PHUSICOS

According to nature

Deliverable D4.1

Comprehensive Framework for NBS Assessment

Work Package 4 – Technical Innovation to Design a Comprehensive Framework

Deliverable Work Package Leader:
UNINA

Revision: 0 – Final
Dissemination level: Public

April 2019

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 776681.

Note about contributors

Lead partner responsible for the deliverable:	UNINA
Deliverable prepared by:	Silvia Autuori, Gerardo Caroppi, Francesco De Paola, Maurizio Giugni, Francesco Pugliese, Marialuce Stanganelli, Gianfranco Urciuoli (UNINA)
Partner responsible for quality control:	NGI
Deliverable reviewed by:	Farrokh Nadim
Other contributors:	Pilar Andrés (CREAF); Sandra Fohlmeister, Aude Zingraff-Hamed, Gerd Lupp, Stephan Pauleit (TUM),

Project information

Project period:	1 May 2018 – 30 April 2022
Duration (no. of months):	776681
Web-site:	www.phusicos.eu
Project coordinator:	Norwegian Geotechnical Institute, (NGI project no.: 20180404)

Project partners:

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1 Introduction

PHUSICOS, meaning 'According to nature', in Greek φυσικός, is a four-year Innovation Action project that started in May 2018 and is funded by the European Union's Horizon 2020 research and innovation programme (Grant agreement No. 776681). The project consortium comprises 15 organizations from 7 countries (Norway, Germany, Austria, Italy, France, Spain and Switzerland) and includes end-user partners from local and regional administrative units.

The main objective of PHUSICOS is to demonstrate that nature-based or nature-inspired solutions (NBSs) for reducing the natural hazard induced by extreme weather events in particularly vulnerable areas such as rural mountain landscapes are technically viable, cost-effective and implementable at regional scale. PHUSICOS's underlying premise is that nature itself is a source of ideas and solutions for mitigating the risk caused by changing climate. As nature's designs are often elegant, effective and frugal, implementing NBSs, including hybrid green/blue/grey infrastructure, can provide ecological, social and economic resilience for society.

Task 4.1 of PHUSICOS (Development of assessment tools for the comprehensive framework to evaluate and verify the performance of NBSs) is devoted to the development of the central assessment tool for PHUSICOS. The central assessment tool, which is described in this document, is a comprehensive framework to verify the performances of NBSs in risk management processes from both technical and socio-economic points of view. The comprehensive framework assesses the beneficial role of NBSs in ecosystem services, which is a crucial metric for the overall evaluation of the implemented intervention and solutions. In addition to ecosystem services, environmental, economic and social indicators are coupled with the above-mentioned risk management indicators, defining positive co-benefits, as well as potentially undesirable side effects and social perceptions.

The evaluation of the new proposed NBSs at both demonstrator sites and concept sites will be based on the assessment tools developed in T4.1 and described in this deliverable. The document presents a brief outline of the following two steps of the assessment framework:

1. Indicator framework
2. Aggregation and weighting methodology

Risk management is a complex task, which relevant aspects cannot be captured from a single perspective (Munda, 2004). The proposed framework is intended to be a starting point for the evaluation of different risk mitigation measures. For a specific application, it should be adapted to local context peculiarities and modelled through stakeholders' contributions. Therefore, the assessment tool is designed such that chosen indicators can be modified and new ones can be added.

The role of the Stakeholders (from local actors to policy makers) and Living Labs (LL) is pivotal to integrating and defining the characteristics of the indicators, their weighting and the aggregation method. Local stakeholders contribute to the identification of relevant assessment criteria, and integration of technical knowledge with local experience. Their involvement in the evaluation and decision-making process will increase not only the democracy (and hence the legitimacy) of the scientific process, but also its quality.

In the comprehensive framework outlined in this deliverable, indicators are aggregated through an approach belonging to the theoretical framework of Multi-Criteria Analysis (MCA), which allows for the assessment of performance of different Design Scenarios (e.g., Baseline Scenario, NBSs Scenarios, Hybrid Scenarios) with reference to different climate scenarios and temporal scales (Short-Term ST, Mid-Term MT, and Long-Term LT).

After the criteria selection, weighting and aggregation steps will be performed with the input of a broader group of actors. The assessment tool should take into account different systems of interest and values (Antunes et al., 2006). Therefore, it is essential to combine MCA with participatory techniques that could be either extracted or inspired to some of the main important recent reworked versions of MCA such as: Social Multi-criteria Evaluation (SMCE) (Munda, 2004, 2008), Participative Multi-Criteria Analysis (Stagl, 2006), Deliberative Multi-Criteria Analysis (Proctor & Drechsler, 2006).

This integration was fully developed in the comprehensive framework for NBSs assessment described in this deliverable through involvement and cooperation with the PHUSICOS partners working on the Living Labs approach of the project, the local case site teams and facilitators of the Living Labs, as well as partners in other relevant work packages and tasks.

2 NBSs Performance Assessment: State-of-the-Art

The PHUSICOS project aims to evaluate improvements in the environmental problems of mountain landscape using NBSs. These solutions allow to mitigate the impact of hydro-meteorological hazards in risk-prone areas, bringing more nature and natural features and processes into cities, landscapes and seascapes through locally adapted, resource-efficient and systemic intervention.

In literature, several tools for evaluation of ecological, socio-economic, chemical and biological effects are available. Nevertheless, their inclusion in a comprehensive framework still results a cogent issue, mainly in evaluating the improvements in the environmental problems of mountain landscape using NBSs. In addition, plans and actions involving protected and preserved areas of a region are often kept separate from the development plans and the key issue is that existing guidelines usually do not usually incorporate NBSs as an option to reduce the impacts and adapt to climate change.

In order to address in depth the aforementioned needs and demonstrate the potential of the NBSs to contribute to the rural mountain landscape challenges, PHUSICOS aims to produce methodology: 1) to increase the resilience at a basin scale focused on climate change mitigation and adaptation and efficient water management, and 2) to assist in the implementation of NBS in an effective way.

In the present report, a methodological framework for NBSs assessment is outlined and some tools to support decision-making are established. In several EU projects (Table 2.1), a large scale and fully replicable demonstration action of NBSs accompanied by innovative business models will provide evidence about the benefits of NBSs contributing to the creation of new market opportunities for European companies, and fostering citizen insight and awareness about environmental problems. However, most of those EU financed projects focus on urban areas.

The focus of PHUSICOS is mainly on mountain landscapes, because mountains amplify hydro-meteorological risks (flooding, landslide, avalanches), and even more so under extreme weather events. Furthermore, mountainous regions have not received the same attention as densely populated urban areas in European disaster risk reduction plans and projects (Table 2.1).

However, there is a lack of adequate proof of concept for NBSs to address hydro-meteorological events in rural and mountainous regions. PHUSICOS will fill the knowledge gap specifically related to NBSs for hydro-meteorological hazards (flooding, erosion, landslides, drought and avalanches) by implementing NBSs at several European demonstrator and concept case studies. These sites comprise 3 large-scale demonstrator sites in Italy, France/Spain and Norway, respectively; and 2 complementary concept cases in Austria and Germany. The three demonstrator sites are representative of hydro-meteorological hazards, vegetation, topography and infrastructure throughout rural and mountainous regions in Europe. The concept cases will be used for testing innovative ideas at local scale.

The framework procedure for the NBSs assessment, in detail examined in Chapter 3, was developed in compliance with further project devoted to the NBSs application both in urban and rural areas. The model is mainly based on the estimation of Performance Indicators, related to technical, economic, social, ecosystem services and environmental aspects, aimed at assessing the effectiveness of either NBSs solution or hybrid ones, against classic grey approaches.

In the following Table 2.1, a synthetic summary of main related Projects, Networks, Organisations and Platforms (as of April 2019) is provided.

NBSS PROJECTS	TOPIC
100 Resilient Cities	100 Resilient Cities—Pioneered by the Rockefeller Foundation (100RC) is devoted to helping cities around the world become more resilient to the physical, social and economic challenges that are a growing part of the 21st century. Cities in the 100RC network are provided with the resources necessary to develop a roadmap to resilience. *WEB SITE: http://www.100resilientcities.org*

BiodivERsA	BiodivERsA is a network of national and regional funding organisations promoting pan-European research on biodiversity and ecosystem services, and offering innovative opportunities for the conservation and sustainable management of biodiversity. BiodivERsA is funded under the Horizon 2020 ERA-NET COFUND scheme. *WEB SITE: http://www.biodiversa.org*
CLIMATE-ADAPT: EU Climate Adaptation Platform	The European Climate Adaptation Platform (Climate-ADAPT) is a partnership between the European Commission (DG CLIMA, DG Joint Research Centre and other DGs) and the European Environment Agency. Climate-ADAPT aims to support Europe in adapting to climate change. *WEB SITE: https://climate-adapt.eea.europa.eu*
Connecting Nature	Coordinated by Trinity College Dublin, Connecting Nature is a partnership of 29 organizations from 16 countries which includes local authorities, communities, industry partners, NGOs and academics. The partnership will work with 11 European cities who are investing in multi–million euro large scale implementation of Nature–Based projects in urban settings. They will measure the impact of these initiatives on climate change adaptation, health and well-being, social cohesion and sustainable economic development in these cities. Innovative actions to foster the start-up and growth of commercial and social enterprises active in producing nature-based solutions and products will also be an integral part of their work. *WEB SITE: https://connectingnature.eu*
EIT Climate-KIC	EIT Climate-KIC is a European knowledge and innovation community, working to accelerate the transition to a zero-carbon economy. Supported by the European Institute of Innovation and Technology, we identify and support innovation that helps society mitigate and adapt to climate change. We believe that a decarbonised, sustainable economy is not only necessary to prevent catastrophic climate change, but presents a wealth of opportunities for business and society. *WEB SITE: https://www.climate-kic.org*
EKLIPSE	EKLIPSE is an EU funded project that will set up a sustainable and innovating way of knowing, networking and learning about biodiversity and ecosystem services. The European Commission requested the EKLIPSE project to help building up an evidence and knowledge base on the benefits and challenges of applying NBSs. In response to the request, the EKLIPSE is an EU funded project that will set up a sustainable and innovating way of knowing, networking and learning about biodiversity and ecosystem services. The European Commission requested the EKLIPSE project to help building up an evidence and knowledge base on the benefits and challenges of applying NBSs. In response to the request, the EKLIPSE Expert Working Group on Nature-based Solutions to Promote Climate Resilience in Urban Areas (EWG) devised the following objectives: 1) To develop an impact evaluation framework with a list of criteria for assessing the performance of NBSs in dealing with challenges related to climate resilience in urban areas; 2) To prepare an application guide for measuring how NBSs projects fare against the identified indicators in delivering multiple environmental, economic and societal benefits; 3) To make recommendations to improve the assessment of the effectiveness of NBSs

