Guidelines for design, construction and maintenance of large-scale NBS

Lessons learned from three NBS case studies throughout Europe

Deliverable D2.8

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Abstract (for dissemination, 100 words)	Through the RECONECT project, NBS for hydro-meteorological risk reduction were implemented in various locations in the EU. After their completion, these guidelines have selected multiple practical lessons drawn from three projects, in mountainous, riverine and coastal areas, through the implementation of solutions benefiting water, nature and people. The integration of these three aspects is crucial to implement a successful NBS. The lessons outlined include how goals were determined, suitable measures were chosen, and how specific barriers were overcome that arose during the project. As a closure the document looks for a synthesis of the three projects.
Keywords	Nature-based solutions, flood prevention, nature development, Room for the River, soil and water conservation, rivers, landslides, floods, water, nature, people

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1 Introduction

1.1 What are Nature-Based Solutions?

Throughout the centuries, water engineers have sought to exert control over natural forces through "hard" engineering practices, such as the constriction of waterways with dams and dikes, and the fortification of coastlines with concrete sea walls, among other methods. However, contemporary factors such as population growth, climate change, and urbanization have prompted engineers to acknowledge the limitations of extensively manipulating these natural processes.

Moreover, in the face of escalating threats posed by climate change and its adverse impacts on urban areas and critical infrastructure, coupled with the diminishing efficacy of traditional hard-engineering structures in confronting these challenges, there is a growing recognition of the urgent need for innovative systems. A paradigm shift is underway, wherein hard engineering is giving way to the application of nature-based solutions (NBS) for water management and climate-related issues. Nature-based solutions are defined differently by different organizations.

The International Union for Conservation of Nature (IUCN) defines NBS as: *“Nature-based Solutions are actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously benefiting people and nature.” (IUCN, 2020)*

The European Commission defines NBS as: *“Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions.”* (EC; 2024)

The benefits of NBS as a tool to manage hydro-meteorological extremes are increasingly recognized by engineers, policymakers and spatial planners. The implementation of NBS provides an opportunity to move away from traditional practices and reconnect land management and development with nature and (local) people. This approach offers multiple benefits to ecosystem services and functions. These measures are even potentially more cost-effective and flexible compared to traditional hard engineering measures. However, designing and implementing cost-effective NBS is only part of the solution. Equally important is the ability to effectively integrate them into diverse local and cultural contexts, as well as broader land and risk management strategies. Understanding the complexity of each case is crucial in order to minimize social, economic, and environmental impacts, while increasing resilience to hydro-meteorological events and ensuring financial viability. Currently, there is a lack of large-scale NBS examples for reducing hydro-meteorological risks that can serve as references for replication and upscaling. NBS RECONECT, through amongst others these guidelines, aims to increase this availability of examples.

1.2 NBS RECONECT

The goal of RECONECT is to contribute to the European reference framework on NBS and stimulate a new culture for 'land use planning' that links the reduction of risks with local and regional development.

The RECONECT project is dedicated to developing a comprehensive ecosystem-based framework that facilitates cross-sectoral and transdisciplinary analyses and evaluations to advance the understanding of Nature-Based Solutions (NBS) in the context of hydro-meteorological risk reduction, with a specific focus on floods, storm surges, landslides, and droughts. RECONECT serves as the foundation for the proof-of-concept regarding large-scale NBS demonstrations by co-creating new cases, connecting to existing cases, and sharing experiences with European and international collaborators within the network of cases. Furthermore, RECONECT identifies and assesses barriers related to the social and cultural acceptance of NBS, as well as policy regulatory frameworks, and proposes strategies to overcome them. The project also collaborates with other relevant projects and initiatives to address these barriers. RECONECT emphasizes and actively pursues innovation in the evaluation, selection, design, operation, maintenance, and decommissioning of NBS, including standardization, as well as in their co-creation through social innovation and the active participation of stakeholders. Additionally, RECONECT enables the replication and upscaling of NBS in different contexts through the RECONECT Roadmap. In developing the Network of cases, RECONECT takes into consideration market dynamics, knowledge creation, institutional entrepreneurship, and brokerage. The project also assesses the potential for replication and expands the knowledge of long-term sustainable data platforms while considering existing initiatives and alternative options, such as OPPLA.

The RECONECT Consortium is a transdisciplinary partnership between researchers, industry partners (SMEs and large consultancies) and responsible agencies at the local and watershed/regional level. The partners include: GISIG, IHE Delft Institute for Water Education, and HydroLogic.

1.3 This guideline’s contribution to NBS implementation

Amidst this paradigm shift, numerous initiatives globally have been devised or accomplished to incorporate nature-based solutions (NBS) in addressing water management and climate concerns. The European Union, acknowledging the significance of deploying such solutions both within and beyond its borders, has noted the initiation or completion of several projects within its member states. In support of the broader adoption of NBS, the EU has launched the Regenerating Ecosystems with Nature-based Solutions for Hydro-meteorological Risk Reduction (RECONECT) project, with the following objectives:

“Contribute to European reference framework on [NBS] by demonstrating, referencing and upscaling large scale NBS and by stimulating a new culture for ‘land use planning’ that links the reduction of risks with local and regional development objectives in a sustainable way” (grant agreement page 89)

This document represents a key outcome of the RECONECT project, aiming to serve as a comprehensive guide for entities interested in applying Nature-Based Solutions (NBS) for large-scale hydro-meteorological risk reduction projects, particularly focusing on rural and natural areas. The intended audience includes both collaborators within the

RECONECT project and a broader community of NBS implementors following the project's completion.

While existing literature and guidelines have extensively covered NBS implementation, this guide seeks to enhance the practical understanding by incorporating already executed NBS projects for hydro-meteorological risk reduction—referred to as demonstrators. These demonstrators span diverse physical and social contexts, providing a valuable resource for connecting theoretical knowledge with real-world applications. The document serves as a repository of NBS projects, offering examples that can be tailored to specific environments for the implementation of new NBS initiatives. This document does not provide specific design requirements or technical details of, for example dimensions or parameters to be used. This document goes into detail instead about the practical lessons learned during the design, construction and maintenance of three example large scale NBS projects.

The structure of this document begins with an exploration of the literary background, offering a summary of existing guidelines. Following this, an in-depth overview of NBS implementation theory is presented, organized into design, construction, and maintenance phases. Subsequent sections delve into the details of each individual demonstrator project, guided by the earlier described NBS implementation theory. The elaboration on demonstrators is further summarized in tables and figures, facilitating easy navigation to relevant sections based on keywords associated with the circumstances of implementation.

1.4 Reading guide

This document synthesizes insights gained from the NBS RECONECT demonstrator projects, focusing on NBS for hydro-meteorological risk reduction. These projects are currently either largely or completely implemented as of the time of writing. To facilitate understanding, the lessons learned are categorized based on different types of physical circumstances, with each category represented by a principal demonstrator project. The specific circumstances and projects considered are as follows (as indicated on Figure 1)

- Mountainous areas, exemplified by the NBS RECONECT project at Portofino, Italy
- Delta areas, showcased by the NBS RECONECT project at the Ijssel River, the Netherlands
- Coastal areas, highlighted by the NBS RECONECT project at Odense, Denmark

The document organizes the lessons learned for each of the mentioned circumstances and projects into distinct chapters, guided by the previously outlined Water – Nature – People framework. A comprehensive synthesis of these lessons across the three projects is presented at the conclusion of this document.

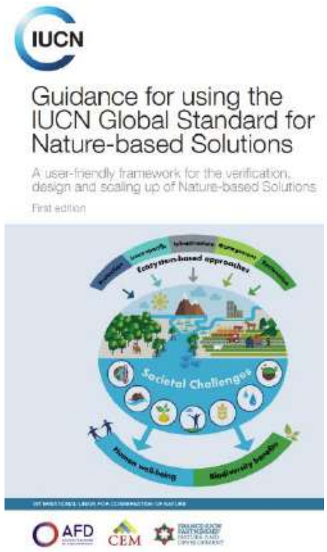
Figure 1: overview of the case studies: Portofino (left), Ijssel River (middle) and Odense (right).

2 Literary background

2.1 Existing guidelines

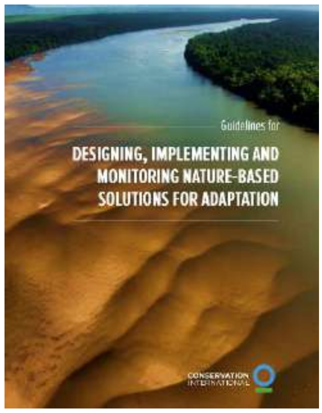
Guidelines for Nature Based Solutions are less well established than for (hard-) engineering techniques. However, an increasing number of studies that contribute to the development of Nature Based Solution guidelines are created.

One of the most influential existing guidelines is the IUCN Global Standard for Nature-based Solutions, aimed at informing a wide public involved with the implementation of NBS, including governmental actors and planners, development organizations, etc. (IUCN; 2020). This guideline defines eight criteria for the implementation of NSB, with each of them further explained with a case study:



1. NBS effectively address societal challenges.
2. Design of NBS is informed by scale.
3. NBS result in a net gain to biodiversity and ecosystem integrity.
4. NBS are economically viable.
5. NBS are based on inclusive, transparent and empowering governance processes.
6. NBS equitably balance trade-offs between achievement of their primary goal(s) and the continued provision of multiple benefits.
7. NBS are managed adaptively, based on evidence.
8. NBS are sustainable and mainstreamed within an appropriate jurisdictional context.

Another influential NBS guideline is the Guidelines for designing, implementing and monitoring nature-based solutions for adaptation (Conservation International, 2021). This guideline offers various stages to go through to achieve a successful implementation of NBS, including the clear definition of activities and outcomes per stage:



1. Stage 1: Assess climate threats in the target region and populations.
2. Stage 2: Identify a set of possible adaptation options.
3. Stage 3: Address the transformative potential of nature-based solutions for adaptation.
4. Stage 4: Select and design the nature-based solution for adaptation.
5. Stage 5: evaluate the effectiveness of nature-based solutions to achieve adaptation outcomes.

The RECONECT partners acknowledge the value of the existing guidelines and recommend their utilization for the implementation of Nature-Based Solutions (NBS). It is essential to clarify that the RECONECT guideline does not seek to replace or scrutinize these established guidelines; rather, its objective is to enhance the existing knowledge base. The RECONECT guideline aims to contribute to this body of knowledge by providing hands-on experience derived from various demonstrator projects.

While the aforementioned existing guidelines provide robust frameworks for NBS implementation, the RECONECT guideline complements them by offering a more practical perspective. It presents concrete examples of how diverse NBS projects have applied the prescribed criteria and stages. Moreover, it elucidates the practical lessons derived from these experiences, thereby offering valuable insights into the real-world application of NBS principles. The RECONECT guideline, therefore, serves as a valuable resource for practitioners seeking a nuanced understanding of NBS implementation.

2.2 NBS literature for further reference

Debele et al., 2019, Ruangpan et al., 2019 and Watkin et al., 2019 did an extensive review on the concepts, classification scheme, databases, benefits, current knowledge gaps and future research prospects of Nature Based Solutions. Debele et al., 2019 presented a present a classification scheme, key features, and elements for designing NBS and mitigating the adverse impacts of Hydro-meteorological hazards in Europe. Furthermore, Ruangpan et al., 2019, critically reviewed the literature on concepts such as Ecosystem-based Adaptions, Green Infrastructure and/or Nature Based Solutions and identifies current knowledge gaps and future research prospects. Lastly, Watkin et al., 2019, presents an evaluation framework that aims to quantify the benefits and co-benefits of implemented NBS. The framework involves five main steps: (1) selection of NBS benefit categories, (2) selection of NBS indicators, (3) calculation of indicator values, (4) calculation of NBS grade, and (5) recommendations.

Nature Based Solutions in urban areas offer, besides flood risk reductions, numerous co-benefits. Alves et al., (2019) included these co-benefits via a cost-benefits analysis because conventionally these were not included into decision making process for flood risk management. A mix of green, blue and grey infrastructure measurements is expected to result in the best adaptation strategy as these three alternatives tend to complement each other.

From a stakeholder perspective, Zinegraf-Hamed (2020) states that NBS projects should benefit from strong collaborative governance models. In this context, real-life constellations are compared to theoretical typologies, and a systematic stakeholder mapping method to support co-creation is adopted. Rather than making one-fit-all statements about the “right” stakeholders, the contribution provides insights for those “in charge” to strategically consider who might be involved at each stage of the NBS project.

Zooming into the people indicator, Han and Kuhlicke (2019) identified six topics that form people’s perceptions of NBS. Namely, (1) valuation of the co-benefits (including those related to ecosystems and society); (2) evaluation of risk reduction efficacy; (3) stakeholder participation; (4) socio-economic and location-specific conditions; (5) environmental attitude, and (6) uncertainty.

3 NBS RECONECT Framework:

3.1 Water – Nature – People

The NBS RECONECT Framework is developed to guide both the design and the monitoring & evaluation procedures to support the implementation of NBS. This framework is built on three pillars: the benefits related to **water, nature**, and **people.**

As the overall goal of NBS RECONECT is to reduce hydro-meteorological risk, **water** related benefits are the core of the proposed framework. The water sub-goals considered in the NBS RECONECT framework are:

- Flood risk reduction:
  Aiming to decrease the frequency and severity of floods, as well as the damage they cause.
- Coastal risk reduction:
  Aiming to decrease the risks posed by the forces of the sea at coastal areas, including shoreline erosion, wave damage and coastal flooding.
- Drought risk reduction:
  Aiming to decrease droughts, often by managing water availability better through time, by increasing storing capacity which can be filled during wet periods, while used during dry periods.
- Landslide risk reduction:
  Aiming to prevent landslides, consisting of movements of a mass of rock, debris and/or earth down a slope under the influence of water, potentially causing large damage and dangerous situations downslope.
- Surface water quality improvement:
  Aiming for the improvement of water quality, which is often of great importance for water use and safety. Water quality is a container term including the consideration of salt, nutrients, metals, chemicals and micropollutants.
- Groundwater management and quality improvement:
  Aiming to improve both quantitative groundwater management, like increasing groundwater recharge to increase long-term water availability, or groundwater quality, similar to surface water quality.

The nature-based solutions aim to use natural forces, including for the benefit of **nature**, as described in the previously provided definition. This means that **nature** should be included in the NBS RECONECT framework, for which the sub-goals are:

- Habitat area increase:
  Aiming to increase the available habitat area (in quantity) of certain flora and/or fauna species, or natural areas as a whole. This should make the overall natural system more robust and therefore less sensitive to (human induced) shocks.
- Improvement of habitat provision and distribution
  Aiming to improve habitat (hence quality-based), which should provide the same benefit as the one described above.
- Maintenance / enhancement of biodiversity
  Although heavily dependent on the above-described goals, biodiversity improvements can be seen as a goal by itself, both for ecosystem robustness as well as for adhering to relevant regulations.
- Improvement of riparian area structures

Riparian areas are often of huge importance to both aquatic and terrestrial ecosystems, hence improving their natural value will have a positive impact on the ecological system.

Though the abovementioned goals by themselves already have a positive impact on well-being of the **people**, this can further be increased by aiming for this specifically during the design of NBS. Not only is human well-being a worthy goal by itself, including it in the design will also increase connectedness between the measure and the local population, as well as create acceptance and ownership of it. The sub-goals of the NBS framework regarding **people** lies on:

- Increasing recreational opportunities:
  Both water and nature areas have an undeniable attraction on people, hence embedding the recreational opportunities of the NBS designs is likely to lead to the enjoyment of the design by the public.
- Economic benefits
  When redesigning an area, which is inherent to the implementation of a NBS measure, economic opportunities, such as green jobs and nature-oriented economic activities can be created, which will provide additional benefit to the local area and population.
- Improvement of air quality
  Green areas often positively influence air quality and carbon capture from the atmosphere, hence taking this into account when designing NBS measures could yield this as an additional benefit.

3.2 Integration of Water – Nature – People in design, construction and maintenance

Each of the identified pillars in the NBS RECONECT framework holds significant importance for the project's goals and, consequently, for the design of Nature-Based Solutions (NBS). As many classic hydro-metrological risk reduction solutions primarily focus on water-related aspects, such as coastal or river flood risk reduction, what sets NBS apart from "grey infrastructure" is their inherent integration of water, nature, and people right from the inception of the design process. This integration allows these three pillars not only to coexist but to be fully interconnected, thereby reinforcing each other.

The successful integration of the three pillars in NBS design necessitates that they be accorded equal consideration. Furthermore, the design process stands to benefit from the involvement not only of (hydraulic) engineers but also of spatial planners, designers, ecologists, and other professionals from various other backgrounds. This collaborative approach enables informed decision-making in the design of NBS measures, taking into account their impact on water, nature, and people for optimal outcomes.

Emphasizing the integration of the three pillars primarily occurs during the design phase, as this phase typically determines the success or shortfall of such integration. In contrast to grey infrastructure, like a dike, which focuses solely on reducing flood risk, the construction phase of NBS is intricately linked to the materialization of the design. Additionally, maintenance, while important for ensuring its long-term functionality, is not inherently different for NBS than for grey infrastructure.

These guidelines are situated within the broader context of the NBS RECONECT project. While various demonstrator projects reached completion during the project, collaborator projects were still in their initial stages. Input from these collaborators was crucial in identifying the information required for the successful implementation of NBS measures.

The document's focus on the design phase and the specific topics covered is a response to the collaborators' needs for guidance in these areas.

It is essential to note that consideration of the construction, operation and maintenance of NBS are ideally integrated into the design phase. By involving future contractors and operators during the design phase, their perspectives can be taken into account. This helps to ensure that the original goals of each of the three pillars are upheld beyond the design phase. The overview of this framework is provided in Figure 2.

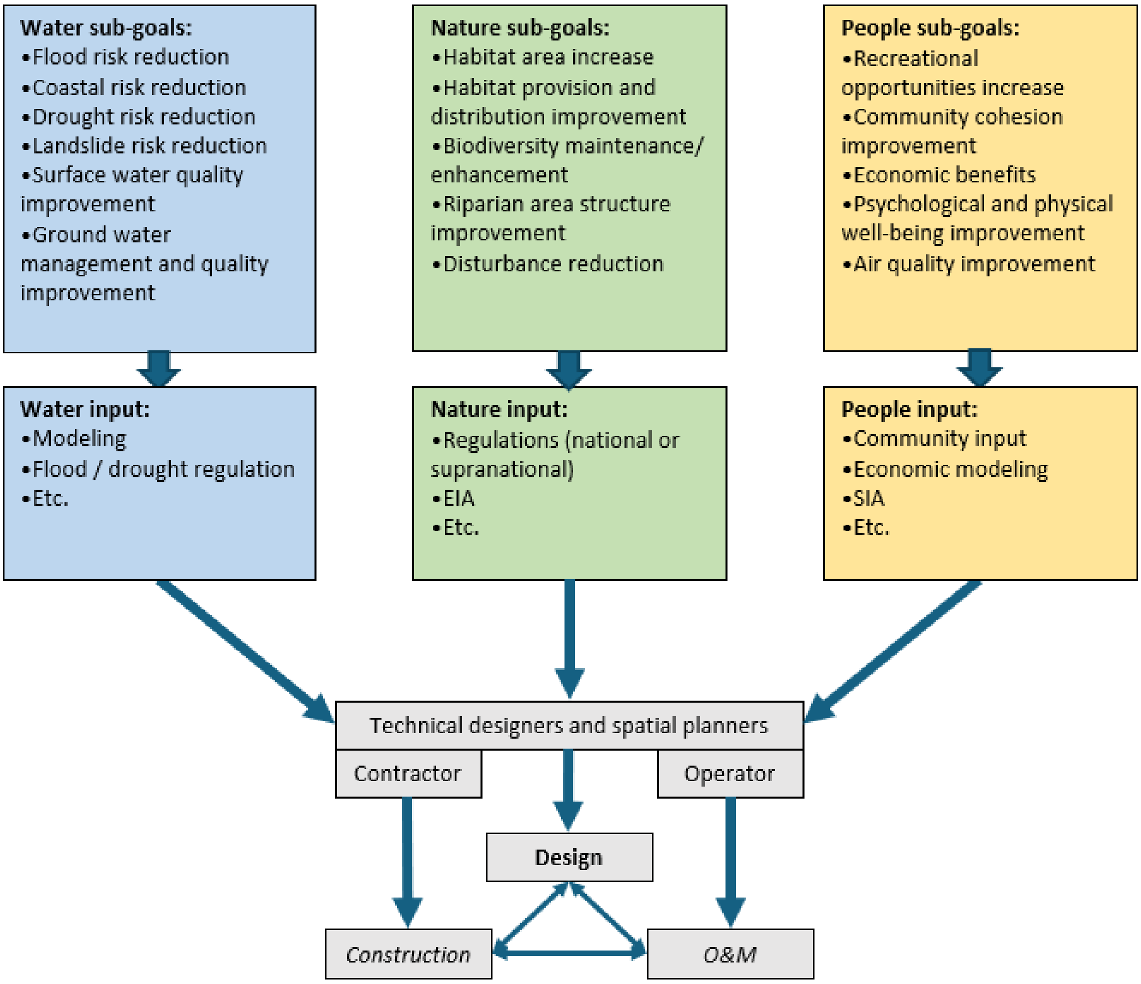


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Figure 2: Overview of the water - nature - people framework.

