating ecosystem service, provided by the rivers. Therefore, the ability to maintain or even increase, over time, the benefits derived from the river ecosystem are threatened.

According to the UN (2015) report, *'The Human Cost of Weather Related Disasters',* flooding affected negatively 2.3 billion people the last 20 years. The 2.3 billion people account for 56% of all those negatively affected by weather-related disasters (droughts, storms). Floods are present in the form of coastal flooding, river flooding and flash floods which are constantly increasing over the last years (UNISDR, 2015). Such facts verify the importance of dealing with flood risk control in terms of river management (Jongman, 2018; Vanneuville et al., 2016; Faivre et al., 2018). Additionally, they reveal the urgency and complexity of fluvial flood risk management due to the aggravated and multisectoral impacts that future flood events will cause (Jongman, 2018). The impacts can be direct (casualties and infrastructure) but also expand on the economic, social and environmental domains. Hence, the multisectoral impacts intensify the need for measures that not only tackle effectively the fluvial flood risk problem but can also address changes in the environmental and socio-economic sectors.

1.2 Flood mitigation practices

Traditionally, flood mitigation practices suggest engineering "grey" measures (Roca et al., 2017) which have to be reinforced to cope with increasing pressures, such as climate change and safety demands. In this context engineering or "grey" measures refer to man-made structures (dikes, dams, floodwalls, geotextiles, rock rolls) that interfere with the natural state of the ecosystem, paying little attention to the ecosystem services. On the one hand, their implementation addresses the flood risk directly and provides direct benefits. For instance dikes, apart from offering flood protection, also provide direct land reclamation and exploitation in favour of the society, making them a popular measure. On the other hand, a strict reliance on these measures can have devastating consequences in case of their failure. This paradox is the so-called "levee effect", whose negative effects need to be confined as much as possible. On top of that, recent studies revealed that "grey" measures appear to have several restrictions regarding their long-term efficiency, resilience and cost-effectiveness (EEA, 2016; EEA, 2017; Pitt 2008; Bauduceau et al., 2015; Loucks, 2019). Last but not least, at the downsides of the grey measures are also the environmental, ecological and social disturbances that they introduce (Dittrich et al., 2019).

A type of measure that is gaining increasing prominence in research and application (Calliari et al., 2019) and could cope better with the above-mentioned complications are the so-called Nature Based Solutions (NBS). Although a widely accepted definition does not exist, the prevailing ones are those formulated by the IUCN and the EC (Calliari et al., 2019), which outline them as measures inspired by nature, resource-efficient, resilient to change and able to address societal challenges while providing several environmental and societal benefits. Since these aspects could contribute to the aspiration for resilient and multi-benefit river flood management approaches, growing attention is being given to NBS in an attempt to enhance their evidence-based support.

Strengthening of the NBS evidence base is also attempted through the Interreg North Sea Region (NSR) 'Building with Nature' program, which supports the practical implementation of NBS projects by developing and monitoring living laboratories, where the potentials of such projects are examined. The laboratories demonstrate projects in coastal and catchment environments, constituting an evidence base for measuring costs, benefits and effectiveness of NBS measures. Project partners from The Netherlands, Belgium, Germany, Denmark, Sweden, Norway, and Scotland combine transdisciplinary cooperation, knowledge and experience in an endeavour to make coasts, estuaries and catchments of the North Sea Region resilient to projected climate changes.

1.3 Sustainability and NBS

In research, sustainability is expressed by the terms 'three pillars of sustainability', 'triple bottom line' and 'three P's (People, Prosperity, Planet)'. These terms reflect on the three sustainability principles: economy, society and environment, which are included in the following prominent sustainability definitions:

- "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland 1987)
- "meeting human needs while conserving the Earth's life support systems and reducing hunger and poverty" (Palmer et al., 2005)
- "to maximise simultaneously the biological system goals (genetic diversity, resilience, biological productivity), economic system goals (satisfaction of basic needs, enhancement of equity, increasing useful goods and services), and social system goals (cultural diversity, institutional sustainability, social justice, participation)" (Barbier 1987)

The sustainability principles are also adopted by the action plan, set by the United Nations in September 2015, the UN 2030 Agenda, aiming at a more sustainable planet by 2030. This agenda comprises of 17 SDGs, 169 targets and 232 indicators (United Nations General Assembly 2015). In the targets are also included partnerships, means for mobilization of resources and capacity-building, factors that need to be strengthened in more vulnerable countries, for achieving the aforementioned goals. These are denoted in the Agenda within Goal 17 as well as within each goal with letters (i.e. 1.a, 13.b).

The SDGs apply to scales ranging from communities to regions, countries, and the planet. However, they work as a non-binding agreement, enabling their contextual adaptation and transdisciplinary involvement. The Sustainable Development (SD) targets and indicators complement the goals, helping at their specification and comprehension. For instance, the broad scope of SDG 6 *'Ensure availability and sustainable management of water and sanitation for all'* is narrowed down and becoming more project-specific at target 6.6, which sets goals for rehabilitation and expansion of water ecosystems. Similarly, SDG 9 *'Build resilient infrastructure, promote inclusive and sustainable industrialization and foster* *innovation',* becomes more concrete at target 9.1 which focuses on cost-effectiveness and human well-being. Therefore, the broad scope of SDGs should not be treated as a set-back rather than as an opportunity for tailoring a path towards the achievement of enduring sustainable development results.

Alike other ecosystem-based approaches, NBS could also create a link to the sustainability principles (Nesshöver et al., 2017). The inclusion of natural elements in the measures creates manifold benefits for all three pillars. From societal perspective, provides access to nature and recreation while adding cultural and heritage value to the landscape. From ecological and environmental perspectives, enhances biodiversity and contributes to the water and air purification. From an economic viewpoint, promotes sustainable and responsible resource management, resulting in cost-effective practices. Lastly, the measure itself is flexible and resource compatible. Therefore, NBS could directly address SDGs by considering the sustainable development targets as an indivisible part of the NBS design and performance.

1.4. Existing NBS approaches, sustainability assessments and gaps

Currently, there are several guidelines and manuals regarding the NBS design and implementation, in an attempt to be applicable in a wide range of societal challenges (Nesshöver et al., 2017; Artmann et al., 2018; Weber et al., 2018). However, specifying the main purpose of the NBS and tailoring it to the local context appear to be crucial aspects for establishing state-reflective indicators and thus optimizing the NBS design and implementation (Raymond et al., 2017; Schipper et al., 2017; Den Dekker-Arlain, 2019; Kabisch et al., 2016).

To date, several indicators have been established called either '(performance) indicators' or 'sustainability indicators' (Kabisch et al., 2016; Den Dekker-Arlain 2019; Schipper 2017; Huthoff et al., 2018; Raymond et al., 2017). The latter ones are usually encountered when the framework makes a link to sustainability. This link is expressed by the reflection of the indicators on the triple bottom line, expressing, for instance, the sustainability of a river project (Schipper et al., 2017; Kistenkas and Bouwma, 2018; Den Dekker-Arlain, 2019). Although a plethora of indicators reflecting on society, economy and environment exists, the technical characteristics of the intervention have not yet been subjected to assessment. In other words, the evaluation of the intervention with respect to its engineering principles, as set during the design phase, is something missing from the current assessment frameworks and methodologies.

Direct link between rivers and SDGs has been attempted (Ge et al., 2018; Ligtvoet, 2018). Ge et al. (2018) have defined SDGs for rivers based on water ecosystems and socioeconomic capabilities**.** Ligtvoet (2018), has already identified the SDGs, related to people and economy, that are negatively affected by river flooding. Therefore, having these studies as relevant sources, it would be interesting to examine whether NBS tackling fluvial flood risk adhere to the same SDGs, compliment them or are lacking in them.

1.5. Research context

This project will focus on NBS mitigating fluvial flood risk. Normally, projects addressing regulation of river flooding should be dealt at catchment scale due to the transboundary nature of rivers, requiring transboundary cooperation. However, such an integrated approach is hardly happening due to -among others- institutional boundaries, conflicting interests, and complex decision-making processes, causing disruptions between upstream and downstream communities. NBS, although usually implemented and examined in smaller than catchment scales, seem to dampen the aforementioned implications, taking into account, the upstream and downstream conditions.

In Figure 2, NBS for flood mitigation along a catchment can be seen. The NBS interacting with the coastal environment, such as salt marshes and beach management, will not be considered in this project. Generally, the coastal flood risk and its interaction with the riverine ecosystem are out of scope for this project.

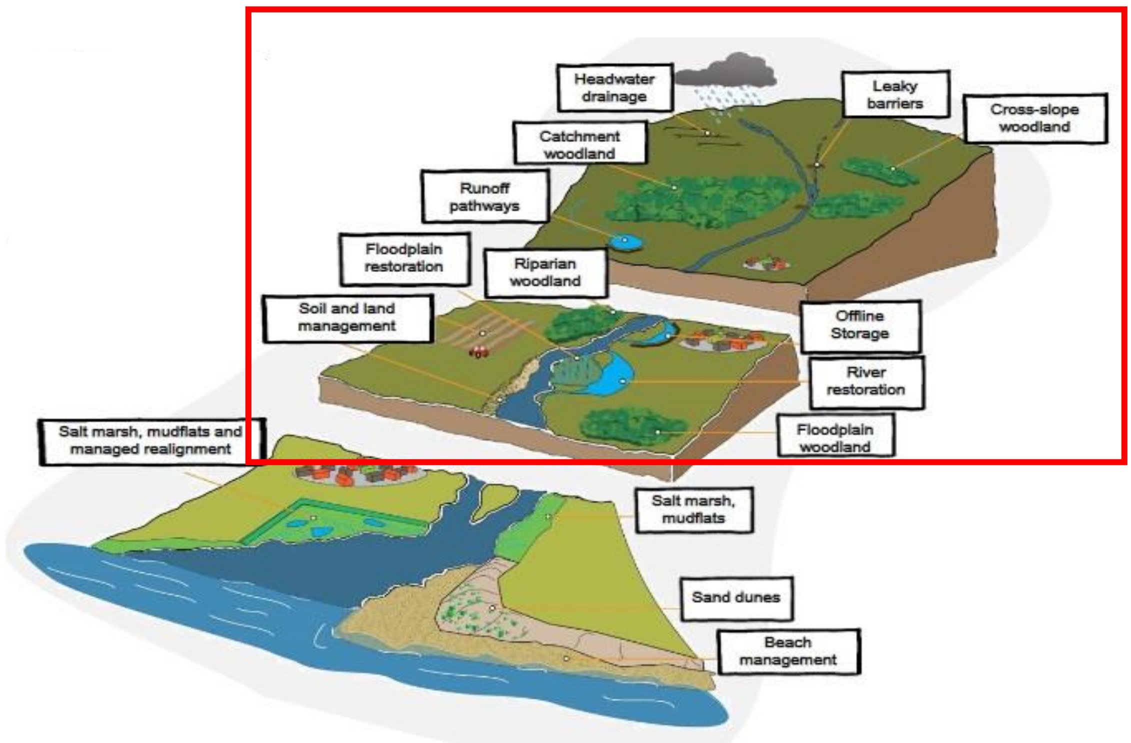

Figure 2: NBS for flood mitigation along a catchment. The red rectangle shows what is in scope for the project. Retrieved from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/681411/Working_with_natural_processes_evidence_directory.pdf

1.5. Research objective

The aim of this master graduation project is to evaluate NBS for fluvial flood mitigation by developing an assessment framework. The framework will address an integrated assessment approach and will use indicators for evaluative and benchmarking purposes of already implemented NBS projects for fluvial flood mitigation. To this end, the NBS assessment framework is meant to assist experts in providing guidance for similar projects and contributing to the transferability and mainstreaming of the NBS practice.

The NBS performance will be evaluated against technical, social, environmental, and economic aspects. Through the social, environmental, and economic aspects, the link to sustainability will be established which will be further developed by examining potential contribution of the NBS projects to the SDGs. The technical aspects will address the engineering characteristics of the intervention.

The novel aspects of this framework are:

- Direct link between the SDGs and framework indicators
- Use the SDGs as one of the criteria while developing the final framework indicator set
- Assess the technical performance of the NBS

<u>The main research question is:</u>

"How to assess a NBS project for fluvial flood mitigation?"

<u>Research sub-questions:</u>

1. What are the existing assessment frameworks and indicators for NBS?
2. What additional information regarding the assessment procedure and indicators can be derived from examination of already realized NBS projects?
3. How NBS projects contribute to the attainment of the SDGs, as set by the United Nations Organization?
4. What are the components of the assessment framework?
5. How does the framework perform in practice?

The investigation of these sub-questions will contribute to answering the main research question.

Subsequent to this introduction, the rest of the progress report has the following structure: *Chapter 2 – Research Approach and Methodology* elaborates on the research approach followed for the development of the framework and the methods used for the identification and collection of its components. *Chapter 3 – Results* is separated into three parts. Firstly, elaborates on the results derived from each method, substantively. Secondly, presents the structure and components of the framework, derived from the composition of the methods' outcomes. The third part includes the testing of the framework on the Eddleston Water project and the interpretation of the results. *Chapter 4 – Discussion* summarizes the outcomes of the framework application and discusses the flexibility, subjectivity and potentials for ex-ante applicability of the framework. *Chapter 5 – Conclusions* answers the research sub-questions while *Chapter 6 – Limitations & Recommendations* refers to the restrictions of the research accompanied by suggestions for future framework improvement.

2. RESEARCH APPROACH AND METHODOLOGY

This chapter elaborates on the research approach followed in order to conceptually develop the framework and the three (3) methods used for forming its structure and components: literature review, analysis of case studies and of the SDGs. Finally, it talks about the testing of the framework.

This research is an endeavour to mainstream the NBS practice for fluvial flood mitigation by developing an assessment framework and involving indicators for the evaluation and benchmarking of the NBS projects. The framework encompasses an integrated NBS assessment approach while organizes coherently and consistently the indicators as part of the assessment procedure. The creation of such a framework comes close to the design-oriented approach.

Design-oriented approach is traditionally used in software research, however, it can also be applicable in other sectors (Verschuren & Hartog, 2005). Wieringa (2014) states that a design-oriented research should align with the following structure:

"Improve a problem context, by treating it with a (re)designed artifact, such that satisfies defined requirements, resulting in achieving stakeholders' goals"

This structure is used as the conceptual base of the proposed framework, considering the three underlined terms as fixed points in the creation of the framework.

Firstly, the *problem context* refers to an identified problematic aspect in a given environment, which constitutes the initiating force for intervention. In this research, the problem treated is fluvial flood risk.

Secondly, the *artifact* refers to (new or additional) measures that could mitigate the major problem, as identified in the *problem context*. In this research project, the artifact is the NBS interventions.

The third term, *requirements*, can be related both to the end-users and to the artifact itself. The NBS should undoubtedly satisfy the purpose it was designed for. In this case, the NBS should tackle fluvial flood risk without severely disrupting other functions. However, Verschuren & Hartog (2005) and Verschuren et al. (2010) also address functional and contextual requirements that are related to the characteristics of the artifact itself. In this case, the technical, social, environmental, economic and procedural needs that the NBS should reflect upon, can be perceived as functional and contextual requirements.

In brief, adapting the design-oriented approach in the present context, the problem addressed is flood mitigation in rivers and will be treated with NBS works. The requirements of the NBS need to be defined and, all the three aforementioned elements, will form the deliverable framework. As final stage, the framework will be tested in order to examine its applicability and limitations.

In the next paragraphs, the methods used for developing the NBS *requirements* and, eventually, forming the framework are elaborated. Important to be mentioned is that the outcomes of each method are feeding into and compared to the outcomes of the other methods, introducing iterative review loops during the development of the requirements. Therefore, the final framework has requirements formed by all three methodologies.

2.1 Literature review of assessment frameworks and indicators

Literature review served as an initial step, providing guidance both for developing a new framework and for identification of already existing indicators. It is separated into three parts: (i) collection of adequate frameworks (ii) analysis of the assessment framework elements and (iii) collection of the already existing in literature indicators.

(i) The research for frameworks was based on the Google Scholar database using the following search terms: *NBS, assessment, evaluation, framework, guidelines.* When useful NBS assessment frameworks were encountered, also the snowballing technique was used in order to detect other related frameworks and guidelines. The final literature framework selection followed the below-mentioned criteria. Due to the strict time frame of this project, 7 frameworks in total are studied; Artmann at al., 2018, Calliari et al., 2019, Weber et al., 2018, Huthoff et al., 2018, Nesshöver et al., 2017, Raymond et al., 2017, Schipper et al., 2017.

The criteria used for the selection of the considered literature:

- Assessing/evaluating character
- Publication date (as recent as possible so as to be aligned with and consider the latest relevant research outcomes)
- Variety of the NBS main objective
- Variety of implementation scales
- Relevant research already conducted by the client

(ii) The frameworks are examined in an exploratory way, aiming at identifying general steps in an assessment procedure. For this purpose, the selected frameworks vary in terms of NBS objective, scale and implementation location, ensuring the identification of key elements that should form part of NBS assessment frameworks and are objective and scale independent. Afterwards, the general steps are synthesized, creating the core elements of the newly developed assessment framework. Finally, a comparative analysis, between the considered frameworks, was done to identify gaps and discontinuities. This process helped to clarify several existing unclear points.

(iii) The collection of indicators is based on the aforementioned selected assessment frameworks and methodologies because some of them include indicators. However, for a more complete overview of the already existing indicators and to ensure that new knowledge is generated and not duplicated, 3 more papers that include assessment and sustainability indicators were studied. The additional examined literature was found based on snowballing, having as starting point the frameworks mentioned before. In total, eight (8) papers were studied.

The considered literature is: Weber et al., 2018, Huthoff et al., 2018, Nesshöver et al., 2017, Raymond et al., 2017, Den Dekker-Arlain 2019, Schipper et al., 2017, Kabisch et al., 2016, Pakzad et al., 2016. The list comprises of both location non-dependent (Weber et al., 2018; Huthoff et al., 2018; Nesshöver et al., 2017) and location-dependent projects (Raymond et al., 2017; Schipper et al., 2017; Den Dekker-Arlain, 2019; Kabisch et al., 2016) in order to collect indicators reflecting upon the whole assessment procedure and not only upon the impacts of the NBS; apart from indicators related to the environment, society and economy, also indicators related to stakeholder involvement, procedural arrangements - constraints and monitoring are expected.

2.2 Case studies-based research

Already realized NBS projects are treated as typical case studies for examination. The aim is dual (i) to calibrate the literature findings and (ii) get insights regarding procedures and criteria that played an important role at the realization of the projects and could not be traced during the literature review. NBS projects are considered projects inspired, supported and/or copied by nature, tackling societal challenges while providing additional benefits. The case studies will be examined in an exploratory way in order to derive general indicators and procedures that are not project specific. The selection of the case studies was based on the following independent choice criteria. Grey literature relevant to the case studies was also studied as an additional source of information. This includes published articles and videos.

- NBS with main objective fluvial flood risk mitigation
- Different geographical regions and scales
- Language of documentation (English)
- Type and number of publications
- Ease of access to relevant information, documentation

The considered case studies are presented in Table 1. They all treat nature-based measures with main objective fluvial flood mitigation. All three case studies are in the developed world. This is because NBS projects in developing countries have as objective to cover more fundamental needs, such as water quality and scarcity, and thus flood mitigation is not, yet, the main driver for the NBS implementation.

PROJECT	LOCATION	REFERENCES
Wave attenuating willow forest	Noordwaard polder, Netherlands	[23], [24], [25], [26], [27], [28], [30]
Colorado Front Range: Recovery from 2013 floods	Colorado river, United States of America (USA)	[29], [30], [31]
Belford Natural Flood Management Scheme	Belford, Northumberland, United Kingdom (UK)	[32], [33], [34], [35], [36], [37], [38], [39], [40], [41], [42], [67]

Table 1: The examined case studies (3)

2.3 Analysis of the Sustainable Development Goals (SDGs)

The SDGs along with their targets and indicators are found in the UN 2030 Agenda (United Nations General Assembly 2015). For the sake of clarity, in the report, the sustainable development indicators of the UN 2030 Agenda are mentioned as ‘SD indicators’ while ‘framework indicators’ denote the ones defined for the framework of this research project. The link between NBS for fluvial flood mitigation and SDGs was attempted through the following procedure:

(i) Define the coupling boundaries

This research project is focusing only on the developed world and therefore any SD target or SD indicator referring to the developing countries will be omitted. In addition, the link is made between SDGs and NBS in riverine ecosystems and consequently, coastal or marine ecosystems and resources are out of the scope of the project.

(ii) Examine the UN 2030 Agenda

The UN 2030 Agenda was initially examined in an exploratory way in order to get a general overview of the Sustainable Development Goals, targets and indicators. The goal is to make the coupling as complete as possible (in accordance with the boundaries) and thus potential contribution of NBS to all the SD goals, SD targets and SD indicators is initially examined.

(iii) Find the relevant, to NBS for fluvial flood mitigation, SD targets and SD indicators

The UN Agenda comprises of goals, targets and indicators in an increasing in detail order. Given the broad scope of the SD goals, the SD targets are examined while having the SD indicators as complementary and more detailed description of the SD targets when the targets are vague or are including a lot of aspects.

Firstly, potentially relevant SD targets are spotted based on the boundary conditions and potential contribution of the NBS to them. When a potentially relevant SD target is identified, its SD indicators are examined ensuring that they are also NBS relevant. If it holds true, then the SD target is considered relevant and its SD indicators are linked to the NBS, making sure that all the relevant aspects of the target are addressed (Figure 3). Relevant SD indicator is defined according to whether a NBS can contribute to it, which is based on self-explanation according to the gained insights from the research. Hence, relevant targets are identified as long as they have at least one relevant SD indicator. In the *Results* Chapter, section 3.3 '*Link between NBS for fluvial flood mitigation and SDGs'*, there is also a detailed example of a SD target that did not have all its SD indicators context-relevant. Finally, important to note is that the SD indicators are not considered as indicators in the newly developed framework.

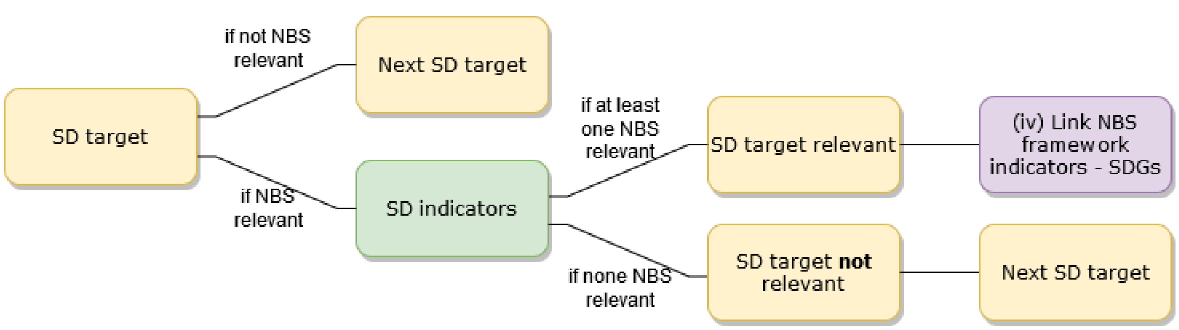

Figure 3: Defining relevant, to NBS for fluvial flood mitigation, SD target and indicators

(iv) Link NBS framework indicators to SDGs

The coupling of the SDGs to the framework indicators was done at SD indicator level. The SD indicator level was preferred because of two reasons. Firstly, many SD indicators are common between different SD targets. Secondly, in one SD target many dimensions might be addressed through its multiple SD indicators. Both reasons resulted from the examination of the Agenda (step ii) and are further elaborated in Section 3.3 "*Link between NBS for fluvial flood mitigation and SDGs*" section. Therefore, when relevant targets are found (step iii), their SD indicators are examined in order to make sure that all the dimensions of the target are addressed during the coupling. Firstly, it is examined whether the already collected framework indicators can be linked to the relevant SD indicators. If this is not the case, additional framework indicators are defined.