	projects, including the identification of knowledge gaps according to the criteria presented in the impact evaluation framework. *WEB SITE: http://www.eklipse-mechanism.eu*
EU Smart Cities Information System (SCIS)	The Smart Cities Information System (SCIS) is a knowledge platform to exchange data, experience and know-how and to collaborate on the creation of smart cities, providing a high quality of life for its citizens in a clean, energy efficient and climate friendly urban environment. SCIS brings together project developers, cities, research institutions, industry, experts and citizens from across Europe. *WEB SITE: https://smartcities-infosystem.eu*
GRaBS	The Green and Blue Space Adaptation for Urban Areas and Eco Towns (GRaBS) project is a network of leading pan-European organizations involved in integrating climate change adaptation into regional planning and development. The project resulted in a number of resources, including the vulnerability and risk assessment tool, adaptation action plans developed by the participating local and regional authorities, a database of case studies presenting the use of green and blue space adaptation to climate change in urban areas around the world, and a number of expert papers. All resources are available from the project website. *WEB SITE: http://www.interreg4c.eu*
GREEN SURGE	The GREEN SURGE project was a collaborative project between 24 partners in 11 countries. It was funded by the European Commission Seventh Framework Programme (FP7). GREEN SURGE intended to identify, develop and test ways of linking green spaces, biodiversity, people and the green economy in order to meet the major urban challenges related to land use conflicts, climate change adaptation, demographic changes, and human health and wellbeing. It elaborated a sound evidence base for urban green infrastructure planning and implementation, exploring the potential for innovation in better linking environmental, social and economic ecosystem services with local communities. *WEB SITE: https://greensurge.eu*
GrowGreen	GrowGreen aims to create climate and water resilient, healthy and liveable cities by investing in Nature-Based Solutions (NBSs). Making nature part of the urban living environment improves quality of life for all citizens and will help business to prosper. High quality green spaces and waterways provide innovative and inspiring solutions to major urban challenges, such as flooding, heat stress, drought, poor air quality and unemployment and will help biodiversity to flourish. By embedding NBSs in long term city planning, development and management, accessible green and blue spaces are a permanent feature of all urban areas around the world, creating harmony between people, economy and the environment, for the benefit of all. *WEB SITE: http://growgreenproject.eu*
ICLEI	ICLEI - Local Governments for Sustainability is the leading global network of more than 1,500 cities, towns and regions committed to building a sustainable future. The ICLEI Network takes an integrated approach to sustainable development, striving to become sustainable, low-carbon, ecomobile, resilient,

	biodiverse, resource-efficient, healthy and happy, with a green economy and smart infrastructure. *WEB SITE: https://www.iclei.org*
INSPIRATION	INSPIRATION is a H2020 funded project. The main aim of INSPIRATION was to develop a Strategic Research Agenda (SRA) to inform environmentally friendly, socially acceptable and economically affordable soil and land use management that meets societal needs and challenges. A SRA built on end-user knowledge needs is more likely to be enthusiastically adopted by funders in order to promote the knowledge creation, transfer and implementation agenda. *WEB SITE: http://www.inspiration-h2020.eu*
International Union for Conservation of Nature	The International Union for Conservation of Nature (IUCN) is a membership Union uniquely composed of both government and civil society organisations. It provides public, private and non-governmental organisations with the knowledge and tools that enable human progress, economic development and nature conservation to take place together. *WEB SITE: https://www.iucn.org*
NAIAD	NAIAD is an ambitious attempt, to operationalise the insurance value of ecosystems for water related risk mitigation, by developing and testing concepts, tools and applications on 9 demo sites across Europe, under the common concept of Nature-Based Solutions (NBSs). At the core of the project is the physical and socio-economic analysis of demonstrator sites, supported with complex modelling and forecast activities, which will, in cooperation with the insurance sector, strive to propose NBSs as technically sound and financially viable option for investors at local level and higher and especially for the insurance sector. *WEB SITE: http://naiad2020.eu*
Natural Hazards Nature-based Solutions	The Natural Hazards – Nature-based Solutions platform is a hub for projects, investments, guidance and studies making use of nature to reduce the risks associated with natural hazards. The objective is to host and facilitate the exchange of knowledge, experiences and lessons learned from a range of stakeholders, to provide guidance on the planning and implementation of nature-based solutions, and to champion these solutions in the arenas of policy-making and investment for disaster risk reduction. *WEB SITE: https://www.iucn.org/resources/issues-briefs/nature-based-solutions-disasters*
NATURE 4 CITIES	Nature4Cities is a H2020 EU-funded project, creating a comprehensive reference Platform for Nature Based Solutions (NBSs), offering technical solutions, methods and tools to empower urban planning decision making. This will help addressing the contemporary environmental, social and economic challenges that face European Cities. *WEB SITE: https://www.nature4cities.eu*
Nature-based Solutions Initiative	This is a new programme of research, policy advice and education aimed at increasing the implementation of Nature-based Solutions through the application of science. Current work focuses on collating scientific information on Nature-based Solutions for climate change adaptation and making this more accessible to decision makers through this platform. The programme also assess the role of Nature-based Solutions in climate change policy, with a focus on the adaptation plans of all signatories of the Paris Agreement. The goal is to

	facilitate the process by which climate pledges are revised and to scale up the role of Nature-based Solutions. This platform will continue to grow with more studies, policy guidance and functionalities to help rapidly access and locate the most relevant evidence. *WEB SITE: http://www.naturebasedsolutionsinitiative.org*
NATURVATION	NATure-based URban innoVATION is a 4-years project, funded by the European Commission and involving 14 institutions across Europe in the fields of urban development, geography, innovation studies and economics. They will seek to develop their understanding of what NBSs can achieve in cities, examine how innovation can be fostered in this domain, and contribute to realizing the potential of nature-based solutions for responding to urban sustainability challenges by working with communities and stakeholders. *WEB SITE: https://naturvation.eu*
OpeNESS	OpenNESS aims to translate the concepts of Natural Capital (NC) and Ecosystem Services (ES) into operational frameworks that provide tested, practical and tailored solutions for integrating ES into land, water and urban management and decision-making. It examines how the concepts link to, and support, wider EU economic, social and environmental policy initiatives and scrutinizes the potential and limitations of the concepts of ES and NC. *WEB SITE: http://www.openness-project.eu*
OPERAs	OPERAs was a 5-years European research project running from 2012-2017 that aimed to put cutting edge ecosystem science into practice. Researchers and practitioners from 27 different organisations helped stakeholders to apply the ecosystem services and natural capital concept into practice. *WEB SITE: https://operas-project.eu/*
Oppla	Oppla is a new knowledge marketplace; a place where the latest thinking on Ecosystem Services, natural capital and nature-based solutions is brought together. Its purpose is to simplify how sharing, obtaining and creating knowledge to better manage the environment. Oppla is an open platform that is designed for people with diverse needs and interests - from science, policy and practice; public, private and voluntary sectors; organizations large and small, as well as individuals. *WEB SITE: https://oppla.eu/*
SUSTAINABLE CITIES PLATFORM	The European Sustainable Cities Platform was launched in 2016, following the 8th European Conference on Sustainable Cities & Towns in the Basque Country. Supported by the City of Aalborg, Denmark, the Basque Country, and ICLEI Europe, it focuses on the uptake of The Basque Declaration, which is the main outcome of the 8th European Conference on Sustainable Cities and Towns. The European Sustainable Cities Platform includes the Transformative Actions Database, which presents existing transformative actions in line with the Basque Declaration as good practice. *WEB SITE: http://www.sustainablecities.eu/*
The Nature of Cities	The Nature of Cities is an international platform for transdisciplinary dialogue and urban solutions. It facilitates the sharing of diverse, transformative ideas about cities as ecosystems of people, nature, and infrastructure. It is committed to the design and creation of better cities for all: cities that are resilient, sustainable, liveable and just. *WEB SITE: https://www.thenatureofcities.com/*

ThinkNature	The objective of the coordination and support action, ThinkNature (Development of a multi-stakeholders dialogue platform and think tank to promote innovation with Nature-based Solutions), is the development of a multi-stakeholder communication platform that will support the understanding and the promotion of NBSs on local, regional, EU, and international level. *WEB SITE: https://www.think-nature.eu/*
TURAS	This project launched in October 2011 and officially ending at the end of September 2016. At the heart of this project was the desire to co-create working links between different agencies involved in city-making, with communities at the centre. In the end, TURAS devised over 80 different novel ideas and processes that would enable communities to transition to a more resilient future. These results are currently accessible from the TURAS website and in the future will be accessible from Oppla - a new knowledge marketplace where the latest thinking on ecosystem services, natural capital and nature-based solutions is brought together. Although the EU investment in TURAS has ended, the next step of the journey has already begun and with unwavering commitment from the partners, communities and companies, we look forward to a better future. *WEB SITE: http://www.turas-cities.org/*
UNalab	UNaLab is a project funded by the European Union under the Horizon 2020 research and innovation programme. The UNaLab consortium is comprised of 28 partners from 10 cities across Europe and beyond, including municipalities, research, business and industry. The UNaLab partner cities commit to addressing the challenges that cities around the world are facing today, by focusing on climate and water related issues, within an innovative and citizen-driven paradigm. With 3 demonstration cities, 7 replication cities and several observers, the UNaLab project aims to develop smarter, more inclusive, more resilient and increasingly sustainable societies through innovative Nature-based Solutions (NBSs). *WEB SITE: https://www.unalab.eu/*
URBAN GreenUp	URBAN GreenUP is a project funded under the European Union's Horizon 2020 programme. Its objective is the development, application and replication of Renaturing Urban Plans in a number of European and non-European partner cities with the aim to mitigate the effects of climate change, improve air quality and water management, as well as to increase the sustainability of our cities through innovative nature-based solutions. *WEB SITE: http://www.urbangreenup.eu/*
weADAPT	weADAPT is a collaborative platform on climate adaptation issues. It allows practitioners, researchers and policy-makers to access credible, high-quality information and connect with one another. It is designed to facilitate learning, exchange, collaboration and knowledge integration to build a professional community of research and practice on adaptation issues while developing policy-relevant tools and guidance for adaptation planning and decision-making. *WEB SITE: https://www.weadapt.org/*
RECONNECT	RECONNECT aims to contribute to European reference framework on Nature Based Solutions (NBSs) by demonstrating, referencing and upscaling large scale NBSs 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. To do that, RECONECT draws upon the network of carefully selected Demonstrators and Collaborators that cover a range of local conditions, geographic characteristics, governance structures and social/cultural settings to successfully upscale NBSs throughout Europe and Internationally. *WEB SITE: https://reconnect-europe.eu/*
OPERANDUM	The OPERANDUM (OPEn-air laboRAtories for Nature baseD solUtions to Manage environmental risks) project develops nature-based solutions (NBSs) to mitigate the impact of hydro-meteorological phenomena in risk-prone areas. Within OPERANDUM, nature-based solutions (NBSs) will be tested as mitigating factors to flooding, landslides, coastal erosion, droughts and salt intrusion on extra-urban territories. Nature-based solutions will include the use of vegetation to re-enforce river banks, basins and the co-design, co-development and realization of vegetated sand dunes to reduce the coastal erosion. *WEB SITE: https://site.unibo.it/operandum/en*

Table 2.1 Main NBSs Projects, Networks, Organisations and Platforms

NBSS NETWORK, ORGANISATION AND PLATFORM	TOPIC
ICLEI NETWORK	ICLEI - Local Governments for Sustainability is the leading global network of more than 1,500 cities, towns and regions committed to building a sustainable future. The ICLEI Network takes an integrated approach to sustainable development, striving to become sustainable, low-carbon, ecomobile, resilient, biodiverse, resource-efficient, healthy and happy, with a green economy and smart infrastructure. *WEB SITE:* https://www.iclei.org
International Union for Conservation of Nature	The International Union for Conservation of Nature (IUCN) is a membership Union uniquely composed of both government and civil society organisations. It provides public, private and non-governmental organisations with the knowledge and tools that enable human progress, economic development and nature conservation to take place together. *WEB SITE: https://www.iucn.org*
SUSTAINABLE CITIES PLATFORM	The European Sustainable Cities Platform was launched in 2016, following the 8th European Conference on Sustainable Cities & Towns in the Basque Country. Supported by the City of Aalborg, Denmark, the Basque Country, and ICLEI Europe, it focuses on the uptake of The Basque Declaration, which is the main outcome of the 8th European Conference on Sustainable Cities and Towns. The European Sustainable Cities Platform includes the Transformative Actions Database, which presents existing transformative actions in line with the Basque Declaration as good practice. *WEB SITE: http://www.sustainablecities.eu/*

The Ambits and Indicators proposed in the comprehensive framework methodology are in line with the other EU projects summarized in Table 2.1.