4 Contribution of knowledge gained from the demonstrators

This chapter delves into the lessons learned from three specific demonstrator projects, each of which has reached (largely) completed status during the writing of this document. These projects are highlighted as illustrative examples because they represent diverse physical environments:

- Flatland river systems, exemplified by the Ijssel River Basin, the Netherlands
- Coastal areas, showcased by the Odense Strand area, Denmark.
- Mountainous areas, represented by Portofino National Park, Italy

By concentrating on the practical aspects of each demonstrator project, these guidelines offer a comprehensive overview of the acquired insights. Engineers, civil servants, and planners can leverage these lessons to effectively design Nature-Based Solutions (NBS) for hydro-meteorological risk reduction. Dedicated sub-chapters within this chapter cover the lessons learned for each specific project, facilitating valuable learning experiences for future NBS implementors. It is strongly recommended that individuals planning NBS projects explore each sub-chapter, as the insights provided are not only relevant to projects in similar physical environments but also offer broader applicability.

4.1 River systems (Ijssel River Basin, the Netherlands)

4.1.1 Introduction

The Netherlands, as a nation, predominantly consists of a delta formed by the Meuse, Rhine, and Scheldt rivers. This geographical characteristic not only results in the Netherlands being largely situated below sea level—hence the name "low countries"—but also entails the passage of some of Europe's largest rivers through its territory. This delta configuration has bestowed numerous advantages upon the Netherlands, including fertile soils, an abundance of fresh water, and extensive riverine connections to Europe's hinterland, notably the industrially significant Ruhr area in Germany. These advantages, in turn, have contributed to the Netherlands becoming one of the most densely populated and economically developed regions globally.

However, the deltaic nature of the Netherlands has not been without its challenges. Throughout its history, the Dutch have grappled with the threats posed by sea and riverine floods. The Rhine River, including its sub-branch, the Ijssel River, has historically been a major contributor to these flooding incidents. As Europe's second-longest river, the Rhine traverses the Netherlands from east to west, being partly fed by glacial water from the Alps and rainwater collected across its extensive watershed. Figure 3 illustrates the location and average discharge of various Dutch rivers, providing a spatial context for a clearer understanding.

Figure 3: Overview of the main rivers of the Netherlands, per annual discharge average between 2000-2011 (Dörrbecker, 2016)

Figure 4: High water levels at houses outside of diked areas in 1995 (HDSR, 2024)

In 1993 and 1995, intense rainfall within the Rhine and Meuse watersheds threatened to flood large areas in the delta. In the proximity of the Rhine and Ijssel rivers, more than 200,000 people were evacuated. Despite the absence of dike failures, the close call underscored the imperative for action. In addition to the increasing population density near these rivers, the flood risk increases due to ongoing climate change and sediment accumulation in the river systems, constraining the space initially designated for controlled annual floods. Responding to the near-disasters of 1993 and 1995, the Dutch cabinet proposed the Spatial Planning Key Decision (SPKD) in 2006. This design plan, with legal status, aimed to facilitate highly innovative structures and modifications of existing structures within the immediate floodplain area (RftR program Directorate, 2005).

Figure 5: The Ijssel River at Deventer in 1993 (Waterschap Groot Salland, 2010a)

Experts provided recommendations on measures to enhance the discharge capacity of the Ijssel River. From this SPKD, the Room for the River (RftR) program emerged—a national NBS-orientated initiative running from 1997 to 2015 with a total budget of 2.3 billion euros (RftR program Directorate, 2005).

Figure 6: Fear of breaching dikes during the high-water event in 1995 (BHIC, 2011)

The primary goals of the RtfR program were to mitigate riverine flood risk and improve spatial quality in the Netherlands by adopting a groundbreaking approach in the traditionally grey civil engineering-oriented Dutch water sector. Instead of constructing taller dikes and levees to contain the rivers, selected structures were intentionally dismantled to provide the rivers with more space. Designated areas were allowed to flood during periods of high water levels, serving as temporary water storage to attenuate the peak flow of the rivers (RftR program Directorate, 2005).

The Room for the River program encompassed four rivers: the Rhine, the Meuse, the Waal, and the Ijssel. The NBS RECONECT project focuses specifically on the Ijssel River, representing the experiences and expertise of the entire Room for the River program. An overview of the RTFR measures implemented for the Ijssel River is provided in Figure 7 (RftR program Directorate, 2005).

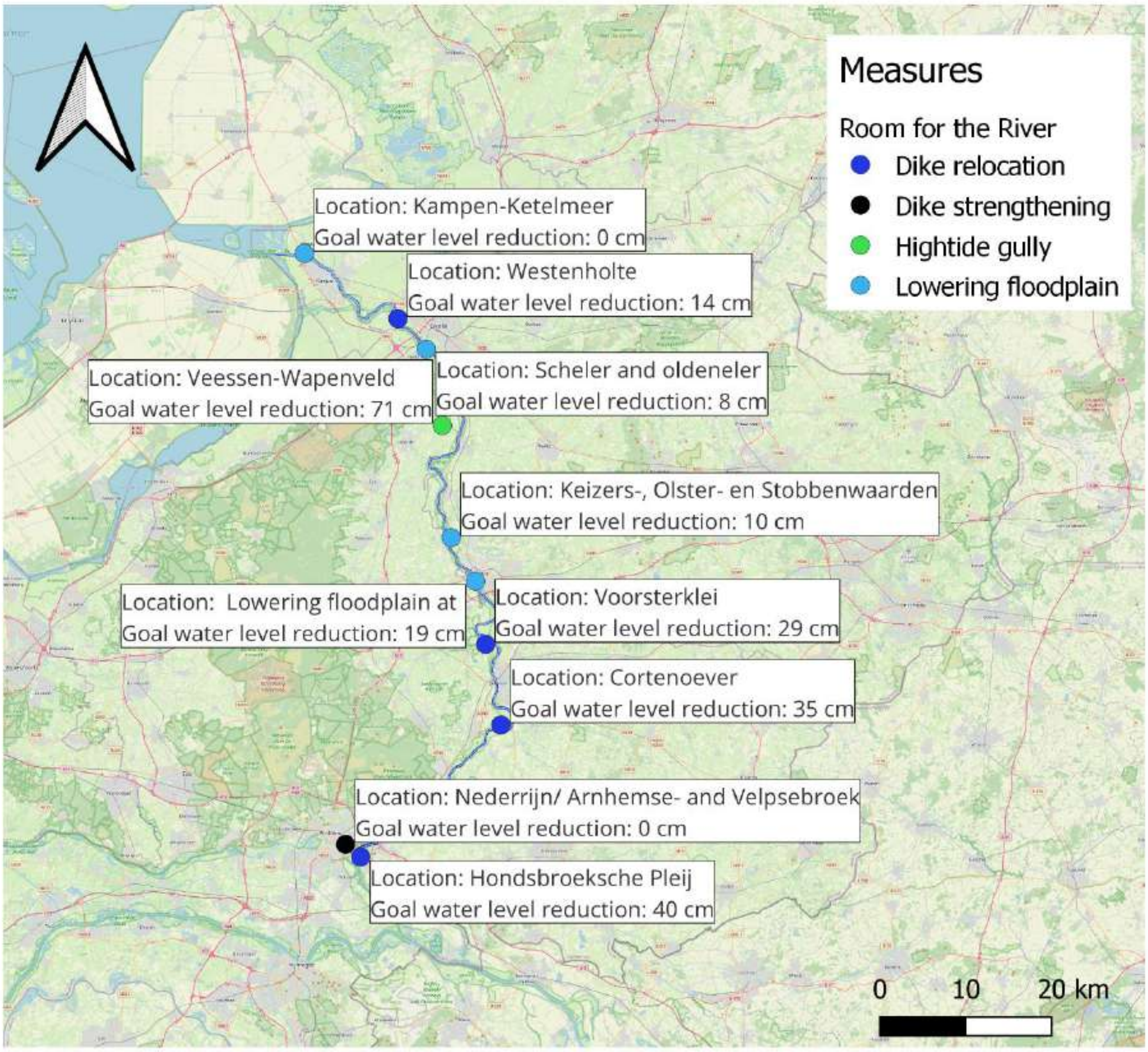

Figure 7: Overview of RftR projects at the Ijssel River, where a total of ten projects were executed, nine of which are considered NBS.

The RftR program comprised various measures designed to provide rivers with more space, ultimately reducing the risk of flooding. These measures can be broadly categorized into the following types, as summarized in Figure 8 (Herk, 2013).

- Constructing floodplains: This involves creating new floodplains, adjacent to the river, which can be intentionally flooded during periods of high water. These floodplains serve to mitigate the risk of flooding in surrounding areas by offering additional space for the river to expand into, thereby alleviating stress on protective dikes.
- Broadening the riverbed: The riverbed at certain locations was widened, allowing the river to discharge more water and minimizing the risk of overflow.
- Removing obstacles from the river: Obstacles, such as vegetation and low dam-like structures, could were removed at strategic points along the rivers to increase the maximum discharge capacity.

- Creating new channels / bypasses: The program involved constructing new channels to divert water away from areas prone to flooding from bottlenecks during periods of elevated water levels.
- Modifying existing structures: Various existing structures, including bridges and weirs, were adapted to guarantee their capacity to accommodate higher water levels.
- Dike strengthening: In instances where the implementation of Nature-Based Solutions (NBS) was deemed impractical or impossible, dike strengthening was considered as a last resort measure.
- Environmental considerations: The program included measures aimed at preserving and enhancing the natural environment, such as the creation of new habitats for wildlife and the restoration of riverbanks.
- Benefits for local people: Part of the program focused on providing access for people to locations where measures were implemented and addressing the needs and desires of the local population.

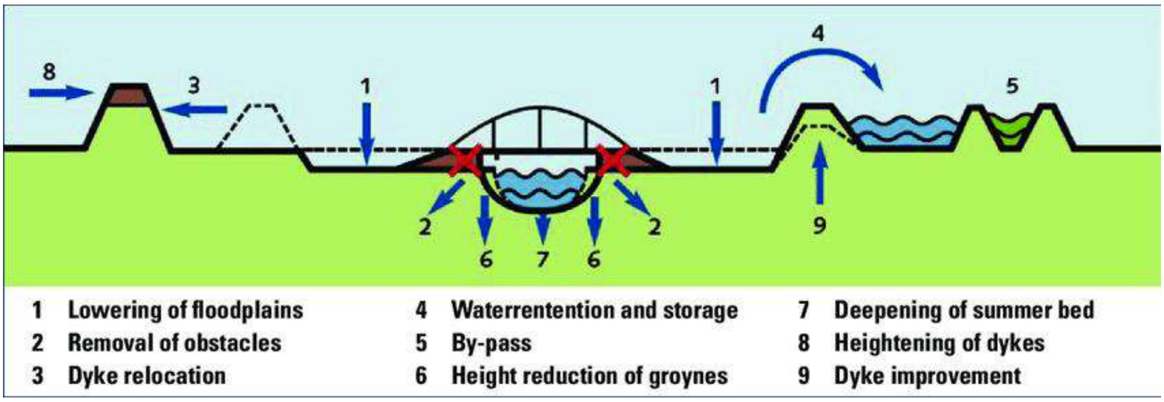

Figure 8: Measures that are applied in the Room for the River Program (Herk, 2013)

Indeed, the list of measures in the RftR program underscores the prominent role of water-related goals, a response to the critical flood event experiences. However, it is crucial to note that the program also prioritized nature and people goals, prompting the implementation and adaptation of various measures to address these broader considerations. This holistic approach reflects a commitment to achieving a balance between water management, environmental preservation, and meeting the needs of the local communities, emphasizing the multifaceted objectives of the RftR program.

4.1.2 Determining the goals of RftR: Water – Nature - People

Critical to the success of any extensive program, particularly one as ambitious as the Room for the River (RftR) initiative, encompassing numerous sub-projects with a focus on water, nature, and people, is the establishment of clear and measurable goals. The foundational framework for these goals was articulated in the Spatial Planning Key Decision (SPKD) (RftR program Directorate, 2005).

The SPKD served as an existing planological framework for major infrastructure projects in the Netherlands, delineating the objectives, budget, and responsibilities for executing spatial projects. It facilitated consensus on project goals and direction before specific designs were starting to be formulated. The SPKD aimed to provide a legal framework for spatial planning, consolidating the plans of various governmental entities (national, provincial, municipal, and waterboards) responsible for spatial planning. Once the framework was developed and subjected to a participation period, it received approval from the national parliament, attaining legal status and a budget, which could only be altered through parliamentary amendments (Eerste Kamer der Staten-Generaal, 2023).

The utilization of the SPKD framework allowed for the participation of all relevant parties and defined the parameters within which the program could be actualized. A notable advantage of the SPKD was its provision for the national government to supersede regional and local governments in planological projects where national interest was at stake, following their participation. The formation of an SPKD, like the RtfR program, involved various steps, enabling input from the general public, houses of representatives, and other governments before formalizing it and rendering it binding for all parties—akin to having legal status similar to a law. Importantly, this inclusive approach garnered widespread acceptance among stakeholders and the general public for the RtfR program. It also ensured that decisions, once made, could not be obstructed by individual regional or local authorities. While the exact project designs are yet to be defined, the process will include public consultation.

The RtfR program, a nationwide initiative, was overseen by the dedicated RftR directorate under the executive agency of the Ministry of Infrastructure and Water Management. Despite its national scope, the project actively pursued collaboration and shared responsibilities with regional governments from its inception. Notably, regional authorities were not merely delegated responsibilities but were equipped with expert knowledge and guidance as needed. The financial support for these responsibilities was derived from the national program's budget. This approach facilitated an optimal synergy, leveraging local expertise and contacts at the regional level while concurrently maximizing the utilization of national knowledge and financial resources (De Boer, 2024).

This cooperative and legally binding process had led to the definition of two main objectives:

- To create a safe river area by reducing riverine flood risks (**water** goals).
- To enhance the spatial quality of the area (**nature** and **people** goals).

From the project's inception, this dual objective was established, focusing on both spatial quality and water safety. Throughout the entire project duration, these two aspects were consistently and equally prioritized. In contrast to many projects where water safety takes precedence, and other benefits are viewed as incidental successes, the RftR approach ensured that both spatial quality and water safety were integral goals, each requiring dedicated attention and achievement (RftR program Directorate, 2005).

Water goals
The overarching water goal of the RftR program was to establish a safe river area by mitigating riverine flood risks. This safety encompassed the protection of human life, property, infrastructure, and the environment.

The principles underlying flood risk norms in the Netherlands revolve around three key factors (RftR program Directorate, 2005):

1. Basic protection for all people:
The primary focus is preventing human casualties due to floods. In the Netherlands, this is operationalized by setting a maximum acceptable risk of an individual perishing in a flood event (currently set at once every 100,000 years). This metric considers factors beyond the return period of a flood, including evacuation

possibilities, human behavior and vulnerability, and the population density in the flooded area.

2. Economic efficiency of water safety investments:
The decision-making process for flood risk reduction measures follows a cost-benefit philosophy in the Netherlands. The total direct and indirect costs of flooding in a specific area are calculated. Combining this data with the probability of flooding and the potential risk reduction through invested funds informs decisions about the accepted level of risk.

3. Control of group risk:
Certain areas, such as urban centers with a high population density, may face a significant loss of lives in the event of a large flood. To address this, areas where a flood could result in substantial loss of life receive an additional level of protection.

Numerical models developed in the Netherlands are employed to calculate risks and costs, allowing for a comprehensive cost-benefit analysis of measures aimed at reducing flood risk. This analysis integrates cost-effectiveness and reduction in lethal risk. Combining numerical cost calculations with hydrological models justifies specific investments aimed at reducing risk levels (Ebregt et al, 2005).

For the RtfR program, the initial norms required that Dutch river systems can safely handle a statistically probable peak water discharge occurring once every 1,250 years. For the Ijssel, this meant the capability to manage a peak discharge increase of 250 m3/s from all tributaries, including 200m3/s from the Rhine intake (RftR program Directorate, 2005).

To achieve this overall goal for the Ijssel, nine sub-projects were executed as part of the RftR initiative. Each of these sub-projects had a specific goal set in terms of reducing the water level during peak discharge.

Nature and **people** goals
The second objective of the RftR program is the "improvement of spatial quality," aligning with both nature and people goals within the NBS RECONECT framework. The government-defined sub-objectives for enhancing the spatial quality include (De Boer, 2024):

- Nature goals:
    - Increase biodiversity through the creation of more natural areas.
- People goals:
    - Improve the accessibility of the area for the broader public through infrastructure improvements.

For the Ijssel, preservation of ecologically, spatially, and culturally valuable elements in floodplains guided the program. Emphasis was placed on reactivating natural river characteristics, like meanders, and enlarging existing floodplains (RftR program Directorate, 2005).

The nature goals within the RftR program were intricately defined by existing legislation, primarily encompassing the National Ecological Network (NEN), Water Framework Directive (WFD), habitat and bird directive and Natura 2000 (RftR program Directorate, 2005).

The NEN strategically aims to connect nature areas within the country and across the EU, thereby expanding the overall habitat area for wildlife. Leveraging the unique geographical features of the 127km-long Ijssel River, the program maximized its potential to link numerous existing nature areas in contributing to the NEN.

Figure 9: Overview of the RftR project near Deventer, showing the large spatial impact and therefor the opportunities for materializing nature and people goals (Rijkswaterstaat, 2024)

During the program's design phase, consideration was given to the WFD, focusing on ecological water quality. Although providing more space for river systems was deemed beneficial for overall ecological water quality in itself, full incorporation of WFD goals was avoided due to anticipated excessive costs. However, the detailed design phase aimed to optimize the RtfR program's contribution to WFD goals (RftR program Directorate, 2005, De Boer, 2024).

Natura 2000, as the European network of protected areas, safeguarded biodiversity by ensuring the continued existence of specific habitat types and bird species. The Netherlands, bound by obligations to the EU, committed to protecting and enhancing the cohesion of the Natura 2000 network. The country also pledged to maintain or restore the species and habitat types vital to the river area, considering Natura 2000 values early in the decision-making process.

To align with the aforementioned legislation, specific choices were made to enhance the nature aspect of the RtfR program in the Ijssel River, including the conservation and optimization of existing nature areas, strengthening connections within and outside dikes, expanding low-dynamic swamp areas, and creating a more natural river valley through dike relocations. Additionally, enlarging and widening floodplains and green rivers aimed to facilitate natural flooding and bolster nature's resilience to inundated situations (RftR program Directorate, 2005).

People goals, through enhancing spatial quality, were often addressed on a smaller scale after the primary design of the measures had been established. Improving nature areas frequently opened up opportunities for local public access, presenting a quick win for the people-centric objectives (RftR program Directorate, 2005).