(v) Address the direct and indirect relation between the NBS framework indicators and the SD indicators

Direct and indirect relations are introduced in order to address the direct and co-benefits and costs of the NBS. Direct relation is associated with the main objective of the NBS considered in this project. Thus, direct relation is considered any effect of the flood risk in any domain: environment, society, economy. Characteristics as well as construction and maintenance costs of the NBS are also having a direct association. Following the same line, the indirect relation refers to benefits and impacts on all the other functions of the river.

2.4 Framework testing

Testing of the framework is achieved through its application on an already realized NBS project. The Eddleston Water Project is used as testing case study. Metadata of the project are acquired from literature search and from consultation with a project expert. The online available references studied are: Werritty et al., 2010, Dochartaigh et al., 2019, Ncube et al., 2018, Spray et al., 2017, Dittrich et al., 2019. Additional material studied was also the presentations made by the Tweed Forum, Professor Chris Spray and Hugh Chalmers as part of conferences (*"Valuing Nature Annual Conference*", Edinburgh, October 2017 and Interreg North Sea Region BwN program, June 2020) and stakeholder meetings (April 2018). Lastly, the "*Case study 9. Eddleston Water Project*", part of the *'Working with Natural Flood Management: Evidence Directory'* was also studied.

3. RESULTS

This chapter comprises of three parts. In the first part (Sections 3.1 – 3.3), the outcomes of the methods are presented; literature review, examination of case studies and analysis of the SDGs. In the second part (Section 3.4), the outcomes of the methods are synthesized resulting in the development of the framework. The third part (Section 3.5) is the testing of the framework along with its outcomes.

3.1 Review of assessment frameworks and indicators

The literature review of existing assessment framework and methodologies works as a starting point, aiming at identifying common key elements of assessment procedures. Additionally, by mapping the differences between the considered assessment frameworks, gaps and blurry points will be revealed, in an attempt to be clarified in the new framework. The second purpose of the literature review is to collect already existing indicators with the goal to evaluate a NBS project. In the following paragraphs, the unaligned terms (differences), the common elements and the already existing indicators between the considered frameworks are presented.

Unaligned terms - Differences

The comparative analysis between the considered frameworks and methodologies yielded terms widely encountered and used when referring to NBS. Such terms are the: definition of NBS, ecosystem services and (co-)benefits/costs, societal challenges, and sustainability. However, their employment per considered framework varies. For this reason and since they are also fundamental NBS-related terms, they are elaborated in the following paragraphs. Table 10, in Appendix A, sums up the differences between the considered frameworks. The employment of the above-mentioned terms with respect to the current framework is presented under Section 3.4.1 '*Framework context*'.

Definition of NBS

The most prevailing NBS definitions are those formulated by the IUCN and the EC (DG, 2015; Cohen-Schacham et al., 2016). This is also apparent in the employed NBS definitions of the considered frameworks (Calliari et al., 2019; Huthoff et al., 2018; Raymond et al., 2017; Nesshöver et al., 2017). The EC defines NBS as '*actions inspired by, supported by or copied from nature, ideally energy, resource-efficient and resilient to change, aiming to help societies address a variety of challenges'* (DG, 2015). Similarly, IUCN describes NBS as 'a*ctions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits'* (Cohen-Schacham et al., 2016). The main difference between the EC and IUCN definitions is that the EC one accounts for cost-effectiveness and resource-efficiency, while the IUCN not (Calliari et al., 2019). Frameworks that do not address either of the aforementioned NBS definitions, refer to specific projects providing their respective definitions (e.g. restoration, UPA, sustainable ports).

Ecosystem services and (co)-benefits/costs

Ecosystem services are benefits acquired from the humankind by the ecosystem (MA, 2005). They are divided into four categories: provisioning or production services, regulating services, cultural services and supporting services. Provisioning or production services refer to products acquired by the ecosystems such as food, water and timber. Regulating services involve flood attenuation, water and air quality maintenance while cultural services address the non-material benefits derived from the ecosystems such as inspiration, recreation and cultural heritage values. Finally, supporting services include processes that yield a healthy ecosystem. Some indicative supporting services are nutrient and water cycling, provision of habitat and production of atmospheric oxygen. Many of the aforementioned services might be provided together repeatedly, the so-called 'bundles', with either positive (synergies) or negative (trade-offs) associations. Positive associations refer to the same direction trends between ecosystem services (e.g. all increasing) whilst trade-offs denote opposing trends between ecosystem services (e.g. some increasing, some decreasing) (Raudsepp-Hearne et al., 2010; Mouchet et al., 2014). Lastly, (direct) benefits and co-benefits do not have any widely applied definitions and each of the examined frameworks utilizes the terms according to their context.

A brief overview of how these two terms are used in the considered frameworks is following while an extended analysis can be found in Appendix A. Generally, ecosystem services and (co-)benefits/costs are terms included in almost all the considered NBS assessment frameworks causing confusion due to the lack of solid definition (this applies only to (co-)benefits/costs) and their unclear relation. To put this into perspective, Calliari et al. (2019) relate both the direct and co-benefits with the ecosystem services while in the case of direct and co–costs, only the latter ones are ecosystem services-related. Artmann et al. (2018) uses three categories (provisioning, regulatory and cultural) of the ecosystem services, as defined by the Millennium Ecosystem Assessment, supplied by the NBS and distinguishes them from the social, economic and environmental impacts of the NBS. Weber et al., (2018) considers ecosystem services but with no distinction, while benefits/costs and co-benefits/costs are not explicitly employed terms. The NSR Interreg framework (Huthoff et al., 2018) does not include the ecosystem services in the developed framework in contrast to the co-benefits which are employed but separated from the NBS main objective. Nesshöver et al. (2017) address the ecosystem services as part of the NBS concept and the benefits derived from them. Negative implications (costs) are also mentioned, along with their resulting trade-offs. Raymond et al. (2017) talks about ecosystem services, without providing neither definition nor categorization, and distinguishes them from the (co-)benefits. Benefits/costs and co-benefits/costs are aligned with the primary and secondary challenges treated and their positive and negative implications, respectively. Finally, Schipper et al. (2017), although do not elaborate on ecosystem services, emphasize the importance of identifying the effects of ports and port-city plans on the social, environmental, and economic sectors.

Societal challenges

The global societal challenges as established by the IUCN report are climate change, food security, water security, disaster risk, human health as well as economic and social development (Cohen-Schacham et al., 2016). The relation of societal challenges and NBS is unequivocal because, as suggested by the NBS definitions, they are measures involving nature and striving for efficient and sustainable ways of mitigating the societal challenges. Not all of the considered frameworks and methodologies make an explicit link to the societal challenges. Some of the frameworks build on the IUCN societal challenges and elaborate more on them, addressing either more specific problems such as land management and agricultural intensification (Artmann et al., 2018) or more spatially-specific challenges such as urban regeneration and coastal resilience (Raymond et al., 2017). Other frameworks either deal with one or two interrelated challenges (Calliari et al., 2019; Schipper et al., 2017) or address challenges related to a specific natural element, such as water-related risks (Huthoff et al., 2018). Lastly, there are frameworks that either apply to any challenge (Nesshöver et al., 2017) or address them implicitly (Weber et al., 2018). In relation to the focus of this research project, the challenge of flood risk and its evolution under climate projections are addressed by 4 out of the 7 examined frameworks (Calliari et al., 2019, Huthoff et al., 2018, Nesshöver et al., 2017, Raymond et al., 2017).

Sustainability

The most prominent sustainability definitions are the ones formulated in the Brundtland report (1987), by Palmer et al. (2005) and by Barbier (1987) (see section 1.3 '*Sustainability and NBS*' for the definitions). The sustainability aspect is, usually, considered in the research through the 'triple bottom line', which also constituted the foundation for the UN 2030 Agenda. However, current research is still expressing sustainability upon the three pillars and not upon the SDGs. This is the case for many of the considered frameworks that either explicitly or implicitly establish the link to the triple bottom line; explicitly through the consideration of the social, economic and environmental sectors (Schipper et al., 2017; Raymond et al., 2017) and implicitly through the reflection of the proposed actions or indicators on the aforementioned sectors (Nesshöver et al., 2017; Artmann et al., 2018; Calliari et al., 2019). Huthoff et al. (2018) and Weber et al. (2018) address sustainability by involving long-term visions, uncertainties, and changes. Calliari et al. (2019) involve sustainability by using the backcasting method, often used in innovation and sustainability research.

General steps in assessment procedures - Commonalities

The framework review yielded several steps that were in common between most of them (Appendix A, Table 11). Listing and formulating them in line with the research context, these are the system analysis, setting of objectives, effects of NBS, process and monitoring. In the following paragraphs, they are elaborated substantively, without addressing their interconnections.

System analysis

System analysis starts with identifying the problem and defining the reference situation. These involve historical analysis, boundary conditions and prevailing patterns of the site of interest. Therefore, the complexity and malfunctions of the system are revealed, indicating the challenges that need to be addressed. Finally, important part of the system analysis is also the consideration of the available budget and the client's project aspirations because they both feed into the considered mitigation measures.

Setting of objectives

Setting of objectives is related to the interventions that could tackle the identified challenge. More specifically, adequate NBS types and implementation locations are identified. At the same time, the NBS goals should be communicated in a way that is widely acceptable, clear and reflects the multipurpose character of the NBS. Finally, all interventions include a level of risk which should be anticipated with adequate planning.

Effects of NBS

This step is based on the potential of the NBS to contribute to several domains: engineering, social, environmental, and economic. Through this step, the relation of the NBS with the ecosystem services and the benefits/costs derived from the NBS implementation will be inferred. It can indicate whether the ecosystem services are enhanced or impeded by the NBS implementation and whether the NBS implementation brings additional benefits (co-benefits) and costs (co-costs). Based on the results of the aforementioned examination, alternative sources of action or even different NBS types are defined, introducing an iterative process between the *Setting of objectives* and the *Effects of NBS*. Goal is the anticipation of benefits and risks, their interactions, and their equitable distribution.

Process

Process addresses the importance of both stakeholder involvement as well as sharing and spreading innovative knowledge throughout the project. Whoever is interested in the management of the project, is a stakeholder. For instance, farmers, residents, and visitors of the project area. Governmental and institutional groups involved in policy management of the project, are also considered stakeholders. Influential, supporting and benefitting actors and instruments are identified which result in the enabling factors and constraints during the NBS design and implementation phases. Additionally, knowledge from already realized NBS projects and interests between different stakeholders are exchanged, stimulating a learning-by-doing approach to tackle emerging risks. Finally, transparent communication between the involved parts is established facilitating necessary institutional arrangements and ensuring productive project progress.

Monitoring

Monitoring in order to identify the extent to which the NBS objective has been reached and the effects of the prevailing conditions to the NBS performance. Besides, *Monitoring* also serves in extending current knowledge, examining, and enhancing long-term adaptation of the interventions.

Generally, not all five steps were identified in all the considered frameworks. The fact that some of the steps, derived from the analysis, are missing can be attributed to the focus of the framework. For instance, Weber et al. (2018) developed a conceptual framework for programming evaluation and maintenance of river restoration projects. Hence, the focus is on accumulating already gained knowledge and experience as well as involving stakeholders rather than analyzing the system and its prevailing conditions. The implementation of river restoration works is taken for granted in his context and, therefore, his framework builds on the *Setting of objectives*, *Process* and *Monitoring* steps. Another reason could be that the steps encountered in a framework or methodology might include more than one of the aforementioned steps. More specifically, in the assessment methodology developed by Schipper et al. (2017), the second step “Description of the port and port-city long term plans” could encompass both the *System analysis* and the *Setting of objectives* steps. The port and port-city long term plans, in this case, are the reference situation in which are also included the potentials and objectives of each port, aligned with the system characteristics.

Existing indicators

Approximately 150 indicators were collected in literature falling into 22 categories, in total. Categories such as biodiversity, ecosystem services and processes, socio-economic, policy frameworks and many more (Appendix A, Table 12). Although each considered paper defines the categories based on its content and the author’s perspective, when putting them altogether some of the categories conceptually overlap. The conceptual overlap is often accompanied by the use of the same or similar indicators. For instance, the ‘health and well-being’ category with the ‘social’ one, are both using indicators related to mental and physical human health. Another example is the ‘recreation’ indicator that is used in the ‘ecosystem services’ category as well as in ‘socio-cultural’ and ‘socio-economic’ categories. In such cases, the categories are merged, and one representative indicator is used. Lastly, 3 out of 8 frameworks (Raymond et al., 2017, Schipper et al., 2017 and Den Dekker-Arlain, 2019) provide sources of quantification for their indicators, strengthening the practical applicability of them.

3.2 Examination of already realized NBS projects – Case studies

The examination of already realized NBS projects is aiming at two main things: (i) to bridge the gap, if any, between literature-theoretical project stages and processes and what has been applied in practice and (ii) to examine whether there are additional indicators, applicable to NBS for fluvial flood mitigation, than the already available ones in the literature. NBS projects will provide insights regarding the aspects considered before, during and after the NBS intervention. Furthermore, impacts of the NBS within and across different sectors (social, economic, environmental, and technical) will be identified. Three case studies are examined: the Noordwaard polder in the Netherlands, Colorado’s Front Range Recovery from 2013 floods in the United States of America (USA) and the Belford Natural Flood Management Scheme in the United Kingdom (UK). These case studies were chosen because they vary in terms of worldwide location, scale and implemented measures. They also had sufficient publicly available data.

The next paragraphs explain why the projects are considered NBS, their objectives, the gained insights and whether there are any complete assessments of the projects. Complete assessments are considered publications that are dated after the completion of the projects. Publications dated within the design and construction period of the projects feed into the gained insights.

‘Wave attenuating willow forest’ - Noordwaard, The Netherlands

The Noorwaard project, which forms part of the Dutch national Room for the River (RftR) program, primarily aims at reducing the flood risk in downstream areas. It is considered a nature supported and inspired project because dikes are removed (de-poldering), providing more space to the Rhine river for flood conveyance and attenuation. Even when de-poldering was not possible, the dikes were lowered and turned into clay-covered ones complemented by native flora (willow trees). Therefore, the adopted measures are integrated into the landscape, fulfilling their purpose, while providing additional natural and landscape values such as wildlife habitat and recreational space.

The main insights revealed by the examination of the Noordwaard project are the added cultural value, the intervention's maintenance costs, the coalitions formed by the stakeholders and the transparent communication between the involved parts. Firstly, using willow forests both enriches the landscape and creates cultural and heritage value as they are native tree species. On top of that, the area could also serve for educational purposes since adults and children can have contact with nature in the immediate vicinity. Secondly, since the dike is a hybrid measure, maintenance and its costs should also be considered to ensure optimal performance and durability of the intervention. Finally, the coalitions formed by the stakeholders created the sense of the 'struggling for the same-aim' team, promoting participation, communication, and collaboration between the involved parts throughout the project. The constant involvement and interest of the stakeholders enhanced the clear communication between the involved parts, aligning the project expectations with the stakeholders' interests.

Assessments for the complete RftR project are indicating that the initial dual objective (water safety and spatial quality) is achieved. The detailed evaluation documents are in Dutch and thus more insights cannot be provided. Assessment indicators have been applied for the effects of the flooding measures along the Rhine basin but not for the individual RftR projects (ICPR, 2016). Generally, individual project assessments are not available yet and that might be because many projects have not yet been exposed to real conditions in order to test their performance. For instance, the Noordwaard polder project was only tested for the first time, under real conditions, beginning of February 2020. Additionally, the effects of the RftR interventions on river navigation and dredging have been studied. According to van Vuren et al. (2015), the river interventions increased the dredging amounts and further hampered the inland navigation. Improving the inland navigation has not been considered as an initial condition in the RftR projects, while the increase in dredging amounts was not expected to be an issue when the projects were planned (van Vuren et al., 2015). Therefore, attention is drawn to additional requirements that should be considered in future river training works to reduce the dredging activity and enhance the natural processes that make the river navigable.

'Colorado Front Range: Recovery from 2013 floods' – Colorado river, United States of America

After having been hit by the disastrous floods of September 2013, Colorado river was subjected to changes using natural processes, river, and ecological functions as basis for providing flood risk management and resilience. Depositional zones, overflow channels and extensive vegetation were some of the measures adopted against flooding while ensuring that they do not cause problems either to adjacent properties or to downstream communities. Along with these measures, additional benefits were derived such as biodiversity abundance, habitat creation as well as valuable lessons for future flood responses.

Through the Colorado project, the important role of the budget and of the partnerships from the beginning until the end of the project are highlighted. Securing an available budget both for the realization of the project phases and the maintenance of the interventions makes the project feasible and meaningful. Furthermore, when treating such large catchments, stakeholder involvement becomes more difficult and time-consuming. In such cases, coalitions and partnerships become the main point of contact for concerned stakeholders as coalition staff are geographically close to and could easily interact with the project managers. Therefore, stakeholders' interests and needs are communicated and measures beneficial for all parties can be found.

The Colorado Front Range flood recovery project was realized in phases, starting from 2013 and was completed in 2018 – 2019. Therefore, complete assessments of the measures or performance indicators cannot, yet, be found. However, a recent study by Crow and Albright (2019), focusing on Colorado's disaster risk recovery project, revealed the effect of the intergovernmental relationships on the outcomes of disaster risk strategies. More specifically, they claim that more successful disaster recovery outcomes and learning processes occur when there are both plenty of resource flows and well-connected local and state governments, in all sectors. That was not the case for all the flood-affected Front Range communities and consequently varying results can be observed with respect to the involved parts and the level of learning.

'Belford Natural Flood Management Scheme' – Belford, Northumberland, United Kingdom

The Belford project is an interesting case study because the nature-based measures were the only way of tackling flood risk. Traditional flood defenses were not cost-effective and feasible due to the low number of population at risk and the lack of space for conventional infrastructure. The small catchment scale (approximately 6km^2) allowed the implementation of Catchment Runoff Management Plans. These plans use runoff attenuation features (RAFs) to manage and attenuate flow pathways while addressing water quality and habitat creation issues.

The Belford case study highlighted the factors of risk, monitoring and public involvement during a project. The initiative of the local people to raise awareness on the flood risk that they were regularly facing, mobilized the competent authorities to act. Since nature-based measures were the only feasible solution, the Belford project became an experimental area for the effectiveness of RAFs in flood risk reduction. For this purpose, monitoring combined with pilot projects played an important role throughout the project. Monitoring clarified the type and location of interventions while pilot projects examined their effectiveness and helped the community to uptake the project. Finally, the element of risk, in case of failure of the RAFs, was addressed. Although the failure consequences were not disastrous, the importance of proper maintenance or even future optimization of the RAFs' performance was highlighted.

The Belford project started in 2008, shortly after the 2007 floods, with a pilot pond project to test the effectiveness of such a measure. With the next flood event in 2008, the hydraulic performance of the pond was verified, and from then on 45 RAFs were implemented along the catchment offering the significant flood peak reduction (~12,000 m^3 storage). Existing assessments are focusing on providing an evidence base for the effect of RAFs in the reduction of flood hazard and its propagation downstream. The findings indicate that storage areas (either online or offline) can be effective in small catchments scales (~10 km^2) and for flood events from 1 in 12.5 to 1 in 100 – year events (Nicholson et al., 2012). However, research is still needed for the effectiveness of such measures in larger catchments or catchments with varying lithology and/or hydrological responses (the Belford catchment is small, rural, steep and has a rapid hydrological response).

Assessment indicators for the whole project were not found. However, the Environment Agency has applied benefit indicators per NBS implemented in Belford (leaky barriers, offline storage areas and runoff management), revealing their relative contribution to 10 benefits based on evidence: cultural activity, aesthetic quality, fluvial flooding, groundwater (GW) or surface water (SW) flooding, air quality, health access, low flows, climate regulation, habitat and water quality. Leaky barriers contribute significantly to water quality, habitat, climate regulation and mitigating fluvial flooding, moderately to low flows and mitigating GW or SW flooding and less to the rest. Similarly, offline storage areas significantly reduce fluvial flooding, SW or GW flooding, moderately contribute to habitat creation and low flows and less to the rest. Finally, also runoff management has the most significant contribution to fluvial, SW or GW flood mitigation and water quality while moderate contribution to all the rest. Therefore, the benefit indicators prove that all the implemented measures in Belford perform well for flood mitigation while complement each other in providing additional benefits.

Overall, the case studies highlighted the importance of maintenance and the public involvement in all the considered projects. Maintenance and its costs, although loosely mentioned in literature, in practice are crucial factors to consider and ensure even before the beginning of the project. Stakeholder participation was also stressed in all the case studies, both as a driving force but also as a necessary component, for the optimal realization and uptake of the project. Public involvement was also encountered in literature as a necessary component of the projects, but through the case studies their impact and importance along the project were highlighted. These two aspects were encountered in all three case studies. An additional aspect encountered in the Belford case study, for the first time so far, was the impact of failure in case the intervention will not work as expected or a more extreme event than anticipated happens. In such a case, an alternative plan should exist. All the aforementioned aspects feed into the framework indicators, which are extendedly explained in Section 3.4.2 '*Framework components*'.

3.2 Link between NBS for fluvial flood mitigation and SDGs

The Sustainable Development (SD) goals, targets and indicators are studied from the 2030 UN Agenda (United Nations General Assembly 2015). The goals are the broadest components of the Agenda followed by the SD targets and lastly the SD indicators. They all constitute versatile guidelines aiming at global sustainable development by 2030, while users need to adapt them in the context of interest. The Agenda is divided into five broad sections; People (Goals 1-5), Planet (Goals 6 and 12-15), Prosperity (Goals 7-11), Peace (Goal 16) and Partnership (Goal 17) (UNCTAD Development and Globalization: Facts and Figures 2016). The coupling between NBS and SDGs initially included all the five sections, but the analysis resulted in the 'Peace (Goal 16)' section not being addressed by the examined NBS projects. All the other sections are addressed, but not all the Goals of them.

For the coupling, starting point constitutes the SD targets because the goals themselves are very broad. However, often, even the targets need further specification because they address multiple topics at once. In such cases, the SD indicators are used in a complementary and validating way to ensure that all the dimensions addressed in the SD target are considered. The examination of the SD targets along with their respective indicators, brought up the following two interesting insights.

- The attainment of most of the SD targets requires cross-sectoral action. In other words, there is not a single action that fulfills the SD target rather than a combination of actions in several sectors. For instance, SD target 1.5 *“By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters”* could trigger actions in policy-making, society and economy. This holds true by looking at its SD indicators that mention affected people, GDP losses and national/local strategies.

- Many SD targets are sharing the same SD indicators. For instance, SD target 11.5, 13.1 and 1.5 are sharing the same SD indicator (1.5.1/11.5.1/13.1.1) “*Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population”*. Similarly, SD targets 8.4 and 12.2 are sharing two SD indicators (8.4.1/12.2.1, 8.4.2/12.2.2); “*Material footprint, material footprint per capita, and material footprint per GDP” and “Domestic material consumption, domestic material consumption per capita, and domestic material consumption per GDP*”. In total, twelve SD indicators are repeated (some with slight amendments) under two or three different SD targets. This phenomenon implies that by considering one SD indicator, progress can be achieved in multiple SD targets.

The aforementioned insights lead to a SD indicator-level link between the NBS and SDGs, executed as described in the relevant methodology Section 2.3 ‘Analysis of the Sustainable Development Goals (SDGs)’. The results of this procedure can be seen in Appendix B, Table 13. Overall, the NBS tackling fluvial flood mitigation can contribute to SDGs 1, 3, 6, 8, 9, 11, 12, 13, 15 and 17.

