



# EVALUATING THE IMPACT OF NATURE-BASED SOLUTIONS

A Handbook for Practitioners

Independent  
Expert  
Report



Green space management



Knowledge building for sustainable urban transformation



Place regeneration



Health and well-being



Participatory planning and governance



Climate resilience



Biodiversity enhancement



Water management



New economic opportunities and green jobs



Natural and climate hazards



Air quality



Social justice and social cohesion

Research and  
Innovation

## Evaluating the Impact of Nature-based Solutions: A Handbook for Practitioners

European Commission  
Directorate-General for Research and Innovation  
Directorate C — Healthy Planet  
Unit C3 — Climate and Planetary Boundaries

Contact Laura.PALOMO-RIOS@ec.europa.eu  
Sofie.VANDEWOESTIJNE@ec.europa.eu  
Email RTD-ENV-NATURE-BASED-SOLUTIONS@ec.europa.eu  
RTD-PUBLICATIONS@ec.europa.eu

European Commission  
B-1049 Brussels

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**EVALUATING THE IMPACT OF**  
**NATURE-BASED**  
**SOLUTIONS**

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**A Handbook for Practitioners**

Adina Dumitru and Laura Wendling, Eds.

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# 06

## How can I ensure NBS work for Disaster Risk Reduction?

Risk assessment  
for DRR

Illustration of  
monitoring  
and assessment of  
NBS for DRR

Why is it important  
to evaluate the  
impacts of NBS?

What constitutes NBS monitoring?

How do I develop a robust NBS monitoring  
plan?

How can I execute monitoring and impact  
assessment activities?

What indicators of NBS impact can I use?

How do I select appropriate indicators of  
NBS impact?

What kinds of NBS  
monitoring data  
can I gather, and how  
should I manage these  
data?

## 6 NBS FOR DISASTER RISK REDUCTION

### **Coordinating Lead authors**

*Nadim, F., Tacnet, J.-M.*

### **Contributing authors**

*Basco Carrera, L., Capobianco, V., Caroppi, G., Gerundo, C., Giugni, M., Manojlovic, N., Oen, A., Pilla, F., Porcu, F., van Cauwenbergh, N., Scheuer, S., Vojinovic, Z.*

### Summary

#### **What is this chapter about?**

Losses and damages due to natural hazards can be dramatic. This chapter provides a global overview of the requirements for risk assessment in the context of Disaster Risk Reduction (DRR). It outlines how NBS as structural measures can effectively reduce risks related to hydro-meteorological disasters, at the same time providing multiple co-benefits. As NBS may lack sufficient physical capacity to provide adequate protection against extreme events, the chapter illustrates how in most cases a hybrid combination of NBS and technical engineering (i.e., green and grey) measures can provide the optimal solution when DRR is the primary goal.

Next, we introduce the assessment of effects and co-benefits of NBS. These co-benefits should be included in cost-benefit analyses when comparing NBS with grey or hybrid solutions. Case studies illustrate selected implementation pathways and exemplify indicators and assessment frameworks that can be used

to assess different aspects of technical, physical, economic, social, human and environmental features of NBS.

***How do I use this chapter in my work with NBS?***

The frameworks, indicators and case study examples provided in this chapter can be used to design a monitoring and evaluation system for an existing or planned NBS for DRR.

***When can I use this knowledge in my work with NBS?***

Assessing the effectiveness of NBS at regional or local level for DRR in the context of hydro-meteorological hazards requires a detailed assessment of the risk level and the expected impact of the implementation of NBS. The knowledge presented in this chapter will assist in designing the monitoring and evaluation system for this purpose, including the selection of appropriate criteria and methods.

***How does this chapter link with the other parts of the handbook?***

This chapter expands the discussion of NBS impact evaluation from the city scale (chapters 1-5) to the catchment scale in the context of large-scale NBS for disaster risk reduction, with a primary focus on hydro-meteorological risk reduction.

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## **6.1 NBS and Disaster Risk Reduction**

As mentioned in the opening sentence of Chapter 1, urban areas cover less than 4% of land all around the world. Yet, almost all of the NBS-related research projects funded by the European Commission (EC) before 2018 focused on problems in urban areas. Nearly 50% of the rural areas in the world are classified as mountainous regions and are exposed to risk from geological and hydro-meteorological hazards. Mountains tend to amplify these risks, and even more so under extreme weather events. However, rural mountainous regions do not receive the same attention as densely populated urban areas in national disaster risk reduction (DRR) plans. National DRR plans focus mainly on regions with highest population density, which tend to be urban and/or coastal areas. Impacts of extreme hydro-meteorological events in mountain areas often affect entire river basins. Some of the natural hazard-related disasters in urban and coastal areas such as flooding caused by landslide dam breaks during and after storms are due to processes and events like flash floods and landslides that initiate in hilly and mountainous regions higher up in the river basin. Nature-based Solutions (NBS) have many advantages to fulfil disaster risk reduction objectives but their implementation is still limited because of lack of evidence of their effectiveness. Four recent H2020 projects – NAIAD, PHUSICOS, OPERANDUM and RECONNECT – focus fully or partially on demonstrating the effectiveness of nature-based solutions and their ability to reduce the impacts from small, frequent events (extensive risks) in rural mountain landscapes and in coastal areas. To demonstrate the effectiveness of NBS in achieving DRR objectives and to measure

their co-benefits, specific methodologies and measurable indicators are needed to provide evidence to stakeholders and decision-makers.

The previous chapters of this handbook review the existing indicators for all environmental challenges in which NBS may be considered. However, it appears that the existing frameworks related to indicators for measuring the effectiveness NBS only partially address the issue of disaster risk reduction. Evaluating the effectiveness of risk reduction measures, and especially NBS, requires understanding and describing the effects of measures (i.e., their physical capacity) on phenomenon's nature, intensity and frequency. The concept of effectiveness itself and the related indicators are linked to the comparison of an objective assigned to a function and a capacity (see Chapter 2).

In the critical domain of disaster risk reduction, demonstrating the physical effects of those measures is therefore a first essential step towards their successful implementation. However, in addition to this somewhere classical and expected effect, NBS can offer other co-benefits that conventional grey infrastructures (e.g., dams, levees) do not provide in terms of environmental, economic, social co-benefits. Indicators in the DRR context are not only physical; they should include other categories like risk perception, environmental impacts, and economic effectiveness.

This chapter extends the existing framework and proposes to address this challenging topic by taking benefit of recent projects dedicated to hydro-meteorological risks, mainly NAIAD, PHUSICOS, RECONNECT and OPERANDUM<sup>51</sup>. It first recalls briefly natural risks contexts, basics of risk assessment, risk reduction measures and then describes relevant indicators and principles that should guide indicator selection for disaster risk reduction. It focuses on the role of NBS for adaptation to and mitigation of impacts of weather events – with some examples taken from projects' representative case studies.

## **6.2 Basics of risk analysis, risk reduction measures, resilience and effectiveness**

Defining, selecting and assessing indicators of NBS effectiveness in the context of DRR is linked to the understanding of risk concepts and the possible effects that NBS may have on those risk components. Depending on phenomena (e.g., floods, mountain-flash floods, debris-flows, landslides, rock falls), the physics of hydrological, geophysical processes may differ, although a common approach can be applied. This section presents those common points.

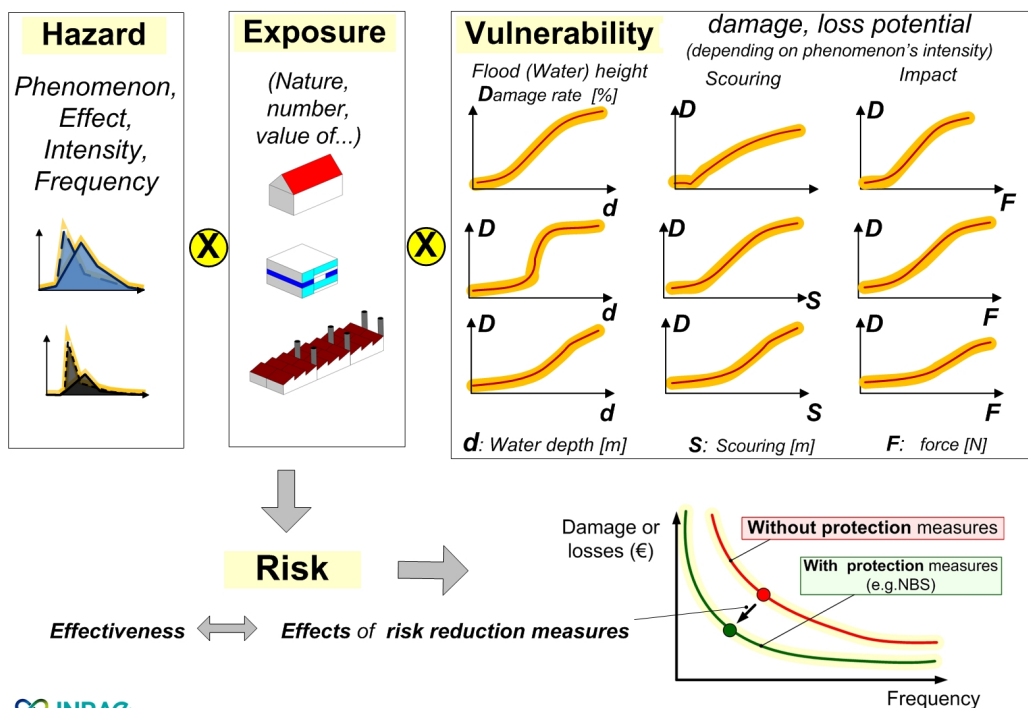
Risks result from a combination of hazard (frequency and intensity), exposure and potential losses as a function of vulnerability and values. Here, vulnerability represents the degree of damage or loss when an exposed element such as an