Moreover, public participation events were utilized to gather specific ideas from the community for enhancing accessible areas. These ideas, often small-scale and easily implementable, aimed to improve the overall experience for local residents. An exemplary case is the "Woeste Willem" nature playground in the floodplains near Deventer (see Figure 10). While technically not part of the RtfR program (completed just after the official program), it illustrates how floodplains can seamlessly integrate with recreation. The playground, strategically designed to adapt to different water levels, features attributes accessible only through steppingstones when water levels rise. These modest investments in Nature-Based Solutions (NBS) projects can significantly enhance the interaction between local communities and the NBS.

Figure 10: Example of a recreational area created: play area Woeste Willem near Deventer.

4.1.3 Measure selection

Implementing Nature-Based Solutions (NBS) involves crucial decision-making on the type and location of measures. Key tools in this selection process include cost-effectiveness analysis (CEA), along with an environmental impact assessment (EIA), facilitating the comparison of options based on various criteria. The RtfR program employed a specially developed tool, the building block tool, to enable diverse stakeholders to compare different measures and locations. This chapter briefly outlines each of these tools and their roles in the measure selection process.

CEA

The CEA involved selecting a set of measures that fitted together from around 700 feasible options, ranging from modifying groins and dike structures to constructing high-water channels. These measures have diverse impacts on water, nature, people, and finances (Ebregt et al, 2005).

To compare these measure packages, cost-effectiveness is determined by ranking aspects such as water safety gain, increase in nature reserve surface area, improvement of spatial quality, and enhanced recreational attractiveness. The other factor of importance is the determination of the cost of each of these packages. Combined, the outcome is expressed as the average cost of the measure per unit of effect, where units could be water safety (cm water level decrease), nature area change (hectares added), spatial quality improvement (river area positively influenced), and increased recreational opportunities (river area made more attractive) (Ebregt et al, 2005)..

The RtfR program emphasizes comparing not only various NBS to each other, but to also assessing them against grey infrastructure options, such as dike heightening and strengthening. This inclusion ensures an objective evaluation, considering whether NBS adds value compared to traditional infrastructure. Some RtfR programs opted for grey infrastructure, emphasizing the importance of cost-effectiveness in decision-making.

Table 1 provides an example of what such a comparison could look like. Keep in mind that each of these measure packages consist of various measures that fit together. For example, the dike relocation could include the realization of bird breeding ponds and a recreational beach in the created floodplain (Ebregt et al, 2005).

Table 1: Example of a cost-effectiveness comparison

Average costs per unit of effect			
Item	Dike relocation	Bypass	Dike heightening / strengthening
Water safety gain (cost per cm water level decrease)	17	25	15
Nature area change (hectares)	235	201	N/a
Spatial quality (amount of km positively influenced)	22	25	n/a
Recreational opportunities (amount of km positively influenced)	35	30	n/a
Classification cost-effectiveness	cheap	expensive	average

It is acknowledged that any cost-effectiveness comparison is a simplification, and various other aspects could be considered. While a cost-effectiveness analysis may focus on specific factors, other considerations can be incorporated in a qualitative manner during the decision-making process.

It was observed that grey infrastructure solutions tended to be more cost-effective when the sole focus was on water safety. However, when additional criteria were taken into account, NBS showed more positive outcomes.

EIA

The CEA offers valuable insights into the cost of achieving program goals, but it's not the sole document guiding measure selection. While cost-effective goal attainment is crucial, broader impacts of the measures also play a vital role. Therefore, after defining potential measure packages: combinations of measures with a broader vision, through the CBA, these are further examined for various environmental impacts. The Environmental Impact Assessment (EIA) serves this purpose, serving both legal requirements and providing a valuable tool for making informed choices. Like the CEA, the EIA contributes to the decision-making process, with recommendations for measure package implementation, but the ultimate decision rests with political leadership.

In developing the EIA for the RtfR program, three distinct pathways were defined, each representing significantly different approaches. For each project location, measures were selected to create a measure package aligned with these pathways. These packages encompass both large, impactful measures, such as constructing a water bypass, and smaller measures that seamlessly integrate into the design, like enlarging an existing nature area. The design process for these alternatives involved analyzing river characteristics and conducting design workshops with experts from private companies and involved governments (RftR program Directorate, 2006). An exemplary overview of the defined alternatives for the RtfR program is provided in the Table 2

Table 2: Example of defined measure package alternatives per locations

Characteristic	Alternative A	Alternative B	Alternative C
Main Feature	***Water-rich, natural, river dynamics***	***Conservative, accessible, cultural landscape***	***Landscape-oriented, natural***
Bolwerksplas	Deepening, smaller surface area, connected to Ossenwaard	Smaller, connected (via siphon) to Ossenwaard	Remains the same, connected to IJsselhotel
De Worp	IJsselhotel on island, park preserved	Siphon in front of IJsselhotel, park preserved	Channel in front of IJsselhotel, park preserved
Ossenwaard	Channel through current nature	Same as Alternative A	Same as Alternative A
Zandweerdplas	Deepening, larger surface area, water sports near water treatment plant	Larger, water sports to Teugse/Veenoordkolk, open (grazing)	Larger, water sports near Rembrandtkade
KSO, low-lying areas	Wet, rugged, spontaneous vegetation growth, “stray (wander) nature”	Two banks without relief; Munnikenhank preserved	Two banks with relief; Munnikenhank integrated
KSO, high-lying areas	Nature, including hardwood floodplain forest	Estate, Nature farm, agricultural use	Nature, upstream and downstream connected

After developing three distinct alternatives for each project area, a preferred alternative was crafted, leveraging expert input. This preferred alternative, considered by developing experts as the most balanced option, aimed to incorporate various criteria comprehensively. Simultaneously, an environmentally most friendly alternative was formulated, focusing on maximizing nature development and minimizing negative impacts, without considering non-environmental factors like water safety, costs, and recreational potential. Following workshops with expert groups, these alternatives were presented to a broader steering group comprising stakeholders such as nature organizations and local business owners. Upon approval by the steering group, the alternatives were presented to the wider public, and suggestions for changes or areas of focus were incorporated as necessary (Municipality of Deventer and Province Overijssel, 2007).

The subsequent step involved evaluating the alternatives through a comprehensive analysis of environmental, social, and economic impacts. The abovementioned alternatives, including the current situation where than scored on a broad range of criteria. Assessment criteria were established based on existing legislation, project goals, and identified areas of concern. Any increase compared to the current situation resulting in a positive score and vice versa. The assessment criteria and method were standardized for the entire RtfR program, with certain criteria scoring requiring separate studies per project, such as hydraulic modeling or ecological studies, as needed (Waterschap Groot Salland, 2010a). An example of such an impact analysis is provided in Table 3, visually summarized in Figure 11.

Table 3: Example of different alternatives being assessed on a variety of assessment criteria.

Assessment criteria		CS	A	B	C	PA	MEFA
Hydrology and safety							
Water level reduction		0	++	+	+	+	**+**
Nature							
Impact on migratory birds		0	++	+	0	+	**++**
Area for nature development		0	+	++	-	+	**++**
Landscape, Cultural history, Archaeology							
Impairment (or enhancement) of spatial visual quality		0	-	+	0	+	**++**
Encroachment on existing relics	Archaeology	0	--	-	-	-	**-**
	Cultural history	0	--	-	-	+	**+**
	Geology	0	-	0	-	-	**-**
Nuisance during execution							
Risk of exceeding air quality requirements*		0	0	X	X	0	**0**
Use and living environment							
Accessibility and accessibility of recreational areas		0	0	++	++	++	**++**
Water sports		0	+	+	++	+	**++**
Loss of agricultural land		0	- -	-	-	-	**-**
Cost							
Implementation costs		**-**	**46-61**	**38-53**	**35-50**	**33**	**35**

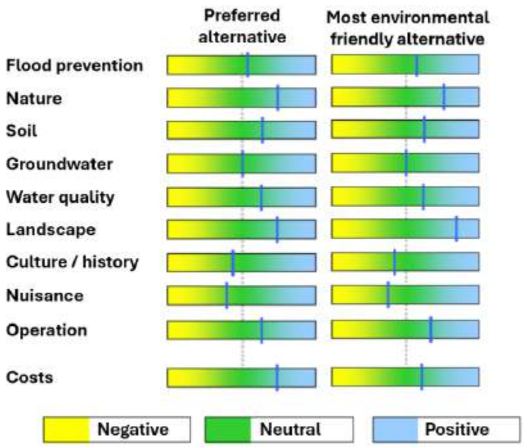

Figure 11: Visual summary of the impact assessment of alternatives (Waterschap Groot Salland, 2010a)

RftR Building block tool

The RftR building block tool is a web application designed for policymakers, stakeholders, and other interested parties to compare various measures for the RftR program. This digital tool enables users to select and evaluate geographically linked measures and observe their precalculated effects on water levels, agricultural land availability, nature, and people/recreation.

Containing nearly 400 potential measures defined by the RtfR program in collaboration with local water management bodies, external experts, and stakeholders, the tool is inspired by the concept of building blocks. Users can create their own package of measures and observe different outcomes based on their choices.

Accessible through any internet browser, the River Toolbox, as it is called, allows users to choose specific river segments, program strategies, and display preferences (map or measure view). The tool aims to establish a structured and reproducible strategy for spatial measures, emphasizing collaborative decision-making. Involving various stakeholders and making the tool accessible to the wider public contributes to informed decision-making and helps mitigate opposition by providing data-driven and scientifically supported information in an easily understandable format. The tool's accessibility and user-friendly interface are crucial for its effectiveness (Rijkswaterstaat, 2023).

4.1.1 Guaranteeing water goals

For each distinct sub-project RftR, specific water level reduction goals during peak flow events were established. These goals, measured in centimetres, varied between 8 and 71 cm for the Ijssel River. The achievement of these goals primarily relied on modelling the impact of the designed interventions. While a consulting firm typically conducted the modelling, the process was guided through guidelines set by Deltares, an independent research and knowledge institute specializing in water-related matters. Deltares as an independent actor played a crucial role in ensuring consistency across all individual projects, despite the involvement of diverse parties. Moreover, Deltares took responsibility for conducting quality checks upon the completion of each modelling exercise (de Boer, 2024).

The modelling efforts encompassed both the existing water discharge conditions and the targeted discharge goals for the river system, which were set at 15,000 and 16,000 m3/s, respectively, at the Rhine River's entry point into the Netherlands. These water levels were simulated for both the river axis and its adjacent banks.

Key inputs for the GIS-based model included the elevation model of the entire area, encompassing both the river (bathymetry) and its dry area, as well as the crest height of various water barriers, weirs, and other water related structures. Additionally, the model incorporated information about vegetation, such as its presence and type, represented through a roughness coefficient taken from the national handbook on roughness coefficients of vegetation in flood plains. These inputs were generated for both the existing conditions and post-project implementation to allow for a before and after comparison, hence determining the effect (Waterschap Groot Salland, 2010b).

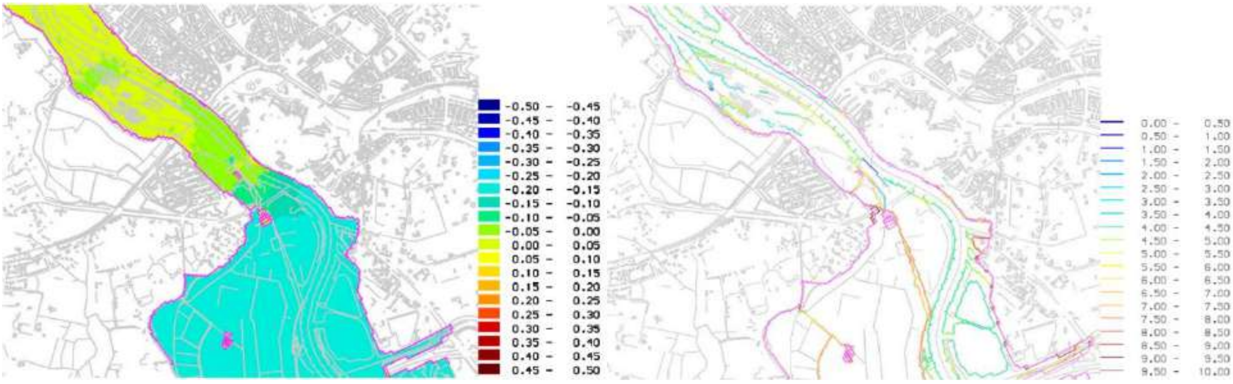

Figure 12: Overview of an analysis of water levels (left) and overflow heights (right) at a project area (Waterschap Groot Salland, 2010b).

The modelling results often identified specific bottlenecks where the water level exhibited a more significant rise than the surrounding areas, indicative of a backwater peak. Such peaks typically elevate water levels and reduce maximum discharge, necessitating preventive measures. Recognizing these locations frequently led to recommendations for design modifications, facilitating a more gradual flow of the river at these points and mitigating adverse effects. This allowed for an iterative process of hydraulically improving the measures.

4.1.2 Guaranteeing spatial quality - nature and people goals

The RtfR program aimed to create a secure river area with superior spatial quality by employing effective tools at both program and project levels.

On a project level, the landscape architect played a crucial role as a custodian of spatial quality, bridging disciplines and policy languages to ensure alignment with planning developments. Additional active discussions and listening to local concerns led to a comprehensive, viable, and community-supported plan, highlighting the significance of community engagement and realistic planning. This allowed the Program Directorate to focus primarily on water safety, budget constraints, and project timelines (De Boer, 2024).

Another vital lesson was to adopt a Design & Construct contract, assigning responsibility for both design and construction to the contractor. To maintain spatial quality and uphold promises made to the local public, this same landscape architect served as a "watchdog", preventing compromises during the integrated contract's execution. This approach fostered innovation while ensuring a steadfast focus on spatial quality throughout the program (Berenschot, 2018).

At the program level, the Q-team played a crucial role as the guarantor of spatial quality in the RtfR program. While ensuring water-related goals was a familiar task for the Dutch government, addressing spatial quality, a subjective matter open to diverse interpretations, required a distinct approach. To navigate this challenge, the RtfR program established the Quality team, or Q-team, incorporating some of the most distinguished landscape architects and spatial quality experts of the country (Q-team, 2012).

The Q-team's philosophy centered on providing advice, both solicited and proactive, on each considered measure, leveraging the expertise of its five independent members in spatial planning. Chaired by the national advisor for landscape, the Q-team not only advised on proposed designs but also documented diverse opinions and experiences in publicly accessible documents, fostering transparency and enabling learning opportunities for external experts, students, and enthusiasts interested in the spatial quality aspects of the RtfR program (Q-team, 2012).

The Q-team had open access to all projects, aiming to offer a final judgment before the definitive design decisions were made. The team prioritized constructive advice, engaging in direct conversations and meetings with designers early in the design phase to ensure their input was an integral part of the design process. Despite not providing legally binding advice, the positive relationship and constructive approach of the Q-team led designers to voluntarily incorporate many of their recommendations. Additionally, the Q-team welcomed local initiatives to contribute to the designs and initiated a separate path by developing an inspiration book titled "Rivieren en Inspiratie" (Rivers and Inspiration), publicly available to drive initiatives for implementing riverine Nature-Based Solutions (NBS) (Q-team, 2012, De Boer, 2024).

In most major infrastructure projects, traditional success metrics revolve around staying within budget and adhering to the planned schedule. While these factors remained essential in evaluating the RtfR program, they did not stand alone as the sole criteria for success. The evaluation process, even in its final stages, considered the judgment of spatial quality by the Q-team for each executed measure. This inclusion compelled the project team to acknowledge spatial quality as a critical factor in their design decisions (Q-team, 2012).

In addition to legislative measures and the landscape architects, the RftR employed one more unusual tool: the "hands-off principle". This principle was instituted to preserve areas considered too vital for nature or people to undergo changes. Designated as hand-off areas through participation processes, this principle not only safeguarded crucial areas but also mitigated potential public opposition, demonstrating a genuine willingness to heed local concerns (De Boer, 2024)

Regarding nature, it is important to note that the Dutch government in principle does not allow any changes to Nature 2000 areas. However, when a project can be shown to positively influence the biodiversity of the nature area, intervention is allowed. This specific law turned a barrier for the implementation of NBS into an enabler (De Boer, 2024)

The biodiversity study conducted around the RftR program revealed promising outcomes for nature. Between 1997 and 2012, over three-quarters of the surveyed floodplains demonstrated an augmentation in biodiversity, benefiting endangered and protected species. Specifically, floodplains where diverse measures were employed, including the establishment of subsidiary channels to promote natural vegetation development and the management of natural grasslands, exhibited noteworthy enhancements in biodiversity. These findings underscore the favorable results achieved through the synergistic approach of nature development and the allocation of extra space for the river (Straatsma et al, 2017)

4.1.3 How to organize the maintenance of NBS

Maintenance of the implemented measures is of crucial importance to ensure their functionality in the future. Not only is this required to prevent the loss of the function (in terms of flood prevention and spatial quality. Another argument for organizing the maintenance of the measures is to increase the return on investment of these projects. The largest costs are the implementation and construction costs. If these measures lose their functionality before the end of their design period, that translates to a loss of investment (De Boer, 2024).

The philosophy of the RftR program regarding maintenance is to divide the responsibility amongst the most capable and suitable existing organizations available. In the Netherlands, regional water management is the responsibility of the water boards. Dedicated nature areas are managed by nature organizations. Local infrastructure is taken care of by local governments. Each of these organizations do not only have the expertise and equipment for the required maintenance, but they also have their own financing structures. As very often the lack of finances after the implementation of a project is the main reason for it lacking maintenance, this finance structure without end-date is potentially the most important factor. Even though the responsibilities are divided in this way, the responsibilities are clearly defined from the onset, avoiding the potential for the lack of accountability (De Boer; 2024).

4.1.4 Final remarks on project management

The RftR program has spanned nearly two decades, witnessing changes in governments, shifts in responsible ministers, the evolution of water safety norms, and updates to climate scenarios. Throughout this dynamic period, the core goals of the RtfR program have remained unchanged. These goals were established early in the program's timeline through the SPKD, providing a legal foundation. However, the approach to achieving these goals, particularly concerning spatial quality, retained a degree of flexibility.

By maintaining a focus on the overarching goals without rigidly prescribing specific designs and methods, the program could adapt in a flexible, efficient, and innovative manner. This flexibility allowed for the incorporation of new information and insights as they became available. Changes and updates were often integrated into future programs, ensuring a continuous progression of the RtfR program without being hindered by external dynamics and avoiding delays (Groothuijse et al, 2018).

Ensuring the timely completion of the RtfR program has been a top priority alongside budget management. This emphasis on meeting deadlines, though often in the hands of regional governments, was facilitated by the RftR directorate through continuous monitoring. Additionally, knowledge sharing and, where necessary, the provision of additional financial resources was instrumental in executing required sprints (Berenschot, 2018).

A crucial contributing factor to meeting deadlines was the inherent sense of urgency and the societal benefits associated with the program. The planning approach varied for different measure packages and specific measures within each package. Rather than being a drawback, this allowed for accurate timelines for each specific measure. Importantly, it enabled sub-projects executed later to incorporate lessons learned from earlier ones (Berenschot, 2018).

Within the RftR planning process, early identification of risks was prioritized, enabling the implementation of controls and preparatory work for subsequent measures while completing ongoing ones. To address common delays arising from processes like contracting and permit issuance, RftR initiated works before the preceding stages were fully concluded, such as granting contracts on a preliminary basis. This proactive approach ensured that when permits were received, the execution of works could commence immediately, avoiding prolonged delays associated with tender processes (Berenschot, 2018).