As a starting point, it is noted that the Global City Indicators Facility (GCIF) successfully developed an international standard on city metrics through the International Organization for Standardization (ISO) under the Technical Committee TC268 on Sustainable Development of Communities. The ISO 37120:2014 "Sustainable Development of Communities - Indicators for City Services and Quality of Life" was published in May 2014. It is the first ISO international standard on city indicators. ISO 37120:2014 was developed using the GCIF framework and input from international organizations, corporate partners and international experts from over 20 countries. ISO 31720:2014 provides a comprehensive set of indicators and a methodology that will enable any sized city in a developed or a developing economy to measure the social, economic and environmental performance related to other cities. The capability of cities to prepare for, respond to, and recover from these threats and challenges with minimum damages to public safety and health, the economy, and security is increasingly referred to as resilience. The standard includes 100 core and supporting indicators across 17 themes (Economy, Education, Energy, Environment, Finance, Fire & Emergency Response, Governance, Health, Recreation, Safety, Shelter, Solid Waste, Telecommunications, Transportation, Urban Planning, Wastewater, Water & Sanitation), of which 46 are cores indicators that cities must report on. Many of the indicators in ISO 37120:2014 address sustainable development and resilience. Assessment of these indicators requires an in-depth study. To this aim, ISO/TC 268 (Technical Committee) has approved the publication of ISO 37121:2017 with the objective of developing an inventory of existing guidelines and approaches on sustainable development and resilience in cities, useable in the future to complement the ISO 37120:2014.

In this field, the ISO 37121:2017 "Inventory and review of existing indicators on sustainable development and resilience in cities" provides an inventory of existing guidelines and approaches on sustainable development and resilience in cities. The latter focuses on resilience understood as the ability of a city, system, community, local government or society exposed to hazards to resist, absorb, accommodate and recover from the effects on a hazard in a timely and effective manner, including through the preservation and restoration of its essential basic structures and functions. It is aimed at both reviewing and developing new indicators on sustainability and resilience (Smart Cities, Emergency Preparedness, Changes in Rainfall and Storm Surges, Protection of Biodiversity, Alternative Energy, Risk Assessment, Resilience Infrastructure, Smart Grid, Economic Resilience, Political Resilience, Walkability & Accessibility, Transit & Mobility, Water & Waste Management, Green Buildings).

Another valuable support tool, which is provided by the Horizon2020 EKLIPSE Knowledge and Learning Mechanism project (Table 2.2), focuses on biodiversity and ecosystem services. The EKLIPSE Expert Working Group on Nature-based Solutions (NBSs) to Promote Climate Resilience in Urban Areas (EWG) selected 10 main challenges:

1. *Climate Mitigation and Adaptation*
2. *Water Management*

3. *Coastal Resilience*
4. *Green Space Management (including enhancing/conserving urban biodiversity)*
5. *Air/Ambient Quality*
6. *Urban Regeneration*
7. *Participatory Planning and Governance*
8. *Social Justice and Social Cohesion*
9. *Public Health and Well-Being*
10. *Potential for new Economic Opportunities and Green Jobs*

NBSs targeted at addressing each of the 10 challenges would also contribute to climate resilience in urban areas.

Potential actions and expected impacts of NBSs were analyzed and examples of KPIs and methods to assess those impacts were suggested (Table 2.2), showing how the proposed actions and NBSs tackle the challenges that the project and each demonstration city is facing. An Application Guide for the Assessment of the Effectiveness of NBSs Projects was in closing presented.

Table 2.2 Core KPI, selected from EKLIPSE Mechanism

CH	Nº	TYPE OF INDICATOR	KPI DEFINITION
Challenge 1	1	Environmental, Chemical	Tonnes of carbon removed or stored per unit area per unit time (ton CO2/Ha) (ton CO2/year). Total amount of carbon stored in vegetation (ton)
	2	Environmental, Physical	Decrease in mean or peak daytime local temperatures (°C)
	3		Heatwave risks (number of combined tropical nights (>20 °C) and hot days (>35 °C)
	4	Others	Use of *Star tools* to calculate projected maximum surface temperature reduction (°C)
Challenge 2	5	Physical indicators	Run-off coefficient in relation to precipitation quantities (mm/%)
	6		Absorption capacity of green surfaces, bioretention structures and single trees (m3/m2) (m3/tree)
	7		Temperature reduction in urban areas (°C, % of energy reduction for cooling)
	8		Areas (Ha) and population (inhab) exposed to flooding
	9	Chemical indicators (water quality)	Drinking water provision (m3 ha-1year-1)
	10		Water for irrigations purposes (m3 ha-1year-1)
	11	Economic indicators (benefits)	Volume of water removed from water treatment system
	12		Volume of water slowed down entering sewer system
Challenge 4	13	Social indicators (benefits)	Accessibility (measured as distance or time) of urban green spaces for population (Tamosiunas et al., 2014).
	14		Weighted recreation opportunities provided by Urban Green Infrastructure (Derkzen et al. 2015)
	15	Environmental (biological)	Production of food (ton/Ha/year)
	16		Increased connectivity to existing GI
	17		Pollinator species increase (number)
Challenge 5	18	Environmental (chemical)	Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities (population weighted) concentration recorded ug/m3
	19		Trends in emissions NOX, SOX
	20	Economic	Monetary values: value of air pollution reduction; total monetary value of urban forests including air quality, run-off mitigation, energy savings, and increase in property values. use of GI val to calculate the value of air quality improvements
	21	Social (physiological)	Number of deaths from air, water and soil pollution and contamination (proposed indicator for SDG target 3.9)
	22		Air quality parameters NOx, VOC, PM etc
Ch 6	23	Urban green indicators (environmental, biological)	Accessibility: distribution, configuration, and diversity of green space and land use changes (multi-scale ;). - Green spaces quantity
	24	Socio-cultural indicators	Savings in energy use due to improved GI
Ch 7	25	Social	Perceptions of citizens on urban nature - Green spaces quality
Ch 8	26	Social Cohesion	Green intelligence awareness.
Challenge 9	27	Psychological indicators (Relaxation and restoration, sense of place, exploratory behaviour, socializing).	Noise reduction rates applied to UGI within a defined road buffer dB(A) m-2 vegetation unit
	28	Health indicators related to ecosystem service provision (Buffering of noise and air pollution, reduced heat, exposure to microflora).	Increase in walking and cycling in and around areas of interventions
Ch 10	29	Economic	Number of jobs created; gross value added

Nevertheless, there is a lack of some specific KPIs for NBSs and others related to the interaction of NBSs with social science and humanities and/or co-creation concepts. For example, in the project URBAN GreenUP, the first step is the definition of a complete set of KPIs and its integration in URBAN GreenUP´s Methodology to consider all related indicators, co-creation and co-design ones included as a decision-making parameter. Some specific indicators (Table 2.3) have been used in the design and demo actions selection to both predict its impact and optimize the required investments.

Table 2.3 Impact categories description in UrbanGreenUp

Category	Description
Citizens (year)	Citizens who interact with the new G.I.
CO2 eq. Emissions Avoided (tCO2 p/year)	CO2eq emissions avoided (tCO2eq p/year) considering a life cycle approach and modelling the environmental impacts regard to indirect savings.
New Green Surface (m2)	New green surfaces at soil level.
I Green Corridor (km)	Length of new sections considered as green corridor, bike lanes, tree series, etc.
New Trees (unit)	Number of new trees planted.
Shadow Surface (m2)	Vertical shadow of structures and trees.
CO2 Sink (tCO2 p/year)	Choice of plant species for preliminary estimations have been realized following the "Guide to estimate carbon dioxide absorptions Spanish Office of Climate Change. Ministry of agriculture, Feeding-stuffs and Environment.
Drainage Surface (m2)	New surfaces with drainage capacity (SUDs includes its area of influence).
Captured/Treated Water (m3/year)	Estimated from the annual rainfall regime in each city.
Water for Irrigation Saved (m3)	Estimated value for a conventional public garden in each city except Liverpool with no irrigation necessities.
Water Storage Capacity (m3)	Design value.
Water for Irrigation Produced (m3/year)	Design value.
Avoided Fertilizers (kg/year)	Estimated value for a conventional public garden in each city.
Soil Health Improvement	Countless category.
Maximum Temperature Reduction (°C)	Design value from in situ studies and literature.
Average Temperature Reduction (°C)	Design value from in situ studies and literature.
Modulation of Relative Humidity	Design value from in situ studies and literature.
NOX Reduction (kg/year)	Design value from in situ studies and literature.
dB Reduction	Design value.
Biodiversity Enhancement	Countless category.
Citizen Well-being Increase	Countless category.
Increase Pollinator Habitat/Activity	Countless category.
Citizen GI Awareness	Countless category.

Starting from this state-of-the-art, to address the needs to mitigate the increased risks due to climate change impact and related environmental threats in mountainous and rural areas, PHUSICOS is going to implement tailored framework tools to:

1) Assess the NBSs application in an effective way;
2) Increase the resilience at a basin scale with focus on risk mitigation and climate change adaptation.

For this purpose, in this Task 4.1 a hierarchic framework tool to assess the NBSs effectiveness is presented. The tool is aimed at both estimating the Performance Indicators (PI) and implementing a multi-disciplinary methodology for aggregation and weighting procedures. A multi-disciplinary/ multi-criteria approach allows the proposed tool to estimate the NBSs benefits from technical, environmental (ecosystem services), social, economic and cultural points of view.

3 Proposed framework for NBSS performance assessment

3.1 First Step: Identification of Indicators

In the First Step of the investigation, the PHUSICOS WP4 team implemented a preliminary framework for evaluation of performance of NBSs based on the Matrix in Appendix A.

The main goal of WP4 is to verify the performance of an NBS in the management of the risk process (Task 4.1), their environmental and socio-economic co-benefit, as well as their effectiveness in comparison/integration with grey solutions and other risk reduction measures (Task 4.5).

It should be emphasised that this approach should be considered as a flexible tool, to be modified or integrated according to the inputs of Stakeholders during the project's lifetime.

Indicators Framework has been built taking into account the specific conditions of the territorial context examined by PHUSICOS: mountainous and rural areas. In these areas, hazard induced by Climate Change (CC) effects, exposure and vulnerability show different properties and characteristics than those detectable in urban areas: i.e. no development of heat island; different hazard issues deriving from run-off; and more relevance of agricultural, fishery and livestock resources. Moreover, also from social and economic points of view, these areas show some specific issues or the increase of some phenomena (i.e. ageing, youth unemployment, scarce accessibility to places and services) against which NBSs could provide the raising of different opportunities.