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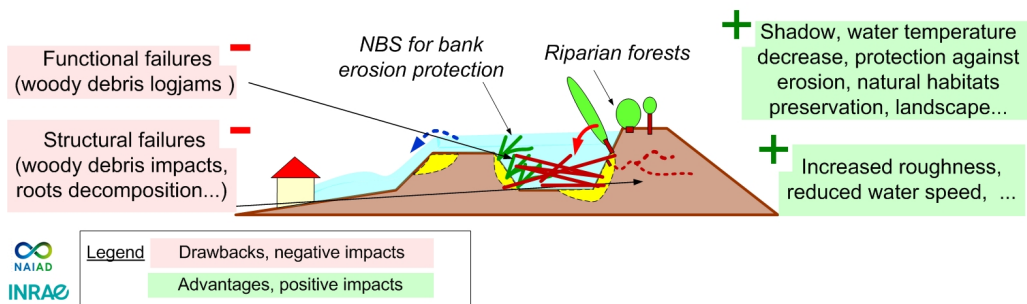
<sup>51</sup> NAIAD: <http://naiad2020.eu/>; PHUSICOS: <https://phusicos.eu/>; RECONNECT: <https://reconnect-europe.eu/>; OPERANDUM: <https://reconnect-europe.eu/>

object, a person, or an activity is impacted by a given level of phenomenon intensity (Figure 6-1).

Intensity depends on the considered phenomenon and its several possible effects. For instance, mountain floods are not only composed of water but also transport solids (sediment and large wood). Measuring only water height may, therefore, not be relevant for computing damages, first, because of bed level change due to deposition or erosion, and, second, because these changes and/or damages due to material load may be the main cause of damage rather than the mere submersion by water (Figure 6-2).

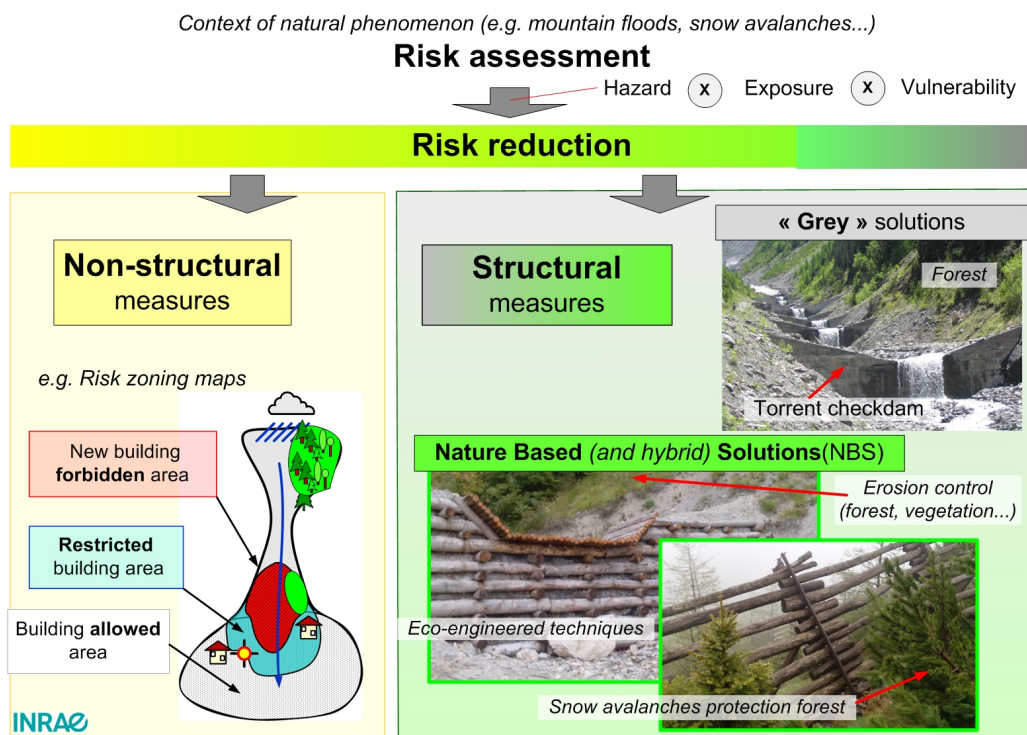


**Figure 6-1.** Basic components of risk: the effectiveness of a risk reduction measure requires to analyse its effects on the phenomenon including (1) the nature of the effects (e.g., flooding, scouring, impact of boulders); (2) their frequency; and (3) their intensity (e.g., flood depth) and their interaction with exposed elements (exposure and vulnerability as a potential of damage).



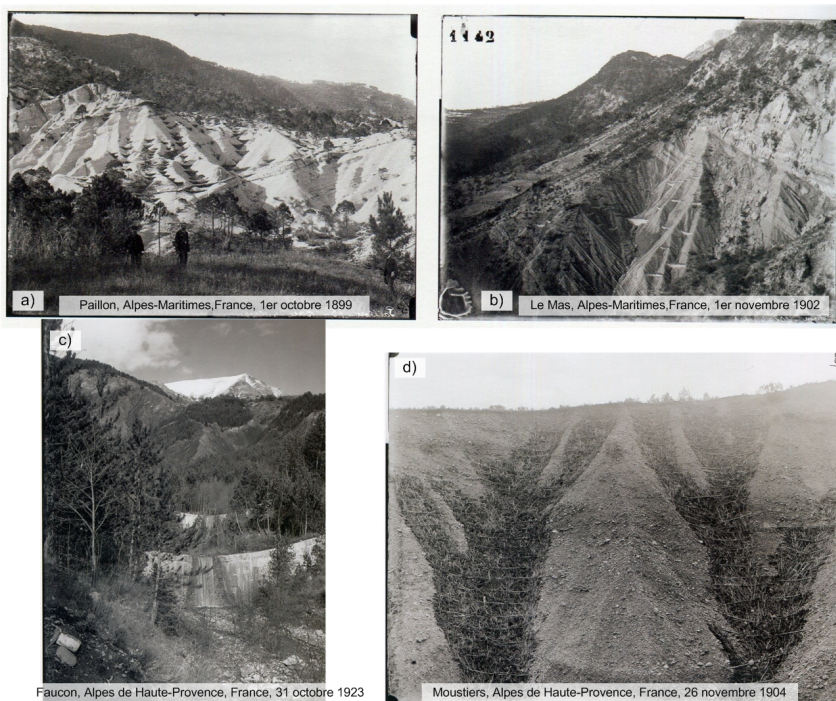
**Figure 6-2.** Positive and negative effects of NBS on phenomena and protections' physical features are addressed to assess measures' effectiveness (Tacnet, 2019).

Risk reduction measures consist of both structural (physical) measures such as protective structures (e.g., check dams) or non-structural measures such as land-use management, land-cover control and risk mapping (Figure 6-3). Structural measures aim to reduce risk by having a physical effect on the main characteristics of a phenomenon (e.g., reducing run-off on a given territory).



**Figure 6-3.** When dealing with DRR, Nature-Based Solutions are part of structural risk reduction strategies.

Nature-based solutions can therefore be considered as a structural measure dedicated to having an effect on the hazard component of risk (i.e., on the frequency or intensity of a given phenomenon). According to Evette et al. (2009), living plants have been used for a very long time throughout the world in structures against soil erosion, as traces have been found dating back to the first century BC. In Western Europe, bioengineering was widely practiced during the eighteenth and nineteenth centuries. For instance, since the 19<sup>th</sup> century in France, soil restoration, protection forests, gully restoration and planting as well as torrent check dams have been aiming to reduce sediment production and risks to people and assets in the valleys. Many techniques and hybrid combinations with civil engineering solutions are therefore not new (Figure 6-4). However, characterising the effectiveness of those measures remains difficult.