Adhering to the standard procedures of the executive organization of the Ministry of Infrastructure and Water Management, each project had a dedicated project manager, stakeholder manager, technical manager, and project control manager. The dedicated project control manager, responsible for risk identification and management, played a pivotal role in minimizing the materialization of risks and their negative impact on the schedule. The use of risk files, dedicated documents detailing identified risks with quantification and defined control measures, were his key risk management tools. These files specified the person responsible for each control measure. Risk reservations in the budget were established based on the risk file, and funds were allocated for potential requirements. Risks were explicitly delineated between decentralized governments and the project team, clarifying responsibilities. The investments made by the RftR program in risk management are believed to have yielded substantial value by significantly reducing the actualization of risks, resulting in both time and cost savings for the program (Berenschot, 2018).

An organizational paradox within the RtfR program was the paradox of a rigorously centralized project management and planning structure with ample autonomy granted to the regional governments responsible for project execution. The success of this arrangement hinged on the close collaboration between the program organization and these regional entities. Regular face-to-face interactions, meetings, and the provision of influence to regional governments fostered mutual trust. This approach not only cultivated acceptance of the project goals and methods but also contributed to the professionalization of the regional teams. The symbiotic relationship between the centralized project management and the regional governments became a key factor in the overall success of the program (Groothuijse et al, 2018).

4.1.1 Integration of Water – Nature – People

The RftR project in the Ijssel River is a great example of how the combination of Water, Nature and People from the onset of the program allowed it to become a true NBS project. The early inclusion of not only water, but also the nature and people goals as official project goals, “forced” the program team to realize these benefits. By allowing the local people and nature organizations to contribute to the designs and having financial resources available successfully allowed these to be integrated into the project. Not only did this result in a better project result, but it also increased cooperation and reduced opposition to the program.

For the selection of the measures, the CEA and the EIA have proven to be valuable tools in providing insights into the impacts that different measures can have on different subjects. It specifically named various water, nature and people influences of the measures, allowing them to be objectively compared to each other.

During the design and construction phase, the use of the Q-team was another guarantor of the spatial quality, and therefore the people and nature goals of the project. At the meantime, the Dutch institute for water management (Deltares) acted as the independent guarantor of the water goals, through extensively checking all the calculation works for the program.

Throughout the program, the goals, budget, timeline and the responsibilities of all different involved governments were legally binding through the SPKD. This ensured that the program directorate always had this document to fall back on, and that changes in various governments did not obstruct the execution of the program.

The general program has been reflected upon by the program directorate, the general public, and by “nature” through analyses of the biodiversity impact to have been a very valuable contribution. Especially after the high-water event of 2023, when not a single riverine flood occurred, stand testimony of the success of the program, and the potential of NBS for hydro-meteorological risk reduction while including benefits for nature and people.
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4.2 Coastal areas (Seden Strand, Odense, Denmark)

4.2.1 Introduction

The threat of flooding due to sea level rise is a major concern for many coastal communities around the world. Seden Strandby, a suburb of Odense located approximately 8 km northeast of Odense, Denmark, is an example of such a community, located on the southern edge of Odense Fjord, on the island of Fyn, which is one of 10 flood-prone areas in Denmark. The area of Seden strand is under direct threat from rising sea levels, which puts 142 private homes and up to 66 hectares of agricultural area at risk (Penchev et al, 2019a).

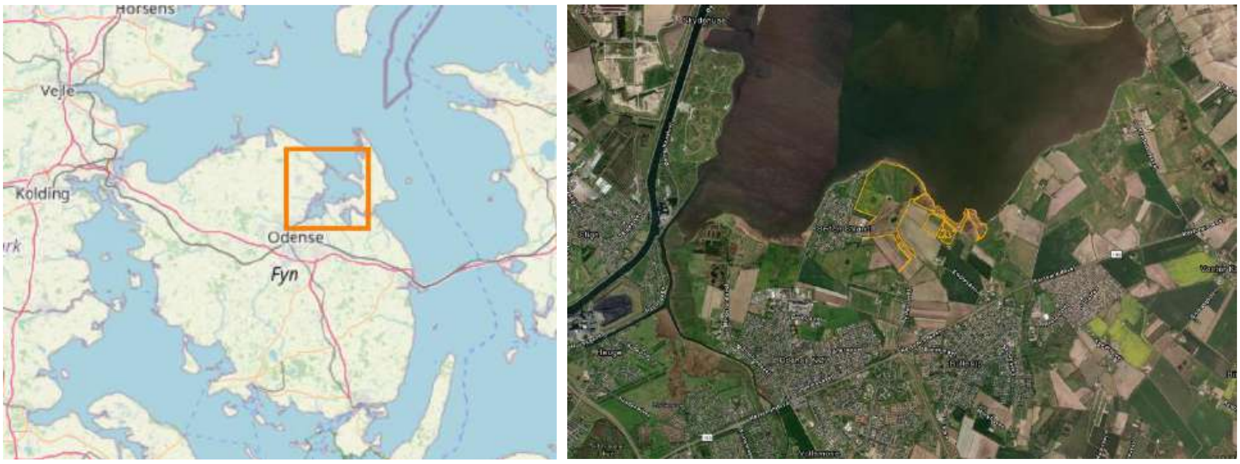


Figure 13: Overview of the location of Seden Strand, Denmark

The Odense Fjord experienced a severe storm and consequential flooding in 2006, when the sea level rose to 1.90 m above DVR90 with DVR90 being the Danish vertical reference system (Penchev et al, 2019).

Odense Fjord is not only an important nesting and resting area for many bird species, but it is also designated as a Natura 2000 area according to the European Habitats Directive. The coastal landscape is a valuable landscape type that needs to be conserved, and this project aims to demonstrate how to combine the interests of minimizing flood risk for the suburban and agricultural areas while improving habitats in the Natura 2000 area and conserving the coastal landscape (Penchev et al, 2019).

Figure 14: The 6th of December 2013 Seden Strand was hit by flooding during the "Bodil". Water level was measured up to 1,72 meters above mean sea level. A 100-year return period. Picture taken by Anders Brændholdt Rasmussen. Citizen of Seden Strandby.

The area of Seden Strand that is part of the project is approximately 0.8 m^2, of which buildings and roads account for 0.2km^2, natural areas for another 0.2 km^2, and agricultural land for about 0.4 km^2. The agricultural land uses include vegetable production and the grazing of horses (Odense Kommune, 2015).

Before the project to implement nature-based solutions for hydro-metrological risk reduction, the area was protected by summer dikes of about 1.5m DVKR90 in height (Kildahl Sønderby, 2024).

The Seden strand area includes two minor streams, which were channeled and relocated in the 1950's. This channeling reduced the original natural meandering nature of the streams to a straight canal controlled by a sluice at the eastern border of the project area. This channel helped in draining the original salt marshes to allow for the cultivation of crops (Odense Kommune, 2015).

Both the need to improve protection against flooding and the call for further nature development have been the motivators to implement nature-based solutions in the Odense Fjord. These motivators have also been implemented into the Natura 2000 action plan for Odense Fjord, and the Risk management plan for Odense Fjord. Both of these were produced by three municipalities around the Fjord. The synergy between nature and water, as well as the importance of inclusion of the local people, made this location ideal for the implementation of NBS based on the RECONECT framework defining goals for water, nature and people.

The **water** goals defined for the Seden Strand case are twofold: Flood hazard reduction and to implement a more dynamic flooding regime of the area. The flood hazard reduction was focused on the area protected by the dikes. The more dynamic flooding regime on the other hand focused on the area outside of the dikes. This more dynamic flooding regime would not only result in water level fluctuation, but also in more saline surface and freatic groundwater, mimicking the pre-human system more closely. This salinity change would link to the defined nature goals (Kildahl Sønderby, 2024).

Figure 15: Drone image of the Seden strand area, showing the Atlantic marshlands (Penchev et al, 2019b, picture taken by Starling Air, December 2016)

Three specific **nature** goals were defined for this project: Increasing habitat area (in terms of quantity), habitat provision and distribution (quality), and to maintain and enhance biodiversity. There was no specific goal set for the amount of area to be converted to nature. Instead, the preliminary assessment identified the potential for the conversion of land to nature, which was what the plan was based on. Additionally, the better the plan could become, the higher the chance was to receive additional financing from the Danish government. This meant that the plan had to focus on a balance between quality and quantity, and to create synergies between nature and climate change adaptation. This synergy formed part of the "quality" goal. In terms of the maintenance and enhancement of biodiversity, both the biodiversity for flora and fauna were targeted, aiming to increase the richness and composition of species (Kildahl Sønderby, 2024).

One specific **People** goal was defined: to increase the recreational opportunities in the area, through changing the attractiveness of the area through the implementation of NBS. This goal largely matches with the nature goals of increasing the habitat quantity and quality of the natural area, and to increase biodiversity. The recreational opportunities are predominantly focusing on nature recreation, such as walking possibilities and attractiveness for bird watching (Kildahl Sønderby, 2024).

4.2.2 Goal setting and climate change scenario

Water goals

As mentioned in the introduction, the water goals focus on flood hazard reduction and a more dynamic flooding regime. The risk management plan for Odense Fjord has, based on climatic forecasts, that the sea level will rise up to 30cm in 2050. This expected sea level rise was combined with the data of the storm surge in 2006, which reached 1.90m DVR90 and had a return period of 250 years. The three municipalities used this return period as their goal. Including a rise of seawater with up to 30 centimeters and adding 20 cm for waves the protection level was set to 2,40 meters DVR90. This is also described in the first generation of the flood management plan (Odense Kommune, 2015).

Regarding the more dynamic flooding regime, the goals have been defined more loosely, subdivided into two measurable goals. Firstly, allowing a larger area to be flooded more often/naturally. Secondly by allowing a more dynamic and natural flooding regime the surface would in general be more saline and support the development of new saltmarshes, allowing a natural flooding regime of a larger area (Odense Kommune, 2015).

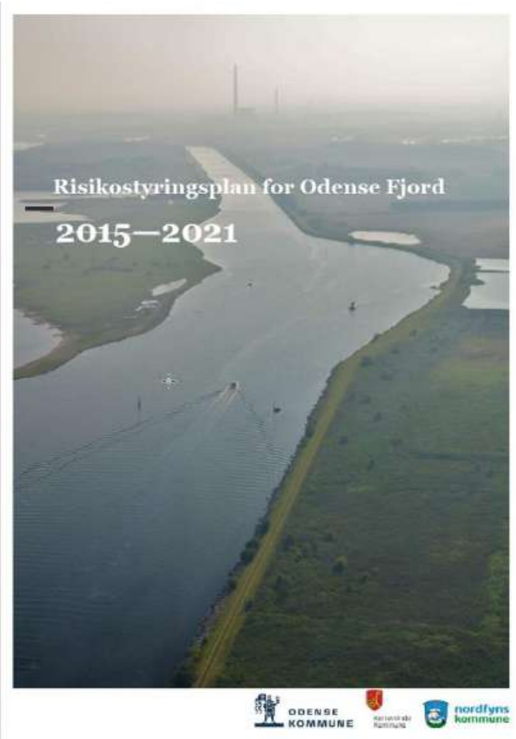


Figure 16: The protection level for Seden Strand was described in the Flood risk management plan 2015-2021.

The goal to establish a more dynamic and natural flooding regime was predominantly focused on re-establishing the original land type of a coastal marshland that regularly floods, consistent with the Natura 2000 habitat type. No specific salinity goals were set, but simply allowing the area to flood was considered a goal in itself. The natural flooding regime at the pre-project outside dike area was to be copied to the new natural area. The salinity etc. of the new area should be similar. This meant that the old dike had to be removed instead of remaining what some farmers wanted (Kildahl Sønderby, 2024).

Nature goals

The Odense Fjord having been designated as a Natura 2000 site, and being protected by the Bird Directive and the Habitat Directive is predominantly based on it being an important resting and breeding area for waders, ducks, geese and swans. As the about 50% of the project area is covered by the Natura 2000 designated area, the defined Natura 2000 goals are applicable to the project area as well, as visible on Figure 17

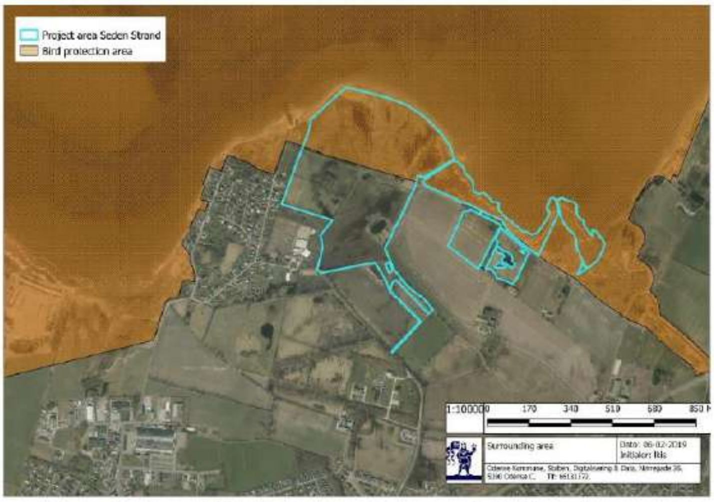


Figure 2-4 Natura 2000 at Seden Strand. It covers 50 % of the project area.

Figure 17: Overview of the Natura 2000 area at the project area.

The Natura 2000 habitat types in the project area are the Atlantic salt meadows (1330) and the barrier beach with perennial plants (1220). The conservation status for the Odense Fjord has been defined as Bad, which means that the habitat is in serious danger of disappearing (at least regionally) (European Environment Agency, 2023).

In order to help restore the specific Natura 2000 habitat, the restoration of the habitat for it's specific target species has been defined as the goal, which include (Penchev et al, 2019a):

- **Barnacle goose (Branta leucopsis)**
- Whooper swan (Cygnus cygnus)
- Goosander (Mergus merganser)
- European golden plover (Pluvialis apricaia)
- Common tern (Sterna hirundo)
- Sandwich tern (Thalasseus sandvicensis)
- **Western marsh harrier (Circus aeruginosus)**
- Mute swan (cygnus olor)
- White-tailed eagle (Haliaeetus albicilla)
- Red-breated merganser (Mergus serrator)
- Pied avocet (Recurvirostra avosetta)
- Arctic tern (Sterna paradisaea)

In a preliminary study, it was determined that the project area was predominantly used by two specific bird species: the European Golden Plover (Pluvialis Apricaria) and the Pied Avocet (Recurvirostra Avosetta). The other bird types are important for the wider Fjord, but not for the project area itself. Additionally, despite not being part of the Natura 2000 area, the Vanellus Vanellus and the Tringa Totanus are targeted as well, as they are on the EU red list, hence increasing the habitat quality of these birds should be the focus of any nature development project in their potential habitat (Odense Kommune, 2015).

Besides the bird target species, the following two target species are also defined for the Odense Fjord:

- Narrow-mouthed whorl snail (Vertigo angustior)
- Harbour porpoise (Phocoena Phocoena)

This project predominantly focused on birds, as opposed to other target species in the Fjord. This decision was made because the salt meadows are very important habitats for wader birds and are sometimes the only remaining habitats where wader birds can still be found in important numbers. Some of them are various widespread bird species with an unfavorable conservation status in Europe due to recent declines in the agricultural landscape. They include wader birds such as Vanellus vanellus (Northern lapwing), Gallinago gallingo (common snipe), Limosa limosa (black-tailed godwit) and Tringa totanus (common redshank). Birds also very often react much faster than e.g. vegetation on changes in habitats (Rasmussen, 2024).

Secondary to the birds was a focus on amphibians, primarily the Natterjack toad (Epidalea calamita) (see Figure 18). These were included because amphibians both improve the structure of the habitat, and they are a signaling species. The amphibians even require a "higher" habitat quality then the birds, so are a great signifier and sign: if they can thrive in this area, so will the abovementioned birds. The birds are a target/umbrella species but benefit greatly from the presence of the amphibians. Also, a red-listed and NX4 species in the habitat directive (Kildahl Sønderby, 2024).

Figure 18: One of the Natterjack toads released at the project area. (Photo: Odense Kommune)

The increase of the abundance of the following species has been used as a goal for both the quality of the natural area, and the biodiversity.

People goals

The goals for people remained relatively simple: to make the area more attractive as a recreational area, with a focus on bird watching and accessibility. Indirectly this increase in attractiveness and appreciation of the area would be beneficial for the local community, and thereby for the value of the area (Kildahl Sønderby, 2024).

4.2.3 Stakeholder analysis and involvement

Methodology

The stakeholder analysis for the NBS RECONECT case for Seden Strand started with four questions:

- Who is potentially affecting the hazard?
- Who is potentially affected by the hazard?
- Who is potentially affecting the NBS?

- Who is potentially affected by the NBS?

After dividing stakeholders into logical groups, like local authorities, civil society and commercial sector, it is important to establish how much is at stake for them. As stakeholders that are more affected, are more important to consult and involve in different stages of the project. For this reason, they are ranked, per the stakeholder matrix as shown in Figure 19 (Hüesker et al, 2019).

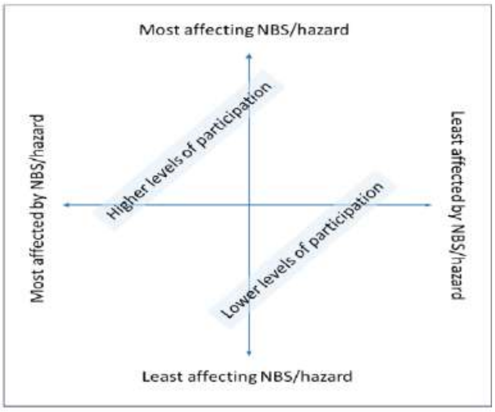


Figure 19: Overview of the framework for the stakeholder analysis.

The level of participation is however not only determined by this matrix, but also specified per stage of planning, as portrayed in Figure 20. This distinguished was made by simply asking the stakeholders when they wanted to be involved, and to what extent. For each of the five phases, they could either be (Hüesker et al, 2019):

- Provided with information, which relies on a one-way form of communication from the project team to the stakeholder. This can be done through various forms, including mailing lists, public meetings or public information availability.
- Consultated, which means their opinion is sought after, either in real life conversation or written. In this way, it is possible for the project team to include the information and perspective of the stakeholder, but no decision-making power is provided to the stakeholder.
- Co-deciding, where in addition to being consulted, the stakeholder has official decision power. This is often organized through roundtable, democratic decision-making, juries, or mediation procedures.

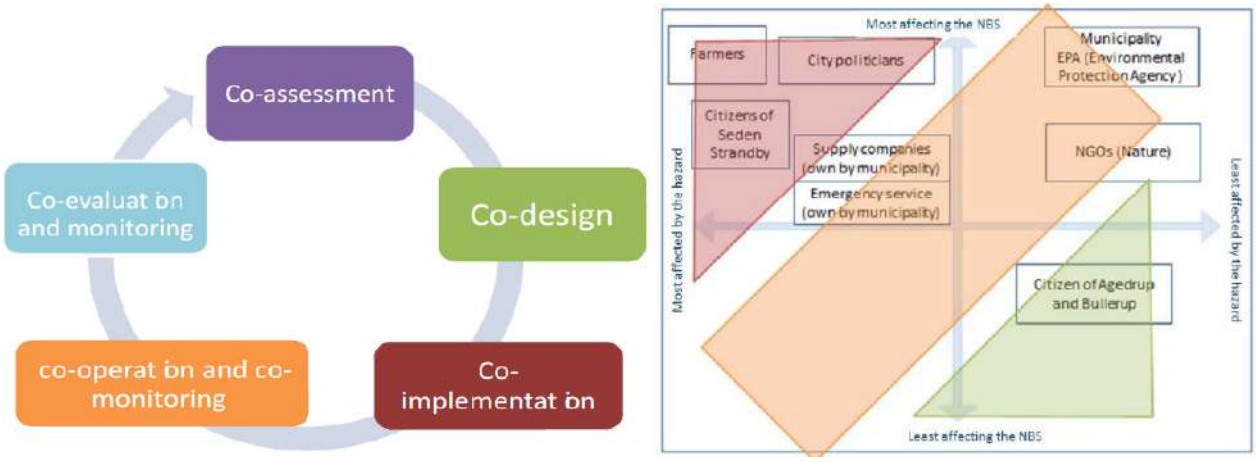


Figure 20: Overview of the stages of planning (left) and level of involvement (right) as used for the stakeholder analysis (Hüesker et al, 2019).