Surprisingly, not all the SD indicators of the relevant SD targets could be linked to the NBS. For instance, Target 6.3 *“By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally”* has two SD indicators; 6.3.1 *“Proportion of wastewater safely treated”* and 6.3.2 *“Proportion of bodies of water with good ambient water quality”*. NBS for fluvial flood mitigation can potentially contribute only to the 6.3.2 SD indicator and thus the 6.3.1 is omitted as irrelevant to the examined type of NBS in the present context. Similarly, all the SD indicators of the relevant SD targets are examined, and the results are presented in Figure 8, Appendix B. An overview of the percentage of relevant SD indicators per relevant SD target is presented in Figure 4.

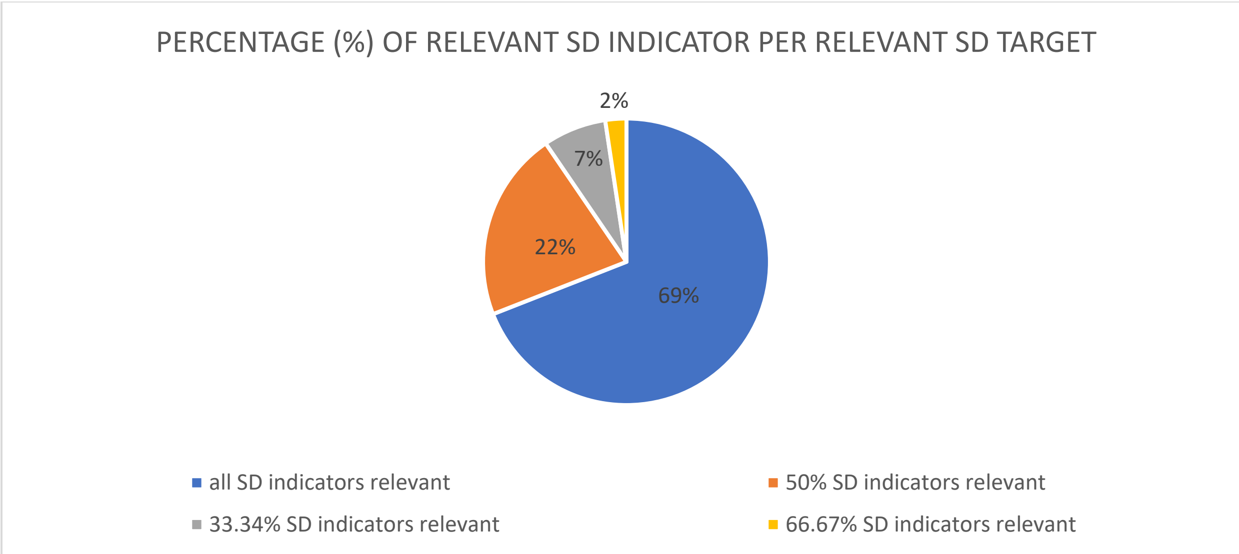

Figure 4: Percentage of relevant SD indicators per relevant SD target

Overall, out of the 42 relevant SD targets, 29 (69%) have all their SD indicators relevant, 9 (22%) have half of their SD indicators relevant, 3 (7%) have 33.34% relevant while 1 (2%) has 66.67% relevant. Percentages of 33.34 and 66.67 are derived when not all the aspects included in a relevant SD indicator are NBS-relevant. For instance, from the SD indicator 8.4.2 *"Domestic material consumption, domestic material consumption per capita, and domestic material consumption per GDP"* only the *'domestic material consumption'* and the *'domestic material consumption per GDP'* are considered relevant and are addressed in the present context. On the contrary, the 'domestic material consumption per capita' is considered irrelevant because expresses the consumption per person which is not encountered in the examined NBS projects. Therefore, the SD target 8.4 is separated into two SD indicators from which only the 2/3 of the second one is NBS relevant, resulting in the 33.34 percentage. The same applies to the SD indicator 12.2.2 (which is the same as 8.4.2) and SD indicator 3.9.2. Similarly, for the SD target 3.9 which has 66.67% (see Figure 8, Appendix B), it has 2 SD indicators (3.9.1, 3.9.2) of which the 3.9.1 is relevant while the 3.9.2 only the "*Mortality rate attributed to unsafe water*" is considered relevant. Hence, relevant SD indicators are the 3.9.1 and the 1/3 of the 3.9.2 = 50% + ((1/3) * 50%) = 66.67%.

3.4 Development of the assessment framework

A sequence of actions; identifying the problem, treating it by means of NBS and setting their requirements, conceptually form the deliverable framework. Its structure and components are formed by synthesizing the outcomes of the methods, as presented in Sections 3.1-3.3. Overall, the framework comprises of 5 stages, 15 themes and 52 indicators, in an increasing in detail order. This structure was created based on the review of existing assessment frameworks and methodologies. However, the conceptual consolidation and the number of the framework components were finalized with the combined insights from the literature review, the case studies, and the link to the SDGs.

In Figure 6, the complete NBS assessment framework can be seen, including all the stages, themes, and indicators. The framework components were reviewed every time that insights were gained from a new method, as highlighted in Chapter 2 '*Research approach and Methodology*'. This interdependency is represented in Figure 6 by the connecting arrows between the 'System Analysis', 'Setting of objectives' and 'Effects of NBS' stages, whose outcomes feed into each other and affect the respective decisions. The 'Process' and 'Monitoring' stages are happening during the entire NBS project, from the beginning till the end, and that is why they are having arrows (upper part of Figure 6) feeding into all the three 'System Analysis', 'Setting of objectives' and 'Effects of NBS' stages. The aforesaid can be graphically seen in Figure 5.

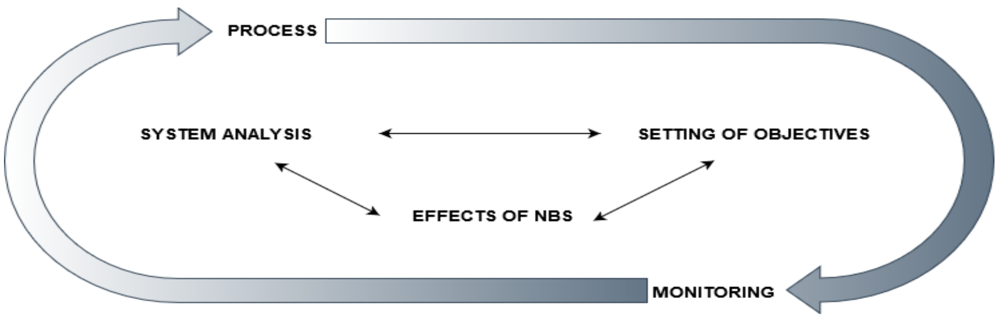

Figure 5: Interconnection between the framework stages

Closing the feedback loop (arrows at the bottom of Figure 6) allows for adaptive decision making and management. The 'Monitoring' and 'Process' stages are both dynamic phases providing constant input in the other three framework stages. Although the 'System Analysis' has relatively stable outputs, compared to the 'Setting of objectives' and 'Effects of NBS', additional background conditions might need examination in line with the changes to the other stages. The 'Setting of objectives' and 'Effects of NBS' are highly interdependent and dynamic. Depending on the extent to which any potential flood risk mitigation measure can address issues on the other domains, amendments are introduced, or its suitability is re-examined. Generally, changes to 'System Analysis', 'Setting of objectives' and 'Effects of NBS' stages are anticipated depending on the input from 'Monitoring' and 'Process' stages, seeking for an optimal combination of problem – measure – co-benefits. To this end, also the 'System Analysis', 'Setting of objectives' and 'Effects of NBS' feed into the 'Process' and 'Monitoring' stages indicating what needs to be discussed and monitored.

The deliverable framework is for expert end-users and was tested for ex-post NBS project application. In other words, the framework was developed and tested with NBS projects that were already completed. For ex-post application, the framework has an assessment character, providing information on the extent and the way the initial project objectives and additional outcomes, if any, were accomplished. Any expert end-user, by following the steps described below, can apply the framework, and get an overview of the current performance of the project, its contribution to the sustainable development goals and to the ecosystem services. Additionally, the framework provides a complete overview of the problem-measures-results, contributing to the transferability of the NBS practice.

1. Decide on the project that wants to assess which has to have as main objective fluvial flood mitigation
2. Get an overview of the project: project location and scale, main and secondary issues addressed, type and location of implemented measures, etc

3. Skim through the 15 themes and 52 indicators, keeping the ones relevant to the project and omitting the ones not addressed
4. Find project metadata to fill in the relevant framework indicators
5. Interpret the project metadata per framework indicator according to the UN 2030 Agenda and the Millennium Assessment to find the project contribution to the SDGs and ecosystem services

The way the project metadata are interpreted using the UN 2030 Agenda and the Millennium Assessment can be read in Sections 3.5.2 and 3.5.3 for the outcomes of the framework for the Eddleston Water Project. In the following paragraphs, the framework context along with its components are presented.

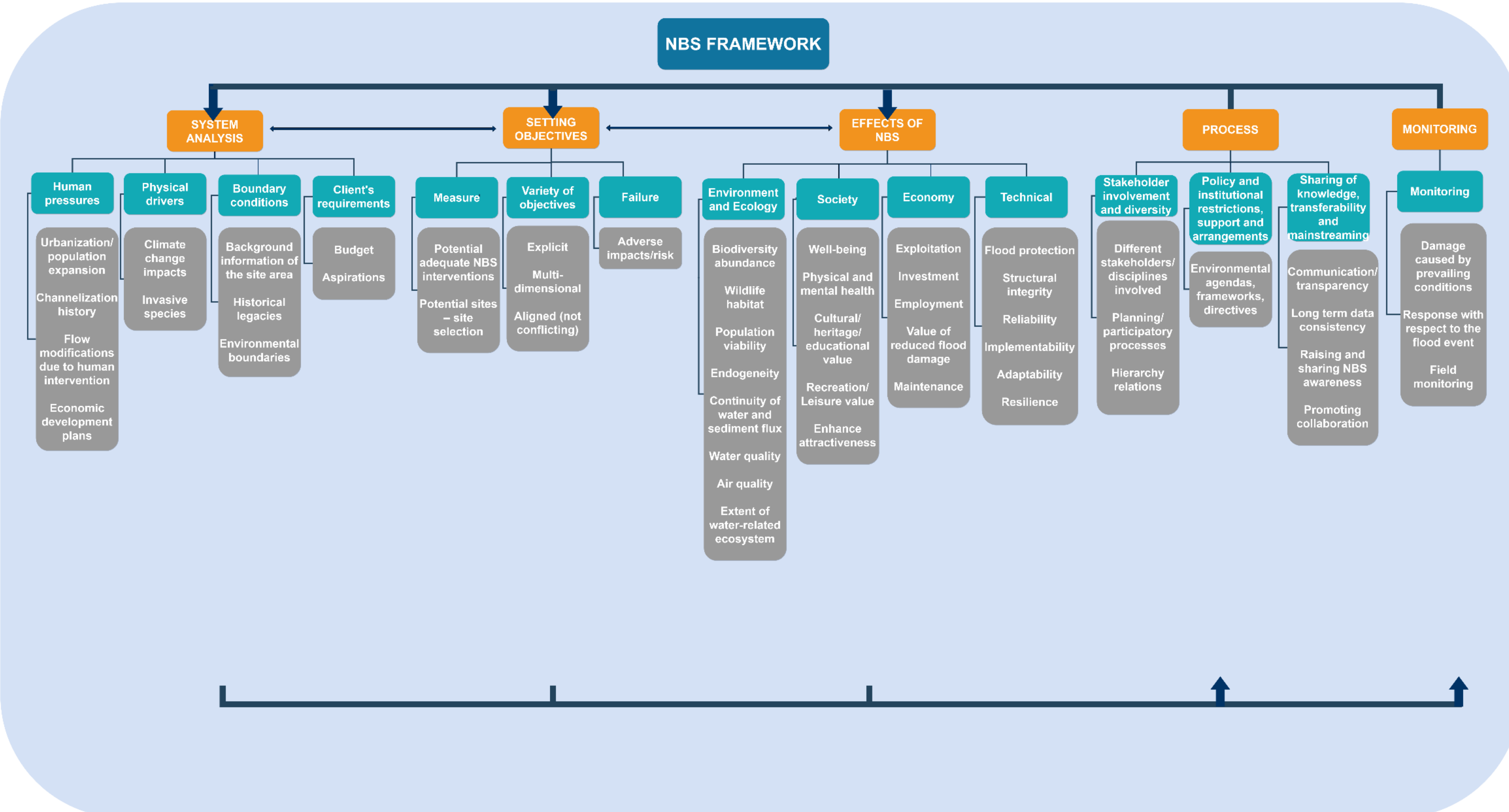

Figure 6: The deliverable NBS assessment framework. The orange boxes are the stages (5), blue boxes the themes (15) and the grey ones the indicators (52).

3.4.1 Framework context

This section defines the focus and the ambiguous terms found in literature, as employed for the present framework: NBS definition, ecosystem-services definition, (co-)benefits/costs, societal challenges addressed, link to sustainability.

The framework addresses the challenge of tackling flood mitigation in riverine ecosystems with NBS. In this project the EC NBS definition is adopted which expresses NBS as "*actions inspired by, supported by or copied from nature. Nature-based solutions aim to help societies address a variety of environmental, social, and economic challenges in sustainable ways… They ideally are energy and resource-efficient, and resilient to change, but to be successful they must be adapted to local conditions*". Thus, following this definition, NBS can not only comprise of natural elements but can also be realized with hybrid solutions, combining ecosystem elements and man-made structures (Table 2). Therefore, it can be argued that a dam is not considered NBS because either does not involve any natural element or is not providing the same opportunities to upstream and downstream communities.

	NATURE-BASED SOLUTIONS (NBS)	
Conventional/Traditional/Grey	**Hybrid**	**Natural**
Man-made engineered structural interventions built to address development and flood risk reduction objectives	Combination of ecosystem elements and man-made structural engineering interventions for addressing development and flood risk reduction objectives	Creation, protection or restoration of only ecosystem elements for addressing development and flood risk reduction objectives

Table 2: Differences of conventional interventions and NBS in terms of their structural strategies.
Source: Adapted from World Bank 2017

Furthermore, it is important to define the term ecosystem services, the societal challenges addressed and the sustainability approach as part of the current framework. The definition provided by the Millennium Assessment (2005) for the ecosystem services and the four categories are adopted. As for the direct benefits/costs and additional benefits/costs of the intervention, the direct benefits are related to the positive effects of the main challenge area of the NBS. Accounting for direct costs (along the same line with direct benefits), comes in contrast with the scope of the measure and thus only construction and maintenance costs are considered as direct ones. Accordingly, co-benefits/costs address the positive and negative impacts on all the other domains apart from the main domain (flood risk). Both benefits and co-benefits can involve supply or enhancement of ecosystem services. Respectively, co-costs might create demand or diminish ecosystem services. For instance, a side-channel for flood regulation will have direct benefits on water levels and peak discharge while recreational space and increase of biodiversity are co-benefits. Respectively, decrease in navigation, due to the lower water levels, is a co-cost. From an ecosystem services' perspective, a side-channel would enhance the regulating services whilst might negatively influence the energy produced by the river, a provisioning service.

The NBS framework focuses primarily on fluvial flood risk reduction, which comes close to the societal challenge of disaster risk reduction but establishes indicators that could reflect on most of the societal challenges as well. Finally, since the sustainability aspect is considered highly interconnected with the notion of NBS, the developed framework builds on the fundamental sustainability definitions, sets indicators that reflect on the three pillars and creates a direct link to the SDGs.

3.4.2 Framework components

Stages, themes, and indicators are the core elements of the framework. In line with was mentioned in Chapter 2 '*Research Approach and Methodology'*, they should address both the needs of the end-users and the functionality of the framework itself. For the end-users, the framework should constitute a complete NBS assessment approach in order to contribute to the guidance and transferability of the NBS practice. For this purpose, stages are defined which act as guidance in an assessment procedure, attempting an integrated approach. More detailed information about the stages is found in the themes and indicators. Both are components of the stages and can be considered as the intrinsic (contextual and functional) requirements of the framework, to which the NBS should comply to. Such requirements can be stakeholder involvement, technical principles and costs associated with the measure. In the next paragraphs the stages, themes and indicators are further elaborated.

3.4.2.1 Stages

The stages resulted from the review and synthesis of the general steps encountered in already existing assessment frameworks and methodologies, as established by the commonalities between the considered frameworks (see Section 3.1, paragraph '*General steps in assessment procedures– Commonalities'*). Therefore, the stages are five: System analysis, Setting of objectives, Effects of NBS, Process and Monitoring.

3.4.2.2 Themes

The themes are the components of the stages and have been developed based on insights from existing, in literature, categories of indicators and calibrated using case studies. Fifteen (15) themes, in total, have been defined. Nine (9) of them were initially formed by merging or keeping the categories of indicators found in literature (Table 12, Appendix A), five (5) I created them myself while one (1) arose from the case studies. The themes can also be seen in Figure 6 with blue color.

In literature, 22 different categories of indicators were encountered (Table 12, Appendix A). The merge was done such that conceptual duplications are avoided and a concise list of themes is created. Some of the categories remained unchanged, considering them directly as themes (e.g. human pressures, stakeholder involvement and diversity, economy). On the contrary, there are also themes that were not encountered in literature and were defined by me. Such themes are the physical drivers, boundary conditions, type of NBS, variety of objectives and technical. Then the themes were re-formulated or enriched based on the case study examination. On top of that, the failure theme was added resulting from the case study examination. All the 15 themes are presented and elaborated below. The presentation order is in accordance with the stage they belong to. Between the different themes, withing the stages, there is no prioritization.

- Human pressures

Human pressures are a stand-alone category found in literature and employed in the present assessment framework. Human pressures refer to stressors generated by or related to human activity such as urbanization, channelization of rivers or streams, human interventions, and economic development plans.

- Physical drivers

Physical drivers are defined in accordance with human pressures but referring to stressors generated by or related to physical phenomena such as climate change. The indicators of this theme provide further insights into what is considered physical driver in the present context.

- Boundary conditions

Boundary conditions frame the essential elements that should be considered at the selection and design of an intervention. They comprise both of the prevailing conditions and the abiotic factors in the area of interest. Characteristics of the site area could be land uses, topography, and litho-geology. Abiotic factors are temperature, salinity, light, and nutrient availability. According to Forbes et al. (2015) essential fluvial monitoring parameters are hydrological (rainfall, river velocity, water level), hydro-morphological (sedimentation) and ecological (fish, invertebrates, plants); which are encountered in the monitoring campaigns in contrast with the aforementioned abiotic factors.

- Client's requirements

The client's requirements are an important variable that should be considered for the realization of the NBS project. The client ensures budget availability throughout the project, making the completion of the project feasible. The consideration of the client in the process entails generating outcomes that satisfy the requirements of the client.

- Measure

This theme involves identifying and listing adequate types and locations of NBS interventions in order to tackle the problem of interest while providing additional benefits. Included actions in this theme could also be preliminary testing, modeling or even pilot projects for contributing to or ensuring the adequate measure selection and location.

- Variety of objectives

The variety of objectives theme is related to the form of actions and decisions that need to be set, scheduled and executed for the progress and completion of the intervention. For instance, decisions should be clear, accepted by everyone and reflect the multi-benefit character of the NBS.

- Failure

The failure theme addresses the case where either the intervention does not work as expected or a more extreme event than anticipated happens. In these cases, it is advisable to have an alternative plan of action for avoiding severe negative implications. Such a plan can be considered a more practical matter and that is why emerged from the case study examination.

- Environment and ecology

The environment and ecology theme involves indicators coming from the literature categories of 'biodiversity', 'environment/planet' and 'ecosystem services and processes'. Therefore, as implied by the aforementioned literature categories, this theme is related to the fauna and flora of the environmental ecosystems and intrinsic ecosystem processes such as the continuity of water and sediment and CO_2 sequestration.

- Society

From the literature categories of 'socio-cultural', 'well-being and health' and 'ecosystem services and processes', the society theme emerged. This theme includes factors related to the physical and mental human health, well-being, and leisure time.

- Economy

The theme of economy was also encountered as a stand-alone category and thus does not include any other literature categories. This theme is associated both with the financial outcomes of the NBS intervention as well as to the investment needed for the realization and maintenance of the project itself.

- Technical

The technical theme is a newly introduced one, not included in any of the identified literature categories. It refers to the fulfillment of the objective of the intervention (flood protection) and to the engineering characteristics that the intervention should comply with. The engineering characteristics comprise of structural integrity, reliability, implementability, adaptability and resilience and are described in Section 3.4.2.3 '*Indicators*' (Table 3).

- Stakeholder involvement and diversity

Stakeholder involvement and diversity involve the 'stakeholder's diversity' and 'knowledge, experience and innovation' literature categories. This theme addresses the importance of the diverse stakeholder presence and participation throughout the whole project as well as the type of processes that yield this.

- Policy and institutional restrictions, support and arrangements

This theme represents the policy frameworks and guidelines that have to be considered in the project. Such policies and frameworks can be either environmental agendas or water and flood-related directives, such as the Floods Directive 2007/60/ EC.

- Sharing of knowledge, transferability and mainstreaming

The theme of sharing of knowledge, transferability and mainstreaming includes the 'knowledge, experience and innovation', 'technological opportunities' as well as 'project characteristics' literature categories (Table 12, Appendix A). It addressed the need for broadening the knowledge base regarding NBS applicability, potentials and performance and thus contributing to their mainstreaming.

- Monitoring

The name of this theme coincides with the name of the respective stage that belongs to. Monitoring is the means for broadening the NBS knowledge base and should be part of every project. It can provide important information even before the project implementation. An optimal monitoring campaign would start before the NBS planning and would continue after the NBS implementation.

3.4.2.3 Indicators

The framework indicators are in total fifty-two (52). Indicators, in this context, act as a measure or metric base that condenses complexity and provides information (Haase et al., 2014). Indicators are useful tools for benchmarking, measuring, and comparing but also reflect on the characteristics of the intervention. The final list of indicators was created by (i) collecting already existing ones from literature, calibrating them, and defining additional ones based on (ii) the insights of the case studies and on (iii) the link between NBS and SDGs. Overall, 37 indicators were identified from literature, 6 from case studies, 2 from the SDGs and 7 were created by me because I considered them essential and relevant to NBS projects and were missing from the examined references. The indicators per theme and per stage, a short description of them and their sources are presented in Table 16, Appendix D.

The role of all the 52 framework indicators is not the same; however, if combined, they result in the integrated assessment character of the framework. On the one hand, the indicators under the 'Setting of objectives', 'Effects of NBS' and 'Process' stages are used as an evaluation tool for the attainment of the objectives and the multi-benefit character of the NBS works. The indicators of these three stages are the ones directly associated with assessing NBS projects for fluvial flood mitigation. On the other hand, the indicators under the 'System Analysis' and 'Monitoring' stages are more generic and when combined with the others, they formulate an integrated framework that contributes to the transferability of the NBS practice. Knowing what was the problem ('System Analysis', 'Monitoring'), how it was treated ('Setting of objectives', 'Process') and what were the outcomes ('Effects of NBS', 'Process'), give a complete overview for successfully transferring the NBS practice. The next paragraphs elaborate on which indicators come from literature, case studies and the SDGs, respectively.

Approximately 150 indicators were found in literature which were narrowed down to 37 with the procedure described in Section 3.1, paragraph '*Existing indicators'*. However, same as for the themes, whenever the literature indicators were not enough, additional indicators were introduced. Such indicators are the budget and aspirations (indicators of the client's requirements theme) and the indicators for the technical theme (Table 3). The indicators found in the examined literature, are assigned either to themes that conceptually overlap with the category in literature that they belonged to (e.g. economy and human pressures indicators) or were part of another category but, due to the merging process of the categories, ended up in another theme. This is the case for many of the indicators falling into the 'socio-economic', 'socio-cultural' and 'health and well-being' categories, that are currently merged under the society theme.