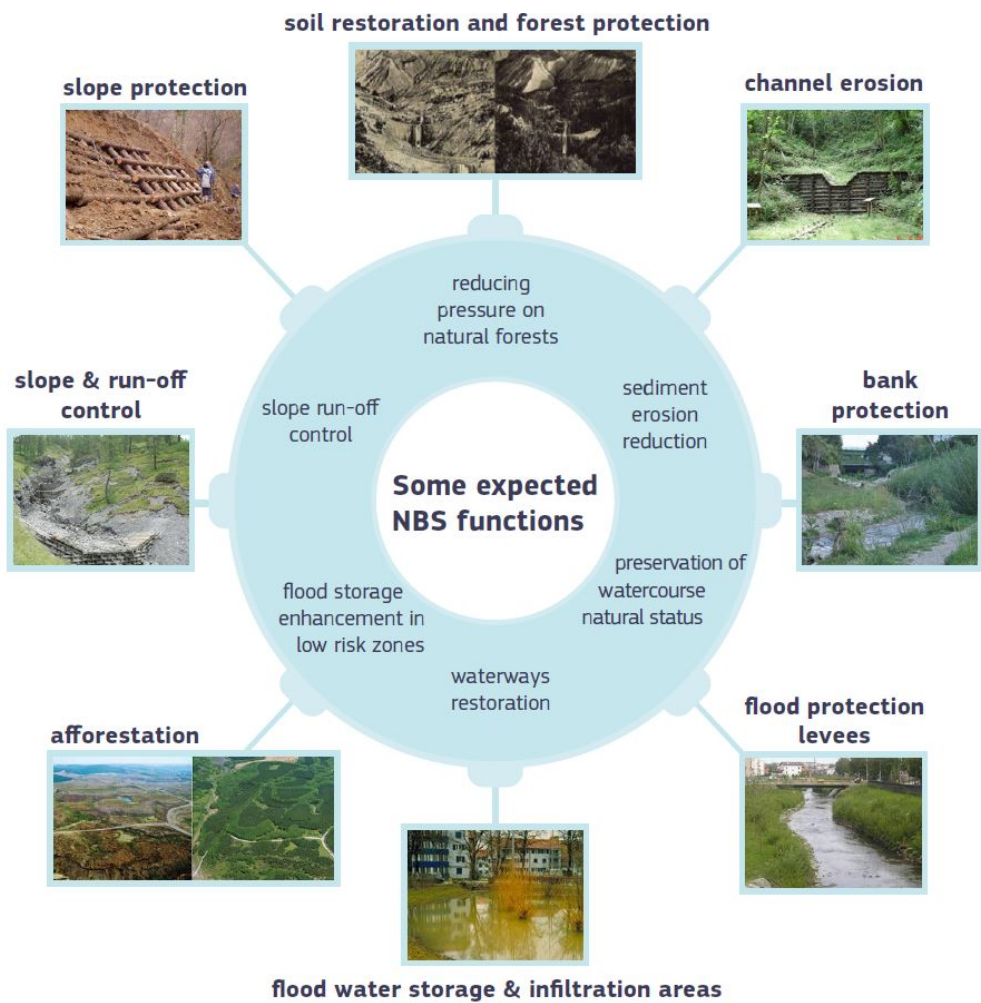


13. Source Conseil Général des Bouches du Rhône, Museon Arlatan, 2004 « Restaurer la montagne, Photographies des Eaux et Forêts du XIX<sup>ème</sup> siècle ».

**Figure 6-4.** Combination of civil-engineered solutions and reforestation (which can be defined as Nature-Based Solutions) have been experimented successfully since the 19<sup>th</sup> and 20<sup>th</sup> century for mountain restoration purpose<sup>52</sup>, here with an example from the south eastern French Alps.

<sup>52</sup> See *Restaurer la montagne. Photographies des Eaux et Forêt du XIXe siècle*. Brugnot, G., Coutancier, B. et al., Paris: Somogy éd. d'art, ISBN: 2-85056-801-5, 188 p.

For flood risk management, many types of NBS exist, each of them corresponding to a specific expected function that will be analysed to check their effectiveness<sup>53</sup> through their comparison between their physical capacity (e.g., a storage volume) and an objective linked to this function (e.g., volume needed) (Figure 6-5).



14.

**Figure 6-5.** NBS used for flood risk management have different functions.

<sup>53</sup> See chapter 2 for a definition of effectiveness

### 6.3 Indicators and methodologies for measuring NBS effectiveness indicators in DRR context

Several recent H2020 projects address the analysis of the effects of NBS. NAIAD, PHUSICOS, RECONNECT and OPERANDUM projects propose generic assessment frameworks for measuring the effectiveness of an NBS that is primarily designed for DRR.

The NAIAD framework is designed for effectiveness assessment and decision-making with respect to the choice of best NBS measures and strategies. The different steps of disaster risk reduction and contributions of NBS are studied within the NAIAD project considering technical, physical but also social, human, environmental and economic features (Figure 6-6). A specific methodology is designed to determine the indicators. Relevant indicators are defined by experts and stakeholders through workshops. A two-level approach is proposed making a difference between technical analysis and decision-making contexts. Expert and technical assessments are used as inputs in a multicriteria decision-making framework which allows to address all kinds of technical, environmental, economic, or social features, and to consider stakeholder preferences as identified during participative workshops (Figure 6-7).

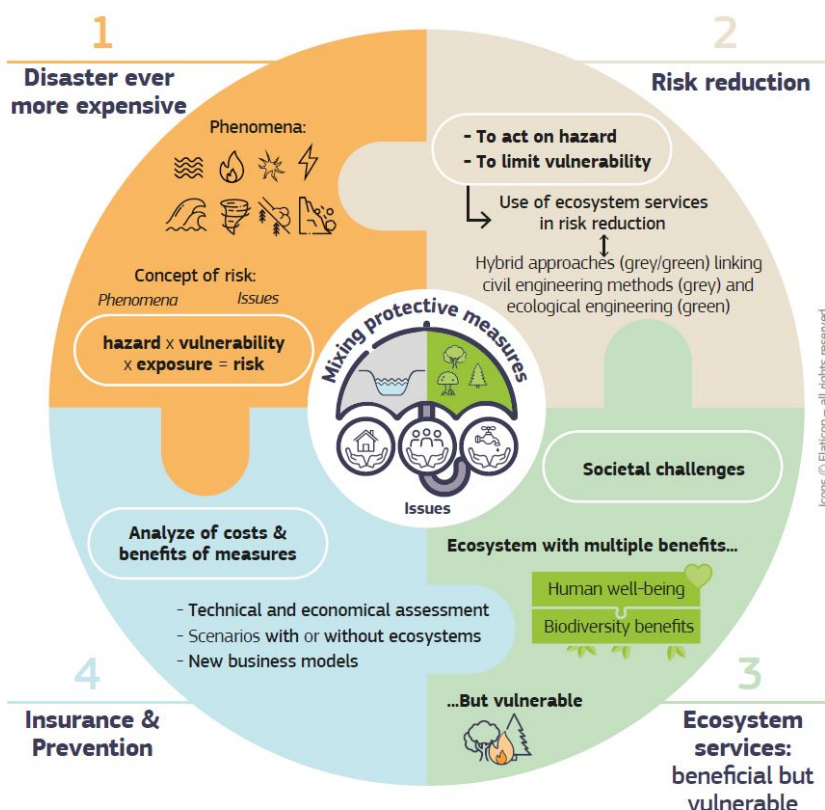
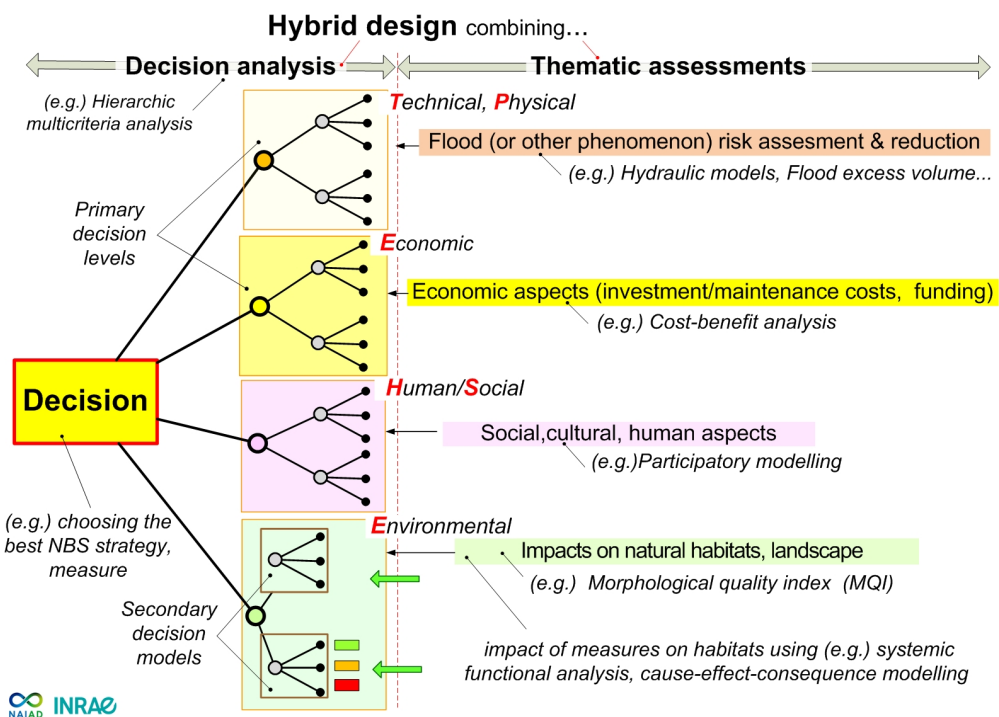