The results of the stakeholder analysis, as shown on the right side in Figure 20, depict interesting results to be used in the involvement of the stakeholders, where roughly the red triangle indicates them to be co-deciding, the orange rectangle for consultation and the green triangle information provision. In general, it is noted that the citizens and farmers in the direct area, together with the local politicians desire to co-decide, while the supply/utility and emergency services, as well as the EPA and NGO's considered with nature would like to be consulted on specific issues. Citizens of the nearby area are barely affected, but still would like to be informed about the area that they use for nature visits as well. It is important to realize that this stakeholder analysis considers different stakeholders and involvement levels per project, this is case-specific and should therefore be investigated for each case (Hüesker et al, 2019).

Besides this summary of results, it is important to not consider this figure to be set in stone. Where specific stakeholders are affected more than expected by certain measures or hazards, or where intense resistance on specific subjects is met during information gatherings, the "locations" of these stakeholders in the figure can change for that specific subject.

Figure 21: Overview of the project area, with the yellow area depicting the area redeveloped as nature area.

Most stakeholders were involved in the development of the project from the start. The most important stakeholders for this project were the landowners / farmers. As participation in the project was completely voluntary for them, convincing them to participate was essential. It took several years of negotiations and information sessions to find a workable solution. It has to be mentioned that substantial financial compensation was part of this process as well: about 50% of the total project budget was used for financial compensation of farmers for land acquisition (Penchev et al, 2019b).

The citizens mentioned in the stakeholder analysis were the citizens of the village to the west of the project area. As this area is more densely populated, very little land was available to implement NBS. For this reason, the project was split in two early on: the east, NBS focused project, and the west, classical flood prevention focused project. By making this decision to focus on where the project could best be implemented early on, it eventually became easier to realize an NBS. As the western area was dropped from the NBS project, the citizens reduced in importance for the project, and were moved in the stakeholder analysis towards the information provision area. As the project did not directly interfere with their living area, they were mostly interested in just flood prevention (Kildahl Sønderby, 2024).

NGOs were regularly consulted, as they possessed valuable information and insights that could contribute to the quality of the project. An example of this is a local bird NGO that proposed the idea of moving the dike further south to increase the flood occurrence of the area. This plan improved the habitat for the target birds and was happily accepted as part of the project design (Kildahl Sønderby, 2024).

Politicians were important for financing and regional planning. Politicians have to approve them. We managed to convince the politicians because we focused on synergies between different areas, like water, nature and people. This includes the obligations to improve biodiversity, reduce flood risk, the Water Framework Directive and

Natura 2000. Odense came up with the initiative to deal with the different problems at the same time. By selling it as a wholistic solution, the politicians were able to deal with different problems and local and national obligations at the same time. In this way, they offered a solution instead of another problem/project. Especially already having some finances form another (Horizon) project, every 1 euro was worth 2 to 4 times as much from external programs. High ambitions of the politicians allow for finding more external funding. Eventually this leads to a higher land value/ enjoyment of the environment and thereby taxes. Create a well selling story. The project area value will not increase, but the Odense area does. Living a couple of kms away, the area has a positive impact on value, monetary and non-monetary (Kildahl Sønderby, 2024).

4.2.4 Measure selection and design (changes)

The main idea of the project, that was to lead the measure selection, was to return to a situation more similar to the original landscape, before humans greatly altered it. The only addition was the set goal for flood prevention.

As outlined in the introduction, goals were set to protect against storm surges with a return period of 250 years, by being protected against a water level of 1,90 m DVR90, and to increase the quantity and quality of the natural area, as well as to increase recreational opportunities. It was determined that there was no alternative to using a dike as flood protection measures. Therefor the main measure was to move the dike further inland. This would allow agricultural land to be returned to natural coastal marshes with recreational opportunities.

A classic flood prevention measure would be to heighten the existing dike right at the coast. However, to create synergies between water and nature, the project looked back at the original functioning of the area. As this area, before diking and cultivation, was a salt marsh, hence this function was chosen to be reestablished. As the area was still to be prevented against flooding, a dike, al be it further inland, was still required, as other types of coastal flood prevention (like dunes) were not naturally occurring in this area and would probably need constant feeding of sand (Kildahl Sønderby, 2024).

If the original dike was heightened, it would have had to be much higher (50cm), and thereby wider as well. This would not open the area or create salt marshes/nature. The salt marshes do have to flood to raise with the sea water level through sedimentation processes. Within 100 years, 50% of salt marshes in Denmark would be lost by upholding the status quo. This had to be countered by opening them up to the sea. Consider landscape point of view: a high dike at the sea level reduces the view and the attractiveness (Kildahl Sønderby, 2024).

The defined primary targets of the NBS were to:

- To improve flood protection
- To improve the possibilities for the development of new nature, allowing nature to migrate
- To conserve the open coastal landscape

In order to further implement co-benefits, primarily focused on water and nature, the following secondary targets were defined (see Figure 22):

- To establish a more natural hydrology by remeandering the two streams in front of the new dike. This option was chosen as the streams used to meander before local people canalized it. This more natural system would also create a more versatile and dynamic river system, which in turn provides a more suitable habitat for the different target species.

- To reduce predation and improve breeding possibilities for waders by clearing trees.
- To establish nature plugins on parts of the backside of the dike. Even though this is not necessarily a naturally occurring phenomenon, nature plugins are an easy way to make a dike more nature inclusive. These dike plugs consisted of small areas in the dike specifically altered to shelter certain species. At some spots, rocky areas were created in the dike, while at other ones nutrient rich or sandy/gravelly material was added to the side of the dike. Each of these plugins would create a microclimate for different insects, vegetation or amphibian species.
- Improvement of the possibilities for nature conservation
- To reduce the emission of nitrogen and phosphorus to Odense Fjord by remeandering the streams and extensifying agricultural areas
- To establish observation towers, nature trails and general improvement of the area

Figure 22: Overview of the executed measures in the project (RECONECT, 2024)

4.2.5 *Project results based on Lidar surveys*

Lidar surveys have been conducted to help monitor the sub-goals. The data from the lidar surveys conducted before construction in 2020 and after in 2022 are used to show potential flood situations using Scalgo Live (https://scalgo.com/da/)

Before construction of the nature-based solution project, including the removal of the coastal dike, the area was occasionally being flooded during winter. The existing dike was originally being built to protect against floods in the growing season.

With the removal of the dike, a larger area was allowed being flooded more frequently and not only in the winter season. Below is the potential flooded area illustrated at different events at meters above mean sea level (amsl) with the situation before and after construction of the nature-based solution.

The illustrations in Figure 23 show how the area is flooded at 0,8-meter amsl. Flooding at this height occurs frequently during the year. After construction a larger area is now more often flooded as larger part of the project is below 0,8-meter amsl. This supports the sub-goals by increasing the habitat area as a more dynamic and natural flooding regime helps restoration of salt marshes.

One the other hand the illustrations in Figure 25 and Figure 24 show the effect of flooding at 1,5-meter amsl and at 1,7-meter amsl, respectively. The illustrations show that the protection of the settlement at “Seden Strandby” has been improved after construction of the new withdrawn dike.

Figure 23: Flooding at 0,8-meter AMSL before (left) and after (right) the implementation of the NBS (Kildahl Sønderby, 2024).

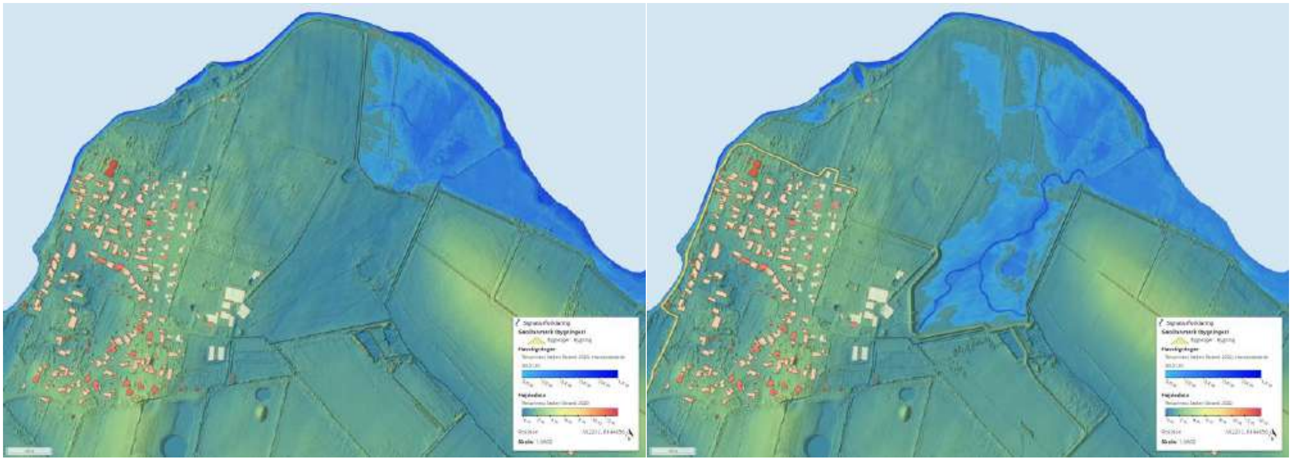


Figure 24: Flooding at 1,5 meters AMSL before (left) and after (right) the construction of the NBS, at a 20-year return period (Kildahl Sønderby, 2024).

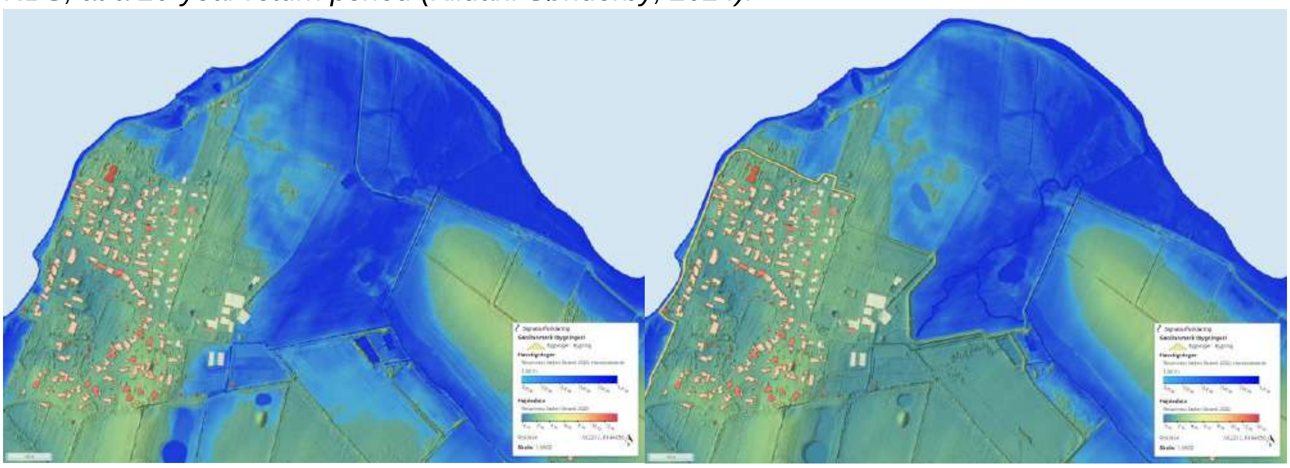
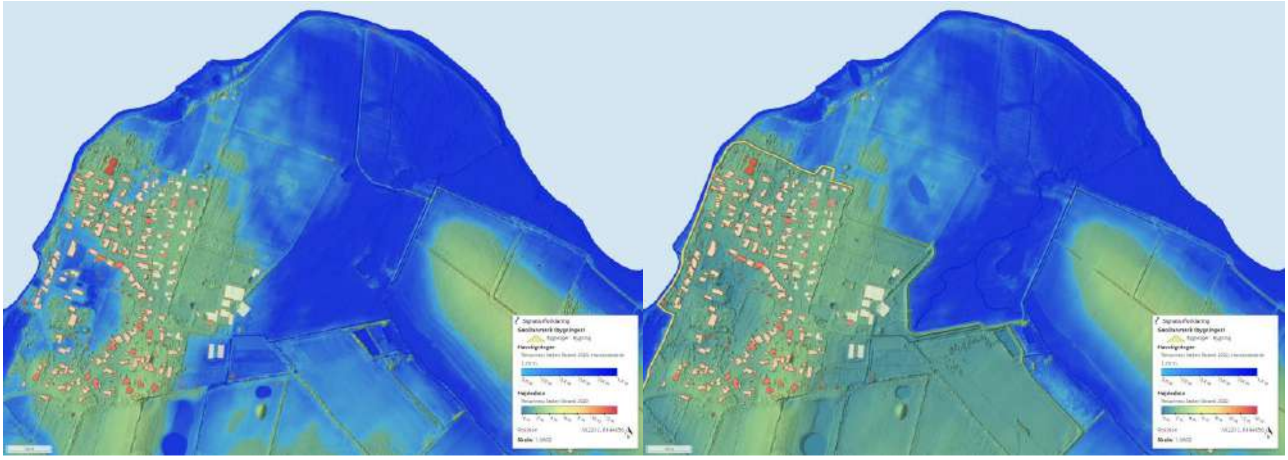


Figure 25: Flooding at 1,7 meters AMSL before (left) and after (right) the construction of the NBS, at a 100-year return period. This is the type of flood that occurred in 2013 (Kildahl Sønderby, 2024).



4.2.6 Integration of Water – Nature – People

The Odense case shows a small-scale project where a sound choice was made for an NBS to protect the area from coastal floods while vastly increasing the available area for nature and allowing local people to enjoy the area. Interestingly, for part of the project area, it was decided that a classic approach of dike strengthening was more beneficial than implementing an NBS. This is a great example of how NBS can be beneficial, but not always under all circumstances: sometimes NBS are better, sometimes other approaches should be chosen.

When designing the measures, the water goals were largely based on the past flood event but adapted to expected climate change to create a more robust solution. For nature, the current legislation and protected species (when present) provided the main guidance for the project goals. Essential to the execution of the project was the stakeholder analysis and engagement. By creating different levels of engagement for different stakeholders, depending on their level of affectedness by both the hazard and the project, the implementation of this project, with its large influence on the living environment of many, was possible to be executed successfully. Unfortunately, a barrier was put up by a local farmer who did not want to participate in the project, but a flexible approach allowed the project to still continue.

The project's end result was an area with increased flood protection, with various nature hotspots through the nature plugins in the dikes, the release of amphibians to strengthen the food web and the more natural flood dynamics, all aided in the restoration of the area to better resemble the original salt marsh this area once was: a biodiversity hotspot for birds and other animals, while improving the protection level of, and the attractiveness for the people living here.

4.3 Mountainous areas (Park Portofino, Italy)

4.3.1 Introduction

Hydrogeological hazards have an increasing impact on many areas of the world. Being weather related, they are subject to the effects of climate change, and they impact territories that tend to be more and more vulnerable. Regarding the impacts of climate change, the Liguria region in Northern Italy is exemplary for the Mediterranean context.

In recent years both intense rain events and related ground effects have affected the Liguria region on the north-west Italian coast. Many events caused damage and even casualties: the larger one happened on 25th September 2011 in the Cinque Terre and Val di Vara area where hundreds of shallow landslides and flash floods were triggered almost simultaneously. Other events throughout the region caused both diffused and concentrated damages in October 2021, October 2020, October 2019, November 2016, October and November 2014, November 2011 and November 2000.

The project area of this NBS project is the mountainous natural park Portofino Promontory in Liguria see Figure 26, which is exemplary for the Ligurian and therefor Mediterranean context. The Promontory is situated between Genoa and the border with Tuscany, and encompasses an area of 18 km^2 with a coastline of 13 km. The terrain topography is rather mountainous, with high elevations over a short distance from the coastline. The promontory's highest point is Mount Portofino, with an elevation of 610 m asl. The area is comprised of several smaller basins with surface areas of less than 1 km^2 and streams along the steep slopes, mostly of the 2° order of sensu Strahler (1951). Within this area, there are also smaller areas such as Cala d'Oro, Rio dei Fontanini, San Fruttuoso, Ruffinale, and Vessinaro, which can only be reached by sea or by hiking trails, as there is no road access along the eastern part of this area, there are two creeks: the Fondaco creek and the Acqua Viva creek (Figure 27).

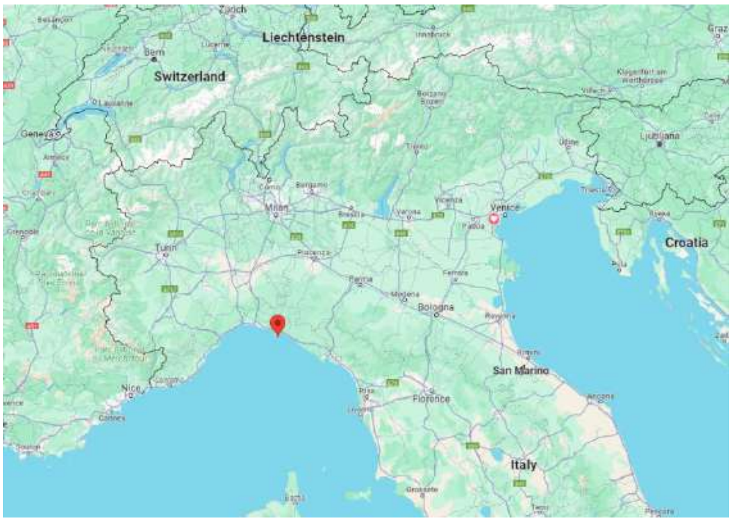


Figure 26: Location of Portofino Promontory in northern Italy

As the measures taken in Portofino Promontory are very local and targeted, the pre-studies of the area were crucial to understand how the hazards and the project area function. Therefore, the introduction of this session is longer but a lesson in itself: what is important to understand when implementing such localized measures to prevent landslides in mountainous areas.

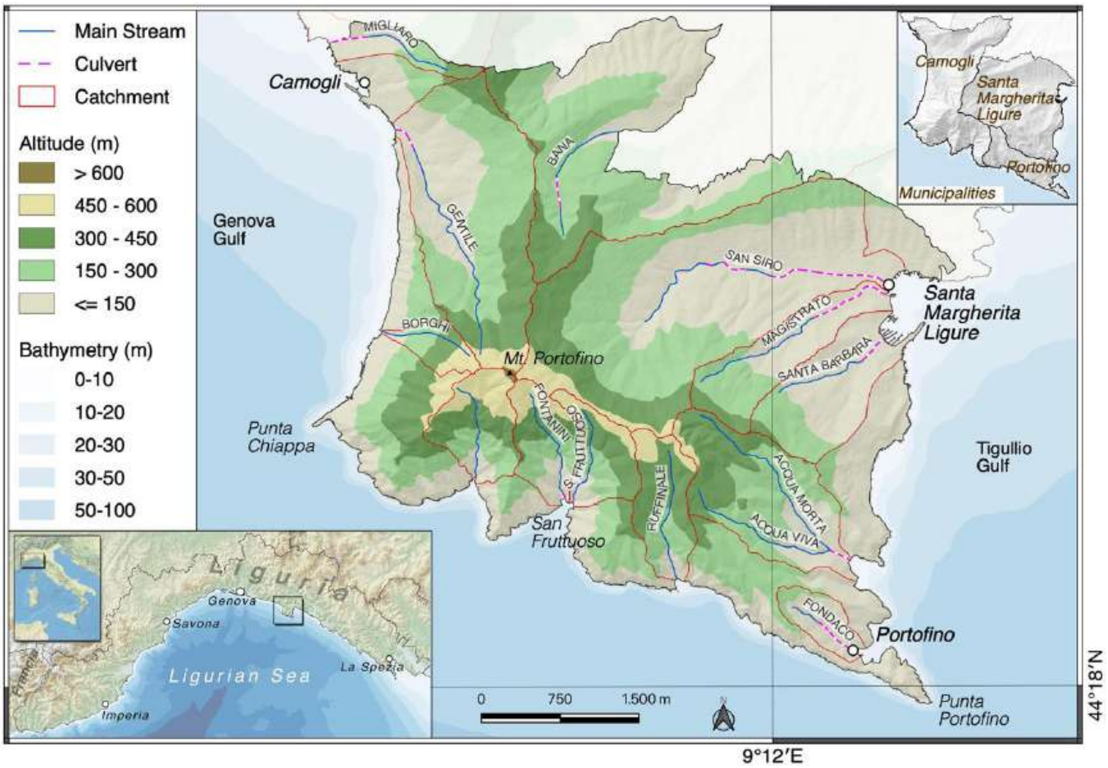


Figure 27 The Portofino promontory localization and altitude: its steep slopes and physiography make it a mountainous area by the sea (Paliaga et al, 2022).