The identification of NBSs Performance Indicators (PI) is based on the hierarchical assessment schematized by the Matrix:

a) Definition of 5 Ambits based on the following Assessment Goals:
   1) Verify NBSs performances and their effectiveness with respect to Risk Reduction;
   2) Assess the technical and economic feasibility aspects;
   3) Assess the beneficial role of NBSs on the environment;
   4) Identify positive co-benefits and potentially undesirable side-effects from the societal point of view;
   5) Assess the effects of the NBSs on the local economy.

Therefore, the chosen <u>Ambits</u> are:

Table 3.1 Ambits (see Framework Column 1 in Appendix A)

AMBIT	
1.	Risk Reduction
2.	Technical and Feasibility Aspects
3.	Environment
4.	Society
5.	Local Economy

b) For each Ambit, Criteria (Framework Column 2) are defined, as per following Table 3.2:

Table 3.2 Criteria (see Framework Column 2 in Appendix A)

AMBIT	CRITERION
Risk Reduction	Hazard
	Exposure
	Vulnerability
Technical & Feasibility Aspects	Technical Feasibility
	Economic Feasibility (affordability)
Environment	Water
	Soil
	Vegetation
	Landscape (Green Infrastructure)
	Biodiversity
Society	Quality of Life
	Community Involvement and Governance
	Landscape and Heritage
Local Economy	Revitalization of Marginal Areas
	Local Economy Reinforcement, including New Job Opportunities

c) For each Criterion, the Indicators (Framework Column 4) are identified, based on specific Sub-Criteria (Framework Column 3).

d) For each Indicator, the following properties are specified:

- Metric (Framework Column 5): unit of measurement;
- *Typology* (Framework Column 6): Qualitative Q (e.g. landscape perception: much better, better, the same, worse, much worse than before); Semi-quantitative S-QT (e.g. landscape quality perception: 1 to 10); Quantitative QT (e.g. total predicted annual soil loss in Tha-1yr-1);
- Direction (Framework Column 7): for each Indicator, a positive direction is set whether it should be maximized referred to the Baseline Scenario B0, defined by the symbol "Max" in Framework Column 7. Negative direction is set whether the Indicator should be minimized referred to the Baseline Scenario B0, instead, setting the "Min" symbol in Framework Column 8.
- Source (Framework Column 8): how to evaluate the Indicator:
    - Survey (S)

- Numerical Model (M)
- Living Lab (LL)
- Geographic Information System (GIS)
- Statistical Data (SD)
- Sampling (SM)

e) Finally, the last 5 columns of the matrix contain attributes useful for both creating different sub-sets of Indicators and focusing the analysis on specific aspects, by opportunely filtering the Indicators. Specifically, for each Indicator the following attributes have been reported:

- Δ (Framework Column 9): owing to their specific nature, not all the Indicators can be defined for both the Baseline and the Design Scenarios. This attribute is assumed equal to Δ when the Indicator can be calculated in the Baseline Scenario and compared to the one evaluated for the project Scenario; NO otherwise.
- Assessment Factors (Framework Column 10): this attribute identifies the role of each Indicator in the evaluation process. For each Indicator the following Assessment Factors are considered (see Chapter 2):
  - Effectiveness (E)
  - Feasibility (F)
  - Co-benefits (C)
  - Resilience (R)
- Time scale (Framework Column 11): it specifies the time scale of the impact of each Indicator, Long-term LT, Medium-term MT and Short-term ST.
- SFDRR (Framework Column 12): each Indicator can be associated to one or more targets of the Sendai Framework for Disaster Risk Reduction (SFDRR) (see Table 3.3).

Table 3.3 SFDRR targets (taken from https://www.unisdr.org/we/coordinate/sendai-framework)

#	GLOBAL TARGET
1	Substantially reduce global disaster mortality by 2030, aiming to lower average per 100,000 global mortality rate in the decade 2020-2030 compared to the period 2005-2015.
2	Substantially reduce the number of affected people globally by 2030, aiming to lower average global figure per 100,000 in the decade 2020 -2030 compared to the period 2005-2015.
3	Reduce direct disaster economic loss in relation to global gross domestic product (GDP) by 2030.
4	Substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience by 2030.
5	Substantially increase the number of countries with national and local disaster risk reduction strategies by 2020.
6	Substantially enhance international cooperation to developing countries through adequate and sustainable support to complement their national actions for implementation of this Framework by 2030.

7	Substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessments to the people by 2030.

- UNSDG (Framework Column 13): each Indicator can be associated to one or more UN Sustainable Development Goals (UNSDG) (Table 3.4).

Table 3.4 UN sustainable development goals (Ref.: https://sustainabledevelopment.un.org/?menu=1300)

#	SUSTAINABLE DEVELOPMENT GOALS
1	No poverty: end of poverty in all its forms everywhere.
2	Zero hunger: end hunger, achieve food security and improved nutrition and promote sustainable agriculture
3	Good health and well-being: ensure healthy lives and promote well-being for all at all ages
4	Quality education: ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
5	Gender equality: achieve gender equality and empower all women and girls
6	Clean water and clean energy: ensure availability and sustainable management of water and sanitation for all
7	Affordable and clean energy: ensure access to affordable, reliable, sustainable and modern energy for all
8	Decent work and economic growth: promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
9	Industry, innovation and infrastructure: build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
10	Reduced inequalities: reduce inequality within and among countries
11	Sustainable cities and communities: make cities and human settlements inclusive, safe, resilient and sustainable
12	Responsible consumption and production: ensure sustainable consumption and production patterns
13	Climate action: take urgent action to combat climate change and its impacts
14	Life below water: conserve and sustainably use the oceans, seas and marine resources for sustainable development
15	Life on land: protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
16	Peace, justice and strong institutions: promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
17	Strengthen Partnerships for the goals: the means of implementation and revitalize the global partnership for sustainable development

Using these attributes, targeted analyses can be performed in order to assess the performance of the project Scenarios under specific assumptions, for example the Long Term (TS = LT) impacts with reference to the reduction of the direct disaster economic loss in relation to global gross domestic product (SFDRR = 3).

In the following Appendix B detailed indications for Indicators estimation are provided. Nevertheless, the users may choose alternative methods, as a function of the local conditions and the peculiarity of the problem to be handled.

Second Step: Aggregation and Weighting of Indicators

The final goal of the procedure, with reference to each demonstrator site and concept case, is the assessment of a reliable comparison between different alternative Design Scenarios (e.g. Scenario 0, NBSs, Grey Solutions, Hybrid Solutions,...), as a function of both different Climatic Scenarios and Time Scales (Short-Term ST; Mid-Term MT; Long-Term LT), for fixed Return Periods (to be implemented in Task 4.5 “Effectiveness of NBSs in comparison/integration with grey solutions and other risk reduction measures as well as analysis of residual risk”).

A multi-criteria approach (Multi-Criteria Decision Analysis, MCDA) is therefore needed for an integrated and global assessment of simulated alternative Scenarios, starting from the Framework defined in the previous Par. 3.1.

A MCDA is able to account for the interaction among different Ambits, including possible cascade events. A rigorous approach to MCDA assessment - addressing uncertainties in all the steps of the analysis - would be complex, requiring resources and expertise of both partners and stakeholders.

As a general rule, the decision-makers can identify the optimal alternative among the feasible ones without undertaking a detailed and rigorous analysis. This decision can be changed during the Project according with other inputs. Therefore, the suggested framework is based on a Multi-Level approach where the decision makers will apply simplified models whenever they are sufficient for the problem at hand.

The MCDA decisional problem consists in determining the optimal Scenario K*, belonging to the set K of the considered Scenarios, as the one having the best overall Total Score SA*, estimated by calibrating the weights of both each Indicator and Ambit, in compliance with the Living Labs and the involved stakeholders.

The method of the Weighted Sum Model (WSM) is probably the most frequently used one, especially for one-dimensional problems, namely involving variables having equal physical dimensions.

To clarify the WSM methodology, let’s suppose that a decision maker could make a decision selecting among n Scenarios K1, K2,..., Kn, each one evaluated considering m criteria C1, C2,..., Cm. Each scenario is then characterized by the scores of the different considered criteria, as indicated in the following Decision Matrix.

Table 3.5 Example of a Decision Matrix

		Criterion			
		C_1	C_2	....	C_m
Criterion Weight		w_1	w_2	....	w_m
Scenario	K_1	$S_{1,1}$	$S_{1,2}$	...	$S_{1,m}$
	K_2	$S_{2,1}$	$S_{2,2}$	...	$S_{2,m}$
	...	...	...	...	...
	K_n	$S_{n,1}$	$S_{n,2}$	...	$S_{n,m}$

In the Decision Matrix of Table 3.5, wj is the relative weight of j-th Criterion, whereas Si,j is the Score of the i-th Scenario with reference to the j-th Criterion.

The total Score of the i-th Scenario is:

$$S_i = S_{i,1} \cdot w_1 + S_{i,2} \cdot w_2 + \ldots + S_{i,m} \cdot w_m \qquad (3.1)$$

The Scenario to be selected is the one achieving the maximum Score Si (in the maximization case) or the minimum one (in the minimization case).

With the reference to the Framework Assessment Tool for NBSs, the WSM is based on a multi-level aggregation method of selected Indicators, Criteria and Ambits, aimed at perform the Indicators' weighting and assessment.

Namely, given a Climatic Scenario and a Time-Scale, being

$K = (K_i \text{ for } i = 1,\ldots, n)$	*a finite group of alternative Design Scenarios*
$I = (I_j \text{ for } j = 1,\ldots, m)$	*a finite set of Indicators to assess the performance of* K_i
$A = (A_a \text{ for } a = 1,\ldots, 5)$	*the considered 5 Ambits (Risk Reduction, Technical & Feasibility Aspects, Environment & Ecosystems, Society, Local Economy)*
$w = (w_{j,i} \text{ for } j = 1,\ldots, m;\ i = 1, \ldots, n)$	*the relative relevance, or weight, of each Indicator* $I_{j,i}$;
$S = (S_{j,i} \text{ for } j = 1,\ldots, m;\ i = 1,\ldots,n)$	*the standardized score of the Indicator* $I_{j\ norm,i}$
$SA = (SA_{a,i} \text{ for } a = 1,\ldots, 5;\ i = 1,\ldots, p)$	*the score of the each* A_a *composed of p Indicators*
$W = (W_{a,i} \text{ for } a = 1,\ldots, 5;\ i = 1,\ldots,n)$	*the relative relevance, or weight, of* A_a
$Y = (Y_{a,i} \text{ for } a = 1,\ldots, 5;\ i = 1,\ldots,n)$	*the standardized score of the Ambit* A_a
$R = (R_a \text{ for } a = 1,\ldots, 5)$	*the total score of* K_i