Figure 6-6. NAIAD’s global framework to assess role of NBS in Disaster Risk Reduction (DRR).



**Figure 6-7.** A multicriteria decision-making framework allows to integrate and combine technical, physical, environmental and economic indicators. Decision makers express their preferences on high-level criteria (protection level, economy of projects, social/cultural and environmental impacts). Experts provide and assess indicators for those categories (adapted from Tacnet et al., 2018).

Regarding DRR, the indicators for measuring the NBS effectiveness in the NAIAD framework are linked to physical effects of measures at different scales. The NAIAD framework is applied ex-ante, the indicators related to physical effects are thus assessed by a combination of numerical modelling and geomorphological analysis. NAIAD proposes a global hierarchical model to combine indicators for various aspects including technical, physical, organisational, environmental, social/human and economic features (so-called TOPHEE approach) in order to assist the decision-making process.

The projects PHUSICOS, RECONNECT and OPERANDUM all focus on NBS for reducing the risk of hydro-meteorological hazards. However, they approach the problem from different viewpoints and their recommended frameworks have their distinct characteristics. Table 6-1 compares some of the characteristics of these frameworks. All three frameworks are built on the basis of the hazards addressed in the case study sites of each project. For example, RECONNECT focuses only on flood and drought risk; PHUSICOS on landslides, snow avalanches, floods and drought; and OPERANDUM focuses on a larger spectrum of hazards (Shah et al., 2020), including coastal erosion, storm surge, nutrient and sediment accumulation, soil salinization, heat waves, and dust storms found in the Open Air Laboratories (OAL).

PHUSICOS and RECONNECT have both selected the risk and co-benefits categories, as well as the initial set of indicators to be assessed on the basis of existing NBS projects, platforms and literature, with a focus on the challenges indicated by the EKLIPSE project. A different approach was adopted by the OPERANDUM team, who identified the indicators through the review of literature available for each of the OAL-specific hazards, together with stakeholder involvement in surveys and focus group discussions. In the OPERANDUM framework, once the potential indicators are identified, their final selection is based on four criteria: Credibility, Salience, Legitimacy, and Feasibility. Stakeholders are involved in all processes, from the co-design of the framework to the co-selection of the indicators, based on their specific needs and priorities. The OPERANDUM framework has not been tested yet, while the other two frameworks were tested on a real NBS case in Thailand within the RECONNECT project, and for three hypothetical scenarios in PHUSICOS: (1) the Baseline Scenario before implementation of any mitigation measure; (2) a NBS Scenario; and (3) a Hybrid Scenario.

Based on the tests carried out to date, it can be noted that RECONNECT approach has been solely used for ex-post assessment of a NBS scenario for potential replication, up-scaling or improvement. This is different from the PHUSICOS framework, which can be used also as a decision-making tool to compare the potential performances and co-benefits of different design scenarios for a specific context prior to their implementation. A main feature of the RECONNECT framework is that each indicator is expressed in a relative manner, i.e., as the difference between its value in the NBS scenario and in the scenario without NBS, whilst for PHUSICOS and OPERANDUM the indicators are expressed using absolute values. This difference highlights the importance that the RECONNECT project attributes to the NBS co-benefits. PHUSICOS and OPERANDUM systematically address the risk reduction provided to a specific context, in terms of changes in exposure, vulnerability and hazard. Furthermore, the OPERANDUM framework treats both the ecosystem and the society as elements exposed to risks posed by hydro-meteorological hazards at each specific OAL, highlighting again the adopted risk-oriented approach.

A general observation that can be made is that the RECONNECT framework is benefits-oriented, the OPERANDUM framework is risk-oriented, and the added value of the PHUSICOS framework is balanced and neutral: risk reduction indicators and co-benefits indicators are structured in a way that the stakeholders can state their preferences through weights assigned to each indicator. An added value of the OPERANDUM framework is that it is applicable from a local to regional/national scale, while both RECONNECT and PHUSICOS are mostly focused at local or catchment scale. An added value of the RECONNECT framework is that it includes, as last step of the evaluation, an analysis of a so-called NBS grade, focusing on the weakest indicators, so that experts and stakeholders can provide recommendations for all indicators, or only those with low scores. Recommendations can include guidance on how to better involve stakeholders in every step of the framework, how to better measure, collect, and analyse data, and how to maintain the NBS to maximize benefits. Finally, all three frameworks are highly flexible, and they can be adapted or redefined to the context where they are applied, depending on the needs of the stakeholders and the most suitable indicators to be assessed.

**Table 6-1.** Key features of the frameworks developed in EC H2020 hydro-meteorological risk reduction projects (based on partial examples presented in case studies).

Framework aspect	NAIAD	RECONNECT	PHUSICOS	OPERANDUM
<b>Key features of the frameworks</b>	Integrated hybrid approach mixing classical engineering, environmental and geomorphological approaches but also systemic analytical, economic and multicriteria decision-aiding frameworks	Five main sequential steps, from the selection and the evaluation, to the scoring of the main indicators for the assessment of the benefits of an implemented NBS	Based on a multicriteria decision analysis (MCDA), which assesses, through a matrix containing indicators aggregated in different sub-criteria, the risk reduction performance and the co-benefits of a design scenario for a specific site	Vulnerability and risk assessment framework, aimed at looking at the impacts of hydro-meteorological hazards on an exposed social-ecological system
<b>Source for the identification of the initial set of indicators</b>	Multidisciplinary indicators, either from existing methods (e.g., EU Reform project for morphological quality index) or self-created (e.g., flood excess volume, FEV)	Indicators as well as the three benefit categories where they fall in (Water, Nature, People), based on the challenges indicated by the EKLIPSE project	Indicators are selected after an extensive review of the main existing NBS project networks and platforms, as well as the challenges indicated by the EKLIPSE project	Systematic literature review combined with stakeholders and expert surveys and focus group discussions
<b>Type of hazards addressed</b>	Flood	Flood, drought	Flood, landslide, snow avalanche, drought	Hydro-meteorological but can be applied to any natural hazard
<b>Main categories</b>	Integrated risk management, Multifactorial NBS effectiveness assessment, Decision-aiding	Water, Nature, People	Risk reduction, Technical and feasibility aspects, Environment and ecosystems, Society, Local Economy	All components of risk (hazard, exposure (social and ecological sub-systems), and vulnerability (social sensitivity and coping capacity; ecosystem

				sensitivity and robustness)
<b>Indicator types</b>	Multicriteria technical, physical, environmental, social/human, organisational indicators (relative, comparative and absolute values) – TOPHEE approach	Relative value	Absolute value	Not specified, but absolute value is implied followed by normalization
<b>Stage of assessment</b>	Ex-ante assessment	Ex-post assessment (can also be applied for Ex-ante assessment)	Ex-ante assessment and Ex-post assessment	Ex-ante (can be visualised, e.g., with scenario development)
<b>Spatial scale of application</b>	Local or catchment scale (can be extended to regional or global scale)	Local or catchment scale	Local or catchment scale	Local to basin scale
<b>Environmental context</b>		<b>Urban and rural environmental contexts</b>		
<b>Stakeholder level of involvement</b>	Stakeholders are involved in the indicator selection process (workshop), the assessment process (validation, communication of technical assessment), the decision-aiding step (identification of preferences, assessment of solutions)	Stakeholders are involved in the process from step 1 (selection of indicators) to step 4 (evaluation of the NBS grade). It is not specified if they are actively involved also in step 5 (recommendations)	Stakeholders are involved in the refinement of the matrix for the specific site, as well as in weighing the ambits, criteria and indicators	Stakeholders are continuously involved, they help to co-design the framework, co-select the indicators, and give a prioritized list of indicators. They will be involved in weighing indicators