ENGINEERING	DEFINITION
Structural integrity	Appropriate material and technique so that it does not become unsteady or unbalanced but retains its resistance to loading (strength, stability, stiffness)
Reliability	Smooth and well function of the structure without many repairs
Implementability	Whether it is feasible to construct and operate the infrastructure
Adaptability	Taking potential future change in the function of an infrastructure into account in the design phase
Resilience	Capacity of the intervention to withstand a second shock of similar magnitude to the first one and yet retain its structural integrity and continue meeting functional requirements

Table 3: Indicators of the technical theme and their definition. Adapted from: Slinger, J.H. (Jill) (2016) Engineering: Building with Nature 101x video #06 – Distilling Engineering Design Principles. TU Delft. Dataset.

The case studies introduced six (6) additional indicators, most of them falling into the 'Process' stage in the themes of stakeholder involvement and sharing of knowledge. Such indicators are the hierarchy relations and the transparency in communications between the involved parts. The hierarchy relations address the gap between the stakeholders and the project managers which hampers the communication and consideration of stakeholders' needs and interests. The transparent communication results in the alignment of the project outcomes with its initial expectations. It involves meetings and workshops between the project managers and the stakeholders, communicating potential project delays and problems. This way, the interest and involvement of stakeholders are enhanced leading to the social support of the project. An additional indicator is also the maintenance falling into the economy theme, representing the amount of money spent on maintenance. Finally, case studies revealed what should be monitored in NBS projects, creating new indicators in the monitoring theme. Such aspects are the hydrological processes in the site of interest, the impact of the surroundings to the intervention and its response to the flood event.

Coupling, between the NBS and SDGs, was done at the level of the most detailed component of the Agenda, the SD indicators (see Section 3.3 '*Link between NBS for fluvial flood mitigation and SDGs*'). In line with that, the framework indicators are linked to the SD indicators. Initially, the possibility of correlating the SD indicators to the already collected framework indicators is examined. Therefore, according to the notion of each relevant SD indicator, a framework indicator was assigned. For instance, the SD target 1.5 has SD indicators reflecting upon the social, economy and process themes and thus different framework indicators are assigned to them; 'well-being' (1.5.1), 'value of reduced flood damage' (1.5.2) and 'Environmental agendas, rigid spending frameworks, compliance to directives' (1.5.3 & 1.5.4) respectively. The common use of SD indicators between SD targets was addressed by using one framework indicator per common SD indicator, whose tracking could contribute to the multiple relevant SD targets.

Generally, the link between the SD indicators and the NBS framework is feasible by using the already collected indicators. However, the SD-framework indicator coupling yielded two (2) additional framework indicators and some re-arrangements of the already collected ones. The 'extent of water-related ecosystem' and the 'well-being' indicators are the new additions in the environment and ecology and society themes, respectively. They are both introduced because the already collected framework indicators could not express them. Table 4 shows the correspondence of the framework indicators to the SD indicators. It was found that 21 out of 52 framework indicators address the relevant SD indicators.

The third column of Table 4 is the direct and indirect relationship between the NBS and SDGs. Direct and indirect relations are established in order to make the connection to the ecosystem services according to the primary and secondary objectives of the NBS (see Section 3.4.1 '*Framework context*'). Following this line, direct relation is considered any effect of the flood risk in any sector while any other effect, coming from the NBS implementation, in any sector is considered as indirect relation. In Table 4, it can be seen that procedural and legislative (institutional, governmental, frameworks etc) arrangements do not have any direct or indirect relation assigned to them. This is because ecosystem services do not include such arrangements.

Finally, in Table 5 there are also 12 relevant SD indicators referring to aspects in which NBS can potentially contribute to if they are successfully upscaled and mainstreamed. Such SD indicators treat management issues or NBS approaches which are difficult to be benchmarked by examining only a few NBS projects. For instance, SD indicators 6.5.1 and 6.5.2 talk about the degree of integrated water resources management and the proportion of the transboundary basin area with an operational arrangement for water. Although the aforementioned SD indicators are linked to the notion of the NBS projects, an answer to them requires mainstreaming and upscaling of the NBS projects. Therefore, no framework indicator has been assigned to them, but the application of the framework might provide some insights regarding the extent to which they are addressed in a single NBS project.

#	FRAMEWORK INDICATORS	SUSTAINABLE DEVELOPMENT INDICATORS	RELATION TO NBS
1	well - being	1.5.1 Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population	Direct
		3.9.1 Mortality rate attributed to household and ambient air pollution	Indirect
		3.9.2 **Mortality rate attributed to unsafe water,** unsafe sanitation and lack of hygiene (exposure to unsafe Water, Sanitation and Hygiene for All (WASH) services)	Indirect
		11.5.1 Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population	Direct
		13.1.1 Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population	Direct
2	value of reduced flood damage	1.5.2 Direct economic loss attributed to disasters in relation to global gross domestic product (GDP)	Direct
		11.5.2 Direct economic loss in relation to global GDP, damage to critical infrastructure and number of disruptions to basic services, attributed to disasters	Direct
3	environmental agendas, rigid spending frameworks, compliance to directives	1.5.3 Number of countries that adopt and implement national disaster risk reduction strategies in line with the Sendai Framework for Disaster Risk Reduction 2015–2030	-
		1.5.4 Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies	-
		11.b.1 Number of countries that adopt and implement national disaster risk reduction strategies in line with the Sendai Framework for Disaster Risk Reduction 2015–2030	-
		11.b.2 Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies	-
		13.1.2 Number of countries that adopt and implement national disaster risk reduction strategies in line with the Sendai Framework for Disaster Risk Reduction 2015–2030	-
		13.1.3 Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies	-
		15.8.1 Proportion of countries adopting relevant national legislation and adequately resourcing the prevention or control of invasive alien species	-
4	water quality	6.3.2 Proportion of bodies of water with good ambient water quality	Indirect
5	extent of water related ecosystems	6.6.1 Change in the extent of water-related ecosystems over time	Indirect
6	planning/ participatory processes	6.b.1 Proportion of local administrative units with established and operational policies and procedures for participation of local communities in water and sanitation management	-
		12.7.1 Number of countries implementing sustainable public procurement policies and action plans	-
7	exploitation	8.1.1 Annual growth rate of real GDP per capita	Indirect
		8.2.1 Annual growth rate of real GDP per employed person	Indirect
		8.9.1 Tourism direct GDP as a proportion of total GDP and in growth rate	Indirect
8	employment	8.3.1 Proportion of informal employment in non-agriculture employment, by sex	Indirect
		8.5.2 Unemployment rate, by sex, age and persons with disabilities	Indirect
9	implementability	8.4.2 **Domestic material consumption**, domestic material consumption per capita, and domestic material consumption per GDP	Indirect
		12.1.1 Number of countries with sustainable consumption and production (SCP) national action plans or SCP mainstreamed as a priority or a target into national policies	Indirect

#	FRAMEWORK INDICATORS	SUSTAINABLE DEVELOPMENT INDICATORS	RELATION TO NBS
		12.2.2 **Domestic material consumption**, domestic material consumption per capita, and domestic material consumption per GDP	Indirect
10	investment	8.4.2 Domestic material consumption, domestic material consumption per capita, and **domestic material consumption per GDP**	Direct
		12.2.2 Domestic material consumption, domestic material consumption per capita, and **domestic material consumption per GDP**	Direct
		9.5.1 Research and development expenditure as a proportion of GDP	Direct
		11.4.1 Total expenditure (public and private) per capita spent on the preservation, protection and conservation of all cultural and natural heritage, by type of heritage (cultural, natural, mixed and World Heritage Centre designation), level of government (national, regional and local/municipal), type of expenditure (operating expenditure/investment) and type of private funding (donations in kind, private non-profit sector and sponsorship)	Direct
11	air quality	9.4.1 CO2 emission per unit of value added	Indirect
12	different stakeholders/ disciplines involved	11.3.2 Proportion of cities with a direct participation structure of civil society in urban planning and management that operate regularly and democratically	-
		12.7.1 Number of countries implementing sustainable public procurement policies and action plans	-
13	recreation/ leisure value	11.7.1 Average share of the built-up area of cities that is open space for public use for all, by sex, age and persons with disabilities	Indirect
14	enhance attractiveness	11.7.1 Average share of the built-up area of cities that is open space for public use for all, by sex, age and persons with disabilities	Indirect
15	adaptability	11.a.1 Proportion of population living in cities that implement urban and regional development plans integrating population projections and resource needs, by size of city	-
		13.2.1 Number of countries that have communicated the establishment or operationalization of an integrated policy/strategy/plan which increases their ability to adapt to the adverse impacts of climate change, and foster climate resilience and low greenhouse gas emissions development in a manner that does not threaten food production (including a national adaptation plan, nationally determined contribution, national communication, biennial update report or other)	-
16	cultural/heritage/ educational value	12.8.1 Extent to which (i) global citizenship education and **(ii) education for sustainable development (including climate change education)** are mainstreamed in (a) national education policies; (b) curricula; (c) teacher education; and (d) student assessment	Indirect
17	biodiversity abundance	15.1.2 Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type	Indirect
18	continuity of water and sediment	15.3.1 Proportion of land that is degraded over total land area	Indirect
19	promoting collaboration	17.14.1 Number of countries with mechanisms in place to enhance policy coherence of sustainable development	-
		17.17.1 Amount of United States dollars committed to (a) public-private partnerships and (b) civil society partnerships	-
20	wildlife habitat	15.5.1 Red List Index	Indirect
21	population viability	15.5.1 Red List Index	Indirect

Table 4: Association between Sustainable Development (SD) indicators and NBS framework indicators. The bold parts of SD indicators (or targets) denote the relevant part of the SD indicator (or target), when the whole SD indicator (or target) is not relevant to the current research scope.

#	SUSTAINABLE DEVELOPMENT INDICATORS
1	6.5.1 Degree of integrated water resources management implementation (0–100)
2	6.5.2 Proportion of transboundary basin area with an operational arrangement for water cooperation
3	12.6.1 Number of companies publishing sustainability reports
4	13.3.2 Number of countries that have communicated the strengthening of institutional, systemic and individual capacity-building to implement adaptation, mitigation and technology transfer, and development actions
5	13.b.1 Number of least developed countries and small island developing States that are receiving specialized support, and amount of support, including finance, technology and capacity-building, for mechanisms for raising capacities for effective climate change-related planning and management, including focusing on women, youth and local and marginalized communities
6	15.6.1 Number of countries that have adopted legislative, administrative and policy frameworks to ensure fair and equitable sharing of benefits
7	15.9.1 Progress towards national targets established in accordance with Aichi Biodiversity Target 2 of the Strategic Plan for Biodiversity 2011–2020
8	15.a.1 Official development assistance and public expenditure on conservation and sustainable use of biodiversity and ecosystems
9	17.6.1 Number of science and/or technology cooperation agreements and programmes between countries, by type of cooperation
10	17.15.1 Extent of use of country-owned results frameworks and planning tools by providers of development cooperation
11	17.16.1 Number of countries reporting progress in multi-stakeholder development effectiveness monitoring frameworks that support the achievement of the Sustainable Development Goals
12	17.18.1 Proportion of sustainable development indicators produced at the national level with full disaggregation when relevant to the target, in accordance with the Fundamental Principles of Official Statistics

Table 5: Sustainable Development indicators not corresponded to framework indicators because they are related to the general NBS notion and its potential achievements.

3.5 Testing the assessment framework in practice: the Eddleston Water Project case study

The testing of the framework is achieved by implementing it in an already realized project, aiming at revealing framework limitations, gaps, and points for further improvement. The Eddleston Water Project is used as a testing case study. It is chosen because of various reasons. Primarily, it adopts a multi-benefit approach, aiming at exploring whether flood risk at the Eddleston and Peebles towns can be reduced by means of NBS while improving the ecological condition of the river and working with landowners and communities for enhancing sustainable land management practices. Furthermore, having implemented the measures since 2016, there are already preliminary outcomes from the monitoring campaigns which are documented in plenty publicly available references, in English. Finally, it is part of the NSR Interreg Building with Nature program, providing good links in case expert consultation is needed.

The Eddleston Water Project is a NBS project realized at the Eddleston Water catchment (red rectangle, Figure 7), part of the Tweed catchment (white outline, Figure 7), located at the Scottish borders. Eddleston Water is a tributary of the River Tweed, about 18km long, flowing south and joining the main river at Peebles town. The Eddleston catchment occupies approximately 70 km^2 out of the 5,000 km^2 of the Tweed catchment and due to its small size favors an integrated hillslope to floodplain natural flood risk management approach. The project site is considered ideal for NBS implementation due to its clear distinction between sources, pathways and receiving flow areas. On top of that, it is a simple river system with steep slopes on both sides of the main stem.

Figure 7: Eddleston catchment. Retrieved from a presentation by Chris Spray and Hugh Chalmers

The project started in 2009/10 with a scoping study, followed by the installation of the monitoring network in 2010–2012 and planning. The implementation of the measures lasted from 2013 to 2016. Currently, further monitoring and evaluation of the NBS measures are carried out, funded by the EU North Sea Region Interreg program. Throughout the project, close stakeholder consultation was necessary, because many parts of the project site were privately-owned, which lead to wide community engagement and uptake of the project. Generally, stakeholders and communities are constantly involved through regular meetings and surveys, ensuring productive continuation of the project.

Given the detailed monitoring outputs of the Scoping Study in 2010 regarding the prevailing site conditions combined with landowners' consultation, adequate and feasible nature-based measures were implemented. A short overview of the interventions and their goals are provided below. For an extended description of the project, reference is made to the Eddleston Water Project Report (Spray et al., 2017).

- 207ha of planting (>310,000 native trees) - both riparian and woodland at the headwaters and floodplains aiming at increasing landscape roughness and infiltration and, thus, slowing down the overland flow.
- 116 features of large woody structures (also called engineered log jams/flow restrictors/leaky dams/ flow attenuation features) - aiming at delaying both the flood peak and the volume of water flowing downstream in high flows and facilitating its conveyance on the floodplains. Additionally, they contribute to reducing the in-channel aggradation.
- 27 off-line ponds (wetland creation) – currently in the upper catchment and only one in the floodplains; under testing for more floodplain ones. Their flood management contribution is to store temporarily the floodwaters.
- 2.2km or re-meandering – in 3 reaches (Cringletie, Lake Wood and Shiphorns) along the watercourse. Re-meandering increased the watercourse length and reduced the gradient resulting in slower channel velocities and thus flow. In terms of ecology, newly created in-channel habitat has encouraged both physical heterogeneity and processes as well as ecological diversity.
- 900m of flood bank removal – along the main stem where the watercourse has been reunited with its floodplains, increasing the water attenuation and storage capacity.

Current measurements and monitoring outcomes suggest a promising project where further monitoring is needed for examining the full potential of the measures at a catchment scale. More specifically, although re-meandering has, yet, a modest impact on the delay of the median peak time between Eddleston and Peebles, has significantly contributed to the diversity and increase of habitat areas within the re-meandered channels. Regarding the wetlands, measurements of the upper-catchment ponds' performance suggest that they can provide immediate runoff arrest by storing water. However, complementary modeling proves that this will only have a small effect on the overall sub-catchment runoff generation. On the contrary, a series of floodplain ponds appear to have better results in locally reducing and delaying flood peak discharge for a 1.5-year event, but their relative contribution to catchment scale is yet to be examined. Flow restrictors also delay the flood peak (30-60 mins) without, though, reducing its volume. Existing mature broadleaf woodlands offer significant infiltration capacity (5-8x of that under grazed pasture), reducing runoff generation during flood events. However, the same is still under examination for newly planted (coniferous or broadleaf) plantations due to their early development stage. From an ecological perspective, the ultimate purpose of the project is to improve the ecological status of the river according to the EU Framework Directive (WFD 2000/60) requirements. Since water quality is not a problem, attention is given to the most degraded river sections. Extra channel length and removal of the embankments are expected to improve the hydro-morphology of the river. Although such outcomes will take longer to be measurable, preliminary results show that 12-months after restoration, community diversity has steadily increased to pre-disturbance levels, creating expectations of further increase beyond the recorded levels prior to channel re-configuration.

FRAMEWORK INDICATORS	DESCRIPTION	META DATA
Urbanization/population growth/expansion	Rates of population living or expanding on natural floodplains	In the last 50 years increased density and housing development in the eastern side of the valley (Werritty et al., 2010). However, land planning laws very strict, controlling urbanization on the floodplains.
Channelization history	Whether the stream has undergone any straightening or cut-off of meanders	By 1811 or earlier, straightening and channelization of much of the 6.5 km main stem from Waterheads to Cringletie, losing up to 16% of its length (Werritty et al., 2010; Spray et al., 2017).
Flow modifications due to human intervention	i.e.Beaver trapping, placer and gravel mining, timber harvest and tie drives, garden walls, residential structures	Overall engineering interventions: 14 locations with bank protection, 3 bridge crossings, 4 weirs and 1 ford (Werritty et al., 2010) ✓ Bank protection poses the most severe engineering impact on the river. ✓ Bridges: Five bridges have low span which may impede high flows, potentially trap debris and thus increasing flood risk. ✓ Weirs: only 2 significant to channel processes. One of them has significant morphological effect on the channel because it causes backwater effects upstream that forces slow glide morphology trapping grave-sized sediment. And immediately downstream a plunge pool has formed. ✓ Ford—crossings: not significant impact on channel morphology maybe responsible for some input of fine sediment during high flows.
Economic development plans	i.e.Construction of roads and railroads	✓ Development policies of the Scottish Borders Council ✓ Piecemeal nature of individual farm plans and the Scottish Rural Development Programme (SRDP) process ✓ Road from Peebles to Eddleston alongside the river (Werritty et al., 2010)
Climate change impacts	i.e. Changes in hydrograph	Current projections for rainfall patterns over the next century predict a 10–30% winter precipitation augmentation in the Scottish Borders by 2080, which will be reflected in south flowing tributaries of the Tweed catchment (Werritty et al., 2010). Generally, climate change was not in the starting considerations of the project but is gaining more and more attention and currently further research is done on the effect of the project on climate change impacts.
Invasive species	Whether invasive species have altered the ecosystem (regeneration, natural) processes	The presence of alien species gives no cause for concern (Werritty et al., 2010). It was not part of the aims, objectives, or constraints.

FRAMEWORK INDICATORS	DESCRIPTION	META DATA
Background information of the site area	land uses, geology, topography, fauna and flora of the site, past flooding events/flooding history of the site area, archaeological findings, roads and railways nearby, river channel	✓ Land uses: most widespread are improved grassland (40%), coniferous plantations (13%). Spatial distribution: moorland and rough grazing occupies mostly higher ground on the west while the uplands on the east are dominated by coniferous plantations. The valley slopes are mainly improved grassland for grazing sheep and cattle, and the valley bottoms improved grassland for grazing and silage production. Between valley bottoms and the stream there is mixed woodland plantations while closer to the stream riparian woodland (Spray et al., 2017). ✓ Geological structure: Peat deposits on the northern and eastern margins of the catchment. Steep eastern tributaries (e.g. Longcote Burn) have local bedrock exposures. Most of the floodplain dominated by a layer of silt and/or clay, 0.5–2 m thick, probably overbank alluvial deposits. The underneath layer is dominated by alluvial sand and sandy gravel, to 4–8 m depth, containing lenses of silt, clay and peat. In the floodplain centre this overlies a layer of glaciofluvial sand and gravel 4–8 m thick (at a depth of 8– 13 m), with discontinuous intervening lenses of clay and peat (Dochartaigh et al., 2019). ✓ Groundwater: The groundwater stores a lot of catchment water and in the case of a flood event might store up to 0.3 m^3/s of water per 100 m river length while the river is still in-bank. The floodplain aquifer system contains groundwater of different ages, but generally less than a decade old. Groundwater across most of the floodplain, except near its edges, is more closely coupled to river flow than local rainfall (Spray et al., 2017). At a broad scale, the Eddleston floodplain aquifer is dominantly permeable and unconfined (Dochartaigh et al., 2019) ✓ Ecosystem services: According to research of the Scottish Land Use Strategy (LUS) in the Eddleston catchment there were six key ecosystem services identified by local stakeholders as important and a priority in this catchment. These include flood control (NFM), alongside crop, livestock and timber production, vegetation carbon resource and water quality regulation (Spray et al., 2017) ✓ Past flooding events: Long flooding history with most recent ones December 2015, January 2016 ('Working with Natural Flood Management: Evidence Directory')
Historical legacies	Taking into account any historical lay-out of the area	Scottish Natural Heritage and Historic Environment Scotland work with site owners to manage flooding where appropriate at designated environmental and/or cultural heritage sites. Eddleston seems to include environmental designated areas but not any cultural heritage areas which are located more downstream of Peebles (Potentially Vulnerable Area 13/04 report)

FRAMEWORK INDICATORS	DESCRIPTION	META DATA
Environmental boundaries	Temperature, salinity, light and nutrient availability, sediments, rainfall, size of the materials available for use, waves, wind	✓ Hydraulic characteristics of the project site: Bankfull discharge in the Eddleston Water at the site is estimated at 9.92m^3/s (Werritty et al. 2010) and average flow in 2012 was 0.75 m^3/s ✓ Hydrology: Mean annual rainfall on the high ground either side of the valley (Moorfoot Hills to the east rising to 543 m, Cloich Hills to the west rising to 462 m) exceeds 1500 mm, declining to less than 850 mm in the valley (Spray et al., 2017) ✓ Hydromorphology: The two main sources of coarse sediment input to the channel are bank erosion and tributaries. Much of the Eddleston Water has banks with near vertical, unvegetated faces which are often not actively supplying appreciable amounts sediment to the channel and are not included as important sediment sources (Werritty et al. 2010)
Budget	Permitting and funding constraints, available amount of money for the intervention	✓ Main funder has been Scottish Government but Tweed Forum has been successful in securing a very wide range of public and private funding sources (Spray et al., 2017) ✓ Public sector – Scottish Government, Water Environment Fund, SRDP, Scottish Borders Council ✓ Private (and charitable) sector – Forest Carbon, CEMEX, Woodland Trust, Scottish Power and landowner contributions. To date, total cash cost of the project 2.2 million pounds, with on-going monitoring.
Aspirations	i.e. integrated flood river management approaches, catchment scale approaches	✓ Promote sustainable and wise use of the Tweed catchment ✓ Holistic management of river basins based on the principles of integrated catchment management (ICM) in an integrated, efficient and cost-effective manner ✓ Empirical approach from the outset, based on detailed data collection, measurement and monitoring, rather than relying solely on models (Spray et al., 2017; Werritty et al., 2010)
(Potential) adequate NBS interventions	Number and type (materials used) of NBS considered	15 types of NFM measures were identified by Dundee University as appropriate for potential development in the Eddleston Water. These were then targeted at those areas where they would have greatest impact under consultation with landowners. Eventually, types of measures applied: breach/set back of embankments/artificial banks, re-meander channel, woodland planting (hillslope, floodplain, riparian and transverse strips), creation of storage ponds (wetlands), large woody structures/flow restrictors/log jams (Werritty et al., 2010; 'Working with Natural Flood Management: Evidence Directory')
(Potential) site selection	Number and identification of potential implementation sites	From 2011 where the installation of the monitoring network took place, potential sites were identified and Tweed Forum contacted several landowners to identify sites where NFM measures could be feasible. For instance, re-

FRAMEWORK INDICATORS	DESCRIPTION	META DATA
		meandering: The choice of sections where re-meandering occurred was driven by two factors; the straightened state of the existing channel and the willingness of the landowner(s) to allow work to be undertaken (Spray et al., 2017)
Explicit	Understood by all the involved parts	✓ Between experts: The objectives have been set by SEPA and agreed with flood risk management authorities following consultation (Potentially Vulnerable Area 13/04 report) ✓ With stakeholders: Given the importance of gaining the trust of the local community and key stakeholders, the project has been run and managed by the Tweed Forum. Leaflet, interviews and community presentations were means of involving and consulting with the locals
Multi-dimensional	Address effects on all possible sectors	The project adopted a multiple-benefits approach, thus any NFM measures introduced should, where possible, also address the ecological degradation without impacting existing agricultural activities of the Eddleston Water and vice-versa.
Aligned (not conflicting)	Not fulfilling one requirement by creating major disturbances in another field	Most significant trade-off was that because the landowners were cooperating voluntarily, the best quality productive farmlands could not be used without their consent. Apart from that there was some tension regarding the benefits coming from the measures, in hydrological and ecological terms, but common ground was always reached.
Adverse impacts/risk	Alternative plan in case the intervention will not work as expected	Main focus of the Flood Risk Management Strategy: for priority areas within each district (called Potentially Vulnerable Areas) there is a description of the causes and consequences of flooding; the agreed goals or objectives of local flood risk management; and the specific actions that will deliver these actions over the short to long term. https://www2.sepa.org.uk/FRMStrategies/pdf/pva/PVA_13_04_Full.pdf
Biodiversity abundance	% of animals using the site and % vegetation cover, inclusion of the 'Nature 2000' network	✓ EU Special Area of Conservation (SAC) for its salmon, lampreys, otters and aquatic plants ✓ Macroinvertebrate: A rapid recolonization of re-meandered channels by aquatic macroinvertebrates. Species richness and diversity increased post-restoration ✓ Salmonid: Eddleston important for breading salmon. Improved salmonid habitat due to restorations in terms of the provision of suitable micro habitat and overall physical diversity. Total available habitat area increased due to the increased channel length and width (Spray et al., 2017)
Wildlife habitat	% of Generation of habitat for flora and fauna	An increase in overall physical diversity of habitats within re-meandered sections, and an increase in habitat area, both greater where there has been a greater degree of re-meandering (Spray et al., 2017).
Population viability	Last of a species in time, natural materials that enhance the fauna abundance	Potential increase in the number and extent of spawning habitats for salmon, as indicated by changes in the spatial distribution of favored micro-habitats for salmonids (Spray et al., 2017).