$K = (K_i \text{ for } i = 1,\ldots, n)$	*a finite group of alternative Design Scenarios*
$I = (I_j \text{ for } j = 1,\ldots, m)$	*a finite set of Indicators to assess the performance of* K_i
$A = (A_a \text{ for } a = 1,\ldots, A)$	*the A considered Ambits (Risk Reduction, Technical & Feasibility Aspects, Environment & Ecosystems, Society, Local Economy)*
$w_{PI} = (w_{PIj,i} \text{ for } j = 1,\ldots, m;\ i = 1, \ldots, n)$	*the relative relevance, or weight, of each Indicator* $I_{j,i}$
$w_C = (w_{Ck} \text{ for } k = 1,\ldots, C)$	*the weight of the* k^{th} *Criterion*
$w_A = (w_{Aa} \text{ for } a = 1,\ldots, A)$	*the weight of the* a^{th} *Ambit*
$S = (S_{j,i} \text{ for } j = 1,\ldots, m;\ i = 1,\ldots, n)$	*the standardized score of the Indicator* $I_{j\ norm,i}$
$SC = (SA_{a,i} \text{ for } a = 1,\ldots, A;\ i = 1,\ldots, p)$	*the score of each Criterion* C_k *of l Indicators*
$P = (P_{k,i} \text{ for } k = 1,\ldots, C;\ i = 1,\ldots, n)$	*the weighted score of the Criterion* C_k
$SA = (SA_{a,i} \text{ for } a = 1,\ldots, A;\ i = 1,\ldots, p)$	*the score of the each* A_a *composed of p Indicators*
$W = (W_{a,i} \text{ for } a = 1,\ldots, A;\ i = 1,\ldots, n)$	*the relative relevance, or weight, of* A_a
$Y = (Y_{a,i} \text{ for } a = 1,\ldots, A;\ i = 1,\ldots, n)$	*the standardized score of the Ambit* A_a
$R = (R_a \text{ for } a = 1,\ldots, A)$	*the total score of* K_i*, the following Multi-Level approach is applied*

the following Multi-Level approach is applied:

LEVEL I: Indicator Scoring

- a set of m Indicators Ij (j = 1,…, m) is quantified from those stated in the Framework Column 4, where m depends on the considered case-study and the stage and accuracy of the assessment;
- the standardization of each Indicator Ij norm,i is performed as a function of the Baseline Scenario B0 to a relative scale from 0 to 100.

With reference to Indicators having Direction "Max" in Framework Column 7, following Eq. (3.2) is applied to standardize each Indicator:

$$I_{j\ norm,i} = \left(\frac{I_{j,i} - I_{j\ min}}{I_{j\ max} - I_{j\ min}} \right) \cdot 100 \tag{3.2}$$

where:

- $I_{j\ norm,i}$: the standardized value of the Indicator I_j at Scenario K_i
- $I_{j,i}$: the value of the Indicator I_j at Scenario K_i

- $I_{j\ min}$: minimum value (worst value) achieved by the Indicator I_j at the Baseline Scenario B_0
- $I_{j\ max}$: maximum value achievable by the Indicator I_j

As an example, the increase of Safety Factor (FS) of the Sub-Criterion Landslide Risk Resilience with respect to the Baseline Scenario B0 represents the improvement obtained with the designed approach.

With reference to Indicators having Direction "Min" in Framework Column 7, following Eq. (3.3) is applied, instead:

$$I_{j\ norm,i} = \left(\frac{I_{j,max} - I_{j,i}}{I_{j\ max} - I_{j\ min}} \right) \cdot 100 \qquad (3.3)$$

with:
- $I_{j\ min}$: minimum value achievable by the Indicator I_j;
- $I_{j\ max}$: maximum value (worst value) achieved by the Indicator I_j at the Baseline Scenario B_0.

As an example, the reduction of Peak Flow of the Sub-Criterion Flooding Risk Resilience with respect to the Baseline Scenario B0 represents the improvement obtained with the designed approach.

Thus, the standardization allows to intend Ij norm,i as a Performance Indicator because able to represent the improvement/worsening of the Indicator Ij with respect to the Baseline Scenario B0.

- Estimation of the Indicator Weight wj,i of each Indicator Ij at Scenario Ki so that the sum of the m Indicator weights adds up to 1:

$$0 \le w_{j,i} \le 1 \quad \text{and} \quad \sum_{j=1}^{m} w_{j,i} = 1 \qquad (3.4)$$

- Calculation of the **Score $S_{j,i}$** of the Indicator I_j at Scenario K_i with Eq. (3.5):

$$S_{j,i} = I_{j\ norm,i} \cdot w_{j,i} \qquad (3.5)$$

LEVEL II: Criterion Scoring

- Calculation of the Criterion Total Score SCk,i of the Criterion Ck at Scenario Ki with Eq. (3.6):

$$SC_{c,i} = \sum_{i=1}^{l} S_{j,i} \qquad (3.6)$$

- Estimation of the **Criterion Weight** $\boldsymbol{w_{j,i}}$ of each Indicator I_j at Scenario K_i so that the sum of the C Criteria weights adds up to 1:

$$0 \le w_{Ck} \le 1 \quad \text{and} \quad \sum_{k=1}^{C} w_{Ck} = 1 \tag{3.7}$$

- Calculation of the **Criterion Weighted Score** $\boldsymbol{SC_{k,i}}$ of the Criterion C_K at Scenario K_i with Eq. (3.8):

$$P_{k,i} = SC_{k,i} \cdot w_{Ck} \tag{3.8}$$

LEVEL III: Ambit Scoring

- Calculation of the **Total Score** $\boldsymbol{SA_{a,i}}$ **of the Ambit** A_a at Scenario K_i with Eq. (3.9):

$$SA_{a,i} = \sum_{j=1}^{p} S_{j,i} \tag{3.9}$$

where p is the number of Indicators belonging to the a-th Ambit A_a being $p \le m$.

- Estimation of the **Ambit Weight** $\boldsymbol{W_{a,i}}$ of each Ambit A_a at Scenario K_i so that the sum of the 5 Ambit weights adds up to 1:

$$0 \le W_{a,i} \le 1 \quad \text{and} \quad \sum_{a=1}^{5} w_{a,i} = 1 \tag{3.10}$$

- Calculation of the **Total Weighted Score of the Ambit** $Y_{a,i}$ by multiplying the Total Score of the Ambit SA_a with the corresponding Ambit Weight $W_{a,i}$ (Eq. 3.11):

$$Y_{a,i} = SA_{a,i} \cdot W_{a,i} \tag{3.11}$$

This further standardization of the produced aggregated values allows to both calculate final output value scores ranging from 0 to the theoretical achievable value equal to 100 and point out the global performance of the i-th Scenario Ki, with reference to the a-th Ambit Aa.

LEVEL IV: Scenario Scoring

- Computation of the **Total Score** $\boldsymbol{R_i}$ of the i-th Scenario K_i:

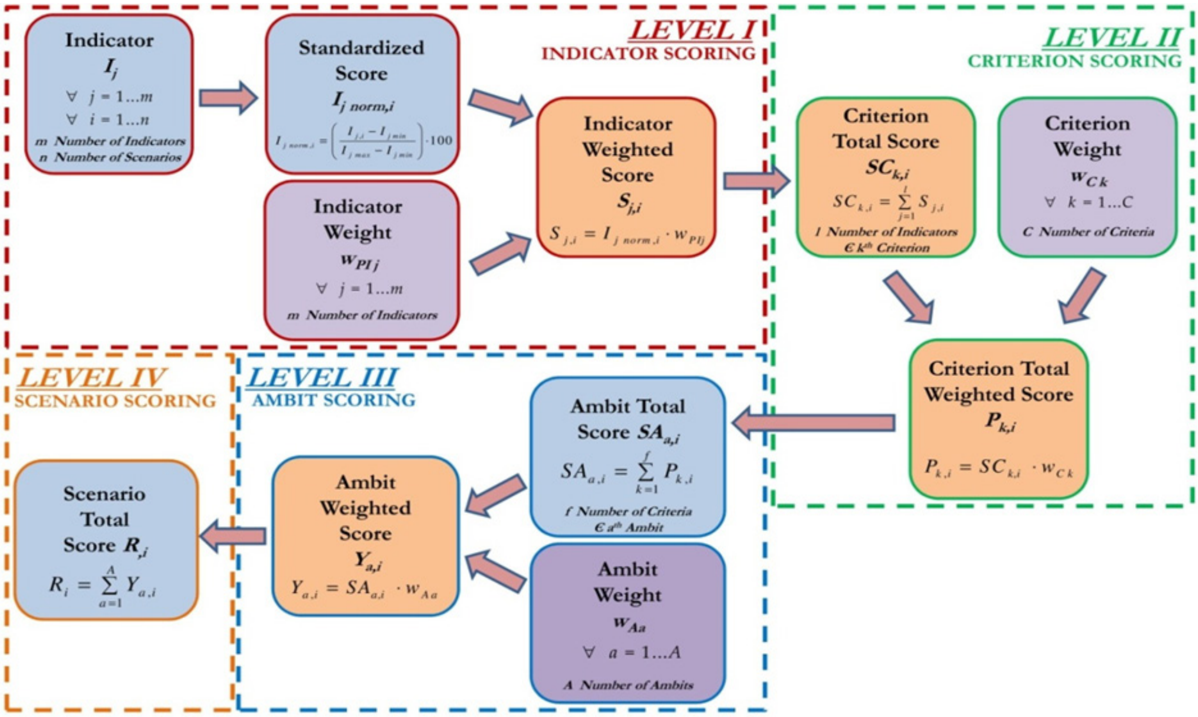
$$R_i = \sum_{a=1}^{5} Y_{a,i} \tag{3.12}$$

- The chosen Scenario K^* is the one scoring the maximum overall **Total Score** $\boldsymbol{R_{,i}}$ (LEVEL IV).

The MCDA allows to compare not only the Total Score Ri of the considered alternative Scenarios, but also the score of the single Ambit Aa or Criterion Ck facilitating the assessment of the effectiveness of each alternative from technical, environmental, social and economic point of view.

The proposed scoring procedure is schematized in the following Fig. 3.1.

Fig. 3.1 Flow Chart of the proposed scoring procedure



Weighting Methods

A final consideration on the double weighting procedure applied in the Multi-Criteria approach.

The hierarchical multi-criteria techniques need either the implicit or the explicit application of weights. In this tool, explicit weights are applied as the relevance of the several performance Indicators might differ with respect to the context, the Stakeholders, and the investigated demonstrator case.

Weight of the Indicators

Thus, following techniques are applicable to weight the Indicators:

- Pairwise Comparison as described in the Analytical Hierarchy Process (AHP; Saaty, 1977, 2005).

This approach is applicable because it both supports the acquisition of relative weights in situations where a ranking of decision alternatives or evaluation criteria is desired and also helps to formalize public participation in decision-making processes (Ananda & Herath, 2003; Mendoza et al., 1999).

- Likert Scale: in this weighting procedure, the stakeholders are asked for stating their preferences referring to a Likert Scale of 1 ("not at all important to me") to 5 ("very important to me") categories. As a result, the relative weights of each Indicator, in comparison to any other, could be estimated.
- Equal Weights: balanced weights could be applied as a third weighting method. Here, the weights are simply generated by dividing 1 by m. This approach could be intended as a sensitivity analysis to test whether weighting exercises with stakeholders involvement led to significant differences in the considered context.

Weight of the Ambits

The global weights of the Ambits (Risk Reduction, Technical & Feasibility Aspects, Environment & Ecosystems, Society, Local Economy) will be analyzed and defined with the specific contribution of Stakeholders. It is clear that different approaches and points of view can lead to different appraisals of NBSs (and other solutions) and to different prioritization of design Scenarios.