<b>Outcome</b>	Fully integrative and versatile framework from indicators design to their aggregation, NBS strategies and measures are assessed in a multicriteria perspective	NBS grade incorporating all the benefits assessed, equal to the average of the scores of each indicator quantified	Overall scenario scoring for comparing two different scenarios, or to assess a specific scenario performance over time	Risk to the social-ecological system
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## **6.4 Case study #1 - NAIAD (La Brague, FR): from indicators assessment to integration and decision-aiding for flood risk management** <sup>54</sup>

### *6.4.1 Context and global framework for assessment of NBS effectiveness*

Several scales and kinds of application test cases were considered in the NAIAD project<sup>55</sup>. This case focuses on La Brague River in the south of France, where the effectiveness of nature-based solutions was addressed through a combination of physical, geomorphological and economic indicators. The Brague River basin is a 68 km<sup>2</sup> catchment located along the French Mediterranean coast between the cities of Cannes and Nice. The Brague is a short river, 21 km long, and is subjected to flash floods as well as woody debris production and transport. Mediterranean climate causes heavy rains mostly in autumn, and the floods of the Brague are often devastating and sometimes deadly. Over the period of 1970–2015, the Brague caused fourteen disastrous floods and eight deaths. The insured damages of the October 2015 flood (which had an estimated return period of over 100 years) amount to about 50 million € in the municipalities of Biot and Antibes. After this flood, several campsites located in the area were closed by state decision due to risk of being flooded. However, dozens of houses remain at risk. This regrettable event provided an opportunity to re-define the economic development strategy of the valley and to design new flood protection strategies to both protect people and infrastructure against flood risk, and to improve the river corridor's natural life, landscape and environmental quality.

Risk analysis is traditionally addressed through hazard and vulnerability assessment. The primary expectations of the selected nature-based strategies for the river corridor would be that these strategies are effective in reducing hazards from a physical point of view by storing water in the upper catchment while easing drainage without overflowing in the lowlands. NBS can provide other important co-benefits but they may appear as secondary if the protection level is not sufficient. When used alone, eco-engineering approaches can propose aesthetic solutions which may not be able to cope with required hydraulic capacity or be strong enough to resist to hydraulic constraints. NBS flood alleviation strategies studied for the Brague catchment are a combination of retention measures by small natural retention areas in the upper catchment, along with a widening of the river corridor in the lowlands enhanced by floodplain reconnection. Floodplain works consist of several measures including bed and bridge widening, forest corridor and wetlands restoration, and large woody debris management. They are integrated in a so-called "giving-room-to-the-river" strategy. Two levels of ambition, namely high and very high, are considered as well as a more classical grey scenario based on huge retention dams for comparison purposes.

NAIAD proposes both indicators and an original approach to formalize the concept of effectiveness to design, assess and combine ad-hoc effectiveness indicators (see also systemic analysis<sup>56</sup>). A multidisciplinary approach draws on the

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<sup>54</sup> J.-M. Tacnet, G. Piton (INRAE/NAIAD)

<sup>55</sup> See Deliverable 6.4 for an extended description of outputs

<sup>56</sup> See NBS handbook, Chapter 2

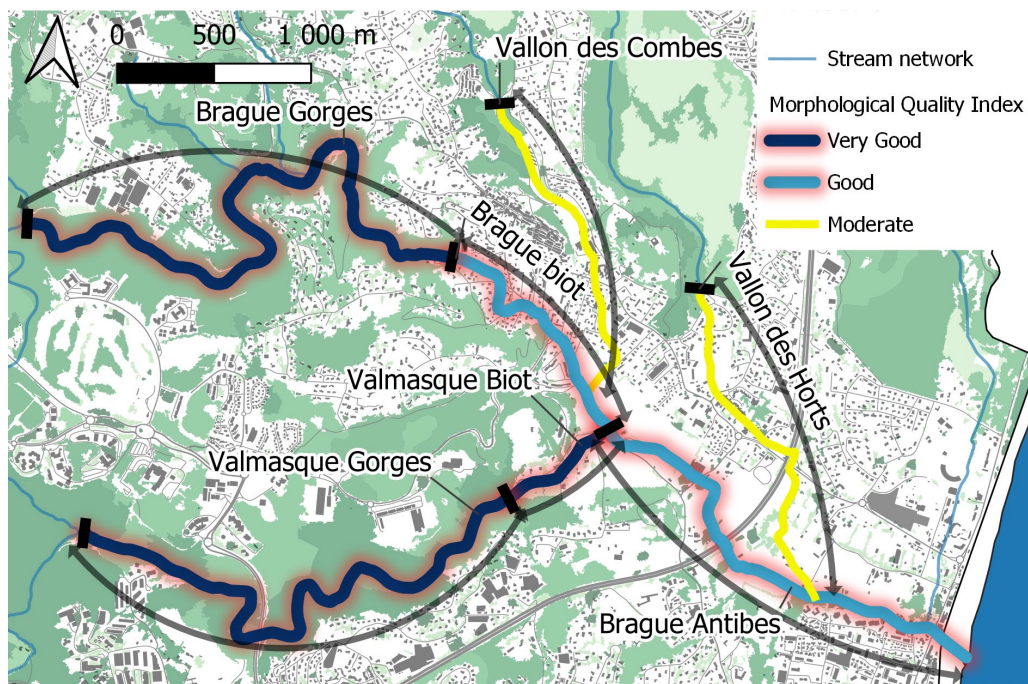
knowledge of experts in forest and river management, natural hazards (floods, erosion, wildfires), vulnerability and damage assessment, economy and decision-aiding to perform an in-depth study of the Brague River catchment and compare the effectiveness of possible grey (civil-engineered), green (nature-based solutions) and hybrid strategies. Experts' analysis and domain-specific methods are used as basic inputs to address technical, environmental and economic indicators. For instance, cost-benefit analysis is used to provide an indicator for economic effectiveness assessment, morphological quality index (MQI; Rinaldi et al., 2013) is used to assess the morphological status of the river while the flood excess volume (Bokhove et al., 2019, 2020) is used to measure the physical hydraulic capacity of measures and comparison with their economic features. Total costs of the three protection strategies were evaluated and compared with mean annual avoided losses (costs) based on historical events and theoretical floods with known return period. The co-benefits related to NBS strategies were also evaluated using two different methods (Arfaoui and Gnonlonfin, 2020a, 2020b). First, transfer of values based on a meta-regression-analysis of values provided in other catchments, and second, a contingent valuation performed locally through interviewing more than 400 persons in the basin. It should be stressed that several intangible criteria, e.g., the improvement of the natural status of the river, are poorly captured by the monetary methods and a complementary multicriteria decision framework was developed to handle both tangible and intangible criteria (Figure 6-7).

#### *6.4.2 Indicators for assessment of technical, physical and economic efficacy of flood mitigation strategies including NBS*

Indicators to describe the **environmental, ecological** and **geomorphological status** of a river have been estimated for the initial state and with assumptions corresponding to the different NBS strategies and scenarios (Figure 6-8 and Table 6-2). The morphological quality index (MQI<sup>57</sup>) aggregates 28 indicators corresponding to geomorphological functionality, artificiality and channel adjustments. It captures degradation of the geomorphological quality of the river for the grey scenario (decreases in MQI, red cells in Table 6-2), whilst the NBS scenarios improve it (increases in MQI, blue cells in Table 6-2). These elements were meaningful for stakeholders interested in river restoration.

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<sup>57</sup> Developed within the EU project REFORM (<https://reformrivers.eu>)



**Figure 6-8.** Map of Morphological Quality Index values – state based on data and maps in 2017.

**Table 6-2.** Morphological Quality Index values for the different reaches (status 2017) and values of intermediate aggregation. Those indicators are then used in the multicriteria decision-aiding framework.