FRAMEWORK INDICATORS	DESCRIPTION	META DATA
Endogeneity	% of invasive species	Invasive species are treated by the program run by the Tweed Forum under SEPA. Nothing additional done in the context of the Eddleston project.
Continuity of water and sediment flux	Erosion, sediment traps, amount of sediment captured	✓ Morphological units: Generally, there is much greater morphological diversity through the reach as a result of restoration, with the most significant change happening at the Lakewood reach with the biggest increase in length (re-meandering). Generally, restoration has resulted in a much more diverse channel morphology, with all morphological unit types present in 2015/6 compared to only three in 2009 (Spray et al., 2017) ✓ Grain size per geomorphic unit: following restoration, the overall grain size and variation was seen to decrease, with units post restoration being better sorted, and grain sizes more distinctive and specific per geomorphic unit (Spray et al., 2017)
Water quality	Nitrates, phosphorus and suspended sediments, water discharge (m3/s)	Water quality is generally good in the Eddleston apart from some isolated incidents of diffuse organic pollution and increased nitrate levels have been in the recent decades. Generally, was not an objective, aim or constraint of the project (Spray et al., 2017).
Air quality	% of CO2 captured by the vegetation/natural elements used	No specific measurements because not a key project issue. However more research is being currently done to this direction.
Extent of water-related ecosystem	% of change of the extent of the water-related ecosystem since the NBS implementation	Re-meandering (approximately 2km): The new courses increase the existing individual lengths of channel by between 8% -56%, reducing the gradient and adding some 300 m (approximately 3,000m^2) of new in-channel habitat (Werritty et al., 2010; Spray et al., 2017). ✓ Cringletie: channel length 474 m (pre–restoration, 2009) and 489 m (post-restoration, 2016) ✓ Lake Wood: 266 m (pre–restoration, 2009) and 362 m (post-restoration, 2015/6) ✓ Shiphorns: 550 m (pre–restoration, 2009) and 574 m (post-restoration, 2015/6)
Well-being	Mortality rate/affected people by water/air pollution, flooding	Modelling from SEPA (SEPA's flood risk assessments) resulted in: ✓ 521 properties in Peebles, ✓ 61 in Eddleston and ✓ 7 rural dwellings

FRAMEWORK INDICATORS	DESCRIPTION	META DATA
		are at risk from a 1:200 year flood event. To date, catchment communities escaped the 2015/16 and late 2016 winter floods (Spray et al., 2017).
Physical and mental health	% of people using the NBS area with an X frequency	People are currently walking along the river on the old railway. Soon multi-use track (biking, walking) will be constructed on the old railway line which will attract even more people. According to Tweed Forum, twenty-six hectare of riparian woodland are accessible and likely to be used for walking.
Cultural/heritage/educational value	Protected or (newly) created value by the intervention	The project works as a living lab, open to public and to schools for raising awareness of flooding in the area and encouraging pupils and teachers to take an active part in the project and learn about their catchment (Spray et al., 2017). Additionally, interpretation boards enhance the commercial use of the area. Finally, many research works around and on the project are being done.
Recreation/Leisure value	Number of new walking/running/biking paths, activities	Soon multi-use track (biking, walking) will be constructed on the old railway line which will attract even more people for recreation.
Enhance attractiveness	Improvement of 'spatial quality' (more appealing habitats), accessibility of the area, number of tourists (enable vacation houses or floating houses)	Intended interpretation boards and this new path which would really improve the recreational side of the Eddleston.
Exploitation	(New) Income per exploitation activity (irrigation, recreation, cattle farming, agriculture, tourists)	✓ Sheep grazing: figures on sheep profitability for 2012/2013 suggest a net margin of £26 per ewe for improved pasture. With the further assumption of 1.5 ewes per 1 ha in the case study area based on land use data (Scottish Government, 2015) and foregone farm income due to the implementation of NFM measures in Scotland (Spray et al., 2017) ✓ The salmon breading and fishery of the Tweed is worth a total of over £24 million a year to the local economy and supports over 500 jobs, so any improvement to fish habitat is important. Although salmon fishing is dominant in the Tweed river, their breading is in the Eddleston river ('Working with Natural Flood Management: Evidence Directory')
Investment	Euros less/meter than with a traditional measure	✓ Under all climate change scenarios, a positive net present value from NFM planting is shown, indicating that the riparian woodland is worth implementing. Annual benefits of c. £80k per year were estimated, with a high average benefit-cost ratio for the riparian woodland of 12.5, though full benefits will not be realised for some 15 years after implementation (Spray et al., 2017).

FRAMEWORK INDICATORS	DESCRIPTION	META DATA
		✓ Riparian woodland: Planting + fences + labour work: 1,504 (low est) – 1,712 (central est) - 1,920 (high est) pounds (Dittrich et al., 2019) ✓ The total cost of physical works amounts to £723k across 20 different landholdings, with the majority of that attributed to fencing and planting.
Employment	Number of additional jobs created (e.g. pruning of trees, mowing, renting canoes, selling local growing products	Not any additional jobs created yet. Maybe some slight vegetation management but nothing bigger. If the track is realized, then yes possibly will be more (including things like renting bicycles).
Value of reduced flood damage	Value of assets that would have been destroyed in case of flood, avoided relocation in case of flood	✓ 6.5 million pounds annual average damages due to flooding in Eddleston, Peebles, Innerleithen, Selkirk, Stow and Galashiels Potentially Vulnerable Area (PVA 13/04) (Spray et al., 2017) ✓ Every afforestation alternative leads to the prevention of damage of a 5% AEP event for all baseline scenarios, which equals a median value of £585,000 worth of benefits (Dittrich et al., 2019) ✓ In the past (1949-2013) there were damages to bridges, railways, agricultural land and properties due to flooding
Maintenance	Amount of money spent for maintenance	Maintenance for afforestation measures: 282 pounds/ha/year (based on the payment farmers currently received for this work) (Dittrich et al., 2019)
Flood protection	Frequency of flooding event or floodplain inundation or reduction in water levels (cm), % of attenuation of the flood due to the natural components of the intervention, delay of the travel time of the peak flow	✓ Ponds: Measurements of pond levels show the 22 ponds in the upper catchment can readily store water, but modelling suggests this will only have a relatively small effect on total sub-catchment runoff at this scale. Downstream, initial modelling of the potential impact of a series of larger ponds on the floodplain suggests that, for a 1.5-year return interval flow event, five such ponds in series could locally reduce the discharge peak by some 18-20% and theoretically delay it by up to 6 hours (Spray et al., 2017) ✓ Large woody structures: Empirically to be associated with a delay in time to peak of 30-60 minutes. Models for the same catchment based on topographical surveys and HEC-RAS hydraulic software showed: (i) Reduction in peak water level and delays in predicted travel time of flood peaks were shown at flows of 1:5 years and above, with higher storage at higher flows, but limited extra gains beyond this (ii) Increasing the number of leaky dams led to greater additional flood storage, up to the 1 in 25 year flood return period event. Generally, the upward trend in the data is much stronger with six years data to early 2017 than with only the initial three years. No relationship with peak flow magnitude has been identified

FRAMEWORK INDICATORS	DESCRIPTION	META DATA
		✓ Main stem re-meandering: In Cringletie and Lake Wood, no upward trend in travel times is visible in the data from the years after the re-meandering was completed in 2013 and 2014. This may be a result of the time required for vegetation to re-establish to levels comparable to the pre-intervention situation or could be a function of changes in the channel bed caused by the June 2012 flood. In Shiphorns re-meandered reach, no clear relationship between time of travel and event magnitude is evident (Spray et al., 2017) Overall, initial analyses of 28 events following re-meandering at Cringletie and Lake Wood (2013) and Shiphorns (2014) show no clear impact on timing or a direct relationship to magnitude of a flood event. However, comparison of peak flows between streams where flow restrictors have been installed and those without show a substantial delay in reaching peak flow, though no overall reduction in magnitude. Severe flood event is still missing for testing of the measures (Spray et al., 2017).
Structural integrity	Proof that by using a natural material instead of a conventional one still stable/sturdy intervention	Green infrastructures made of timber. So far timber structures robust apart from a series of log jams in the upland which were replaced with bigger and sturdier trunks. Exception is at the point where the river meets the road where rocks have been used to keep the meander stable.
Reliability	Number of repairs since construction	✓ A small section of the remeandered site was undercut during a high water event, resulting in the rootwads being lifting out of position. This section has been repaired and, in subsequent sites, rootwads have been installed with large boulders weighing down the ends to reduce the risk of undercutting causing the rootwad to lift out of position ('Working with Natural Flood Management: Evidence Directory') ✓ Some early log jams in the headwaters were replaced
Implementability	Availability (and use) of resources and materials available on site	Generally, all interventions are made of local timber by recently felled trees in the forest. Only exception the rocks where the meander approaches the road, which were imported. ✓ Large woody structures: On the Middle Burn, nearby conifers were felled and pinned across the channel. ✓ Woodland and riparian woodland planting with native trees: Species included oak, ash, willow, birch, aspen, and hazel (Spray et al., 2017)
Adaptability	Future changes in function considered	Although measures put in are accounted for permanent, they are all subject to natural ecological and hydrological processes and thus they will eventually need replacement. So potential change in the land of the area must be feasible and project managers are willing to facilitate and work with the landowners for land use changes.

FRAMEWORK INDICATORS	DESCRIPTION	META DATA
Resilience	Whether another major intervention will be needed in due course (long term perspective with respect to safety)	Further planting, flow restrictors, ponds and set of re-meanders are under negotiation ('Working with Natural Flood Management: Evidence Directory').
Different stakeholders/disciplines involved	Number of different stakeholders/disciplines involved	Landowners (to date, 25 farmers and landowners have been involved and 19 have hosted measures on their land), Peebles Community Council, Scottish Government, SEPA, Tweed Forum and Dundee University, British Geological Survey, Forest Commission Scotland, Scottish Borders Council, Environment Agency, Scottish Natural Heritage and National Farmers Union (Scotland), Cbed Eco- Engineering ('Working with Natural Flood Management: Evidence Directory'; Spray et al., 2017).
Planning/participatory processes	Kind of participatory/planning process used: Top-down/bottom-up, formal/informal rule oriented, trust-based, consultation processes, collaborative learning, learning by doing, workshops, meetings	✓ Shared policy development and implementation: the Trusted Intermediary, Tweed Forum, spent significant time and effort was spent informing and engaging with the local community and landowners in framing the project prior to implementation ✓ Regular meeting and presentations with the Peebles Community Council ✓ Interviews with landowners ✓ Leaflet to locals outlining and explaining aims of the project before the start of it ✓ Hands on participatory engagement at local shows ✓ Questionnaire survey for the implemented measures (Werrity et al., 2010; Spray et al., 2017)
Hierarchy relations	Issues encountered due to the gap between local stakeholders and projects managers/central bosses (committed and accessible project managers)	Eddleston is part of the HELP basin UNESCO program where key component is that the stakeholders set the agenda and closely monitor the science base as it engages with the specific goals set. This means that scientists have to set aside a degree of professional autonomy and deliver to agendas set by the stakeholders — for some this can be a challenging change of roles (Werritty et al., 2010)
Environmental agendas, rigid spending frameworks, compliance to directives	Assessments, (Water, Floods, Birds) Directives, Natura 2000	✓ Tweed EU Special Area of Conservation (SAC) ✓ Tweed Site of Special Scientific Interest (SSSI), ✓ Water Environment and Water Services (Scotland) Act 2003 ✓ Flood Risk Management (Scotland) Act 2009 ✓ Eddleston Water forms part of the River Tweed which has been designated as a HELP basin following the UNESCO programme ✓ Scottish Rural Development Programme (SRDP) scheme (Werrity et al., 2010; Spray et al., 2017)

FRAMEWORK INDICATORS	DESCRIPTION	META DATA
Communication/transparency	Alignment of project expectations with promises	Positive advertisement and public response so far. Headline pieces in local journals, 'visible' project both in terms of efficiency and the measures themselves. Key aspect: regular updates of the stakeholders.
Long term data consistency (e.g. data bases)	Existence and/or maintenance of data bases relevant to the project info	There were a lot of monitoring campaigns since the scoping study (2009), already 2 year before the implementation of the measures. There are consistent databases of the project since the beginning, which most of them are publicly available because it was all paid by public money.
Raising and sharing NBS awareness	Number of visits on respective sites/forums, republication on social media, citations/newspapers, public consultations about how the people feel after the completion of the intervention (public engagement meeting)	✓ https://restorerivers.eu/wiki/index.php?title=Case_study%3AEddleston_water ✓ https://tweedforum.org/our-work/projects/the-eddleston-water-project/ ✓ https://www.nfm.scot/case-studies/eddleston-water-tweed-catchment ✓ educational project visits and part of BwN programs (NSR Interreg)
Promoting collaboration	Coalitions, partnerships	Generally, a partnership approach has been followed and Tweed Forum has brought together the landowners, the community and the project experts (Werritty et al., 2010; Spray et al., 2017).
Damage caused by prevailing conditions	Long term intervention and flora damage due to fauna	Precautions were taken; young trees were protected from domestic and wild herbivores animals (sheep, cattle, deer, rabbits and mice). Besides these, there were some small local erosion incidents which were tackled immediately and since then no other damage has been observed.
Response with respect to the flood event	Observation data, monitoring data	Monitoring of groundwater levels, river flow and rainfall. Initial analyses of 28 events following re-meandering show no clear impact on timing or a direct relationship to magnitude of a flood event, however, a severe flood event has not yet happened to properly test the interventions (Spray et al., 2017).
Field monitoring	Types of overland flow, ecology etc	Measurements of biology and 'ecological status' (WFD) are being done but in alternate years, they are not changing that fast.

Table 6: Framework application for the Eddleston Water Project

The following Sections 3.5.1 – 3.5.3 are devoted to the interpretation of the framework results for the Eddleston Water Project. The framework's performance during application (3.5.1), the Eddleston's project contribution to the SDGs (3.5.2), and ecosystem services (3.5.3) are extendedly discussed and compared to relevant studies.

3.5.1 Performance of the framework

During the testing, the framework indicators were evaluated against five quality criteria (data availability, responsiveness, concreteness, practicality and indicativeness) which were defined and applied with the aim to critically examine the applicability of the framework (Appendix C). In terms of data availability, although most of the framework indicators (69%) were filled in with data publicly available online, for 25% of the indicators a project specialist was needed for acquiring the necessary data. There was also a 6% of the indicators which were filled in with information both from literature and expert consultation. Expert consultation was needed for the following framework indicators (13): climate change impacts, aligned objectives, endogeneity, air quality, physical and mental health, recreation/ leisure value, enhance attractiveness, employment, structural integrity, adaptability, communication/ transparency, long term data consistency and damage by prevailing conditions. Both qualitative and quantitative data were gathered since not all the indicators were requiring a numerical value. For instance, framework indicators treating background information, such as channelization history and geology, were filled in with descriptive data. On the contrary, 'well-being' or 'extent of water-related ecosystems' were filled in with quantitative data. Responsiveness reflects on the time scales in which changes are detected; short-term (1-3 years) or long-term (decadal scales or longer). Indicators that were not expressing measurable data were not assessed against this criterion. Most of the indicators scored low in this criterion since they are outcomes of long-term monitoring. However, monetary values (i.e. maintenance, value of reduced flood damage, investment) and indicators which can have preliminary early outcomes (flood protection, extent of water-related ecosystems) score high in the 'responsiveness' criterion.

In terms of data concreteness, most of the data were evidence-based. However, data which were modeling outcomes, estimates or not evidence-based interpretations, were considered to have low concreteness. Furthermore, the indicativeness of the data was evaluated; having data available and accessible does not mean that they sufficiently answer the framework indicator. Most of the framework indicators were sufficiently answered by the available data, besides some which either were not addressed by the project (i.e. water quality, climate change) or more detailed data than the ones available were needed (investment, maintenance). Lastly, practicality is addressing the extent of needed data per indicator for its evaluation: single value or time series. This criterion is reasonable to be applied only to the framework indicators that needed quantitative data. Framework indicators such as 'biodiversity abundance', 'continuity of water and sediment' and 'monitoring', needed time series in order to be answered, suggesting that their usage is time-consuming if the data are not already available. On the other hand, 'extent of water-related ecosystems' or 'investment' framework indicators are answered with one single value, adding to their ease of use. A detailed evaluation of the performance of each framework indicator during the framework testing can be seen in Table 15, Appendix C. Overall, 43 out of 52 framework indicators seem to perform well under all criteria, 5 had moderate performance (urbanization, structural integrity, resilience, communication/ transparency and impact of features) while 4 had poor performance for the Eddleston Project either because were not initially addressed in the project (climate change impacts and air quality) or is still early to have a clear overview (population viability and employment).

Lastly, some overlaps in terms of the required data per framework indicator were observed. More specifically, for the 'endogeneity' and 'invasive species' indicators, it was observed that the same data answered sufficiently both indicators. When setting the indicators, 'invasive species' were reflecting on the background characteristics of the area while the 'endogeneity' indicator on the impact of the intervention on the invasive species. However, the invasive species for the Eddleston project were not of concern and that is probably the reason for the overlap of the two aforementioned indicators. The same applies to the 'physical and mental health', 'recreation/leisure value' and 'enhance attractiveness'. Although the attractiveness of the area has been enhanced and is being used by the public, more plans are yet to come that will further increase the recreational value of the area. To this end, there is a limited extent of data for these three indicators, leading to their current overlap. However, for a case study where all the interventions would have been finalized, these three indicators might have provided different information. Thus, further testing of the framework, in other case studies, is recommended.

3.5.2 Contribution to Sustainable Development Goals (SDGs)

Using the SDGs to develop the framework indicators and answering them with project metadata, provide us with an overview of (i) whether a NBS project contributes to the attainment of the SDGs and, if this is the case, (ii) to which SDGs and (iii) how. The Eddleston project contributes to SDGs 1, 6, 8, 9, 11, 12, 13, 15 and 17. Table 8 presents an overview of the contribution of the Eddleston Project to the SDGs per theme. The rest of the section elaborates on how the Eddleston contributes to the aforementioned SDGs.

	Themes				
	Legislations, (planning, participatory) strategies	Economy	Society	Environment	Technical
Sustainable Development Goals	SDG 1	SDG 1 *	SDG 1	SDG 6	SDG 8
	SDG 11	SDG 11 *	SDG 11	SDG 9	SDG 12
	SDG 13	SDG 8 *	SDG 13	SDG 15	SDG 13
	SDG 6	SDG 9	SDG 12		SDG 11
	SDG 12				
	SDG 17				

Table 7: Overview of the contribution of the Eddleston project to SDGs per theme. The (*) means no-support by the found data but is implied by the context.

According to the link that has been established (see Section 3.4.2.3 '*Indicators*'), 21 out of 52 framework indicators link to the SDGs (Table 4). The following bullets elaborate on the contribution of the Eddleston project to the SDGs per framework indicator. The contribution is examined in terms of the relevant SD indicators per framework indicator, as established in Table 4.

- **Well-being**: Data suggest that after the NBS implementation communities coped successfully with the 2015/2016 and late 2016 winter floods. Generally, the success of the NBS is expected to be proved during small magnitude but with frequent return period events. However, it is still early to expect NBS impacts on the whole catchment scale. As for the air quality, there is no evidence for affected people due to air pollution. Additionally, Eddleston is not a river from which drinking water is extracted and water quality is not of concern. Thus, there are no data for affected people due to unsafe water. Therefore, with the available indications, the Eddleston project contributes to SDG 1, 11 and 13 and not to SDG 3 in terms of unsafe water for the human health.
- **Value of reduced flood damage**: Eddleston, Peebles, Innerleithen, Selkirk, Stow and Galashiels are considered vulnerable areas (PVA 13/04) and are having 6.5 million pounds annual average damages due to flooding. Additionally, in the past (1949-2013), there were damages to bridges, agricultural land and properties due to flooding. Although there are not updated estimates of the annual average damages after the NBS implementation, logic suggests that since people escaped the 2015/2016 floods, due to the measures, also average damages will be less than before. Therefore, although it is not evidence-based, Eddleston project could contribute to SDGs 1 and 11.
- **Environmental agendas, rigid spending frameworks, compliance to directives**: The Eddleston project was designed and implemented in line with the Flood Risk Management (Scotland) Act 2009 which is the Flood Risk Management Directive 2007/60/EC transposed into Scottish law. Such Directives constitute national strategies for risk reduction which is the focus of the Sendai Framework as well. Regarding the invasive species, there is no evidence for concern in the Eddleston catchment due to a successful campaign for mapping and controlling invasive species, run by the Tweed Forum, under Scottish Environment Protection Agency (SEPA). On top of that, the Eddleston catchment is part of the EU Special Area of Conservation (SAC) for its salmon, lampreys, otters and aquatic plants and thus increased attention is paid at its flora and fauna. Therefore, the Eddleston project attains SDGs 1, 11 and 13 while does not contribute to SDG 15 when referring to invasive species.
- **Water quality:** Eddleston's water quality was not a project objective since it is generally good. Thus, the Eddleston project does not contribute to SDG 6 in terms of water quality.
- **Extent of water related ecosystems**: "Quick win" of the NBS in Eddleston is the increase of the ecosystem's area. All the re-meandered river reaches increased their length, reduced their gradient and thus new in-channel habitat area was introduced. Therefore, Eddleston contributes to SDG 6.
- **Planning/participatory processes**: Core element of the realization of the Eddleston project was stakeholder participation. To this end, Tweed Forum was responsible for aligning the project status with the landowners and thus ensuring its successful progress. Tweed Forum is an NGO focusing on stakeholder involvement while withing Scotland is also assisting the implementation of the River Basin Management Plans (Werritty et al., 2010). Community meetings, interviews, leaflets, surveys, and pilot projects were means of involving local communities. Thus, there was a lot of successful

effort in the locals' engagement. Finally, sustainable land management practices are currently being promoted aiming at "GOOD" status in the WFD for the Eddleston river. Hence, Eddleston adheres to SDGs 6 and 12.