The geology of the Portofino Promontory (Figure 28) is characterized by the conglomerate in its south facing part between Punta Chiappa in the west and the Lighthouse of Portofino in the east (Giammarino et al, 1979). The substrate of Mount of Portofino, from Camogli to Rapallo, is characterized by marly limestone flysch (Corsi et al, 2001). The morphology of the promontory is linked to a structure bounded by direct faults, typical of a continental margin subject to disjunctive tectonics.

The geological setting and the Mediterranean climate determine the landforms and the geomorphological dynamics in this region (Figure 28). The southern slope of the Portofino Promontory is characterized by rocky cliffs with heights of up to 200 m, which are some of the highest areas in the Mediterranean (Brandolini et al, 2007). The slope angle ranges between 45° and 65°. The action of the wind is important, coming from both the south-east (Scirocco, reigning wind) and the south-west (Libeccio, dominant wind). Sea storm surges are frequent, involving waves of up to 5 m in height, and can cause some considerable damage to the surrounding buildings and infrastructure.

Frequent rockfalls occur along the southern slopes. On the western slope, the cliff is formed mainly in the flysch of Mount Antola, with terrain elevations exceeding 100 m. In this area, the frequent waves cause erosion of cliffs and represent one of the triggers of rapid landslides or debris flow with high destructive power (Brandolini et al, 2007). There are also frequent landslides in the southern part of the area, which often affect the surrounding buildings and infrastructure (Brandolini et al, 2006).

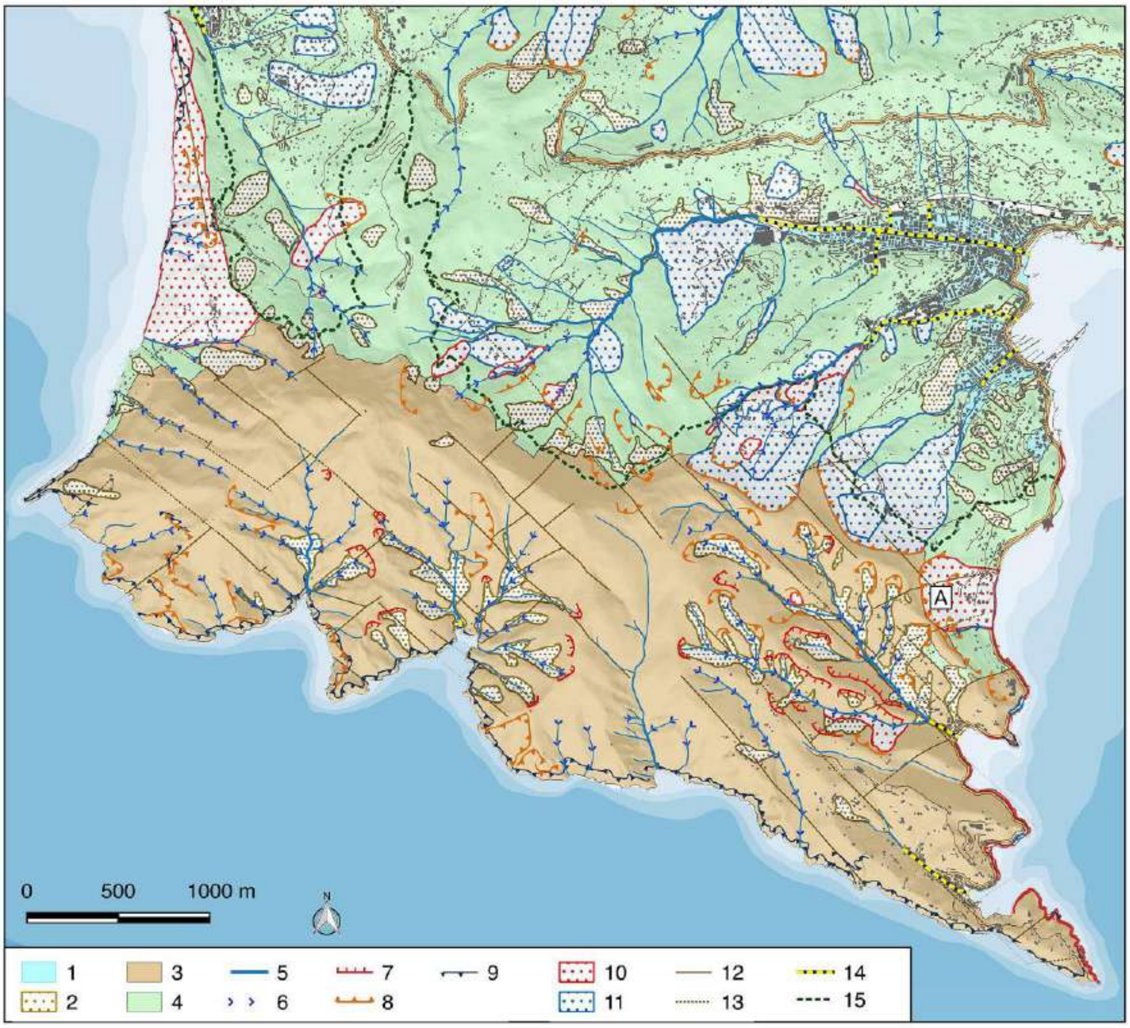


Figure 28 A geomorphological map of the Portofino Promontory: (1) alluvial deposit; (2) debris cover; (3) conglomerates with sandstone layers; (4) marly limestones, clayed marls, and marls; (5) hydrographical network; (6) downcutting talweg; (7) degradation scarp; (8) landslide scarp; (9) cliff; (10) active landslide; (11) inactive landslide; (12) fault; (13) presumed fault; (14) culvert; (15) Portofino Natural Regional Park boundary (map obtained from data survey and data integration of [20–22,26]). (A) mountain slope deformation.

Among the anthropic landforms in the area, there are many terraces with dry stone walls. These terraces have been constructed over hundreds of years, often by local farmers seeking to stabilize the slope to conduct agriculture, often in the form of olive farms. There are also considerable terraced areas in Paraggi, Portofino, and San Fruttuoso creeks, and they all represent important cultural assets in this area (Paliaga et al, 2016). Besides, due to its almost perennial presence of water, the small Paraggi catchment in the past saw the presence of over 30 small mills supplied by boats landing in the small bay.

The area is very popular for tourism throughout the year: over a million tourists visit the small town of Portofino, while the nearby small village of San Fruttuoso receives about 400,000 tourists from the sea by boats. There are also a considerable number of hikers that come to this area (Figure 29), with hiking paths extending over 80 km in length (Brandolini et al, 2006).

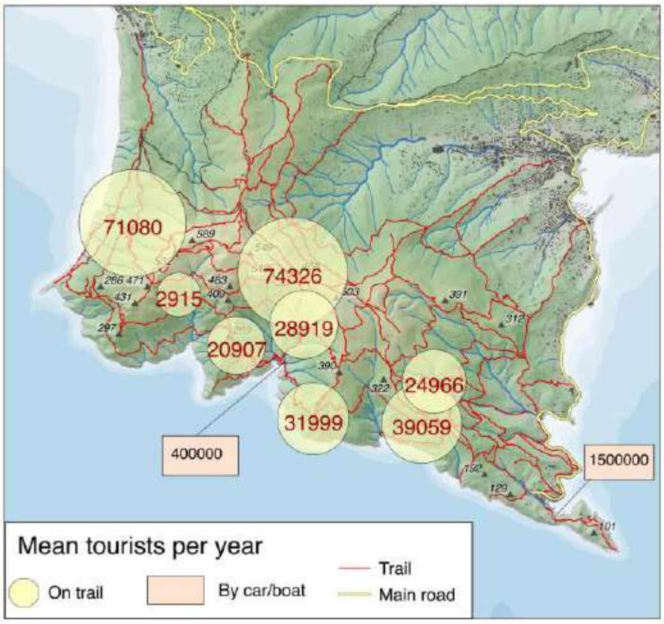


Figure 29 Mean yearly tourists frequentation of the Portofino promontory: figures along the trails are recorded by eco-counters installed by the park authority.

The promontory is characterized by urbanization that mainly develops along its eastern side and to a lesser degree at its northern and western sides. Land cover largely reflects the morphology and geology asset: the typical steep slopes on the conglomerates offered scarce settling features. Modifications to the territory due to urbanization include the construction of roads and culverts at the stream mouths with a discharge capacity that nowadays is inadequate for the high intensity rainfalls (Figure 30). Finally, considering that shallow landslides are triggered during the high intensity rainfall, their effects are increased by the debris transport capacity and possibly saturating the culverts discharge capability.

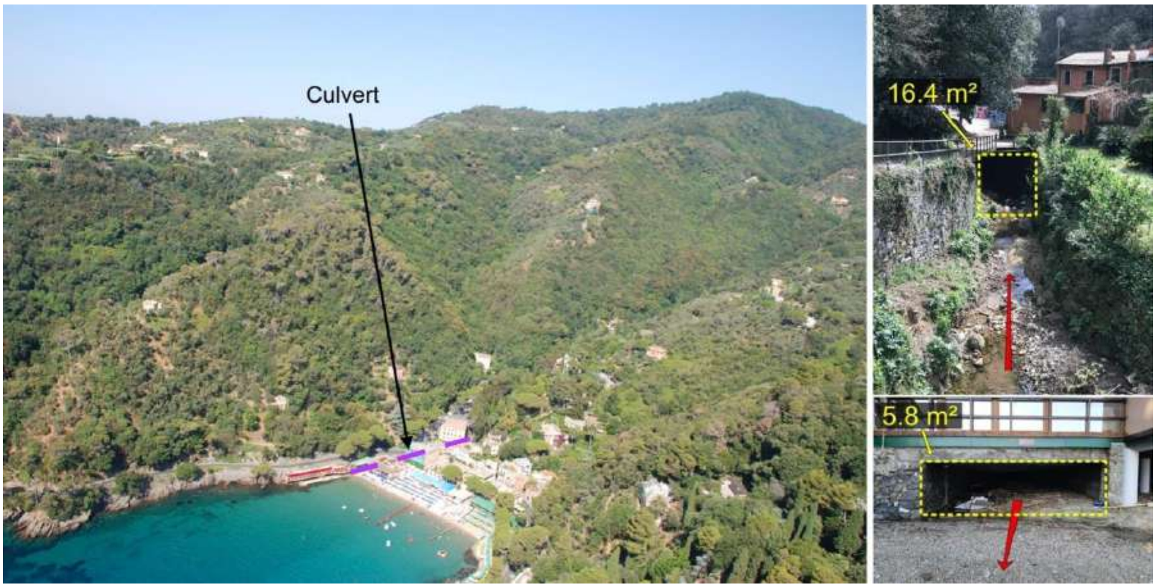


Figure 30 The culvert at the mouth of Paraggi stream, on the left. On the right the culvert's inlet (up) and outlet (down) with the respective cross section.

The exemplary physical and climatological conditions of Portofino Promontory, combined with the different and historical land uses, make it an ideal project area for the implementation of NBS solutions for hydro-metrological risk reduction. By using this a project area, Portofino can function as an example project for the implementation of NBS in the larger Mediterranean area.

4.3.2 Project drivers and goals

Hydro-meteorological hazards

A natural hazard is one of the components that contribute to the definition of risk induced by hydro-meteorological events. A hazard is defined as the probability that a natural phenomenon (e.g., floods or a landslide) may occur in a certain area with a given return period (Kron, 2005). Elements at risk include the population, structures, infrastructure, and socio-economic features (Paliaga et al, 2019a; Turconi et al, 2019; Paliaga et al, 2019b; Palladino et al, 2018). Vulnerability represents the degree of loss of elements exposed to risk, because of the occurrence of a natural phenomenon of a given intensity. The risk corresponds to the expected value of the loss and can be expressed as the product of the three terms: hazard, vulnerability, and value of the elements exposed to risk (Canuti et al, 2001).The Portofino promontory is exposed to a high hazard and, due to the characteristic of the exposed elements, even to a high hydrogeological risk. However, this hazard affects many Mediterranean hilly or mountainous coastal zones: from Italy's Tyrrhenian Sea facing areas, to Cote d'Azur in Franc, the Balearic Island in Spain, the Balkan peninsula and Greek archipelago and mainland. These areas share similar morphological conditions: steep slopes, small catchments and urbanization concentrated along the coastline. Additionally, due to the scale, what happens at a catchment scale quickly impacts the urbanized coastlines.

The more intense meteorological phenomena in Liguria are tied to the so-called depression of the Genoa Gulf ("Genoa Low") (Trigo et al, 1999). The low pressure is generated by the inflow, into the Mediterranean Sea, of North Atlantic moist air through the Rhone Valley. A complex interaction is established with the orographic contexts of Liguria. Also, the contrast between the mass of cold and damp air and the warmer water of the Ligurian Sea generates a low-pressure area on the Ligurian Sea, right near Genoa. The depression produces rainfall that is often very intense and accompanied by wind and sea storm surges.

Each of the abovementioned goals related to water, nature and people eventually come back to reducing the identified hazards. The key to the reduction of these hazards is the geomorphic system that rules the landscape evolution of the area and determines the hazards previously described. Then, hazards are part of the processes acting in the area, which are related to climate, to geological and morphological circumstances, and to anthropogenic modifications. The hazards include gravity induced processes and fluvial induced ones, whose results are erosion and degradation of the slopes.

Then, the geomorphic hazards threatening the area are:

- Shallow landslides, mud-debris flows and rockfalls.
- Flash floods.
- Relict landslides reactivation.

As emerged from the analysis of the shallow landslides that have been triggered after intense rain events in the period 1910-2019, the phenomenon looks to be increasing in recent years. Besides, it often involves abandoned terraced slopes whose presence is largely hidden by wild vegetation. The dry-stone walls and terraces, being an anthropogenic immobilization of debris and soil along the slopes, play the role of possible source areas for shallow landslides. In fact, the terracing practice substantially subtracted debris and soil from the degradation processes generated by the geomorphic system: this system remained in equilibrium as long as continuous maintenance was performed. However, after the large abandonment, the erosion process reoccurred. Besides the larger shallow landslides, even relatively small masses gain a high kinetic energy which can cause buildings and infrastructures to collapse, as it happened to the Mediaeval San Fruttuoso abbey in 1915 (Paliaga et al, 2022a).

The presence of these hydro-meteorological hazards in the Mediterranean and, more zoomed in, the Portofino area have been the main project driver for NBS implementation in the Promontory. However, the increasing hazard requires a new approach rather than the after-event damage repair: a prevention mitigation strategy that should be based on a holistic approach at the catchment scale (Turconi et al, 2020), which includes a focus on **water**, **nature** and **people**. In Portofino Promontory, a preliminary monitoring activity was dedicated to improving both the knowledge and comprehension of the territory and of the active processes, as it is the basis of every problem-solving process. Then, the mitigation plan has been designed through a series of small NBS works spread throughout the catchment: they have been realized in order to work in synergy with each other. Finally, this approach is coherent with the natural, landscape and touristic value of the area where both a natural park and a Nature 2000 area are established. The works, due to their limited extension, are easy to be realized even poorly accessible areas and their limited cost allow a time scheduling planning.

Water goals

The Mediterranean region, including the Portofino Promontory, is considered to be one of the two main hotspots for climate change at a global scale (Giorgi, 2006), suggesting that changes appear to be larger than in other areas: both a decrease in mean precipitation and a strong precipitation variability are expected, together with a large increase in temperatures. Recent analysis of extreme weather events proxy data at the Mediterranean scale in the period 1979-2018, show these changes related to high intensity rainfall increase related ground effects (Paliaga and Parodi, 2022b).

Heavy rains are the main trigger for flash flooding and shallow landslides, Flash flooding and fast-moving shallow landslides often hit buildings, infrastructure and cultural heritage with high energy.

The Portofino Promontory is historically affected by hydrogeological events (Figure 31): they can produce natural instability processes related to the interaction between meteorological phenomena and the geological environment, thus potentially impacting the elements at risk. The most frequent categories of processes are (1) shallow landslides and flash floods, (2) sea storm surges, and (3) rockfalls and mud–debris flows. Shallow landslides are often triggered in terraced slopes that then assume the role of possible debris/mud flow source areas. Finally, different processes occur often simultaneously during a violent meteorological event, causing a domino effect.

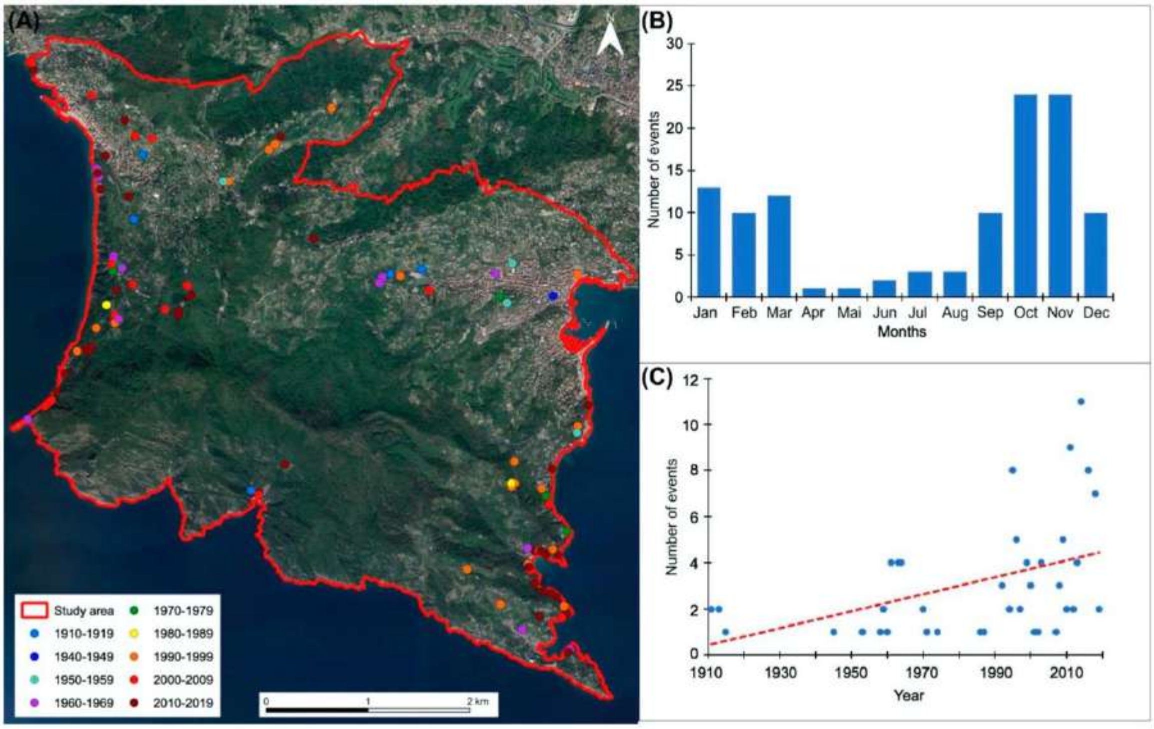


Figure 31 Spatial distribution of the rainfall-induced shallow landslides and mud-debris flows that affected the Portofino promontory over the 1910-2019 period. B) Monthly distribution of slope instabilities triggered by precipitations over the 1910-2019 period. C) Distribution of annual landslide occurrences over the 1910-2019 period (Roccati et al 2020).