Strategy	Reach	Brague Gorges #1	Brague Biot #2	Brague Antibes #6	Valmasque Gorges #5	Valmasque Biot #4
<b>Current status</b>	MQI <sub>current</sub>	0.94	0.82	0.80	0.94	0.85
<b>Grey</b>	MQI	0.87	0.79	0.76	0.87	0.82
	MQI-MQI <sub>current</sub> =ΔMQI	-0.07	-0.03	-0.04	-0.07	-0.03
<b>NBS ambitious</b>	MQI	0.97	0.86	0.90	0.97	0.88
	MQI-MQI <sub>current</sub> =ΔMQI	0.03	0.04	0.1	0.03	0.03
<b>NBS very ambitious</b>	MQI	0.97	0.87	0.95	0.97	0.88
	MQI-MQI <sub>current</sub> =ΔMQI	0.03	0.05	0.15	0.03	0.03

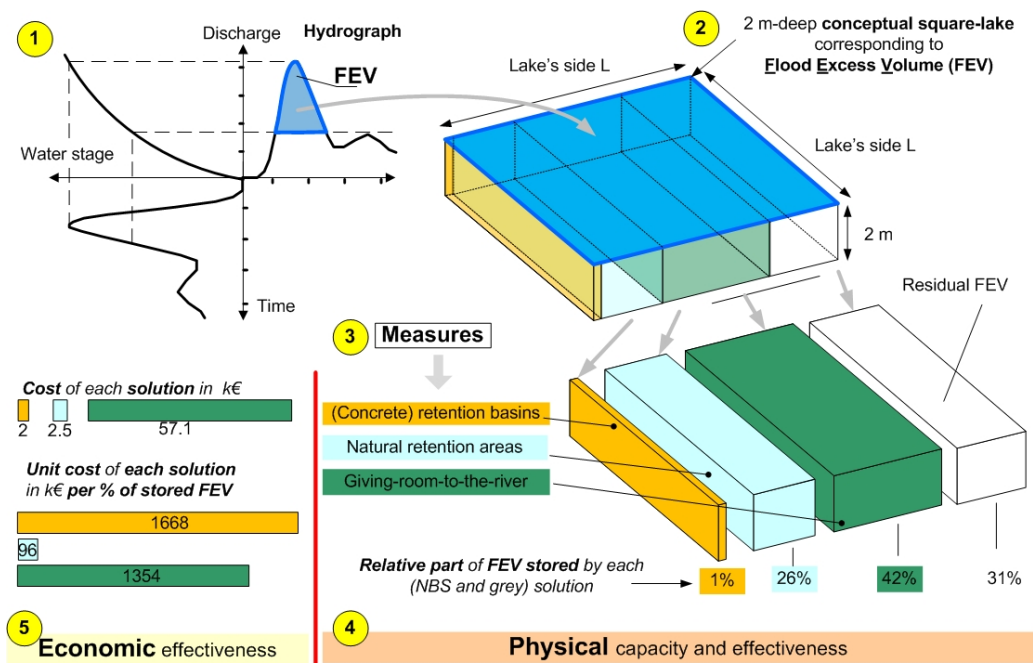
Note: MQI = 0 = river status totally altered; MQI = 1 = No alteration to the natural status

Providing an objective, easily understandable method to assess **indicators of physical and economic effectiveness** of NBS is essential to guarantee security but also to increase acceptance by stakeholders. The **Flood-Excess-Volume (FEV) method** has been developed to quickly assess cost-efficacy of flood-mitigation strategies by allowing generic flood-mitigation strategies to be tailored to specific river-catchment scenarios. Produced through a collaboration between the University of Leeds, UK, and the NAIAD project, it has been successfully tested on data accrued from real flood events occurring in the UK (Aire and Calder Rivers), France (La Brague, NAIAD demonstration) and Slovenia (Glinsisca river, NAIAD demonstration), see Bokhove et al. (2019, 2020) and Pengal et al. (2020).

FEV identifies and utilises indicators of flood severity that are quantifiable, easy to understand and to measure, hence making it objective, transparent to scrutiny and user-friendly. It is repeatable, flexible and capable of rapidly verifying whether or not a given ensemble of protection measures is sufficient to mitigate against *a priori* specified degree of flood severity. The input data required by the tool are the project-flood hydrograph (i.e., the water-discharge time series), the water stage-discharge curve (i.e., the channel capacity) and the threshold level (i.e., the discharge above which severe flooding occurs). In Figure 6-9, the computed FEV represents the amount of water that cannot be contained by existing flood defences for a given flood (Figure 6-9(1)). It then computes the size of a virtual lake, 2 m deep and square in shape, that could retain the computed FEV (Figure 6-9(2)). The last step is to split the lake into constituent components, each of which is associated with a specific flood-protection measure such as restored wetlands, leaky dams, floodplain reconnection, flood-retention dams and giving-room-to-the-river, and to compare with their relative costs (Figure 6-9(3)).

The tool has already proved useful in stakeholder workshops for raising public awareness of flood risk assessment. This visualisation — of a virtual square lake of human-scale depth — helps stakeholders to assimilate in a meaningful way the excess of water that must be contained and/or confined in order to offer flood protection. The simplified visualisation deliberately allows, and hence empowers, a wide, non-expert audience to comprehend the magnitude of the amount of water that needs to be contained/confined to mitigate flooding. The feedback from end-users has been unanimous: the tool has unequivocally bridged the gap between the design of local measures that were formerly unable to establish the full picture of the catchment size flooding with advanced numerical modelling that was, although powerful and precise, either too slow or too computationally expensive to explore a plethora of potential protection strategies in a cost-efficient manner.

In essence, it is by tailoring our approach to the catchment peculiarities using relevant tools with various degrees of complexity that NAIAD helped decision-making in the Brague catchment.



In collaboration with

**Figure 6-9.** Different steps and results of Flood Excess Volume methodology: physical and economic effectiveness of Nature-Based solutions are assessed and compared for different strategies.

## 6.5 Case study #2: A green barrier to reduce the risk of floods due to snowmelt and extreme rainfall, Gudbrandsdalen Valley, Norway

### 6.5.1 General background and hazard type

The Gudbrandsdalen is one of the most populated valleys in Norway. The valley encompasses an area of ca. 15 km<sup>2</sup> and is rich in floodplains along the river, which are extensively used as farmland. Due to lack of other available land, many settlements are located along the river. Historically, the valley is susceptible to snowmelt flooding. However, this has been changing in recent years with an increased risk of flooding due to heavy rainfall, also in combination with snowmelt. Two major flood events in 2011 and 2013, causing massive damages to infrastructure along the river (Figure 6-10), were the driving factors behind the initiative to develop a Regional Master Plan for the Gudbrandsdalen and its tributaries. The master plan proposes providing more "room for the river" in flood-prone locations.



**Figure 6-10.** Valley of Gudbrandsdalen during the flood of 2013.

### 6.5.2 *Co-benefits of the proposed NBS*

The receded green barrier will provide space for the river during periods of flooding, foster the natural processes in the watercourse and thus contribute positively to the floodplain ecosystem. The landscape architect company AgenceTer (PHUSICOS partner) highlighted the potentialities of the receded barrier through its support of multiple activities such as a fishing platform, picnic area, and panoramic views, also maintaining the scope of the barrier to be "in line with the landscape". Other measurable co-benefits include an enhanced local economy that will benefit from the reduced risk of inundation of the agricultural lands behind the green barrier. However, with this solution, few agricultural lands are expected to be floodable (Figure 6-11) and this caused some discontent among stakeholders.



**Figure 6-11.** Aerial photo of the area with the location of the existing flood barrier and the new flood barrier (top); Visualization of the area with the potential multiple actions that can be supported by the flood barrier (by AgenceTer, bottom).

### 6.5.3 Indicators for the NBS performance assessment

The indicator matrix tailored to this demonstrator site encompasses a total of 47 indicators. Quantitative, risk-related indicators include *Peak Flow volume*, *Flooded Area* — calculated through hydraulic modelling — and *Exposed residential and productive areas*, obtained by GIS mapping. Ecosystem indicators are aimed to assess both the effects on water quality, such as the *Change in physical and*

chemical water parameters, and water quantity, such as the *Total predicted soil loss (RUSLE)*, or enhanced *Water storage capacity*. Indicators for assessing the improved value of the forested floodplain include *Typical vegetation species cover*, and *Diversity in plant and animal functional groups*. Societal-related indicators include the *Number of visitors in the new recreational areas* and *New pedestrian/cycling paths*, whilst the *Number of jobs created in the nature-based sector* is one of the economy-related indicators. The variables and key performance indicators selected to be monitored in the Gudbrandsdalen demonstrator site are listed in Table 6-3.