- **Exploitation**: Estimates suggest that the NBS interventions led to improved pasture, fish habitat and farm income which in turn resulted in an increased GDP per capita and per employed person. As for the GDP increase due to tourism growth there is not any evidence but given that the attractiveness of the area is and will be further enhanced (planned multi-use track), it is logically implied that there is an increase in GDP for tourism and per capita. Thus, although not evidence-based, the Eddleston project is probably contributing to SDG 8.
- **Employment**: Currently there are not any additional jobs created due to the NBS apart from some slight vegetation management. If the multi-track is realized, then possibly more job opportunities will be created (including things like renting bicycles). Therefore, currently, Eddleston is not contributing to SDG 8, in terms of employment.
- **Implementability**: Large woody structures are constructed by recently felled native tree trunks. In the same line, woodland and riparian planting were realized by using native flora species. Hence, domestic elements were used as much as possible. An exception were some rocks that were imported to the site to stabilize the riverbanks close to the road. However, it was only locally and to a limited extent. More detailed data for the cost of the domestic materials per service could not be found. Thus, Eddleston contributes to SDGs 8 and 12.
- **Investment**: Generally, estimates reveal a high benefit-cost ratio for planting as a NBS measure, gaining approximately 80k pounds annually (Spray et al., 2017). The total cost of physical works is approximately £723k in 20 different landholdings and most of them are costs of planting and fencing. Although it is not expressed as proportion of GDP, the economic benefits of planting as an intervention are obvious. Costs for the rest of the interventions could not be found. Finally, regarding the cultural expenses, although the exact costs could not be found, the Eddleston catchment is considered a Special Area of Conservation (SAC) and thus the total expenditure of the project was also for the protection and conservation of the area. Thus, Eddleston contributes to SDGs 9 and 11 and, most likely, also in SDGs 8 and 11.
- **Air quality**: Air quality was not a key project issue and thus, currently, there are no specific measurements. However, planting undoubtedly contributes to carbon sequestration and thus more research is being done for specifying it. Thus, the Eddleston project does contribute to SDG 9 in terms of carbon sequestration but the extent is yet to be examined.
- **Different stakeholders/disciplines involved**: A necessity in the Eddleston project was stakeholder participation. Thus, since the beginning of the design, community meetings, interviews, leaflets, consultations, and demonstration sites were employed, encouraging public involvement. On top of that, the intermediary communication between project managers and the public was led by an NGO, Tweed Forum, with a successful history on stakeholder engagement. Lastly, sustainable land management practices are currently being promoted aiming at "GOOD" status in the WFD for the Eddleston river. Hence, Eddleston adheres to SDGs 11 and 12.

- **Recreation/Leisure value** and **Enhance attractiveness**: Green measures have undoubtedly made the area more attractive. Currently people are walking along the river but soon a multi-use track will be constructed, attracting more people for recreation. Thus, the Eddleston project has added recreational space accessible to everyone with future enhancement, contributing to SDG 11.
- **Adaptability**: Although measures put in are accounted for permanent, they are all subject to natural ecological and hydrological processes and thus they will eventually need replacement. So potential change in the land of the area must be feasible and project managers are willing to facilitate and work with the landowners for land-use changes. In terms of urbanization, the planning law is very strict prohibiting expansion on the floodplains and thus is not considered a reason for future alteration of the measures. Finally, although climate change was not in the objectives of the project from the outset, currently more research is carried out to examine the effects of the interventions on climate change projections. Thus, both SDGs 11 and 13 are or will soon be addressed by the Eddleston Project.
- **Cultural/heritage/educational value**: The project works as a living lab, open to the public and to schools for raising awareness of flooding in the area and encouraging pupils and teachers to take an active part in the project and learn about their catchment. Additionally, interpretation boards facilitate and enhance the commercial use of the area. Thus, all the aforesaid show contribution to SDG 12 for the Eddleston project.
- **Biodiversity abundance**: Eddleston river is protected by the EU Special Area of Conservation for its salmon, lampreys, otters, and aquatic plants. The Eddleston project protected and enhanced natural biodiversity. More specifically, there was a rapid recolonization of macroinvertebrates in re-meandered reaches. Additionally, salmonid habitat was also enhanced due to the river restoration measures. Thus, the Eddleston project contributes to SDG 15.
- **Continuity of water and sediment**: Generally, restoration has brought diversity in the channel morphology. All morphological units (riffles, pools, glides, runs) are present at all restored reaches. In terms of grain size distribution, restoration led to better sorted reaches (Spray et al., 2017). Thus, degraded reaches are being restored contributing to SDG 15.
- **Promoting collaboration**: The strategy of the Eddleston project from the beginning involved stakeholder engagement, promoting awareness and knowledge of sustainable risk management practices involving flood management and land practices. Although financial incentives are found to be more popular than the non-financial ones, evidence on money spent on coalitions and partnerships was not found. Eventually, Tweed Forum managed to bring together local communities, keep them informed and involved and facilitate both the progress and the uptake of the project. Hence, there is contribution to SDG 17.
- **Wildlife habitat** and **Population viability**: The Red List Index (RLI) is a database that keeps track of the trends of the under-extinction species and is used by governments for relevant decision making. Both framework indicators are relevant because reflect on the habitat creation and last of species in time based on the prevailing site conditions. Both are encountered in the Eddleston project; an

increase in the overall habitat area and diversity, expecting to ameliorate the spawning habitat for salmon in the long term. Thus, the Eddleston project contributes to SDG 15.

Apart from the 21 above-listed framework indicators that are linked to the SD indicators, Table 5 contains 12 additional SD indicators reflecting on the general contribution and impact of the NBS practice to the methodological approaches, tools, and legislative sectors. These SD indicators are not linked to any framework indicator because a sufficient answer to them requires examination of multiple NBS projects, which was not feasible within the time frame of this research. However, in the next paragraph, it is attempted to answer them for the Eddleston Water Project, yet not all of them can be addressed.

Starting from SD indicator 6.5.1, the Eddleston project adopted an integrated approach of all the water resources since they were fundamental in determining the source-pathway-receptor scheme. Furthermore, Eddleston is a small catchment where specialized focus and strengthening of locals' interest and involvement was needed for the realization of the project (13.3.2). This was achieved through participatory processes and engagement strategies which although were new to the area, were effective. These processes were also a way of ensuring equitable share of benefits over all the sectors considered in the project (15.6.1). The science provider of the Eddleston project was Dundee University, which is in Scotland, and thus the project was generated and developed by country-owned institutions, before attracting wider interest (17.15.1). Finally, many monitoring campaigns are running, aiming at evaluating the outputs of the measures, biodiversity, and hydro-morphological changes and thus progress on SDGs and biodiversity strategies can be achieved (15.9.1, 15.a.1, 17.16.1). SD indicators 6.5.2, 12.6.1, 13.b.1, 17.6.1, 17.18.1 cannot be addressed by the Eddleston project because it is not a transboundary project with many companies and countries involved. However, it constitutes an evidence-based inspiration for testing NBS projects in bigger scales. Overall, the Eddleston project addresses SD indicators 6.5.1, 13.3.2, 15.6.1, 15.9.1, 15.a.1, 17.15.1 and 17.16.1 from the ones listed in Table 5.

Wang and Winsemius (Ligtvoet, 2018) have identified the negative effects of fluvial flood risk to SDGs 1, 2, 3, 6, 8, 9, 10, 13 and 16 for people and economy (specifically on agriculture). The outcomes of the framework application show that Eddleston can ameliorate the negatively affected SDGs by river flooding as established by Wang and Winsemius, apart from SDGs 2, 10 and 16. Although Wang and Winsemius do not mention how the link was established, it is important to stress out that they established the link between river flood risk and SDGs which is broader than the link established in this study, NBS for fluvial flood risk and SDGs. SDG 2 treats food security issues and agricultural practices, which were considered farfetched for the functions of fluvial flood mitigation NBS considered in this research. For instance, in the Eddleston project, although sustainable agricultural practices were promoted, acted as a complementary action in the overall change that the NBS interventions brought. SDG 10 refers to the reduction of inequalities between countries, in terms of providing the same means of coping with flood risk between developing and developed countries. NBS could address such an aspect, however, needs examination in a broader context combined with geopolitical considerations. Similarly, SDG 16 talks about justice and inclusivity in societies, which can be promoted as part of the general NBS notion but are farfetched for this study. Therefore, Eddleston positively affects 6 out of 9 SDGs mentioned by Wang and Winsemius; SDGs 1, 3, 6, 8, 9, 13.

Ge et al. (2018) link river to SDGs in terms of water, ecosystem, socioeconomic and ability-related issues. As his connection sectors are extended, finds all SDGs relevant apart from SDG 7. The water-related SDGs (6, 11, 12, 14) and the ecosystem-related SDGs (14, 15) coincide with the SDGs derived from the present study, apart from SDG 14. SDG 14 was out of scope for the current research context because it focuses on the coastal environment. The socioeconomic-related SDGs were omitted because focus mostly on food security, justice and inequalities which are farfetched impacts of the fluvial NBS for the present thesis and thus not considered. The ability-related SDGs (9, 11, 13, 17) completely coincide with the ones derived from the present thesis because refer to structural actions and strategies for conserving and protecting the rivers. Hence the present study agrees with 7 out 8 water, ecosystem and ability-related SDGs proposed by Ge et al. (2018); SDGs 6, 9, 11, 12, 13, 15, 17.

3.5.3 (Co-)Benefits/costs and ecosystem services (ES)

The benefits/costs and co-benefits/costs of the Eddleston project were derived following the reasoning of the intervention's impact on the main and secondary domains (see Section 3.4.1 '*Framework context'* and Section 2.3 '*Analysis of the Sustainable Development Goals (SDGs)– step (v)*'). The next paragraphs present the benefits/costs and co-benefits/costs of the Eddleston Project and how they enhance or impede the ecosystem services.

In terms of river functions, the Eddleston project addresses water safety, nature development, spatial and economic development as well as recreation and attractiveness of the area. Given the scope of this research, direct benefit of the Eddleston project is the flood regulation. The implemented measures perform successfully so far, however more time is needed for reaching their full potentials. Asset damages and affected people are also considered direct benefits since they are reduced after the interventions. On the other hand, the investment and maintenance expenditures are considered direct costs. As for the co-benefits of the Eddleston project, the biodiversity abundance, habitat generation, community cohesion, better land practices and recreational spaces are some of them. On the opposite side, the biggest trade-off was the agricultural land that had to be taken for implementing the NBS works. Since the Eddleston is a predominantly rural catchment, such a trade-off was of great importance for the local economy. However, common ground was found by placing landowner consultation on the front line. The aforementioned benefits, co-benefits and co-costs supply, enhance or impede the ecosystem services.

PROVISIONING SERVICES	REGULATING SERVICES	CULTURAL SERVICES	SUPPORTING SERVICES
Fishing, timber, livestock market development	Water regulation	Introduction of educational value	Provisioning of habitat
Habitat enhancement	Erosion control	Enhance of aesthetic value	Primary production (production of organic matter from CO2)
	Increase of pollination	Social inclusion and co-existence	Production of atmospheric oxygen
		Increased recreational	

Table 8: Overview of the Ecosystem Services enhanced by the Eddleston Water Project

The benefits and co-benefits/costs of the Eddleston project impact various ecosystem services. The improved aquatic biodiversity enhances the provisioning ecosystem services in terms of food production, by empowering the fisheries which are an important source of income for the Tweed community. On top of that, the vast new woodland and grassland plantations are enhancing timber and livestock activities. Furthermore, the green measures along with the promoted sustainable land practices contribute significantly to the regulating ecosystem services: water regulation, erosion control and pollination. Affecting the volume, timing and peak of the flood is the main goal of the measures and some first results validate their potentials. Additionally, re-vegetation combined with re-meandering of many sites resulted in more evenly distributed sediments and diversity in the morphological units. To this end, favorable conditions for biodiversity abundance were created, leading to richness and diversity that did not exist before the interventions. In terms of cultural ecosystem services, the Eddleston works address educational values, aesthetic values, social relationships, and recreation. The project is meant to constitute a living lab for educational purposes while raising awareness and involvement of students. Additionally, the enhancement of the natural elements in many project sites has attracted people for recreational activities. Considering that are more yet to come (multi-purpose track and interpretation boards), these values are expected to grow further. Finally, the Eddleston catchment is an area where both fisheries and agricultural societies co-existed. The measures applied have considered the equitable share of benefits to both groups, maintaining their co-existence. The supporting services are more difficult to be measured, however, provisioning of habitat, primary production and production of atmospheric oxygen are undoubtedly present due to the interventions. More specifically, there is evidence that re-meandering resulted in habitat generation and diversity. Besides, riparian and woodland planting provides more vegetation for photosynthesis, enhancing the primary and oxygen production. Most likely, due to their interdependency, the rest of the supporting service are also present, however further monitoring is needed for their detection. Finally, on the other side of the table, the decrease of productive land due to the NBS work impedes the provisioning services in terms of agricultural production. However, other edible sources were strengthened, making the trade-off fair.

According to the outcomes of the Ncube et al. (2018), in 2009, increased supply in the Eddleston catchment had some provisioning (livestock, timber) and regulating (flood control, vegetation carbon) ecosystem services. Unsustainable land management practices had undermined biodiversity (supporting ES), water quality, soil erosion and pollination resources (regulating ES). The Eddleston project evidently ameliorates most of the aforementioned ES while further research is being done on mapping and measuring the ecosystem services' benefits. Finally, Eddleston Project constitutes the starting point of an ongoing effort of integrating the valuation of the ecosystem services with the whole process of assessing flood risk appraisal options.

4. DISCUSSION

This chapter starts by summarizing the outcomes of the assessment framework for the Eddleston case study (4.1). Afterwards, discusses the framework potentials for extension to NBS other than fluvial flood mitigation (4.2) and ex-ante application (4.3). Finally, it talks about the subjectivity and completeness of the deliverable framework (4.4).

4.1 Overview of the framework assessment for the Eddleston Water Project

Heretofore, Eddleston Water Project is fulfilling its objectives. However, ongoing monitoring and evaluation have still a lot to reveal regarding the extent to which flood risk is reduced at catchment scale and the extent of the hydro-morphological improvement of the Eddleston stream. With respect to the WFD status, the implemented NBS works have already turned the water body status from 'Bad' to 'Moderate', according to the MImAS (Morphological Impact Assessment System) assessment system. Optimal goal is the 'Good' status, which can be achieved combining the NBS outcomes with sustainable land practices. Table 7 provides an overview of the Eddleston project assessment as derived by the framework. Extended analysis of the performance of the framework, the Eddleston contribution to the SDGs, ecosystem services and (co-)benefits/costs can be found in Sections 3.5.1-3.5.3.

OVERVIEW OF PROJECT ASSESSMENT

EDDLESTON WATER PROJECT	Flood Risk Reduction	YES
	Improve River Hydro-Morphology – Status WFD	YES – "MODERATE"
	SDGs	1, 6, 8, 9, 11, 12, 13, 15, and 17
	(Direct) benefits/ costs	Benefit: Flood regulation, reduced flood damages Costs: investment and maintenance
	Co- Benefits, Trade-Off	Co- benefits: Recreation, cultural and educational value, improved area attractiveness, future site-enhancement plans, community's cohesion and raised awareness, flora, and fauna abundance Trade off: occupation of productive land
	Ecosystem Services	Contributes to all 4: provisioning, regulating, cultural and supporting services

Table 9: Overview of the outcomes of the assessment framework for the Eddleston Water Project

4.2 Potentials for extending the framework to NBS other than fluvial flood mitigation

The deliverable framework was developed and tested with a focus on NBS for fluvial flood mitigation. However, there are also NBS projects with other primary aims such as ecological improvement, coastal resilience, and protection. To this end, the arising question is whether the present framework could be applicable in NBS with main objective other than fluvial flood risk.

The framework structure (stages-themes-indicators) could work for any NBS project because it was derived from literature review of frameworks addressing various NBS objectives. The stages are significant general steps in a NBS project scheduling and therefore can be present in any type of NBS project. The themes and the indicators were formed from the combined insights of literature, case studies and SDGs and thus they are more fluvial risk oriented. Hence, although they will probably still be applicable for NBS other than fluvial flood risk, several re-arrangements, changes, or additions will be needed. For instance, for a NBS with main objective ecological restoration, the indicators for monitoring need to change into more ecological-related ones such as pioneer species, keystone species and ecological succession.

Similarly, for some of the themes and indicators of the 'System Analysis' and 'Effects of NBS' stages. The 'Setting of objectives' and 'Process' stages and their respective themes and indicators can be applicable in any NBS project because they are means for negotiating and deciding on the measures. Overall, the framework could be used for NBS other than fluvial flood mitigation with amendments and adjustments depending on the objective of the NBS project. Significant insights with respect to the framework changes can be gained through case study examination.

4.3 Potentials for ex-ante framework applicability

The deliverable framework was applied after NBS implementation. However, the insights gained during its development, show potentials for using the framework also before the NBS implementation. In such a case the framework does not have, anymore, an assessment character rather than a guiding one, providing all the ingredients for a good project scheduling. In other words, when consulted before the NBS implementation, it could assist in guiding and listing the necessary components of a successful NBS project since it encompasses an integrated approach of the NBS project procedure.

To put the anterior use into the framework perspective, the stages represent the essential components of an NBS project scheduling. More specifically, 'Process' and 'Monitoring' stages should start before the project planning for measuring and setting the reference situation. Both stages should also continue after the NBS implementation for evaluating and optimizing purposes. The stages 'System Analysis', 'Setting of Objectives' and 'Effects of NBS', indicate what should be done once the baseline has been defined. The dynamic and interdependent character of the stages, as explained in Section 3.4 *'Development of the assessment framework'*, is significant for anterior framework use, indicating that all the actions during the project scheduling are interconnected and feed into each other until an optimal problem – measure – additional benefits combination is achieved. Finally, the themes and indicators are providing a complementary and more detailed idea of what should be considered per stage.

4.4 Subjectivity and completeness of the framework

The deliverable framework has been developed and tested with a limited extent of references and case studies due to the time frame of the project. To this end, the more the framework is reviewed and applied, the more insights will be gained with respect to its biases, limitations, and gaps. For instance, the research showed that SDG 7, which treats energy resources, can be potentially linked to the framework indicators. More specifically, although the Noordwaard polder project provided some clues about energy production from biomass, the other case studies did not. Therefore, SDG 7 was not included in the link between NBS and SDGs. To this end, a broader case study examination will provide more concrete insights regarding the potentials of energy production in NBS interventions. Generally, the more the framework is reviewed, the more remarks such as the aforesaid one will emerge. Therefore, the framework is structured in such a way that additions are feasible, and its feedback loop enables immediate involvement of the new aspects.

5. CONCLUSIONS

Nature-based solutions are a promising practice to fight fluvial flood risk while achieving multiple other benefits. To date, their evidence base is constantly enriched through ongoing projects. However, they are still under a testing phase seeking for ways of addressing their full spatio-temporal potentials whilst creating a common line for enabling their mainstreaming and eventually upscaling. To this end, this research proposes a NBS assessment framework that introduces an integrated approach for assessing NBS projects, by using indicators for evaluating and benchmarking purposes. The benchmarking of NBS outcomes can then work as guidance for similar projects, eventually leading to the transferability and mainstreaming of the NBS practice.

- *What are the existing assessment frameworks and indicators for NBS?*

Section 3.1 and Appendix A – Existing assessment frameworks and methodologies considered in this research are: Artmann at al. (2018), Calliari et al. (2019), Weber et al. (2018), Huthoff et al. (2018), Nesshöver et al. (2017), Raymond et al. (2017), Schipper et al. (2017). Similarly, for the existing indicators: Weber et al. (2018), Huthoff et al. (2018), Nesshöver et al. (2017), Raymond et al. (2017), Den Dekker-Arlain (2019), Schipper et al. (2017), Kabisch et al. (2016), Pakzad et al. (2016). The deliverable framework builds on the aforementioned frameworks and indicators. It is notable that although there are indicators which reflect on the three pillars of sustainability (society, economy, and environment), a direct link to the SDGs has not heretofore been addressed. Additionally, although there are several indicators expressing wider contexts included in the planning, evaluation, and maintenance of NBS projects, there are not any evaluation criteria on the engineering characteristics of the NBS intervention. To this end, there lacked an assessment framework which both establishes a direct link to SDGs and addresses the technical characteristics of a NBS project.

- *What additional information regarding the assessment procedure and indicators can be derived from examination of already realized NBS projects?*

Section 3.2 – Noordwaard polder, Belford Flood Scheme and Colorado Front Range Recovery, already realized NBS projects, are studied as case studies for additional data regarding the NBS works and potential indicators. Case studies also confirm that what exists in literature reflects to reality. They place the literature findings in a real context, providing a holistic overview of the projects, highlighting the challenging but crucial factors for their successful completion. Public involvement, either in the form of consultation or for informative and awareness purposes, prove to be a driving factor throughout the projects. Additionally, they shed light to practical aspects such as maintenance costs and emergency plans that are determinative in practice and usually skipped in theoretical approaches. Overall, case studies constitute the evidence base of this research while also act as calibration for the literature-based data (framework and indicators).

- *How NBS projects contribute to the attainment of the SDGs, as set by the United Nations Organization?*

Section 3.3 and Appendix B – The present research suggests that any NBS project tackling fluvial flood risk can potentially contribute to SDGs 1, 3, 6, 8, 9, 11, 12, 13, 15, and 17. These SDGs contributions are derived by examining the NBS effects on social, economic, environmental, technical, and procedural domains. Afterwards, in order to be able to examine the contribution of a specific NBS project to the SDGs, NBS framework indicators, capturing the multi-sectoral NBS effects, are linked to the Sustainable Development (SD) indicators. To do so, the 2030 UN Agenda was studied, and the link between the framework indicators and all the relevant SD indicators was established, according to the scope of the research. During the framework application, NBS project metadata are given as input to the respective NBS framework indicators. Therefore, given the availability of the corresponding metadata, contribution (or not) of a specific NBS project to the SDGs can be inferred by interpreting the outputs according to the UN 2030 Agenda.

- *What are the components of the assessment framework?*

Section 3.4 and Appendix D – The assessment framework comprises of three layers: stages, themes, and indicators in an increasing in detail order. They were all formed based on the outcomes of the literature, case studies, and UN 2030 Agenda examination. The visualization of the framework can be seen in Figure 6.

- *How does the framework perform in practice?*

Sections 3.5 and 4.1 - Since the framework was created from scratch, its testing provided significant insights for its practical applicability. The testing was done by assessing the Eddleston Water Project case study. Overall, the framework performs well, showing that the NBS works of the Eddleston project are fulfilling the initial project objectives while having additional benefits on the environment, economy, and society. It also shows contribution of the Eddleston to SDGs and ecosystem services. To the downsides, expert consultation is needed for acquiring project metadata for some of the indicators -for which (sufficient) data could not be found online- while some overlaps are also observed with respect to the data needed per framework indicator. Although these overlaps are most likely attributed to the objectives of the Eddleston project, framework application with other case studies is strongly recommended.