The occurrence of landslides on the promontory is rather widespread and frequent: large relict landslides with slow kinematics (Brandolini et al, 2007) and rapid mud–debris flows (Paliaga et al, 2016), which are triggered by heavy rainfalls. Table 4 and Figure 32 show the rainfall events and related triggered shallow landslides in the period 1910-2019: a total of 85 shallow landslides have been recorded and the phenomena look to be increasing in the last 30 years (Roccati et al, 2020). Besides, in 1915 an intense rainfall event (>400 mm/3 h in Santa Margherita Ligure) triggered a debris/mud flow in San Fruttuoso, whose fast-moving mass hit the Medieval San Fruttuoso abbey causing the collapse of its western part (Figure 32). After the event a small beach was left in the bay.

Table 4: Rainfall events triggering shallow landslides and mud-debris flows on the Portofino promontory starting from the year 1910, organized in decades. For each year, the number in round brackets represents the number of rainfall events that triggered landslides (Roccati et al 2020).

Period	Date, Number of Events
1910–1919	1911 (1)–1913 (1)–1915 (1)
1920–1929	No events
1930–1939	No events
1940–1949	1945 (1)
1950–1959	1953 (1)–1958 (1)–1959 (2)
1960–1969	1960 (1)S–1961 (3)–1963 (3)–1964 (3)
1970–1979	1970 (2)–1971 (1)–1974 (1)–1978 (1)–1979 (1)
1980–1989	1986 (1)–1987 (1)
1990–1999	1992 (1)–1994 (2)–1995 (3)–1996 (1)–1997 (2)–1999 (3)

2000–2009	2000 (2)–2001 (1)–2002 (1)–2003 (1)–2007 (1)–2008 (3)–2009 (4)
2010–2019	2010 (2)–2011 (5)–2012 (2)–2013 (4)–2014 (8)–2016 (5)–2018 (6)–2019 (2)

Figure 32 A comparison of the ancient abbey in San Fruttuoso as it appears nowadays (A) and as it was after the partial collapse in 1915 (B). (Paliaga et al, 2022a).

Finally, recurrent marine weather phenomena, such as sea storm surges and downbursts, are particularly prominent in the western region of the Portofino Promontory due to the exposure of the coast to winds (“Libeccio”). Particularly destructive storms occurred in 1989, 1993, 1999, 2008, and 2010 in Camogli, while in the eastern region, exposed to the Libeccio swell, the most destructive storms occurred in November 2000 and October 2018, which resulted in serious damage to the nearby infrastructure. A phenomenon attributable to a “downburst” occurred on 14 October 2016, when a low-pressure convective structure formed at the Gulf of Tigullio triggered wind gusts between 100 and 120 km/h (hurricane on the Beaufort Scale) near the coast, causing damage to buildings and infrastructure, as well as injuries to the surrounding population (Turconi et al, 2020).

Based on the above phenomena, the main water goal for Portofino Promontory was to reduce the risk of flash floods and precipitation induced landslides in the national park.

Nature goals

Due to its landscape and climate features, significant biodiversity of fauna and vegetation characterizes the Portofino Promontory area (Gestro et al, 2004; Balletti et al, 2015).

Mediterranean vegetation covers the southern maritime slopes with a predominant presence of evergreen species, adapted to high temperatures and reduced rainfall conditions. The main observable vegetations types are the following:

1. Coast vegetation, covering the cliffs overlooking the Ligurian Sea, which is resistant to salinity and wind. Typical examples are marine fennel (*Chrithmum maritimum*) and statice cordata (*Limonium cordatum*). Other small plants are the spiny Euphorbia (*Euphorbia spinosa*) and specimens of the genus Sedum (for example, *S. album*), covering the most exposed maritime slopes in the sun. Instead, ivy (*Ivy helix*), Polipodio vulgare (*Polypodium vulgare*), and Sassifraga spatolata (*Saxifraga cochlearis*) are present on the more humid and shaded rocks.
2. Shrubs, covering maritime slopes, including broom (*Spartiumjunceum*), spiny broom (*Calycotome spinosa*), Cisto female (*Cistus salvifolius*), thyme (*Thymus vulgaris*), and Euphorbia arborea (*Euphorbia dendroides*).
3. Grassland, dominated by *Ampelodesmos mauritanicus*.
4. Evergreen species, such as myrtle (*Myrtus communis*), lentisco (*Pistacia lentiscus*), alaterno (*Rhamnus alaternus*), terebinth (*Pistacia terebinthus*), fillirea (*Phillyrea latifolia*), strawberry tree (*Arbutus unedo*), and madder (*Rubia peregrine*).
5. Pine grove, covering the Portofino promontory. Three main species can be found. In particular, domestic pine (*Pinus pinea*), maritime pine (*Pinus pinaster*), and pinewood (*Pinus halepensis*).
6. Holm oak (*Quercus ilex*) forest.
7. Chestnut (*Castanea sativa*) forest.
8. Mixed mesophilic forest, covering the north-oriented slopes. Its main species are black hornbeam (*Ostrya carpinifolia*) combined with chestnut (*Castanea sativa*), laburnum (*Laburnum anagyroides*), and other trees.
9. Riparian vegetation on the stream banks and near springs (e.g., Valle dei Mulini area). Among the species are black elderberry (*Sambucus nigra*), black alder (*Alnus glutinosa*), and numerous ferns.

Also, a significant variety of animals live in this area. The most common representatives of the local fauna are insects and amphibians. Among the others are the two-tailed pasha (*Charaxesjasius*), being a typical Mediterranean butterfly, and the stag beetle (*Lucanus cervus*). Among the amphibians, the reported ones are the spectacled salamander (*Salamandrina perspicillata*), two varieties of frogs (*Hyla meridionalis* and *Rana italica*), and one variety of newt (*Speleomantes strinatii*). Naturalists have identified more than 100 bird species, including the peregrine falcon (*Falco peregrinus*). The rugged and unspoiled nature of the park has allowed the adaptation of other birds such as the kestrel, the buzzard, the hallow, the owl, and the barn owl. The most important mammals for naturalists are micro-mammals, such as the Etruscan Shrew (*Suncus etruscus*), as well as some species of bats. Among the larger mammals are foxes and martens, squirrels, wild boar, and goats.

Given the importance of nature in this area, both in terms of flora and fauna, the holistic NBS approach aimed to protect this natural area. Besides their protection, the project also aimed to specifically use and plant the native vegetation types, to use their occurrence and soil retention capacities to add to the overall goal to reduce the hazards in the area.

People goals

The Portofino Promontory contains various important human aspects. Firstly, it houses the San Fruttuoso abbey and related historical buildings, which construction began in the 10th century. These historical buildings, combined with the hiking trails and beach in front of San Fruttuoso abbey are a huge tourist attraction.

Amongst the historical buildings, people also live in the area, predominantly in the valleys where large amounts of floodwater and landslides end up when occurring.

Additionally, large parts of these territories have been anthropogenically modified since historical times to practice agriculture: man-made terraces allowed to gain sub-horizontal surfaces in steep areas. This large scale but diffused practice consists of a soil and water conservation activity that modified the original slope profile on very large areas, artificially immobilizing soil and debris along the slopes. These morphological anthropogenic features need to be constantly maintained, avoiding water runoff concentration that causes erosion and collapses. The socio-economic changes after the end of the II World War, caused the progressive abandonment of terraced areas and consequently a lack of required maintenance. Nowadays, as a result, terraced areas in case of heavy rains often act as source areas for shallow landslides which may be small in dimension but are diffuse a occur in large numbers. Besides, the fast-moving masses gain a high kinetic energy and destructive power.

Based on the above, the people goals of the project included the protection of the historical buildings, the tourist infrastructure, and the residential areas. Additionally, the restoration of the cultural heritage in the form of the man-made terraces was a goal set for the project.

Integration of the water nature people goals

The project goals are based on the project drivers above exposed and on the specific natural features of the area. The strategy is to adopt a catchment scale ecosystem-based approach, then realizing a series of small works intended to pursue the mitigation through a mutual synergy. Besides, the works must be coherent with the Nature 2000 site and in general with the natural context and value.

The overarching goal of the project was to reduce hydro-metrological risk reduction for Portofino Park. This goal, however, can be divided into various sub goals.

The adopted project goals were:

- Reducing the erosion along the slopes and increasing stability.
- Improve hydraulic/geohydrologic conditions along the streams and compluvium.
- Reducing the possible saturation in discharge capability of the culverts.
- Maintain and reduce erosion along the trails.

4.3.3 Selection of measures

Based on the identified project goals and solutions already known in the area for similar projects, the main solutions that were applied were as following:

- Dry-stone terrace maintenance and reconstruction along the slopes
- Terraces with natural materials (often wood)
- Hydraulic-forestry cleaning along streams
- Weir and selective weirs to intercept sediments and floating transportation before the culverts.
- Bioengineering works along the trails

The reason to choose natural materials versus stone for the construction of terraces is often financial. The stone terraces are often more expensive. In this project, the area at Paraggi was a lot larger than that of San Fruttuoso. Because of this reason, stone was predominantly used in the San Fruttuoso catchment, and natural materials in the Paraggi area to balance the investment required for the two areas.

Along with terraces recovery, re-vegetation is obtained using endemic Mediterranean species to improve both terraces stability and the habitat.

The sites for measures' implementation were selected basing on the following criteria:

- The presence of conglomerates, with large areas of rocky outcrops, both along the coast (from cliffs) and on the slope (from landslides), from which instability phenomena occur systematically. In itself, conglomerate is quite stable, but it generally comes with a steep morphology. Additionally, when a lot of fractures are present in the conglomerate, the rock will be less stable.
- Small catchments, less than 1 km^2, with steep slopes which often lead to frequent flash floods and hyper-concentrated flows.
- The drainage network, in addition to the steep slopes, is often filled with debris and wood cover, which enhances the frequency of debris and mud flow events, as well as the solid transport.
- The presence of anthropogenic morphologies, with terraces supported by dry stone walls built in historical times and nowadays largely abandoned.
- Significant elements at risk at the mouth streams, both with high cultural (e.g., the Medieval Abbey of San Fruttuoso) and landscape values (Paraggi). These elements are frequently visited by tourists and then they represent an important source of income for the area.
- The reduced hydraulic capacity of the streams makes them insufficient to transport the flows safely, in particular at the culverted stream mouth. This is of importance because in case of large rain event, the current hydraulic networks are not sufficient, especially culverts which have not been evolved/improved to deal with more intense rain events (>100mm in 1 hour).
- Several areas are highly vulnerable. For example, the villages of San Fruttuoso and Paraggi, which have already suffered repeated damage from geo-hydrological events in the last century.

Identifying the critical terraced areas which are more susceptible to triggering shallow landslides, and the areas with exposed elements, are the basic drivers in the mitigation activity. The assessment will point out the spatial relationships, focusing the works on the most critical areas: terraced slopes to be maintained or recovered, their possible collapse impacting buildings and infrastructures or into streams and other works whose effects contribute to the overall mitigation at the catchment scale.

4.3.4 The GIS approach for selecting measure locations

According to the project drivers and mitigation strategy a series of measures have been designed for pursuing the risk mitigation in the two selected pilot areas: the Paraggi catchment and the 7 small catchments in the San Fruttuoso Bay (Figure 33) whose features are shown in Table 5.

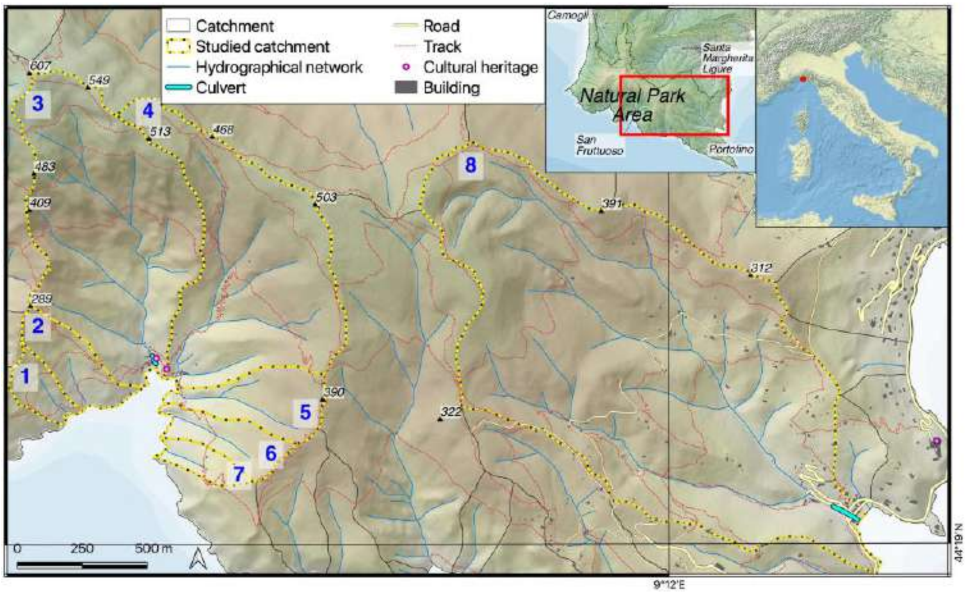


Figure 33 The project pilot sites: 7 small catchments in San Fruttuoso and the Paraggi one (modified from Paliaga et al, 2022c).

Table 5: Main features of the small catchments and percentage of terraced areas: Q Mean = mean altitude; Q Max = maximum altitude; Mean G = mean slope gradient (Paliaga et al, 2022c)

Catchment Nr.	Area (m^2)	Q Mean (m)	Q Max (m)	Mean G (%)	Terraced Area (%)
1	41,232	118	239	86	2.0
2	78,086	126	285	76	11.9
3	574,300	305	600	78	2.3
4	494,664	327	537	66	14.5
5	107,611	229	393	78	4.0
6	69,427	159	332	77	7.8
7	34,288	123	269	76	8.7
8	1,513,544	124	477	52	44.4

After deciding what catchments to focus on, it is important to identify the exact areas that are susceptible to landslides. This Landslide Susceptibility Mapping (LSM) has been done spatially based on the predisposing factors as provided in Table 6.:

Based on an analysis of 85 historic rain events and 114 shallow land slides in the period of 1910-2019, an assessment was made on the influence that each of these factors had on the susceptibility of landslides in the project area. These calculated weights are also provided in Table 6.

Table 6 Conditioning factors for landslide susceptibility, including the classes and calculated weight for the project area based on historical analysis (Roccati et al, 2021)

Conditioning factor	Number of classes	Classes	Calculated weight
Lithology	5	Heterogeneous clayey and sandy materials (Alluvial deposits) Incoherent soils (Thick slope covers)	0,155

		Heterogeneous materials of anthropic origin (Fills and artificial deposits) Marly limestone and marls (Flysch of Monte Antola) Conglomerate (Conglomerate of Portofino)	
Aspect	9	North North-east East South-east South South-west West North-west Zenith	0,09
Acclivity/slope	7	0–10% 11–20% 21–35% 36–50% 51–75% 76–100% >100%	0,311
Land use	10	Urban fabric Industrial, commercial and transport areas Artificial, non-agricultural areas Arable land Permanent crops Pastures Heterogeneous agricultural areas Forests Shrubs and/or herbaceous vegetation association Open spaces with little or no vegetation	0,197
Terraced area	2	Presence of terraces	0,064
Hydrographic elements	4	Spring, distance < 10 m Watercourses, distance < 10 m Spring, distance > 10 m Watercourses, distance > 10 m	0,034
Man-made cuts	4	Trail, distance < 5 m Main road, distance < 5 m Minor road, distance < 5 m Man-made cuts, distance > 5 m	0,031
Man-made structures	4	Buildings, distance < 10 m Other manufacts, distance < 10 m Retaining walls, distance < 10 m Man-made structures, distance > 10 m	0,055
Existing Landslide (IFFI)	5	Active/reactivated/suspended Dormant Inactive/stabilized Area affected by widespread shallow landslides	0,063

		Assumed stable area, distance < 50 m Assumed stable area, distance > 50 m	

Based on these weighted susceptibility factors, a risk map of landslides was made for the project area. This risk map is provided in Figure 34

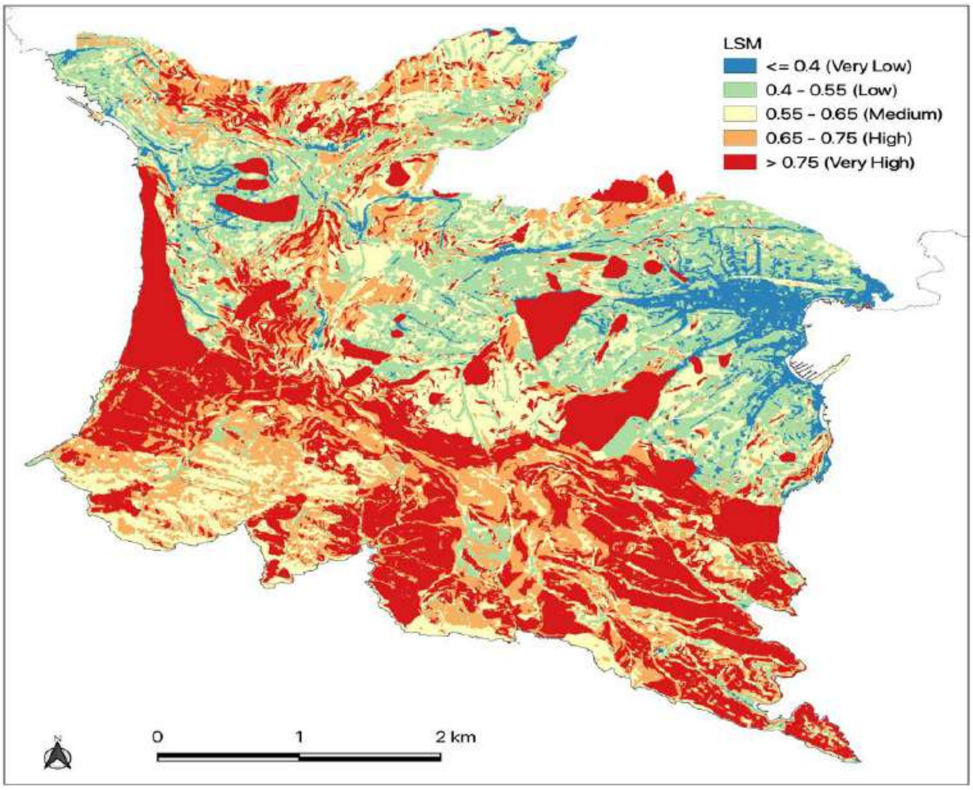


Figure 34: Landslide risk map for Portofino Promontory (Roccati et al, 2021)

As mentioned earlier, the historical presence of terraces has been used as one of the factors to determine where to construct or rebuild these terraces, as the presence of their remnants allows for a relatively easy application of measures. To identify this presence, a remote sensing approach is essential, and it has been conducted through a LiDAR survey, whose analysis allowed to get a 0.5 m Digital Terrain Model (DTM). The usage of LiDAR data is proven to guarantee a high affordability and data quality. The algorithms are LUC, local upslope curvature; SKF, sky view factor analysis; LiHA, LiDAR image highlighting algorithm.

For the LUC, every cell of the DTM is defined as the mean of local curvatures of the upslope neighboring cells. The SKF is an algorithm to determine the ratio of visibility of a certain point from an entire hemispheric radiant around that point. An example is provided in Figure 35. These two methods were already existing and used before the project in Portofino. The LiHA algorithm was developed specifically for this project. This algorithm is based on the following steps (Paliaga et al, 2020):

1. Based on the terrain elevation data, an input grid was created. The input grid consisted of columns and rows, where a node containing terrain elevation information for that position was placed at every node.