Nevertheless, the proposed procedure, based on the application of many Performance Indicators, could be significantly simplified by considering a lower number of Indicators Ij (i.e. one for each Criterion in Framework Column 2), to be selected in compliance with both the monitoring activities and the Stakeholders' evaluations.

Decision-making context

The proposed approach is a flexible tool and is thought for the application at different levels of the project implementation and decision-making process, depending on the stage at which the performance assessment analysis has to be done. Indeed, depending on the assessment stage (ex-ante or ex-post, with reference to the implementation of the project Scenarios), the number of Indicators to be taken into account can be modified, simplifying the methodology consistently with the aim and the accuracy of the assessment.

In the Ex-Ante stage, a first assessment can be performed for a quick evaluation and selection of the possible project scenarios, as to evaluate, in first approximation, the most suitable Scenarios among the entire set of feasible alternatives (NBSs, Grey, Hybrid Scenarios). At this stage, the use of a Simplified Matrix, created by opportunely selecting at least one Indicator (among the most relevant ones for the considered project scenario) for each Criterion, is suggested. If more detail is requested, the Simplified Matrix can be defined by extracting one Indicator (among the most relevant ones for the considered project scenario) for each Sub-Criterion.

Once the most suitable project alternatives have been defined, a more accurate assessment is needed and can be performed referring to the Extended Matrix (including the whole set of measurable Indicators). Otherwise, if lower level of detail is needed, a Simplified Matrix can be adopted.

In the Ex-Post stage, a detailed performance assessment of the implemented Scenario can be needed (for example in order to provide evidence base for policy decisions, etc.). In this case the use of the Extended Matrix is suggested. In the ex-post stage, a quick assessment of implemented Scenarios on specific topics (the time scale, the agreement with the UN Sustainable development Goals, the compliance with the targets of the SFDRR) can be performed by considering the Assessment Factor Matrix, by properly selecting the Indicators on the base of the attributes of Columns 9-13 of the Framework Matrix.

The suggested tools to be used at the different decision-making contexts are summarized in the following Table 3.6.

Table 3.6 Specification of the Assessment Tool for Ex-Ante and Ex-Post stages

STAGE OF ASSESSMENT	AIM OF ASSESSMENT	ASSESSMENT TOOL
Ex-Ante	Quick Assessment of different project scenarios (NBS, Grey, Hybrid)	Simplified Matrix
Ex-Ante	Assessment of a suggested NBS project at demonstration sites before implementation	Simplified Matrix or Extended Matrix
Ex-Post	Quick assessment of existing NBSs for statistical analyses on specific topics	Assessment Factor Matrix
Ex-Post	Detailed performance assessment of an implemented NBS to provide evidence base for policy decisions, etc.	Extended Matrix

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H2020 Project PHUSICOS
Grant Agreement No. 776681

Appendix A

Assessment Framework Matrix

AMBIT	CRITERION	SUB - CRITERION	INDICATOR	METRIC	TYPOLOGY	DIRECTION	SOURCE	Δ	ASSESSMENT FACTOR	TIME SCALE	SFDRR	UNSDG
RISK REDUCTION	Hazard	Landslide Risk Resilience	Safety Factor	km²	QT	min	M	Δ	R	ST		13
			Occurred landslide area/Risk area	km²	QT	min	M/S	Δ	R	ST		13
			Velocity of Occurred Landslide	m/s	QT	min	M/S	Δ	R	ST		13
		Flooding Risk Resilience	Peak Flow	m³/s	QT	min	M	Δ	R	ST		13
			Peak Volume	m³	QT	min	M	Δ	R	ST		13
			Flooded Area	ha	QT	min	M/GIS	Δ	R	ST		13
		Snow Avalanche Risk Resilience	Snow Cover Map, Digital Terrain Model (DEM), Land Relief [to be integrated according to Living Labs]	-	QT		GIS/SD	-	R	ST		13
		Drought Risk Resilience	Standardized Precipitation Index (SPI)	-	QT		M	Δ	R	ST		13
			Effective Drought Index (EDI)	-	QT		M	Δ	R	ST		13
	Exposure	Potential Areas Exposed to Risks	Urban /Residential Areas	ha		min	GIS	Δ	R	ST	1; 2	11
			Productive Areas (Agriculture, Grazing, Industries)	ha	QT	min	GIS	Δ	R	ST	3	8
			Natural Areas, Site of Community Importance (SCI), Special Protection Areas (SPA)	ha	QT	min	M/S	Δ	R	ST	3	15
		Potential Population Exposed to Risks	Inhabitants	nr/ha	QT	min	SD	Δ	R	ST	1; 2	3
			Other People (Workers, Tourists, Homeless)	nr/ha	QT	min	SD	Δ	R	ST	1; 2	3
			Elderly, children, disabled	nr/ha	QT	min	SD	Δ	R	ST	1; 2	3
		Potential Species Exposed to Risks	Domestic and Wild Fauna (livestock and protected species)	nr/ha	QT		SD	Δ	R	ST	1	15
		Potential Buildings Exposed to Risks	Housing	nr	QT	min	SD	Δ	R	ST	3	11
			Agricultural and Industrial Buildings	nr	QT	min	SD	Δ	R	ST	3	8
			Strategic Buildings (Hospitals, Schools, Waste-treatment Plants,...)	nr	QT	min	SD	Δ	R	ST	4	9
		Potential Infrastructures Exposed to Risks	Roads	km	QT	min	SD	Δ	R	ST	4	9
			Railways	m/km²	QT	min	SD	Δ	R	ST	4	9
			Lifelines (Water main, Sewerage, Pipeline,….)	m/km²	QT	min	SD	Δ	R	ST	4	9
	Vulnerability	Potential Population Vulnerable to Risks	Population	nr	QT	min	SD	Δ	R	ST	1; 2	3
		Potential Economic Effects due to Risks	Economic Value of the Productive Activities Vulnerable to Risk (i.e. Economic Value of the Fields, Workers Nr.)	€/km²	QT	min	SD	Δ	R	ST	3	8
		Potential Infrastructures Vulnerable to Risks	Buildings	nr./km²	QT	min	SD/GIS	Δ	R	ST	4	11
			Transportation Infrastructures and Lifelines	m/km²	QT	min	GIS	Δ	R	ST	4	9
TECHNICAL & FEASIBILITY	Technical Feasibility (Affordability)	Cost-Benefit Analysis of the Intervention	Initial costs	mln €	QT	min	M	NO	EF	ST		12
			Maintenance costs	mln €	QT	min	M	NO	EF	ST		12
			Replacement costs	€	QT	min	M	NO	EF	ST		12

AMBIT	CRITERION	SUB - CRITERION	INDICATOR	METRIC	TYPOLOGY	DIRECTION	SOURCE	Δ	ASSESSMENT FACTOR	TIME SCALE	SFDRR	UNSDG
			Avoided costs	mln €	QT	max	M	NO	EF	ST		12
			Payback Period	Year	QT	min	M	NO	EF	ST		12
		Application of Suitable Materials and Technologies	Material used coherence	0/1	QL	max	S/LL	NO	CB	ST		11
			Techniques used coherence	Yes/No	QL		S/LL	NO	CB	ST		11
ENVIRONMENT & ECOSYSTEMS	Water	Effects on Water Quality	Extended Biotic Index (EBI)	-	S-QT		M/S	Δ	E	ST		6; 14
			Fluvial Functionality Index (FFI)	-	S-QT		M/S	Δ	E	ST		6
			Physical parameters	°	QT		M/S	Δ	E	ST		6
			Chemical Pollution Parameters	-	S-QT		M/S	Δ	E	ST		6
		Effect on Water Quantity	Water Storage Capacity Enhancement	m^3	QT	max	M/S	Δ	E	ST		12
	Soil	Soil Physical Resilience	Total Predicted Soil Loss (RUSLE)	Tha^{-1}yr^{-1}	QT		M/S	Δ	E	ST		13
			Erodibility	mm^{3}ha^{-1}	QT		M/S	Δ	E	ST		13
			Soil Water Holding Capacity	semi-quantitative	S-QT		M/S	-	E	ST		13
			Land Take Index (LTI)		QT		GIS	Δ	E	ST		11
			Polluted Soils		QT		GIS	Δ	E	ST		3
		Stability of the Soil Communities and Derived Environmental Services	Soil Food-Web Stability	S parameter for stability	S-QT		M/S	-	E	ST		2
		Soil Fertility	Soil Available Nutrients and Texture		S-QT		SM	-	E	ST		2
			Soil Structure		S-QT		SM	-	E	ST		2
			Modelled C And N Cycling	Tha^{-1}yr^{-1}	S-QT		S	-	E	ST		2
		Carbon Sequestration in Soil	Decomposition Rate	% mass loss	QT		S	-	E	ST		
			Modelled C Content In The Upper Soil Layers	Tha^{-1}	QT		S	-	E	ST		
	Vegetation	Aboveground C Cycle	Aboveground Tree Biomass	Tha^{-1}	QT		GIS	-	E	ST		13
			Tree Biomass Stock Change	Tha^{-1}yr^{-1}	QT		GIS	-	E	ST		13
		Structural Diversity	Woody Vegetation Cover	%	QT	max	GIS	Δ	E	ST		3; 13
			Non-Woody Vegetation (Herb) Cover	%	QT	max	GIS	Δ	E	ST		3; 13
			Total Vegetation Cover	%	QT	max	GIS	Δ	E	ST		3; 13
		Stages of Forest Stand Development	Number Of Diameter Classes	#	QT		SM/GIS	-	E	ST		15
			Tree Regeneration	#	S-QT		M/GIS	-	E	ST		15
			Canopy Gaps	Y/N	S-QT		M/GIS	-	E	ST		15
		Typical Local Species Promotion and Development	Typical Vegetation Species Cover				SM/GIS	Δ	E	ST		15