6. LIMITATIONS & RECOMMENDATIONS

Although this research has attempted to evaluate the NBS performance in multiple aspects, further research and improvements are recommended. The developed framework was tested only for a single lowland river case study, the Eddleston Water Project. However, for supporting its mainstreaming and guidance aspirations, further application is needed.

The Eddleston Project had much available information, providing a good overview of the performance of the framework. However, it adopted an exploratory approach towards the outcomes that can be achieved from the NBS works. In other words, it did not have specific pre-defined targets for flood risk reduction and thus the extent to which the goal of flood regulation is currently achieved cannot be quantitatively assessed. For instance, if the framework would have been applied in a 'Room for the River' project, where pre-defined targets for the water levels or the Rhine's conveyance capacity had been set, then a quantitative assessment could have been made regarding the extent to which the water levels had been reduced. Hence, it is strongly recommended to test the framework in projects where quantified targets exist and see whether the framework could derive a scored evaluation (i.e. percentage of the pre-defined target).

In the same line, it would also be interesting to apply the framework in several different case studies in terms of scale, location, and type of measures. Even though this was within the goals of this research, it was not feasible due to the strict time frame. Hence projects in upland rivers, transboundary projects and bigger scale projects are some suggestions. Additionally, given that the framework addresses the SDGs, case studies in developing countries would give interesting insights as to whether they adhere to more SDGs. Finally, an alternative testing method would be interviews with experts as to whether this framework encompasses all the fundamental aspects of an NBS project, seeking for suggestions as end-users of the framework. In doing so, we could get insights regarding their expectations and their willingness to use the framework.

Another recommendation for framework improvement would be to prioritize the indicators based on the main and secondary river functions. For this research, although water security was the main river function while ecosystem development, water quality and recreation issues were also addressed, no prioritization was considered. However, in a realistic case, rivers have multiple functions (water supply, navigation, water quality, nature development) that weight less or more depending on the focus of the project. Therefore, tools such as Multi-Criteria Analysis (MCA) would both bring the framework outputs closer to reality and better assist decision-makers in river management decisions.

The involvement of the SDGs in the framework was based on self-explanation according to the insights gained throughout the research. More specifically, the NBS-SDG coupling was determined by the insights from literature and case studies and the boundaries that were set based on the scope of the research. To this end, a more experienced person could make the NBS-SDG coupling in another way. This comes in line with the potential integration of SDG 7 to the framework indicators, as discussed in Section 4.4.

Finally, some recommendations for the use of the framework and its indicators. The framework was tested in a project where most NBS works have been completed. However, it would be interesting to examine whether it would be feasible to have ex-ante framework application. Although the ex-ante implementation of the framework is not examined in the present research, its potentials (as discussed in Section 4.3) favour further research. Lastly, regarding the indicators, the framework is meant to be used by experts and thus the indicators were assessed (by the 5 quality criteria, Appendix C), accordingly. However, it would be interesting to examine whether the indicators would still be applicable/perform the same if end-users were also stakeholders or generally people not competent with the SDG notion.

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APPENDICES

Appendix A: Literature review

The following paragraphs, treat each considered framework and methodology individually, providing extended insights on their employed notions of the ecosystem services and (co-)benefits/costs.

- Calliari and co-authors (2019) state that multifunctionality is a NBS property which results in direct benefits/costs and co-benefits/costs. On the one hand, the definition of direct benefits is associated with the primary ecosystem service used to achieve the objective (e.g. flood regulation). The definition of ecosystem services is not explicitly mentioned but considers the three out of four categories set by the Millennium Assessment (MA), regulating, provisioning and cultural services. On the other hand, in the case of direct costs, they are restricted to the construction and maintenance costs, not having any connection to the ecosystem services. Additionally, any direct social or environmental costs are excluded under the premise that neither measure is designed nor implemented to be detrimental. Along the same line, the co-benefits are the positive effects, of the measure, on the non-primary ecosystem services while the co-costs coincide with the ecosystem disservices. Therefore, the framework of Calliari et al. (2019) relates both the direct and co- benefits with the ecosystem services while in the case of direct and co–costs, only the latter ones are ecosystem services-related.
- Artmann et al. (2018) recognizes the multifunctionality as a property of NBS leading to societal, ecological, and economic benefits and ecosystem services supplied by the NBS. Both the ecosystem services and the societal, environmental, and economic impacts are considered co-benefits. Therefore, co-benefits are used as an umbrella term. Ecosystem services are defined according to the UN's Millennium Ecosystem Assessment report (MA, 2005) but only the provisioning, regulatory and cultural services are considered, omitting the supporting ones. This way an overlap of some ecological impacts with the supporting services is avoided (e.g. habitat provision). The ecological, societal and economic impacts, falling in the umbrella term of co-benefits, represent benefits not directly derived from the ecosystem, such as jobs, positive media attention and cultivation of environmental-friendly behaviour. Finally, the term (co-)costs is not employed, however, drivers and constraints of the implementation process are mentioned with the concept that implementation of NBS leads to its co-benefits. Therefore, Artmann et al. (2018) uses three categories (provisioning, regulatory and cultural) of the ecosystem services, as defined by the Millennium Ecosystem Assessment, supplied by the NBS and distinguishes them from the social, economic and environmental impacts of the NBS.
- Weber et al. (2018) although does not provide definition of ecosystem services, they are taken into account in his conceptual framework for monitoring. Although he identifies factors related to river restoration projects in several domains (e.g. human pressures, technological opportunities, socio-economic) playing a role in planning, implementation, evaluation and maintenance phases, the terms of co-benefits/costs and multifunctionality are not employed. This can be attributed to the scope of the framework which focuses on the establishment of systematic maintenance and evaluation of river restoration projects. Therefore, the ecosystem services are taken into account but with no distinction, while benefits/costs and co-benefits/costs are not explicitly employed terms.

- The NSR Interreg framework (Huthoff et al., 2018) adopts the Kabisch et al. (2017) approach which defines ecosystem services according to the UN's Millennium Ecosystem Assessment (MA, 2005) and considers them a concept not interacting with the NBS. Therefore, the ecosystem services are not treated in the NSR evaluation framework. Furthermore, only the term 'co-benefits' is used, defined as "*the added value that a particular solution may have*". Important also to be mentioned is that there is a distinction between the main objective of the intervention and its co-benefits. Finally, along the same line with the co-benefits, the term 'trade-offs' is used denoting interlinkages between the implications that the interventions might have. Hence, the ecosystem services are not included in the developed framework while co-benefits are, separating them from the NBS main objective.
- Nesshöver et al. (2017), addresses the ecosystem services as employed by the Millennium Assessment (MA, 2005), mentioning all four categories (provisioning, regulating, cultural and supporting). He clearly makes the connection of the ecosystem services with natural capital related projects by stressing the importance of linking the ecosystem services with the economic and ecological parts of the projects. He also examines the Ecosystem Services as an already existing approach, that could enhance the solutions during the NBS design and assessment. However, he stresses the fact that a full range of ecosystem services and their respective beneficiaries should be considered. As for the benefits supplied by the NBS, he does not make any distinction between them and ecosystem services, using the term 'benefits' like a general term including ecosystem services. Although 'co-benefits' term is not used, there is a distinction between direct and indirect impacts derived from the NBS, without further explanation though. Costs and trade-off relations emerging from the NBS implementation are also accounted in the framework. Therefore, ecosystem services are part of the NBS concept and of the benefits derived from them. Apart from the benefits, negative implications (costs) are also addressed and their resulting trade-offs.
- Raymond et al. (2017) explicitly addresses the difference between ecosystem services and co-benefits (or costs) within and across different sectors such as environment, socio-cultural, economy and biodiversity. He considers NBS as measures supplying or enhancing ecosystem services while also providing additional benefits (co-benefits) for the people (e.g. community cohesion, inclusivity). Definition for the ecosystem services is not provided nor any categorization of them. As for the co-benefits, it is implied that they address positive impacts on other challenge areas, apart from the main dealt one, such as health, economy, social justice and cohesion. Following the same concept, the direct benefits are the positive implications derived by the implementation of the NBS on the primary challenge area. Respectively for the costs and co-costs. It should be mentioned, though, that none of the aforementioned terms (benefits/costs and co-benefits/costs) are explicitly defined. Therefore, ecosystem services are present, however neither definition nor categorization are mentioned, and they are distinguished from the (co-)benefits. Benefits/costs and co-benefits/costs are aligned with the primary and secondary challenges treated and their positive and negative implications, respectively.
- Schipper et al. (2017) does not directly involve ecosystem services in his assessment because he treats already existing port(-city) plans. However, the importance of identifying and addressing the ecosystem services is stressed, in order to achieve a 'no- impact' port development. The assessment

methodology, although does not use the term ‘co-benefits/costs’, involves the social, environmental and economic, positive or negative, impacts of port(-city) plans. Hence, although the assessment methodology does not elaborate on ecosystem services because of its starting point, emphasizes the importance of identifying the effects of the examined projects on the social, environmental and economic sectors.

The following tables (Tables 10, 11, 12) map the differences, the common points, and the categories of indicators in the examined literature, respectively. They were all formed during the literature review and their key points are elaborated in Section 3.1 ‘Review of assessment frameworks and indicators’.

#	Title [Ref]	Definition of NBS	Ecosystem services included	Co-benefits included	(Co) – costs included	Testing	Societal challenges considered	Link to sustainability
1	The role of urban agriculture as a nature-based solution: a review for developing a systematic assessment framework [1]	(Peri) – Urban Agriculture (UPA)	YES -regulating, provisioning, cultural (MA, 2005)	YES	constraints	NO	10 related to urbanization	Three pillars
2	An assessment framework for climate-proof nature-based solutions [2]	EC, 2015	YES – provisioning, regulating, cultural and supporting (MA, 2005)	YES	YES	NO	Disaster risk reduction /Climate change adaptation	Through backcasting method
3	Goals and principles for programmatic river restoration monitoring and evaluation: collaborative learning across multiple projects [3]	Restoration - SER (2017) & Roni et al. (2008)	YES – no definition	NO	NO	NO but mentions facilitating aspects	NO	Long-term visions, uncertainties, changes
4	Evaluating Nature-Based Solutions. Best practices, frameworks and guidelines [4]	EC, 2015	NO	YES	NO – mentions trade-offs	YES	Reducing water-related risks	Long-term visions, uncertainties, changes
5	The science, policy and practice of nature-based solutions: An interdisciplinary perspective [5]	IUCN, 2012 & Cohen-Schacham et al. (2016) & EC, 2015	YES – provisioning, regulatory, supporting and cultural	~ not with this term (direct-indirect impacts)	YES - mentioning trade-offs	NO	Any	Three pillars
6	A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas [6]	EC, 2015	YES	YES	YES	NO – mentions steps	10	Three pillars
7	A sustainability assessment of ports and port-city plans: comparing	sustainable port development = new port or port expansion plans that meet (or even exceed) typical operational requirements and that provide economic growth that is	NO	YES - not with this term though, but as positive and	NO	YES	Economic and social development	Three pillars

#	Title [Ref]	Definition of NBS	Ecosystem services included	Co-benefits included	(Co) – costs included	Testing	Societal challenges considered	Link to sustainability
	ambitions with achievements [7]	compatible with environmental and social needs, including ways to manage the transition to this new and balanced paradigm		negative impacts)				

Table 10: Mapping the differences of the reviewed frameworks and methodologies

#	Title [Ref]	Type of framework	Applicability	Framework steps
1	The role of urban agriculture as a nature-based solution: a review for developing a systematic assessment framework [1]	Assessment	Whether a UPA can be considered NBS	Three main steps: 1. Vision definition 2. Implementation efficiency 3. Impact efficiency These steps involve more detailed steps for their achievement: (i) Define key social challenges that UPA should address (ii) Types of UPA contributing to these challenges (iii) If and with which efforts UPA can be implemented (iv) Supporting actors (v) Supportive instruments (multi-scale governance, professional coordination) (vi) Multifunctionality (co-benefits not directly derived from the ecosystem) (vii) Ecosystem services supplied by UPA (viii) Benefitting actors
2	An assessment framework for climate-proof nature-based solutions [2]	Dynamic assessment	(i) ex-ante to support the choice between NBS and traditional and (ii) climate-proof	Framework steps: 1. Baseline definition (description, analysis, boundaries, trends) 2. Setting objectives (desired situation, goals/actions, opportunities) 3. Identification of enabling factors and constraints externally (political, economic, environmental, demographic) 4. Definition of alternative courses of action (based on the relation of ES supply-demand) 5. Climate-proof alternatives (check possible measured regarding long/short term perspectives, hazard they are designed to tackle) 6. Identification of evaluation criteria 7. Performance analysis of the alternatives (based on the indicators defined) 8. Evaluation (putting everything together with MCA, cost-benefit) 9. Monitoring, evaluation, adaptation
3	Goals and principles for programmatic river restoration monitoring and evaluation: collaborative learning across multiple projects [3]	Conceptual framework	Guidance for the development of programming evaluation and maintenance (ProME)	4 main goals: 1. Account for complexity, uncertainty, and long-term change 2. Promote collaborative learning and adaptation 3. Verify to what extent restoration has been achieved 4. Identify why the observed effects were present Means to achieve these goals: 1. Assure stakeholder commitment (vision, funding, personnel, time) 2. Evaluate against clear objectives (S.M.A.R.T.) 3. Coordinate with related activities (synergies mentioned) 4. Answer well defined questions 5. Standardize the sampling design (indicators, methods, spatio-temporal scale) 6. Compare multiple projects 7. Decide on where (which project) and when (for how long) to learn 8. Process and disseminate the findings 9. Review the program at regular intervals
4	Evaluating Nature-Based Solutions. Best practices, frameworks and guidelines	Qualitative comparative evaluation	Added value of NBS compared with	Aspects of the framework: 1. Defining the scope and addressing uncertainties 2. Define the reference situation to evaluate objectives and co-benefits

#	Title [Ref]	Type of framework	Applicability	Framework steps
	[4]		traditional (grey) solutions	3. Monitoring output, outcome, process and flexibility These aspects are reached by monitoring and evaluating indicators regarding: 1. Whether the solution satisfies the principles of the design (output) 2. Whether the solution adequately addresses the societal challenge (outcome) 3. Whether co-benefits of the solutions are addressed (process) 4. How easily and at low cost the solution can be adjusted (flexibility)
5	The science, policy and practice of nature-based solutions: An interdisciplinary perspective [5]	Evaluation and monitoring	Aid implementation of interventions intended to work with nature in order to tackle societal challenges	5 key elements for enabling effective and equitable development of NBS: 1. Dealing with uncertainty and complexity (e.g. adaptive management) 2. Ensuring involvement of multiple stakeholders 3. Ensuring sound use of multi- and transdisciplinary knowledge 4. Developing common understanding of multifunctional solutions trade-offs and natural adaptation 5. Evaluate and monitor for mutual learning Sustainability in NBS is included through: 1. Set up long term investment and financing to reap benefits of NBS 2. Develop and implement appropriate institutional arrangements/designs 3. Ensure equitable distribution of benefits and risks 4. Ensure environmental targets to be included and monitored
6	A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas [6]	Assessment	Guide thinking and identifying the multiple values of NBS implementation	The NBS assessment framework entails: 1. Understanding the environmental and socio-ecological context of NBS design, implementation and evaluations 2. Design NBS in ways that address multiple interconnected challenges to take advantage of NBS co-benefits 3. Implementing NBS across multiple scales using a learning-by-doing approach to tackle emerging risks 4. Managing, maintaining, monitoring and assessing NBS to navigate trade-offs These yield a seven-stage process to guide the assessment of NBS co-benefits: 1. Identify the problem or an opportunity 2. Select and assess NBS and related actions 3. Design implementation processes 4. Implement NBS 5. Frequently engage stakeholders and communicate co-benefits 6. Transfer and upscale NBS 7. Monitor and evaluate co-benefits across all stages
7	A sustainability assessment of ports and port-city plans: comparing ambitions with achievements [7]	Assessment methodology	Compare and assess sustainability and verify the realized impacts related to social, economic and environmental aspects	The assessment method comprises from the following 6 steps: 1. Consideration of environmental, social and economic performance 2. Description of the port and port-city long-term plan 3. Assessment of sustainability of measures in the context of the performance indicators 4. Impact of port services on sustainability development 5. Classification and ranking of port sustainability

Table 11: Content of the frameworks/methodologies considered. The five steps are denoted according to the color: system analysis, setting of objectives, effects of NBS, process, monitoring.

Goals and principles for programmatic river restoration monitoring and evaluation: collaborative learning across multiple projects [3]	Evaluating Nature-Based Solutions. Best practices, frameworks and guidelines [4]	The science, policy and practice of nature-based solutions: An interdisciplinary perspective [5]	A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas [6]	A sustainability assessment of ports and port-city plans: comparing ambitions with achievements [7]	Sustainable rivers - Determining the applicability of the three P's of sustainability for rivers and whether its implementation achieves sustainability for rivers [18]	Nature-based solutions to climate change mitigation and adaptation in urban areas: perspectives on indicators, knowledge gaps, barriers and opportunities for action [13]	Developing a sustainability indicator set for measuring green infrastructure performance [45]
• Biodiversity • Ecosystem services • Ecosystem processes • Biophysical setting • Human pressures • Socio-economics • Policy framework • Stakeholder diversity • Project characteristics • Technological opportunities • Available knowledge and experience	• Stakeholder diversity • To what extent has been delivered what promised • Adequate solution for the societal challenge • Flexibility/ Adaptability	• Economy/ Prosperity • Social/ People • Ecosystem services • Ecological functions, responses to the ecosystems to climate change, disturbances and environmental variability	• Economy/ Prosperity • Social/People • Environment/ Planet	• Economy/ Prosperity • Social/People • Environment/ Planet	• Economy/ Prosperity • Social/People • Environment/ Planet	• Ecosystem services • Stakeholder diversity • Health and well being • Transferability of the project and Monitoring	• Economy/ Prosperity • Health • Ecology • Socio-cultural indicators

Table 12: Categories of indicators found in literature

Appendix B: Link between NBS for fluvial flood mitigation and SDGs

The explanation of the contribution of the NBS to the SD indicators (fourth column) along with the description of the indicators (Table 16) are the reasoning for the link between the framework indicators and the SD indicators. A framework indicator is chosen according to the explanation of the contribution of the NBS to the SDGs.

SD goals	SD targets (by 2030)	SD indicator	Explanation of the contribution of the NBS to the SD indicator
Goal 1. End poverty in all its forms everywhere	Target 1.5 Build resilience, reduce exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters, of the poor and vulnerable	1.5.1 Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population	Protect from/reduce exposure of people to flooding
		1.5.2 Direct economic loss attributed to disasters in relation to global gross domestic product (GDP)	Prevent or minimize economic losses due to flooding
		1.5.3 Number of countries that adopt and implement national disaster risk reduction strategies in line with the Sendai Framework for Disaster Risk Reduction 2015–2030	Introduced to/becoming part of the national flood risk reduction strategies
		1.5.4 Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies	Make feasible the alignment with national flood risk reduction strategies
Goal 3. Ensure healthy lives and promote well-being for all at all ages	Target 3.9 Reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination	3.9.1 Mortality rate attributed to household and ambient air pollution	Can contribute to air purification due to the natural elements used/enhanced
		3.9.2 **Mortality rate attributed to unsafe water**, unsafe sanitation and lack of hygiene (exposure to unsafe Water, Sanitation and Hygiene for All (WASH) services)	Protect from/reduce exposure of people to poor quality water
Goal 6. Ensure availability and sustainable management of water and sanitation for all	Target 6.3 Improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, having the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally	6.3.2 Proportion of bodies of water with good ambient water quality	Can contribute to water purification due to the natural elements used/enhanced
	Target 6.5 Implement integrated water resources management at all levels, including through transboundary cooperation as appropriate	6.5.1 Degree of integrated water resources management implementation (0–100)	Require integrated water resources management
		6.5.2 Proportion of transboundary basin area with an operational arrangement for water cooperation	Can potentially achieve that
	Target 6.6 Protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes	6.6.1 Change in the extent of water-related ecosystems over time	By enhancing the natural processes the ecosystem expands
	Target 6.b Support and strengthen the participation of local communities in improving water and sanitation management	6.b.1 Proportion of local administrative units with established and operational policies and procedures for participation of local communities in water and sanitation management	They require inclusive processes and stakeholder participation in the management of the water resources

SD goals	SD targets (by 2030)	SD indicator	Explanation of the contribution of the NBS to the SD indicator
Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	Target 8.1 **Sustain per capita economic growth in accordance with national circumstances** and, in particular, at least 7 per cent gross domestic product growth per annum in the least developed countries	8.1.1 Annual growth rate of real GDP per capita	New jobs or increased income in existing ones due to the intervention
	Target 8.2 Achieve higher levels of economic productivity through diversification, technological upgrading and innovation, including through a focus on high-values added and labour-intensive sectors	8.2.1 Annual growth rate of real GDP per employed person	Income related to jobs created or enhanced by the intervention
	Target 8.3 Promote development-oriented policies that support productive activities, decent job-creation, entrepreneurship, creativity and innovation, and encourage the formalization and growth of micro-, small- and medium-sized enterprises, including through access to financial services	8.3.1 Proportion of informal employment in non-agriculture employment, by sex	Ameliorate existing jobs by providing opportunities and better prevailing conditions, create new ones due to the intervention
	Target 8.4 Improve progressively global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10-Year Framework of Programmes on Sustainable Consumption and Production, with developed countries taking the lead	8.4.2 **Domestic material consumption**, domestic material consumption per capita, and **domestic material consumption per GDP**	Use of locally available materials and limited cost compared to grey materials
	Target 8.5 By 2030, achieve full and productive employment and decent work for all women and men, including for young people and persons with disabilities, and equal pay for work of equal value	8.5.2 Unemployment rate, by sex, age and persons with disabilities	New job opportunities
	Target 8.9 By 2030, devise and implement policies to promote sustainable tourism that creates jobs and promotes local culture and products	8.9.1 Tourism direct GDP as a proportion of total GDP and in growth rate	Money gained and jobs created/enhanced, attractiveness of the area/ tourism
Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	Target 9.4 Upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities	9.4.1 CO_2 emission per unit of value added	C02 sequestration by the natural material used

SD goals	SD targets (by 2030)	SD indicator	Explanation of the contribution of the NBS to the SD indicator
	Target 9.5 Enhance scientific research, upgrade the technological capabilities of industrial sectors in all countries, encouraging innovation and substantially increasing the number of research and development workers per 1 million people and public and private research and development spending	9.5.1 Research and development expenditure as a proportion of GDP	Research and pilot projects needed for the implementation the NBS
Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable	Target 11.3 By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries	11.3.2 Proportion of cities with a direct participation structure of civil society in urban planning and management that operate regularly and democratically	Stakeholder involvement in NBS design and implementation
	Target 11.4 Strengthen efforts to protect and safeguard the world's cultural and natural heritage	11.4.1 **Total expenditure** (public and private) per capita spent on the preservation, protection and conservation of all cultural and natural heritage, by type of heritage (cultural, natural, mixed and World Heritage Centre designation), level of government (national, regional and local/municipal), type of expenditure (operating expenditure/investment) and type of private funding (donations in kind, private non-profit sector and sponsorship)	NBS also implemented for cultural heritage protection
	Target 11.5 Substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations	11.5.1 Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population	Protect from/reduce exposure of people to flooding
		11.5.2 Direct economic loss in relation to global GDP, damage to critical infrastructure and number of disruptions to basic services, attributed to disasters	Prevent or minimize economic losses due to flooding
	Target 11.7 Provide universal access to safe, inclusive and accessible green and public spaces in particular for women and children, older persons and persons with disabilities	11.7.1 Average share of the built-up area of cities that is open space for public use for all, by sex, age and persons with disabilities	NBS also create/enhance accessibility, recreation and leisure space
	Target 11.a Support positive economic, social and environmental links between urban, peri-urban and rural areas by strengthening national and regional development planning	11.a.1 Proportion of population living in cities that implement urban and regional development plans integrating population projections and resource needs, by size of city	Part of the NBS design
	Target 11.b By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015–2030, holistic disaster risk management at all levels	11.b.1 Number of countries that adopt and implement national disaster risk reduction strategies in line with the Sendai Framework for Disaster Risk Reduction 2015–2030	NBS are part of flood risk reduction strategies which align with Sendai FDRR
		11.b.2 Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies	Make feasible the alignment with national flood risk reduction strategies