**Table 6-3.** PHUSICOS project key performance indicators (KPIs) to be evaluated for Gudbrandsdalen demonstration site.

Ambit	Criterion	Sub - Criterion	Indicator	Metric	
RISK REDUCTION	Hazard	Flooding Risk Resilience	Peak Flow	m <sup>3</sup> /s	
			Flooded Area	ha	
	Exposure	Potential Areas Exposed to Risks	Urban /Residential Areas	ha	
			Productive Areas (Agriculture, Grazing, Industries)	ha	
			Potential Population Exposed to Risks	Inhabitants	no./ha
				Other People (Workers, Tourists, Homeless)	no./ha
		Elderly, children, disabled		no./ha	
		Potential Buildings Exposed to Risks	Housing	no.	
			Agricultural and Industrial Buildings	no.	
		Potential Infrastructures Exposed to Risks	Roads	km	
			Lifelines (Water main, Sewerage, Pipeline, etc.)	m/km <sup>2</sup>	

	Vulnerability	Potential Population Vulnerable to Risks	Population	no.		
		Potential Economic Effects due to Risks	Economic Value of the Productive Activities Vulnerable to Risk (i.e. Economic Value of the Fields, Workers No.)	€/km <sup>2</sup>		
		Potential Infrastructures Vulnerable to Risks	Buildings	No./km <sup>2</sup>		
			Transportation Infrastructures and Lifelines	m/km <sup>2</sup>		
		TECHNICAL & FEASIBILITY ASPECTS	Technical Feasibility (Affordability)	Cost-Benefit Analysis of the Intervention	Initial costs	million €
					Maintenance costs	million €
Replacement costs	€					
Avoided costs	million €					
Payback Period	years					
Application of Suitable Materials and Technologies	Material used coherence			0/1		
ENVIRONMENT & ECOSYSTEMS	Water	Effects on Water Quality	Physical parameters	°		
			Chemical Pollution Parameters	-		
			Water Storage Capacity Enhancement	m <sup>3</sup>		
	Soil	Soil Physical Resilience	Total Predicted Soil Loss (RUSLE)	T·ha <sup>-1</sup> yr <sup>-1</sup>		
	Vegetation	Typical Local Species Promotion and Development	Typical Vegetation Species Cover	-		
	Landscape (Green Infrastructure)	Green Infrastructure	Abundance of Ecotones/Shannon Diversity	km/ha/Shannon index		

	Biodiversity	Functional Diversity	Diversity of Functional Groups (Plant Functional Diversity)	Shannon index
			Diversity of Functional Groups (Animal Functional Diversity)	Shannon index
		Protected Areas	Site Community Importance (SCI) And Special Protection Areas (SPA)	ha
SOCIETY	Quality of life	Leisure and Connections Increasing	Number of Visitors in New Recreational Areas	no.
			Different Activities Allowed in New Recreational Areas	no.
			New Pedestrian, Cycling and Horse Paths	m
		Social Justice	Rate of Increase in Properties Incomes	%
	Community Involvement and Governance	Participatory Processes and Partnership	Citizen Involved	no.
			Stakeholders Involved	no.
			Public-Private Partnership Activated	no.
			Policies Set Up to Promote NBS	no.
	Landscape and Heritage	Identity	Social Active Associations	no.
		Heritage Accessibility	Natural and Cultural Sites, Made Available	no. of sites

		Landscape Perception	Viewshed	km <sup>2</sup>
			Scenic Sites and Landmark Created	no.
LOCAL ECONOMY	Revitalization of Marginal Areas	Promotion of Socio-Economical Development of Marginal Areas	Jobs Created in The Nature-Based Sector	no.
			Jobs Created in The Nature-Based Solution Construction and Maintenance	no.
			Gross Profit from Nature-Based Tourism	€/area/y
			Touristic Activeness Enhancing	no. visitors/y
	Local Economy Reinforcement	New Areas for Traditional Resources	New Areas Made Available for Traditional Activities (Agriculture, Livestock, Fishing, ...)	ha

## 6.6 Case study #3: Landslides and debris flows, Portofino Natural Park, Italy

The Portofino Promontory (Liguria, Italy) belongs to the Natural Regional Park of Portofino, located between Genoa and the border with Tuscany. The promontory encompasses an area of 18 km<sup>2</sup>, with a coastal development of 13 km. The terrain topography is rather mountainous, with high elevations over a short distance from the coastline (e.g., Mt. Portofino with an elevation of 610 m above sea level). Due to its unique geomorphological features, the Portofino Promontory is historically affected by geological instabilities produced by meteorological events, with potential impacts to the elements at risk. The most frequent hazards are (1) shallow landslides and flash floods; (2) sea storm surges; and (3) rock falls and mud-debris flows.

Considering the high naturalistic value of the area, NBS are the most suitable risk mitigation measures to be adopted, to conserve landscape, natural and cultural heritage, and touristic value of the promontory. The primary NBS ambition in San

Fruttuoso is to address the following challenges: (1) stabilisation of rock masses; (2) reduction of geo-hydrologic risks in order to intercept and reduce the floating and solid transport along the rivers and to reduce erosion; (3) wood amelioration, by removing allochthones and degraded species of old vegetation; and (4) construction of dry stone walls and restoration of abandoned terraces, with the aim to valorise the terraced landscape and promote agricultural activities.

The RECONNECT project foresaw the selection, installation, and operation of hydro-meteorological instruments that will include three weather stations, two hydrological measuring stations, and two cameras. The necessary equipment will be purchased and installed once the selection of indicators for the evaluation of NBS is complete. Monitoring activities further include remote sensing activities such as LIDAR surveys, orthophotography, and infrared aerial photography.















The RECONNECT project team has identified the key variables and indicators that need to be monitored and assessed in all NBS demonstration sites. The variables and key performance indicators selected from the original performance indicator table to be monitored in the Portofino Natural Regional Par, are listed in Table 6-4. These assessments will be cross-referenced and compared with other RECONNECT sites that have similar morphological features (Turconi et al., 2020).

Several benefits and co-benefits are expected to be obtained from the Portofino NBS demonstration case:



1. Decrease of geo-hydrological vulnerability for the main infrastructures and the cultural heritage;
2. Re-building/maintenance of dry stone walls, which will contribute to the restoration of old terraces and will re-incentivize agricultural activities with benefits for the farmers, as well as for geo-hydrological risk mitigation;
3. Decrease of the impacts by landslides and slope instability at the coastal sediment amount level;
4. Decrease of the risk of injuries among the park visitors due to slope instability of interesting hiking paths during heavy rainfalls;
5. Support for the interaction between private landowners;
6. Integration of the proposed NBS with regional policies for land management/planning and with the Basin Master Plan;
7. Improvement of the visibility and governance model of the Portofino Natural Regional Park, also in the perspective of becoming a National Park; and
8. Improvement of the collaboration between the park authority and stakeholders.

**Table 6-4.** RECONNECT project key performance indicators (KPIs) to be monitored in the Portofino Natural Regional Park area (following Turconi et al., 2020).

	Performance key indicator	Variable	Base-line <sup>1</sup>	Specific Monitoring Details		
				Monitoring Approach	Data <sup>2</sup>	Phase <sup>3</sup>
WATER	Possible source of debris/hyper-concentrated flow	Precipitation (mm), Rainfall intensity (mm/h)	✓	Weather stations (a)		2
		Maintenance level of man-made terraces	(b)	Assessment of terraced area extent (e.g., LIDAR), Aerial photo interpretation and Field survey to evaluate terrace conditions		2
	Floating transport in hydrographical network	Dead trees within 20 m buffer along the hydro-graphical network		Field survey		2
	Landslide reduction—debris and hyper-concentrated flow triggering	Land use	✓	Aerial photo interpretation		2
NATURE	Changes in riparian habitat	Riparian habitat area (km <sup>2</sup> )	✓	Aerial photo interpretation and Field survey		2
	Changes in terrestrial habitat	Terrestrial habitat area (km <sup>2</sup> )	✓	Aerial photo interpretation and Field survey		2
	Changes in vegetation along watercourses	Vegetation along watercourses (survey)	✓	Aerial photo interpretation and Field survey		2
		Trends and status of range	✓	Aerial photo interpretation and Field survey		2
		Trends and status of the area	✓	Aerial photo interpretation and Field survey		2
		Structure and function including typical species	✓	Aerial photo interpretation and Field survey		2
	Change in land cover	Land cover		Aerial photo interpretation		1
	Number and type of protected species	Type of protected species	✓	Field survey		2
Number of protected species		✓	Field survey		2	

PEOPLE	Footpath network recovery through erosion reduction and improvement of path smoothness	Length of improved path		Field survey		2
		Water drainage improvement		Field survey		2
	Increasing recreational opportunities of NBS area	Number of recreation activity in the area		Field survey		2
	Number of tourists	Number of tourists		Automatic counter		2
	Maintenance and management cost of NBS	Economic losses and properties loss during hydro-meteorological events		Survey		2
		Cultural heritage loss		Survey		2
	Reduced need for management and maintenance	Maintenance and management cost of grey infrastructure (if implemented)		Survey		2
		Maintenance and management cost of NBS		Survey		2

<sup>1)</sup> ✓ indicates an existing baseline

<sup>2)</sup> ≡ indicates text data;  indicates vector data;  indicates spreadsheet data (e.g., Excel)