AMBIT	CRITERION	SUB - CRITERION	INDICATOR	METRIC	TYPOLOGY	DIRECTION	SOURCE	Δ	ASSESSMENT FACTOR	TIME SCALE	SFDRR	UNSDG
		Moisture	Moisture Index		QT		LL/M	-	E	ST		13
		Flammability	Flammability Index		QT		GIS/S	Δ	E	ST		13
	Landscape (Green Infrastructure)	Green Infrastructure	Hanski Connectivity Index	ha of potential habitat	QT		M	Δ	E	ST		3; 15
			Abundance Of Ecotones/Shannon Diversity	km/ha/Shannon index	QT		M	Δ	E	ST		3; 15
	Biodiversity	Functional Diversity	Metagenomic Map		QL		GIS/M	-	E	ST		15
			Abundance Of Functional Groups		S-QT		S/M	-	E	ST		15
			Diversity Of Functional Groups (Plant Functional Diversity)	Shannon index	QT		S/M	-	E	ST		15
			Diversity Of Functional Groups (Animal Functional Diversity)	Shannon index	QT		S/M	-	E	ST		15
		Forest Habitat Fragmentation	Effective Mesh Density	ha	QT		GIS	Δ	E	ST		15
		Protected Areas	Site Community Importance (SCI) And Special Protection Areas (SPA)	ha	QT		GIS	-	E	ST		15
SOCIETY	Quality of life	Leisure and Connections Increasing	Number Of Visitors In New Recreational Areas	nr.	QT	max	M/GIS	Δ*	CB	MT		8
			Different Activities Allowed In New Recreational Areas	nr.	QT	max	M/GIS	Δ*	CB	ST		3
			Average Distance Of Natural Resources From Urban Centres/Train Station/Public Transportation	km	QT	min	M/GIS	Δ	CB	ST		11
			New Pedestrian, Cycling And Horse Paths	m	QT	max	M/GIS	Δ*	E, CB	ST		3, 11
			Sustainable Transportation Modes Allowed	nr.	QT	max	M/GIS	Δ*	E, CB	ST		11
			New Links Between Urban Centres/Activities	nr.	QT	max	M/GIS	Δ	CB	ST		11
		Social Justice	Area Easily Accessible For People With Disabilities	km^2	QT	max	M/GIS	Δ*	CB	ST		10
			Rate Of Increase In Properties Incomes	%	QT		M/GIS	Δ	CB	LT		10
		Ageing Contrast	Population Increasing (Natality + Immigration)	%	QT		SD	Δ	CB	LT		11
			Elderly Rate Decreasing	%	QT		SD	Δ	CB	LT		11
	Community Involvement & Governance	Participatory Processes and Partnership	Citizen Involved	nr.	QT	max	SD	NO	P	MT		17
			Stakeholders Involved	nr.	QT	max	SD	NO	P	MT		17
			Public-Private Partnership Activated	nr.	QT	max	S	NO	EF	MT		16; 17
			Policies Set Up To Promote NBS	nr.	QT	max	S	NO	EF, P	MT		16
	Landscape and Heritage	Identity	Traditional Knowledge And Uses Reclamation	Yes/No	QL		SD/S	Δ*	CB	ST		3
			Traditional Events Organized In The New Areas	nr.	QT	max	S	Δ*	CB	MT		3
			Social Active Associations	nr.	QT	max	S	Δ	CB	MT		3
		Heritage Accessibility	Natural And Cultural Sites, Made Available	nr. Site	QT	max	SD/M	NO	CB	ST		3

AMBIT	CRITERION	SUB - CRITERION	INDICATOR	METRIC	TYPOLOGY	DIRECTION	SOURCE	Δ	ASSESSMENT FACTOR	TIME SCALE	SFDRR	UNSDG
		Landscape Perception	Viewshed	km²	QT	max	GIS	Δ*	CB	ST		3
			Scenic Sites And Landmark Created	nr.	QT	max	M/GIS	NO	CB	ST		3
			Scenic Paths Created	km	QT	max	M/GIS	NO	CB	ST		3
LOCAL ECONOMY	Revitalization of Marginal Areas	Promotion of Socio-Economical Development of Marginal Areas	Jobs Created In The Nature-Based Sector	nr.	QT	max	M/SD	Δ	CB	MT		8
			Jobs Created In The Nature-Based Solution Construction And Maintenance	nr.	QT	max	M/SD	Δ	CB	MT		8
			New Employment In The Tourism Sector	nr.	QT	max	M/SD	Δ	CB	MT		8
			New Activities In The Tourism Sector	nr.	QT	max	M/SD	Δ	CB	MT		8
			Gross Profit From Nature-Based Tourism	€/area/year	QT	max	M/SD	Δ	CB	MT		8
			Touristic Activeness Enhancing	nr. visitor/year	QT	max	M/SD	Δ	CB	MT		8
	Local Economy Reinforcement	New Areas for Traditional Resources	New Areas Made Available For Traditional Activities (Agriculture, Livestock, Fishing,….)	ha	QT	max	M/GIS	Δ	CB	ST		2; 8
			Forest Area Planted	km²	QT	max	M/GIS	Δ	E, CB	LT		8
		Enhancement of Local Socio-Economic Activities	Rural Productivity Index (RPI)	€/ha	QT	max	M/GIS	Δ	CB	ST		8

Appendix B

Suggested Approach for Explication of Framework Matrix Indicators

This Appendix provides indications on the methods adoptable for the explication of Framework Matrix Indicators. Depending on the local conditions and problem context, the user(s) may choose to modify the approach(es) and/or replace them with other approach(es) that may be more appropriate for the specific considered problem.

B1 AMBIT: Risk Reduction

B1.1 CRITERION: Hazard

Process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage. The term is used to describe actual hazard events as well as the latent hazard conditions that may give rise to future events. Natural hazard events can be characterized by their magnitude or intensity, speed of onset, duration, and area of extent. For example, earthquakes have short durations and usually affect a relatively small region, whereas droughts are slow to develop and fade away and often affect large regions. In some cases hazards may be coupled, as in the flood caused by a hurricane or the tsunami that is created by an earthquake (UNISDR Terminology, 2009).

B1.1.1 SUB-CRITERION: Landslide Risk Resilience

Sub-Criterion Table: Landslide Risk

SUB-CRITERION	Indicators will assess....
Landslide Risk Resilience	the site response to Landslide phenomena based on susceptibility indicators: slope angle, pore water pressure, groundwater depth, soil properties, land use, land cover

A landslide is defined as the movement of a mass of rock, debris, or soil down a slope due to gravity (Cruden, 1991). The materials may move by falling, toppling, sliding, spreading, or flowing. Figure B.1 shows the terminology describing a landslide. Slope movement occurs when forces acting down-slope (mainly due to gravity) exceed or equalize the soil strength that composes the slope. Landslides can be triggered by rainfall, snowmelt, changes in water level, stream erosion, changes in groundwater, earthquakes, volcanic activity, disturbance by human activities, or any combination of these factors. Landslides can move slowly (millimetres per year) or can move quickly and disastrously, as is the case of debris flows. Various types of landslides are associated with specific mechanics of slope failure and the kinds of material involved. Other classification systems incorporate additional variables, such as the rate of movement and the water, air, or ice content of the landslide material. Figure B.2 shows the classification of soil movements proposed by Varnes in 1978. Furthermore Vaunat et al. (1996) and Lerouueil et al. (1996) (Fig. B3) suggest to consider following 4 movement phases of a landslide:

1. Pre-failure
2. Failure
3. Post-failure
4. Reactivation

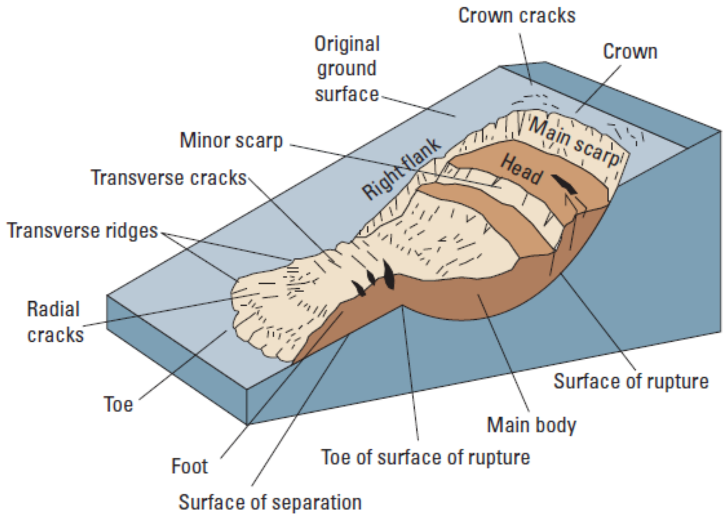

Fig. B.1 An idealized slump-earth flow with nomenclature for labelling the parts of a landslide (https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html)

TYPE OF MOVEMENT		TYPE OF MATERIAL		
		BEDROCK	ENGINEERING SOILS	
			Predominantly coarse	Predominantly fine
FALLS		Rock fall	Debris fall	Earth fall
TOPPLES		Rock topple	Debris topple	Earth topple
SLIDES	ROTATIONAL	Rock slide	Debris slide	Earth slide
	TRANSLATIONAL			
LATERAL SPREADS		Rock spread	Debris spread	Earth spread
FLOWS		Rock flow (deep creep)	Debris flow (soil creep)	Earth flow
COMPLEX		Combination of two or more principal types of movement		

Fig. B.2 Types of landslides. Abbreviated version of Varnes classification of slope movements (Varnes, 1978)

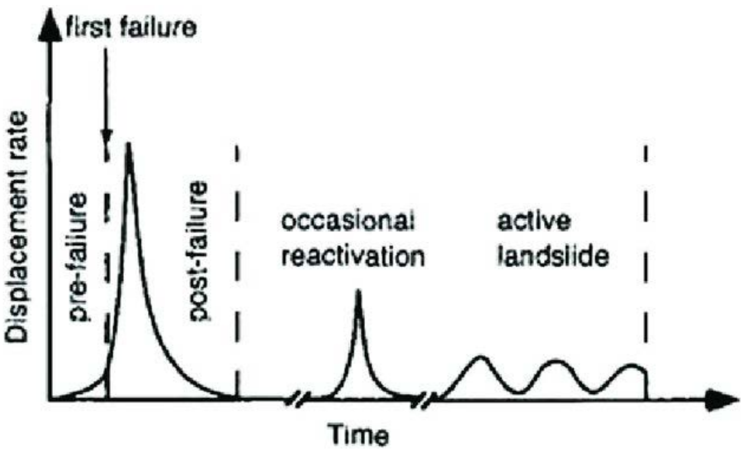

Fig. B.3 Stages of Slope Movements (Leroueil et al., 1996)

Limit equilibrium methods are commonly used to evaluate the slope stability from which derive the reliable indication of stability as the Factor of Safety. Probabilistic slope stability analysis allow uncertainty parameters (i.e. soil properties, environmental conditions, unexpected failure mechanisms, human mistake in design…) to be quantified and incorporated rationally into the design process (El-Ramly et al., 2002). Probabilistic factor of safety can be combined with spatial distribution of the intensity, in order to represent hazard maps (Haneberg, 2004).

In Europe, many countries have created or are creating a landslides inventory for regional landslides databases (LDBs), in order to obtain a quantitative zoning of landslide susceptibility, hazard and risk. Landslide inventory should give insight into the location (geographical coordinates, landslide site name, municipality, province or county, and region or state), landslide type, date of occurrence or last reactivation, state of activity, volume or surface extent. Additional information may include landslide geometry (surface dimensions and depth of failure surface), geology (lithology, structure and material properties), hydrogeology, land cover/use, slope geometry, triggering factors, impact (casualties and damage), remedial measures, surveying methods and date, surveyor's name and bibliographical references. Table B.2 summarizes some national landslide databases in Europe. For Italy more information on national and regional landslide databases can be collected from P.A.I. (Piano Stralcio di Bacino per l'Assetto Idrogeologico), it can be translate as Basin Plan for Hydrogeological Risk.