SD goals	SD targets (by 2030)	SD indicator	Explanation of the contribution of the NBS to the SD indicator
Goal 12. Ensure sustainable consumption and production patterns	Target 12.1 Implement the 10-Year Framework of Programmes on Sustainable Consumption and Production Patterns, all countries taking action, with developed countries taking the lead, taking into account the development and capabilities of developing countries	12.1.1 Number of countries with sustainable consumption and production (SCP) national action plans or SCP mainstreamed as a priority or a target into national policies	NBS include sustainable use/consumption of naturally available materials
	Target 12.2 By 2030, achieve the sustainable management and efficient use of natural resources	12.2.2 **Domestic material consumption**, domestic material consumption per capita, and **domestic material consumption per GDP**	Use of locally available materials and limited cost compared to grey materials
	Target 12.6 Encourage companies, especially large and transnational companies, to adopt sustainable practices and to integrate sustainability information into their reporting cycle	12.6.1 Number of companies publishing sustainability reports	NBS could contribute to
	Target 12.7 Promote public procurement practices that are sustainable, in accordance with national policies and priorities	12.7.1 Number of countries implementing sustainable public procurement policies and action plans	NBS involve inclusive strategies and actions and are sustainable by notion
	Target 12.8 Ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature	12.8.1 Extent to which (i) global citizenship education and (ii) **education for sustainable development** (including climate change education) are mainstreamed in (a) national education policies; (b) curricula; (c) teacher education; and (d) student assessment	Offer education through the enrichment of the area and close contact with the nature
Goal 13. Take urgent action to combat climate change and its impacts	Target 13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries	13.1.1 Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population	Protect from/reduce exposure of people to flooding
		13.1.2 Number of countries that adopt and implement national disaster risk reduction strategies in line with the Sendai Framework for Disaster Risk Reduction 2015–2030	NBS are part of flood risk reduction strategies which align with Sendai FDRR
		13.1.3 Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies	Make feasible the alignment with national flood risk reduction strategies
	Target 13.2 Integrate climate change measures into national policies, strategies and planning	13.2.1 Number of countries that have communicated the establishment or operationalization of an integrated policy/strategy/plan which increases their ability to adapt to the adverse impacts of climate change, and foster climate resilience and low greenhouse gas emissions development in a manner that does not threaten food production (including a national adaptation plan, nationally determined contribution, national communication, biennial update report or other)	Offer multi-benefit approach which applies at NBS design and implementation

SD goals	SD targets (by 2030)	SD indicator	Explanation of the contribution of the NBS to the SD indicator
	Target 13.3 Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning	13.3.2 Number of countries that have communicated the strengthening of institutional, systemic and individual capacity-building to implement adaptation, mitigation and technology transfer, and development actions	NBS result from and contribute to development
	Target 13.b Promote mechanisms for raising capacity for effective climate change-related planning and management in least developed countries	13.b.1 Number of least developed countries and small island developing States that are receiving specialized support, and amount of support, including finance, technology and capacity-building, for mechanisms for raising capacities for effective climate change-related planning and management, including focusing on women, youth and local and marginalized communities	Strengthening the evidence and experience in NBS would spread their application for climate resilience
Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	Target 15.1 Ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements	15.1.2 Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type	Protection and conservation of Natura places are taken into account during NBS design and implementation
	Target 15.3 Combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world	15.3.1 Proportion of land that is degraded over total land area	NBS can contribute to haltering erosion
	Target 15.5 Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species	15.5.1 Red List Index	Generation of wildlife habitat and population viability are addressed by NBS
	Target 15.6 Promote fair and equitable sharing of the benefits arising from the utilization of genetic resources and promote appropriate access to such resources, as internationally agreed	15.6.1 Number of countries that have adopted legislative, administrative and policy frameworks to ensure fair and equitable sharing of benefits	NBS are designed in order to provide as much benefits as possible in multiple sectors
	Target 15.8 By 2020, introduce measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems and control or eradicate the priority species	15.8.1 Proportion of countries adopting relevant national legislation and adequately resourcing the prevention or control of invasive alien species	Contribute to awareness and prevention of alien species in riverine ecosystems
	Target 15.9 By 2020, integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts	15.9.1 Progress towards national targets established in accordance with Aichi Biodiversity Target 2 of the Strategic Plan for Biodiversity 2011–2020	Enhance biodiversity as part of the NBS goals

SD goals	SD targets (by 2030)	SD indicator	Explanation of the contribution of the NBS to the SD indicator
	Target 15.a Mobilize and significantly increase financial resources from all sources to conserve and sustainably use biodiversity and ecosystems	15.a.1 Official development assistance and public expenditure on conservation and sustainable use of biodiversity and ecosystems	Part of the NBS project goals
Goal 17. Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development	Target 17.6 Enhance North-South, South-South and triangular regional and international cooperation on and access to science, technology and innovation and enhance knowledge-sharing on mutually agreed terms, including through improved coordination among existing mechanisms, in particular at the United Nations level, and through a global technology facilitation mechanism	17.6.1 Number of science and/or technology cooperation agreements and programmes between countries, by type of cooperation	NBS could enhance science and technology cooperation between countries
	Target 17.14 Enhance policy coherence for sustainable development	17.14.1 Number of countries with mechanisms in place to enhance policy coherence of sustainable development	The broad involvement needed in NBS projects could lead to policy coherence for sustainable development
	Target 17.15 Respect each country's policy space and leadership to establish and implement policies for poverty eradication and sustainable development	17.15.1 Extent of use of country-owned results frameworks and planning tools by providers of development cooperation	NBS intervention aligned with national policies and development plans
	Target 17.16 Enhance the Global Partnership for Sustainable Development, complemented by multi-stakeholder partnerships that mobilize and share knowledge, expertise, technology and financial resources, to support the achievement of the Sustainable Development Goals in all countries, in particular developing countries	17.16.1 Number of countries reporting progress in multi-stakeholder development effectiveness monitoring frameworks that support the achievement of the Sustainable Development Goals	NBS can contribute to SDG progress through the multi benefit approach which includes society, environment and economy
	Target 17.17 Encourage and promote effective public, public-private and civil society partnerships, building on the experience and resourcing strategies of partnerships	17.17.1 Amount of United States dollars committed to (a) public-private partnerships and (b) civil society partnerships	Partnerships and coalitions formed/enhanced through NBS
	Targets 17.18 Data monitoring and accountability	17.18.1 Proportion of sustainable development indicators produced at the national level with full disaggregation when relevant to the target, in accordance with the Fundamental Principles of Official Statistics	NBS can create trackable indicators

Table 13: Relevant Sustainable Development (SD) goals, targets and indicators to NBS. The bold parts of SD indicators (or targets) denote the relevant part of the SD indicator (or target), when the whole SD indicator (or target) is not relevant to the current research scope. The colors are according to the Guidelines for the use of the SDG logo including the color wheel, and the 17 icons from the UN.

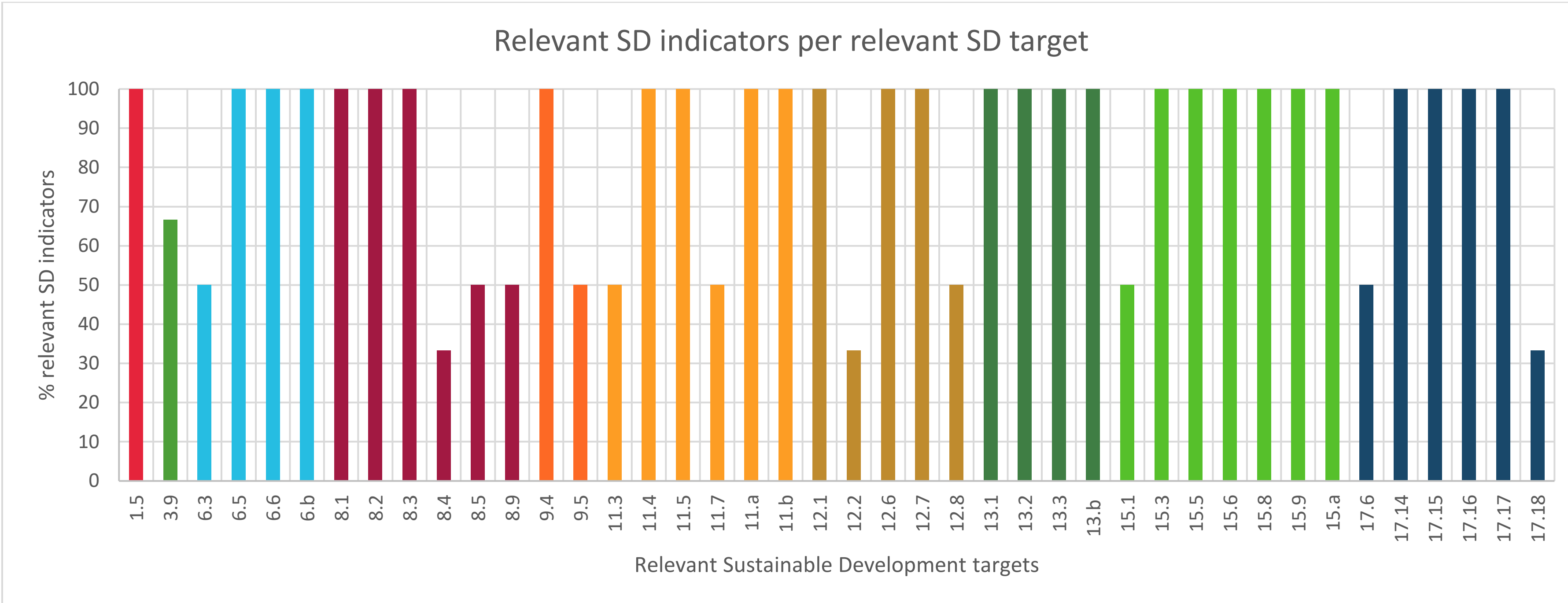

Figure 8: Relevant Sustainable Development (SD) indicators per relevant Sustainable Development (SD) targets. The colors are according to the Guidelines for the use of the SDG logo including the color wheel, and the 17 icons from the UN.

Appendix C: Performance of framework indicators

Fifty-two (52) framework indicators were determined based on literature search, case study and SDGs analysis. These indicators will be used for evaluative and benchmarking purposes of NBS projects. However, in line with the testing of the framework, there is a need to critically evaluate the indicators as well. For instance, data availability, indicativeness and data extent required per indicator are factors contributing to their ease of use for an end-user of the framework. To this end, I defined five (5) quality criteria in order to critically examine the performance of the framework indicators. In Table 15, I scored the framework indicators against the 5 criteria based on my own reasoning and with a critical viewpoint as an end-user, for the metadata of the Eddleston case study.

The quality criteria are formed based on literature research and self-creation according to the targets of the framework; evaluative/benchmarking purposes, guidance for similar projects, transferability and mainstreaming of the NBS practice. Possible quality criteria were studied from the references: Schipper et al., 2017; Den Dekker-Arlain, 2019; Puig et al., 2017; Puig et al., 2017; Rice, 2003; De Leffe et al., 2003; Rice et al., 2005; Leung et al., 2015; Shenton et al., 2004. In Table 14, the chosen quality criteria are presented. The scoring of the quality criteria is done using High (H) and Low (L) values, as shown in both Tables 14 and 15. High denotes easy and trustworthy compliance of the indicators to the quality criteria while low the opposite. In Table 15, the overall column, high (H) represents good performance, (~) moderate while low (L) poor performance.

#	CRITERIA	EXPLANATION	REFERENCES
1	**Data availability**	Available data that allow monitoring and benchmarking of the indicators: ◦ available online existing data (literature search, modelling) **[H]** ◦ not publicly available data **[L]**	[7], [18], [49], [64]
2	**Responsiveness**	Ability of the indicator to detect changes in a certain way; time scales in which the changes are detected: ◦ short-term outputs (1-3 years) of implementation of measures **[H]** ◦ long term responses (to management on decadal scales or longer) **[L]**	[7], [18], [48], [49]
3	**Concreteness**	Source of data: ◦ direct/evidence-based observations **[H]** ◦ interpretations of a person/model, not proven **[L]**	[49]
4	**Practicality**	Extent of data needed for evaluation: ◦ single value **[H]** ◦ time series **[L]**	[50]
5	**Indicativeness**	Whether the data provide an overview/ sufficient information of the indicator: ◦ Yes **[H]** ◦ No **[L]**	-

Table 14: Quality criteria. High [H] denotes easy and trustworthy compliance of the indicators to the quality criteria while low [L] the opposite

FRAMEWORK INDICATORS	DATA	RESPONSIVENESS	CONCRETENESS	PRACTICAL	INDICATIVEVESS	OVERALL
URBANIZATION/ POPULATION GROWTH/ EXPANSION	~	-	L	-	H	~
CHANNELIZATION/ ARMORING HISTORY	H	-	H	-	H	H
FLOW MODIFICATIONS DUE TO HUMAN INTERVENTION	H	-	H	-	H	H
ECONOMIC DEVELOPMENT PLANS	H	-	H	-	H	H
CLIMATE CHANGE IMPACTS	L	-	L	-	L	L
INVASIVE SPECIES	~	-	H	-	H	H
BACKGROUND INFORMATION OF THE SITE AREA	H	-	H	-	H	H
HISTORICAL LEGACIES	H	-	H	-	H	H
ENVIRONMENTAL BOUNDARIES	H	L	H	L	H	H
BUDGET	H	-	H	-	H	H
ASPIRATIONS	H	-	H	-	H	H
POTENTIAL ADEQUATE NBS INTERVENTIONS	H	-	H	-	H	H
POTENTIAL SITES – SITE SELECTION	H	-	H	-	H	H
EXPLICIT	H	-	H	-	H	H
MULTI-DIMENSIONAL	H	-	H	-	H	H
ALIGNED (NOT CONFLICTING)	L	-	H	-	H	H
ADVERSE IMPACTS/RISK	H	-	H	-	L	H
BIODIVERSITY ABUNDANCE	H	~	H	L	H	H
WILDLIFE HABITAT	H	L	H	L	H	H

FRAMEWORK INDICATORS	DATA	RESPONSIVENESS	CONCRETENESS	PRACTICAL	INDICATIVEVESS	OVERALL
POPULATION VIABILITY	H	L	L	L	L	L
ENDOGENEITY	L	H	H	L	H	H
CONTINUITY OF WATER AND SEDIMENT FLUX / SEDIMENT CONTINUITY	H	L	H	L	H	H
WATER QUALITY	H	N/A	H	N/A	L	H
AIR QUALITY	L	N/A	H	N/A	L	L
EXTENT OF WATER-RELATED ECOSYSTEM	H	H	H	H	H	H
WELL-BEING	H	H	L	H	H	H
PHYSICAL AND MENTAL HEALTH	L	-	H	-	H	H
CULTURAL/HERITAGE/EDUCATIONAL VALUE	H	-	H	-	H	H
RECREATION/ LEISURE VALUE	L	-	H	-	H	H
ENHANCE ATTRACTIVENESS	L	-	H	-	H	H
EXPLOITATION	H	-	~	-	H	H
INVESTMENT	H	H	L	H	L	H
EMPLOYMENT	L	-	L	-	H	L
VALUE OF REDUCED FLOOD DAMAGE	H	H	L	H	H	H
MAINTENANCE	H	H	H	H	L	H
FLOOD PROTECTION	H	H	H	L	H	H
STRUCTURAL INTEGRITY	L	L	H	-	H	~
RELIABILITY	~	L	H	-	H	H

FRAMEWORK INDICATORS	DATA	RESPONSIVENESS	CONCRETENESS	PRACTICAL	INDICATIVEVESS	OVERALL
IMPLEMENTABILITY	H	-	H	-	H	H
ADAPTABILITY	L	-	H	-	H	H
RESILIENCE	H	-	H	-	L	~
DIFFERENT STAKEHOLDERS/DISCIPLINES INVOLVED	H	-	H	-	H	H
PLANNING/PARTICIPATORY PROCESSES	H	-	H	-	H	H
HIERARCHY RELATIONS	H	-	H	-	H	H
ENVIRONMENTAL AGENDAS, RIGID SPENDING FRAMEWORKS, COMPLIANCE TO DIRECTIVES	H	-	H	-	H	H
COMMUNICATION/TRANSPARENCY	L	L	H	-	H	~
LONG TERM DATA CONSISTENCY (E.G. DATA BASES)	L	-	H	-	H	H
RAISING AND SHARING NBS AWARENESS	H	-	H	-	H	H
PROMOTING COLLABORATION	H	-	H	-	H	H
DAMAGE CAUSED BY PREVAILING CONDITIONS / IMPACT OF FEATURES	L	L	H	-	H	~
RESPONSE WITH RESPECT TO THE FLOOD EVENT	H	L	H	L	H	H
FIELD MONITORING	H	L	H	L	H	H

Table 15: Scoring of framework indicators against quality criteria during the framework testing phase. [H] means high, [L] low, [-] not applicable for the indicators, [N/A] means that normally would have value but does not for the Eddleston project. In the first four columns, the [~] means that the data were not clearly in the [H] or [L] side. In the last column [~] means moderate performance.

Appendix D: Description of framework indicators

The description is examples of qualitative or quantitative aspects that could answer the indicators. The description of the indicators along with the explanation of the contribution of the NBS to the SD indicators (Table 13) are the reasoning for the link between the framework indicators and the SD indicators. A framework indicator is chosen according to the explanation of the contribution of the NBS to the SDGs.

STAGES	THEMES	INDICATORS	DESCRIPTION
SYSTEM ANALYSIS	Human pressures	Urbanization/ population growth/ expansion	Rates of population living or expanding on natural floodplains
		Channelization history	Whether the stream has undergone any straightening or cut-off of meanders
		Flow modifications due to human intervention	i.e.Beaver trapping, placer and gravel mining, timber harvest and tie drives, garden walls, residential structures
		Economic development plans	i.e.Construction of roads and railroads
	Physical drivers	Climate change impacts	i.e. Changes in hydrograph
		Invasive species	Whether invasive species have altered the ecosystem (regeneration, natural) processes
	Boundary conditions	Background information of the site area	land uses, geology, topography, fauna and flora of the site, past flooding events/flooding history of the site area, number of properties at risk in case of flooding, hydrological characteristics, archaeological findings, roads and railways nearby, river channel
		Historical legacies	Taking into account any historical lay-out of the area
		Environmental boundaries	Temperature, salinity, light and nutrient availability, sediments, rainfall, size of the materials available for use, waves, wind

STAGES	THEMES	INDICATORS	DESCRIPTION
	Client’s requirements	Budget	Permitting and funding constraints, available amount of money for the intervention
		Aspirations	i.e. integrated flood river management approaches, catchment scale approaches
SETTING OF OBJECTIVES	Measure	Potential adequate NBS interventions	Number and type (materials used etc) of NBS considered
		Potential sites – site selection	Number and identification of potential implementation sites
	Variety of objectives	Explicit	Understood by all the involved parts
		Multi-dimensional	Address effects on all possible sectors
		Aligned (not conflicting)	Not fulfilling one requirement by creating major disturbances in another field
	Failure	Adverse impacts/risk	Alternative plan in case the intervention won’t work as expected, calamities
EFFECTS OF NBS	Environment and Ecology	Biodiversity abundance	% of animals using the site and % vegetation cover, inclusion of the ‘Nature 2000’ network
		Wildlife habitat	% of generation of habitat for flora and fauna
		Population viability	Last of a species in time, natural materials that enhance the fauna abundance
		Endogeneity	% of invasive species

STAGES	THEMES	INDICATORS	DESCRIPTION
		Continuity of water and sediment flux / Sediment continuity	Erosion, sediment traps, amount of sediment captured
		Water quality	Nitrates, phosphorus and suspended sediments, water discharge (m3/s)
		Air quality	% of CO2 captured by the vegetation/natural elements used
		Extent of water-related ecosystem	% of change of the extent of the water-related ecosystem since the NBS implementation
	Society	Well-being	Mortality rate/affected people by water/air pollution, flooding
		Physical and mental health	% of people using the NBS area with an X frequency
		Cultural/heritage/educational value	Protected or (newly) created value by the intervention
		Recreation/ Leisure value	Number of new walking/ running/biking paths, activities
		Enhance attractiveness	Improvement of 'spatial quality' (more appealing habitats), accessibility of the area, number of tourists (enable vacation houses or floating houses)
	Economy	Exploitation	Income per exploitation activity (irrigation, recreation, cattle farming, agriculture, tourists)
		Investment	Euros less/meter than with a traditional measure
		Employment	Number of additional jobs created (e.g. pruning of trees, mowing, renting canoes, selling local growing products

STAGES	THEMES	INDICATORS	DESCRIPTION
		Value of reduced flood damage	Value of assets that would have been destroyed in case of flood, avoided relocation in case of flood
		Maintenance	Amount of money spent for maintenance
	Technical	Flood protection	Frequency of floods or floodplain inundation or reduction in water levels (cm), % of attenuation of the flood due to the natural components of the intervention, delay of the travel time of the peak flow
		Structural integrity	Proof that by using a natural material instead of a conventional one still stable/sturdy intervention
		Reliability	Number of repairs since construction
		Implementability	Availability (and use) of resources and materials available on site
		Adaptability	Future changes in function
		Resilience	Whether another major intervention will be needed in due course (long term perspective with respect to safety)
PROCESS	Stakeholder involvement and diversity	Different stakeholders/disciplines involved	Number of different stakeholders/disciplines involved
		Planning/participatory processes	Kind of participatory/planning process used: Top-down/bottom-up, formal/informal rule oriented, trust-based, consultation processes, collaborative learning, learning by doing, workshops, meetings

STAGES	THEMES	INDICATORS	DESCRIPTION
		Hierarchy relations	Gap between local stakeholders and projects managers/central bosses (committed and accessible project managers)
	Policy and institutional restrictions, support and arrangements	Environmental agendas, rigid spending frameworks, compliance to directives	Assessments, (Water, Floods, Birds) Directives, Natura 2000
	Sharing of knowledge/innovation, transferability and mainstreaming/upscaling	Communication/transparency	Alignment of project expectations with promises
		Long term data consistency	Existence and/or maintenance of data bases relevant to the project info
		Raising and sharing NBS awareness	Number of visits on respective sites/forums, republication on social media, citations/newspapers, public consultations about how the people feel after the completion of the intervention (public engagement meeting)
		Promoting collaboration	Coalitions, partnerships
MONITORING	Monitoring	Damage caused by prevailing conditions	Long term intervention and flora damage due to fauna
		Response with respect to the flood event	Observation data, monitoring data
		Field monitoring	Types of flow in the field and their effects, ecology etc

Table 16: Stages (5), themes (15) and indicators (52) along with a short description of the indicators. Source of the indicators: case studies (6): hierarchy relations, transparency in communication, maintenance, field monitoring, damage caused by prevailing conditions and response to the flood event. UN 2030 Agenda (2): extent of water-related ecosystems, well-being. Introduced by the author (7): budget, aspirations, structural integrity, reliability, implementability, adaptability and resilience. The rest of the framework indicators come from literature (37).