<sup>3)</sup> Number of checks in the monitoring phase: (1) represents pre- and (2) post-NBS implementation monitoring

<sup>a)</sup> Providing data with high temporal (hourly) resolution

<sup>b)</sup> The extent of terraced areas is only partially known as baseline

## **6.7 Case study #4: Floods in dense urban environments, Dodder Catchment, Dublin, Ireland**

This case study illustrates the case of reducing flood risk in dense urban environments using NBS, using the example of the OPERANDUM's OAL in the Dodder Catchment in Dublin, Ireland. The River Dodder is one of the principal rivers in Dublin, it flows from the Dublin Mountains through a number of high-value dense residential areas of Dublin before discharging into the River Liffey estuary at Ringsend (recently named "Silicon Docs" because located where all the headquarters of the Tech Companies are). The River Dodder has a history of flooding and is known as a river which responds quickly to a rainstorm event (Pilla et al., 2019), mostly because of the steep gradient of the river in its upper section. In the last century, it has overflowed its banks on numerous occasions causing damage to adjacent properties: in 1986, when Hurricane Charlie hit Dublin, over 300 properties surrounding the Dodder catchment were flooded (De Bruijn and Brandsma, 2000); in February 2002, a strong high tide occurred and over 600 properties were flooded (Javelle et al., 2002); in October 2011, a similar number of properties were flooded throughout the catchment.

Over the past few decades, Dublin has experienced increasing pressure on land due to population growth, urbanisation and industrialisation. The change in land use and land cover (LULC) patterns in Dublin over the past two decades was assessed performing both supervised as well as unsupervised classification on LANDSAT satellite imagery data, and the effect of LULC change in streamflow simulation was quantified by using a rainfall-runoff model (Basu et al., 2020). Furthermore, a set of indices such as vegetation index, building index, water index and drought index were estimated, and their changes were monitored over time. Soil Water Assessment Tool (SWAT)-based rainfall-runoff models were used to simulate the changes in runoff due to the LULC changes in watershed over two decades. The results indicated an increased rainfall-runoff in Dublin due to the high level of urbanisation, with negative impacts on flood risk in the OAL area. This pressure is going to increase in Dublin as result of climate change in the near future (Gharbia et al., 2016).

The high premium for land in Dublin due to the pressure on house and commercial rental markets is resulting in less available space for the deployment of NBS to mitigate flood risk. After a reiterative co-design approach with high level stakeholders aimed at highlighting local challenges and drivers, and at identifying suitable locations and typologies of interventions, the green roof was selected as the potential NBS. The green roof has high potentials in terms of water retention, and it could be deployed in several locations in a dense urban environment where land has a high premium. Subsequently, rainfall-runoff-based hydrological modelling was performed to assess the potential flood hazard areas and to identify an effective location for implementation of NBS. For this purpose, the hydrological model was simulated with and without the presence of NBS at different potential locations and the site exhibiting highest flood control was selected to be the optimal location. The selected location is in correspondence of the CHQ building and adjacent to River Liffey, which is the main river in Dublin (Sarkar et al., 2020). This intervention in the OAL will also be assessed through quantitative and qualitative comparative analysis to quantify the biophysical and economic values of different NBS alternatives and ecosystem services in Dublin

using two spatially explicit integrated models, Integrated Valuation of Ecosystem Services and Trade-off (InVEST) and Soil Water Assessment Tool (SWAT), to provide valuable data for future policies and replication of the NBS across the city (Sannigrahi et al., 2020).

The green roof will be deployed on a roof area of around 70 m<sup>2</sup> using modular units. The modular units will be built using exclusively recyclable materials. In order to demonstrate the effectiveness of the green roof NBS, some of the modular units will be left empty without any soil and vegetation: this will allow to assess the performances of the vegetated units in terms of water retention during the pilot time. The assessment will be carried out by instrumenting the green roof with a dense network of sensors. Specifically, the following sensors will be deployed: (1) rain gauges to measure rainfall; (2) sensors to measure wind speed/direction, humidity, temperature, and solar radiation; (3) soil moisture sensors for the piloted modular units; (4) rain gauges to measure the water exiting the modular units; and (5) cameras to visually monitor the green roof and create time-lapse videos for engagement activities. A dashboard with the sensors data and the time-lapse will be displayed on a screen in the CHQ shopping centre to increase the public awareness on the green roof NBS and its potential to reduce flood risk. The concept behind this solution is to bring nature online as the next frontier in ecosystem management with the aim to change the relationship with the natural world in an age of rapid urbanisation and digitisation (Galle et al., 2019).

The framework developed by the OPERANDUM consortium for vulnerability and risk assessment of social-ecological systems (SES) subjected to natural hazards will then be utilised to more comprehensively assess the green roof intervention (Shah et al. 2020), with the aim to provide the City Council with valuable information for future policies and thus foster the replication of the NBS piloted in the OAL in Dublin. The detailed smart green roof approach will then be replicated on other public buildings owned by Dublin City Council to further mitigate flood risk in the dense urban environment of Dublin city.

Finally, the OAL activities related to the assessment and wider deployment of the green roof NBS include the spatial reconfiguration and optimisation of the dense network of rainfall sensors (over 50) in the Dublin area. This is done with the support of Dublin City Council who provided access to the sensors. The statistical models used for this task replicate and expand the work detailed in Basu et al. (2019), which allows the identification of redundant rain gauges and influential ungauged locations in the Greater Dublin area based on hourly and daily rainfall data by considering covariance factor, kriging, Shannon entropy and annealing approaches. The data from the optimised network of rain gauges will be then used, in conjunction with the measurements from the river level sensors, to generate Artificial Intelligence forecasting models for river levels, which will allow to alert the Council of potential flood events according to different weathers, replicating an approach used previously in another Irish catchment (Assem et al., 2017).

## 6.8 Concluding Remarks

Effective disaster risk reduction strategies require a combination of several techniques, and implementation of structural and non-structural measures. Choosing the optimal strategy is a key objective for local authorities and infrastructure managers.

NBS can be considered as structural measures with sometimes limited capacity (for mitigating the impacts of extreme events, for example) but also with additional co-benefits in comparison with classical grey measures. Needless to say, no solution can be universal and work in all situations. NBS may exhibit some drawbacks: during extreme floods, riparian forests supply woody debris which worsen the risk level. Most of time, a hybrid combination of green and grey measures will provide the optimal solution when DRR is the main goal (e.g., riparian buffers and a rack to trap large debris just upstream sensitive bridges). NBS assessment requires consideration of several criteria and combined methods. Assessment frameworks based on classical deterministic approaches cannot be used alone anymore. Other frameworks such as decision-aiding methods and systemic analysis offer new opportunities and methodologies. A paradigm shift in DRR engineering is probably emerging through the recent NBS projects (see Tacnet et al., 2019).

To assess the effectiveness of any measure, the analyst must identify its function, the required capacity of the measure being assessed and a measurable indicator for evaluating this capacity. Classical indicators used for risk assessment can be employed for this purpose. The case studies provided here are only partial examples and should be considered more as non-exclusive methodological pathways to characterize NBS effectiveness. The fact that NBSs are effective for mitigation of the impacts of extreme events has still to be demonstrated. To mitigate the risk of extreme natural hazard events, classical civil engineered techniques and hybrid solutions may be the optimal measures in the foreseeable future.

Finally, a DRR strategy based on NBS faces the same large challenges linked to any DRR strategy, including multi-risk situations, global change effects and uncertainties.

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The Handbook aims to provide decision-makers with a comprehensive NBS impact assessment framework, and a robust set of indicators and methodologies to assess impacts of nature-based solutions across 12 societal challenge areas: Climate Resilience; Water Management; Natural and Climate Hazards; Green Space Management; Biodiversity; Air Quality; Place Regeneration; Knowledge and Social Capacity Building for Sustainable Urban Transformation; Participatory Planning and Governance; Social Justice and Social Cohesion; Health and Well-being; New Economic Opportunities and Green Jobs.

Indicators have been developed collaboratively by representatives of 17 individual EU-funded NBS projects and collaborating institutions such as the EEA and JRC, as part of the European Taskforce for NBS Impact Assessment, with the four-fold objective of: serving as a reference for relevant EU policies and activities; orient urban practitioners in developing robust impact evaluation frameworks for nature-based solutions at different scales; expand upon the pioneering work of the EKLIPSE framework by providing a comprehensive set of indicators and methodologies; and build the European evidence base regarding NBS impacts. They reflect the state of the art in current scientific research on impacts of nature-based solutions and valid and standardized methods of assessment, as well as the state of play in urban implementation of evaluation frameworks.

### *Studies and reports*