2. The input grid was considered to consist of a group of columns, that is, the concept of row was put aside; the group of columns contains the same information that is contained in the input grid.
3. Terrain elevation figures along every column were considered as being seismic wave amplitude data. Then, each column was considered as being a seismic trace (ST) composed of amplitude figures.
4. Thus, by considering one ST at a time and applying a set of seismic data processing algorithms to the ST, weak or subtle events occurring at each ST were enhanced; these subtle events correspond to the weak topographic features contained in the input grid. The same set of enhancement algorithms was applied to all STs.
5. After being processed, all STs were placed back in the same position as in the input grid obtaining a new grid where the weak topographic features contained in the original grid appeared enhanced. This new resulting grid is called a ground ALS-derived grid with LIHA applied.

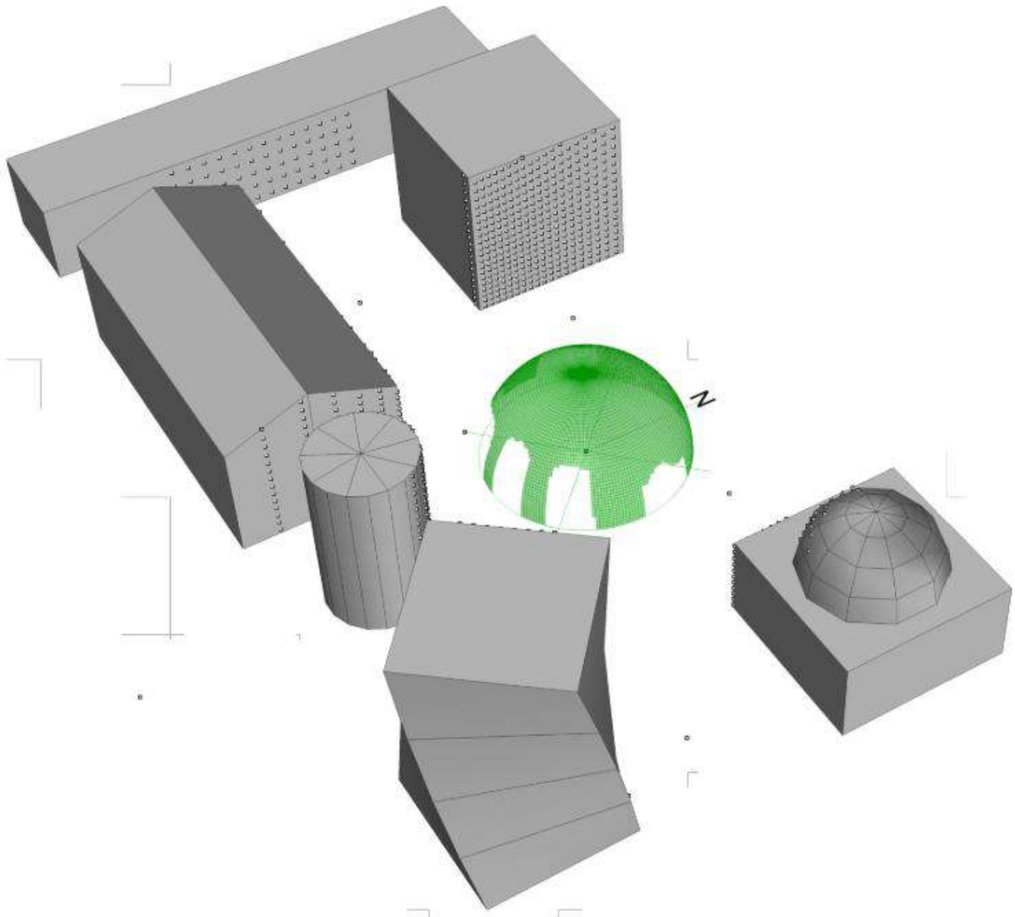


Figure 35: Example of SKF application, where the dot inside the green hemisphere is the considered location, and the ration of green in the hemisphere the SKF (Al-Sudani et al, 2017

The outcome of these different GIS analyses for the identification of historic terraces is provided in Figure 36. A is a visual image, where it is hard to distinguish any terraces. B LUC analysis, where many of the terraces are visible. C and D are the outcome of the

SKF and LUC algorithms, respectively. C has a higher accuracy than B, and D has the highest accuracy.

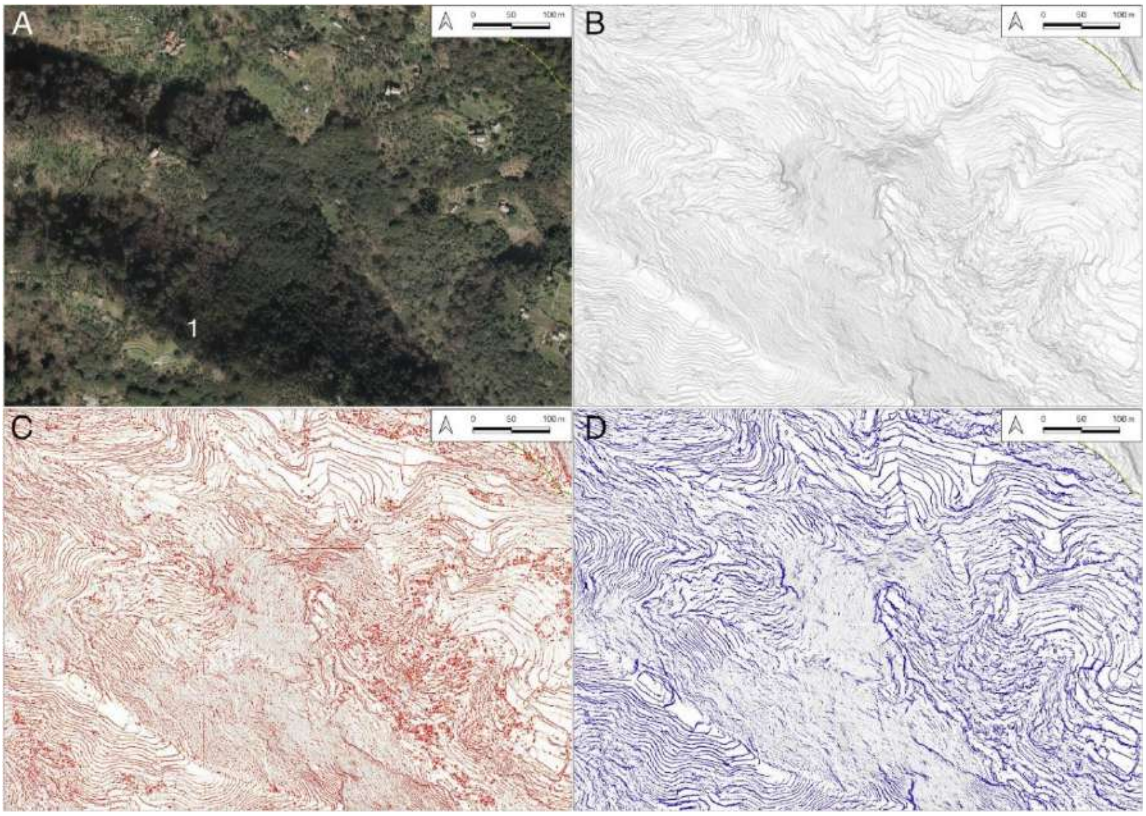


Figure 36 The 3D model showing the detection of terraces in a portion of Paraggi catchment. (A): the orthophotography; (B): the sky-view factor (SKF) visualization; (C): both sky-view factor and LUC; (D): both sky-view factor and LIHA (Paliaga et al, 2022c).

The combination of these GIS analyses provided a clear image of the areas to be targeted for the (re)construction of terraces. The result is shown in Figure 37, including their proximity to the historical and residential areas of importance.

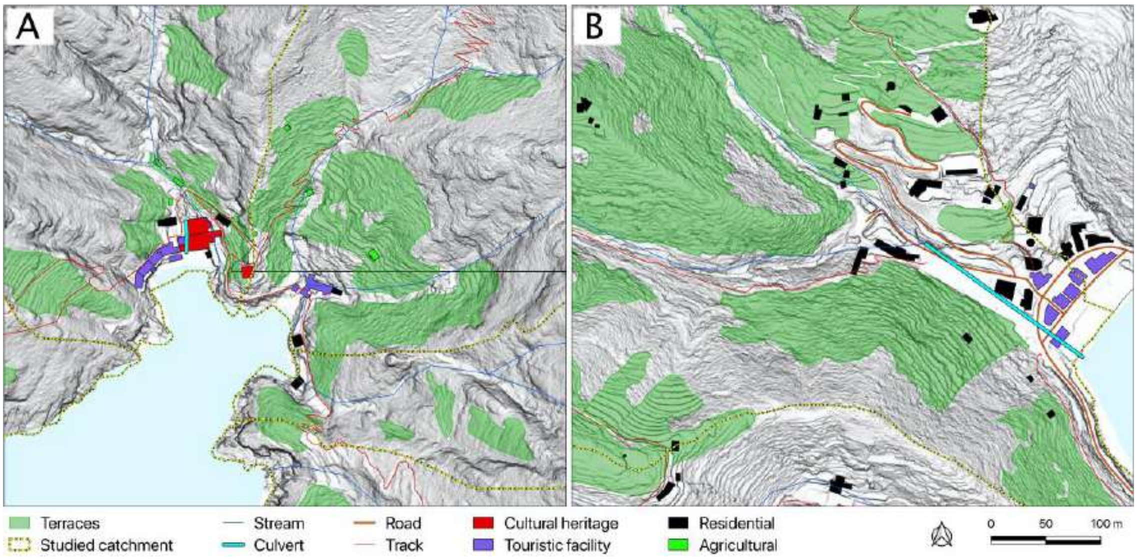


Figure 37 The spatial relationships between terraced areas and cultural heritage, buildings and roads at the mouth of the main studied catchments: (A) in San Fruttuoso and (B) Paraggi catchments (Paliaga et al, 2022c).

4.3.5 The designed measures

In **Error! Reference source not found.** the works realized in the San Fruttuoso are shown, according to the following description:

- 1) Draining running water in the compluvium with small stone walls in order to reduce erosion along the slopes; protection of the footpath and the Casa dell'Arco.
- 2) Compluvium maintenance with selective cutting of vegetation and erosion reduction; selective weir and stone weir to reduce floating and solid transport into the stream. Consolidation of rock slopes for footpath and buildings safety.
- 3 and 4) Stone walls recovery and maintenance (historical olive orchard) and bioengineering works for slopes stabilization and erosion mitigation; proper planting of Mediterranean autochthonous shrub species to reduce erosion and improve slope and footpath stability and safety.

The historical olive orchard has a particular importance as it is probably the most ancient terraced area in Liguria as it was realized after the first Medieval abbey foundation. Besides, erosion was accelerated by the highly frequented trail that passes through it, then mitigation measures have multiple positive effects.

Dry stone walls are essential elements for the conservation of various species of plants, invertebrates and small vertebrates, some of which are included in the annexes of the Habitats Directive.

They are complex microhabitats in which we can distinguish upper parts subject to greater drainage, vertical lateral walls with gradually increasing water and nutrient availability from the top to the base and finally accumulation of nutrients and high humidity at the foot. The number, type and arrangement of stones and cavities, the type of relationship between the cavities and the ground behind them are important characteristics for the full development of the conservation role of these plant and animal species. By taking this into account during the construction of the stone wall terraces, small biodiversity hotspots for specific species were created throughout the project area.

The adopted measures with a comparison between the situation before and after are shown in Figure 38 and Figure 39.

Figure 38 Terraces recovery in the San Fruttuoso historical olive orchard: the comparison between the before condition, on the left, and final one, on the right. Terraces have been recovered reconstructing the stone walls, while bioengineering

techniques have been used to reduce linear erosion along the slope and for the trail maintenance.

Interventions along small compluvium's were often required near hiking trails. These trails experience higher rates of erosion due to a lack of vegetation, frequent footsteps and a concentration of runoff. These small compluvium's therefor received extra attention in terms of interventions. The locations where this was required were visually established. Since these were often hiking trails, the locations with high erosion rates were known by the park staff (Paliaga, 2024).

Figure 39 NBS measures in San Fruttuoso Bay: on the left terraces' recovery and Mediterranean scrub re-vegetation; on the right, trail maintenance with bioengineering techniques.

In **Error! Reference source not found.** the works realized in the Paraggi catchment are shown, according to the following description, with pictures of the measures provided in Figure 40 and Figure 41:

- 1 and 2) Terraces recovery to slope stabilization and to avoid strong contribution of solid transport into the stream.
- 3a) Selective weir to avoid saturating transport capacity of the culvert.
- 3b) Stone weirs in order to reduce water flow and then the erosion along the stream.
- 3c) Vegetation maintenance along the stream and water flow improvement.
- 4a and 4b) Footpath maintenance and recovery; vegetation cleaning along the foot-path and water flow improvement.

Figure 40 Terraces recovery in the Paraggi catchment - area 2: comparison between the before condition, on the left, and final one, on the right. The use of the less expensive bioengineering techniques than stone walls is compatible with the superintendence rules.

*Figure 41 The floating transport selective weirs at the point 3a (**Error! Reference source not found.**) on the left, and stone and selective weir at the point 3b, on the right.*

4.3.6 Implementing measures in privately owned areas

The project faced a major limitation that already emerged during previous projects and activities focusing on hydrogeological risk mitigation: the availability of realizing interventions on terraces that are in private areas.

Terraces are usually on privately owned areas and owners often do not want to see interventions made by others. Besides, it often happens that the property of terraced land is fragmented between several private owners, probably after being inherited: this is a further limitation as it makes it even harder to reach an agreement between multiple owners. Often, owners are not living near the property anymore as they inherited it. Because of this, the ownership issue is a strong barrier, which limits the ability of implementing recovery interventions at all sites where this would be needed (Paliaga, 2024)

4.3.7 NBS Maintenance

The area is characterized by old man-made terraces. As outlined before, these ill-maintained terraces eventually became a hazard instead of a solution. This stresses the need for a decent organization of the maintenance of the structures. If the NBS constructed as part of RECONECT would not be properly maintained, they would suffer the same faith eventually.

The adopted measures need to be maintained periodically from the degrading action of the geomorphic processes. In particular, after intense rain events, the realized structures must be checked and, if it is the case, the proper maintenance must be done.

Sediments and floating elements weirs, as well terraces need to be monitored in their efficiency, as running water may cause damage: terraces degradation is connected by the lack of proper maintenance which is crucial after the impact of intense rainfall.

Then a suitable maintenance program is adopted and a first intervention has already been done to clean weirs from accumulated floating transportation and debris at point marked 2 in **Error! Reference source not found.** in San Fruttuoso area.

During the history of the Portofino Promontory, as well as that of the wide Mediterranean area, maintenance of the measures was the responsibility of the landowners themselves. In the Promontory, it was opted to place this responsibility in the hands of the park authority. As many areas are not actively cultivated anymore, and the hazard is mainly threatening the infrastructure or people downslope, the maintenance has become a common interest, which can best be taken care of by an overarching authority like the park authority.

4.3.8 Integration of Water – Nature – People

Different from the Odense and Ijssel cases, the NBS measures implemented at Portofino Promontory aimed at reducing flash floods and landslides in the mountainous area of the Mediterranean. This inherently required the dispersed implementation of small-scale measures, due to the many slopes, streams and valleys in the Promontory. Additionally, the previous existence of terraces in the area that could be repaired instead of newly constructed, makes it a different case, but comparable to many other locations around the Mediterranean.

Part of the integration of water, nature and people goals was the reconstruction of the cultural heritage of the former terraces, including by using native vegetation. Additionally, the historical buildings require decent protection, and play a large role in the local tourism industry, including history, nature and leisure tourists.

5 Synthesis of lessons learned through the three case studies on the integration of water, nature and people in a NBS project

In many NBS projects, the water goals are dominant. This in itself makes sense, because they are often from their inception focusing on hydro-meteorological risk reduction, i.e. water issues. This often ensures that these goals are met, as they are the primary objective of the entire project. We can clearly see this when looking at the triggers for each of the different projects: the near floods for the Netherlands in the 1990's, the flood at Odense in 2006 and the various flash floods and landslides in Portofino.

Nature goals are often guided by legislation: Especially European legislation, like the Natura 2000 often plays a crucial role in defining the goals and target species. Additionally, the quantitative growth of natural areas or the increase of biodiversity are often named as additional goals to strive for.

People goals are often the hardest to define in a measurable way. Often an increase of recreational area or nature enjoyment can be mentioned, but they often remain smaller in scale than the water and nature goals. What especially the Ijssel case has shown, is that by allowing local people to contribute to the setting of people goals, they often become more tangible and practical.

Regarding the integration of the three pillars, a lot can be said based on these cases. Some of the highlights of this topic are the following:

- Early goal setting
- Tradeoffs between water, nature and people
- Creation of synergy between water, nature and people
- Clear responsibility and budget for each pillar throughout the project
- Involvement of locals and use of local practices
- Use of data (including spatial data) and science for effective measure implemenation

Each of the three case studies benefited greatly from the early definition of specific goals for water, nature and people. By making these goals clear and specific, but sometimes also legally binding, no further discussion occurred about the benefit of focusing on these goals. The goal was clear and simply had to be reached.

Sometimes, water, nature and people goals can be accomplished simultaneously. Unfortunately, they often lead to choices having to be made to choose for one or the other. A great example of how the removal of vegetation in a riverbed can be beneficial for the maximum discharge of the river but have a negative effect on the natural value. By making the options explicit, for example in a matrix like utilized in the RftR program, where all impacts of a measure are clearly depicted, an informed decision can be made. The contradictions for these goals cannot always be prevented, but by at least being transparent about the options and choice made, the best solution can still be chosen.

In other instances, water, nature and people goals can strengthen each other. This creates the perfect situation for an NBS measure and should be seized whenever possible. Some great examples of this are the nature plugs as implemented in Odense, adding nature value to an otherwise water safety focused piece of infrastructure, or the use of as much native species as possible to be planted on terraces to increase stability while at the same time. Each of the cases, especially Odense and Portofino, also showed the convincing power that a project can have when combining various goals in one project. By offering the Danish politicians a solution to both their nature obligations and flood prevention issues, more financing was acquired. For Portofino, the presence of the culturally historical, but also touristic objects, made it easier to make a case for the NBS intervention.

Ambitions are great, but accountability and budget for specified goals are the main key to the success of a NBS project. As mentioned before, water goals often play a dominant role in these kinds of projects. In order to guarantee the nature and people goals as well, it is essential to have budget available from the beginning of the project. Without a dedicated budget, the secondary objectives of a project are often disappearing into the background. When a clearly accountable person or body is responsible for these goals, they are even more likely to be met. A great example of this is how the goals and responsibilities, including budget for certain parts of the project, were already defined and made legally binding for the RftR program. Additionally, the responsibility of the Q-team was to critically assess all the program's projects, constantly holding the different organizations involved accountable for the spatial quality.

NBS are inherently projects that change the environment, and therefore have an impact on local people. This means that it is essential to include these local people and (nature) organizations in the project as early as possible. On the one hand, they could provide valuable local knowledge. On the other hand, by allowing them to have a say in the process, they are more likely to gain a sense of ownership and therefore pride and acceptance of the project. At the Ijssel project, this led to some great, small scale initiatives regarding recreation and accessibility benefitting the local people. At Odense, we see the two faces of cooperation with local people. The positive story is how a lot of nature could be created, and the area could be made safer from floods by working together with the local landowners and nature organizations, with the landowners being able to take on the responsibility of the maintenance for some of the structures. Unfortunately, one of the landowners could not be convinced to cooperate, resulting in the change of plans and designs for the project. In addition to using the current stakeholders and their ideas, ancient ideas can sometimes be utilized as well. As is shown in the Portofino case, by identifying the ancient terraces, a lot of the important locations for measures to be implemented were already identified. They only had to be reconstructed.

The cases of the Ijssel River, Seden Strand and Portofino Promontory each teach us valuable lessons as learned from the implementation of nature-based solutions for hydro-meteorological risk reduction. Despite each of them being implemented under different physical circumstances, lessons can be drawn from each of them that can aid any new implementation of large scale NBS. By taking these lessons into account, and applying them to the local situation, goals and circumstances, a valuable contribution of the NBS can be made to water, nature and people conjunctively.

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