The landslide databases are crucial for the assessment of susceptibility, hazard and risk. Based on the definitions of The International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE) Technical Committee 32, various landslide zoning are available and can be improved:

- *Landslide Susceptibility zoning*
- *Landslide Hazard zoning*
- *Landslide Risk zoning*

National landslide databases in Europe (EU Member States and EFTA Countries)

Country	Database name	Holder (not necessarily producer)	Weblink
Albania	Landslide database	Albanian Geological Survey (GSA)	
Andorra	Natural hazard database of Andorra	Andorran Research Institute (IAE)	http://www.cenma.ad/mbaseriscos.htm
Andorra	Terrain zonation according to geological–geotechnical problems	Andorran Government	http://www.ideandorra.ad/geoportal/framesetup.asp
Austria	GEORIOS	Geological Survey of Austria (GBA)	http://geomap.geolba.ac.at/MASS/index.cfm
Bosnia and Herzegovina	The engineering geology map of Federation of Bosnia and Herzegovina	Federal Geology Survey	
Bulgaria	Map of landslides	Ministry of Regional Development and Public Works	
Czech Republic	National Landslide Register	Czech Geological Survey (CGS)	http://www.geology.cz/app/dbsesuvy (intranet; no public access)
Former Yugoslav Rep. of Macedonia	Landslide Cadastre	Ministry of Economy, Sector for Mineral Resources	
France	National Database of Ground Movements (BDMvT)	French Geological Survey (BRGM)	http://www.bdmvt.net
Greece	Geodatabase I.G.M.E./ eng_geol/ ground_failures	Institute of Geology and Mineral Exploration (IGME)	http://maps.igme.gr/website_ext/igme_master_ext/viewer.htm
Hungary	National Landslides Cadastre	Hungarian Office for Mining and Geology	
Iceland	OLI	Icelandic Meteorological Office (IMO) and Icelandic Institute of Natural History (IINH)	
Ireland	National Landslide Database	Geological Survey of Ireland (GSI)	http://www.gsi.ie/mapping.htm
Italy	IFFI Project	Institute for Environmental Protection and Research (ISPRA)	http://www.sinanet.apat.it/progettoiffi
Italy	Areas Affected by Landslides and Floods in Italy (AVI)	National Research Council, Research Institute for Hydrogeological Protection (CNR-IRPI)	http://avi.gndci.cnr.it; http://sici.irpi.cnr.it
Norway	National Landslide Database	Geological Survey of Norway (NGU)	www.skrednett.no
Poland	SOPO	Polish Geological Institute (PGI)	
Portugal	Disaster database	Centre of Geographical Studies, University of Lisbon	
Slovakia	Landslide Register	Geological Survey of the Slovak Republic (SGUDS)	
Slovenia	GIS_UJME (part of larger database)	Ministry of Defense	
Spain	Spanish Database of Geological Hazards	Geological and Mining Institute of Spain (IGME)	
Sweden	Swedish Natural Hazards Information System (MSB)	Swedish Civil Contingencies Agency (MSB)	http://ndb.msb.se/
Sweden	SGI Landslide database	Swedish Geotechnical Institute (SGI)	http://gis.swedgeo.se/skred/; http://www.geodata.se/
Switzerland	InfoSlide	Federal Environmental Office (OFEV)	
United Kingdom	National Landslide Database	British Geological Survey (BSG)	http://www.bgs.ac.uk/landslides/ (only information on the database)

SAFETY FACTOR (F_S): the evaluation of slope stability safety factors is a routine practice, defining a not unique Factor of Safety of slopes. In the conventional limit equilibrium methods, the Factor of Safety is intended as “the factor by which the shear strength of the soil would have to be divided to bring the slope into a state of barely stability equilibrium” (Duncan, 1996). This definition, called “the strength-reserving” definition, is the most familiar to engineers (Zheng et al., 2005). For example, referring to the equilibrium equations of a slice, the shear force acting on the slice bottom along a slide line is assumed to be:

$$\frac{1}{F_{Ss}}(cl + N\text{tg}\varphi) \qquad \text{(B.1)}$$

in which l is the length of the slice bottom, N is the normal force acted on the slice bottom, c and φ are shear strength parameters, and F_S denotes the Safety Factor associated with the strength reserving definition. The subscript s in F_{Ss} represents “strength-reserving”.

Other authors as Farias & Naylor (1988), Wang, Yamagami & Ueta (1988), Zou and Williams (1995) suggest the following definition of the Factor of Safety in the finite element slope stability analysis, called the “overloading” definition (Zheng et al., 2005):

$$F_{So} = \min_{s \in S} \frac{\int_S [\tau_f] ds}{\int_S \tau ds} \qquad \text{(B.2)}$$

The subscript o in F_{So} represents “overloading”. τ_f is the shaft strength of soil, τ is the shaft stress at the possible surface of slip line, S is a set of some potential slip lines (straight or arc) and s represents a certain slip line in set S.

<u>OCCURRED LANDSLIDE AREA/RISK AREA (L_A/R_A)</u>: index coming out from both analytical and observational considerations. It represents the observed surface which moves downward of a mass of rock, earth, or artificial fill on a slope (L_A) divided by the surface subjected to the high and medium landslide risk obtained by analytical modelling (R_A) (in percentage). The main scopes of the index is to assess the effectiveness of the adopted design solution for either the entire or the partial area referred to the total risk area.

<u>VELOCITY OF OCCURRED LANDSLIDE (V_L)</u>: factor having significant relevance in the landslide classification. A velocity range is connected to the different types of landslides, on the basis of observation of either case histories or site observations (Cruden & Varnes, 1996).

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	mm/sec	Class	Description	Example nos. (Table 3.4)		mm/sec
		7	Extremely rapid	1-7		
3 m/sec	3×10^3	-------	-------------------	----------	5 m/sec	5×10^3
600		6	Very rapid	8	100	
0.3 m/min	5	-------	-------------------	----------	3 m/min	50
288		5	Rapid	9	100	
1.5 m/day	17×10^{-3}	-------	-------------------	----------	1.8 m/hour	0.5
30		4	Moderate	10	100	
1.5 m/month	0.6×10^{-3}	-------	-------------------	----------	13 m/month	5×10^{-3}
12		3	Slow	11,12	100	
1.5 m/year	48×10^{-6}	-------	-------------------	----------	1.6 m/year	50×10^{-6}
25		2	Very Slow	13-16	100	
0.06 m/year	1.9×10^{-6}	-------	-------------------	----------	16mm/year	0.5×10^{-6}
		1	Extremely Slow			

Fig. B.4 Velocity Classes (Cruden & Varnes, 1996)

Sub-Criterion Indicators: Landslide Risk Resilience

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Safety Factor	Model	Model	Model
Occurred Landslide Area/Risk Area	Model/Survey	Model/Survey	Model/Survey
Velocity of Occurred Landslide	Model/Survey	Model/Survey	Model/Survey

B1.1.2 SUB-CRITERION: Flooding Risk Resilience

Sub-Criterion Table: Flooding Risk Resilience

SUB-CRITERION	Indicators will assess....
Flooding Risk Resilience	the site response to Flooding phenomena based on susceptibility indicators: land use cover, run-off coefficient, rainfall intensity and duration

The hydrological cycle reproduces how the water leaves the atmosphere and falls to earth as precipitation, entering surface waters or percolating into the water table and groundwater and eventually is taken back into the atmosphere by transpiration and evaporation to begin the cycle again. It is composed of following main physical processes (https://water.usgs.gov/edu/watercyclecondensation.html):

- *Evaporation*: the process by which water changes from a liquid to a gas or vapour. Evaporation is the primary pathway that water moves from the liquid state back into the water cycle as atmospheric water vapour;
- *Transpiration*: aspect of evapotranspiration, essentially provoked by the evaporation of water from plant leaves. It accounts for about 10% of the moisture in the atmosphere, with oceans, seas, and other bodies of water (lakes, rivers, streams) providing nearly 90%, and a tiny amount coming from sublimation (ice changing into water vapour without first becoming liquid);
- *Condensation*: process by which water vapour in the air is changed into liquid water. It is responsible for the formation of clouds. These latter may produce precipitation, which is the primary route for water to return to the Earth's surface within the water cycle. Condensation is the opposite of evaporation;
- *Precipitation*: precipitation in the form of rain, snow and hail comes from clouds. Clouds move around the world, propelled by air currents. When they rise over mountain ranges, they cool, becoming so saturated with water that water begins to fall as rain, snow or hail, depending on the temperature of the surrounding air;
- *Surface Runoff*: excessive rain or snowmelt can produce overland flow to creeks and ditches. Surface runoff is visible flow of water in rivers, creeks and lakes as the water stored in the basin drains out. It is affected by meteorological factors (type of precipitation, rainfall intensity, rainfall amount, rainfall duration, distribution of rainfall over the drainage basin, direction of storm movement, precipitation occurring earlier and resulting soil moisture, other meteorological and climatic conditions such as temperature, wind, relative humidity and season) and physical characteristics (land use, vegetation, soil type, drainage area, basin shape, elevation, topography, drainage network patterns, ponds, lakes, reservoirs, sinks,...);

- *Percolation*: some of the precipitation and snow melt moves downwards, percolates or infiltrates through cracks, joints and pores in soil and rocks until it reaches the water table where it becomes groundwater;
- *Groundwater*: subterranean water is held in cracks and pore spaces. Depending on the geology, the groundwater can flow to support streams. It can also be tapped by wells. Some groundwater is very old and may have been there for thousands of years.

The surface runoff is the main process to generate the surface flows. With reference to the rainfall-runoff modelling, the peak flow of a river derives from the hydrograph (graph showing the flow rate, or discharge, versus time past a specific point in a river, channel, or conduit carrying flow) in response to a rainfall event represented by and input as a hyetograph (graphical representation of distribution of rainfall intensity over time). Rainfall-runoff models may include other input variables, such as temperature, information on the catchment or others. In other words, the model calculates the conversion of rainfall into runoff. It is defined flood when the rainfall event is such that the discharge submerges areas usually dry, having different land uses.

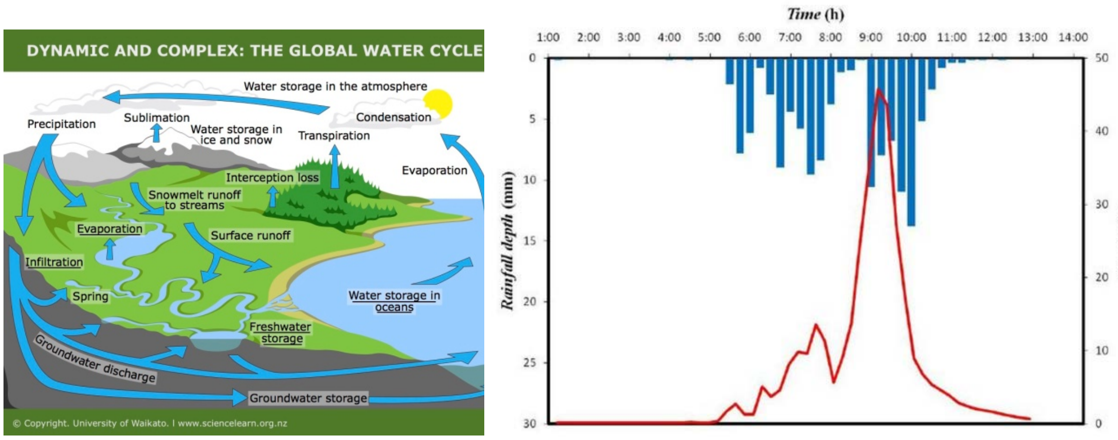

Fig. B.5 Scheme of the global water cycle (left) and sample of hyetograph and corresponding hydrograph (right)

- PEAK FLOW: maximum rate of discharge during the period of runoff caused by a rainfall event. For a time period of T years, the T years-recurrence peak flow Q_T is defined as a value of discharge, which occurs statistically each T years. More precisely, Q_T is defined by the fact that probability to have a maximal annual discharge greater than Q_T is equal to *1/T*. It is influenced by both the basin (size, shape, geographical location, topography, geology, type of vegetal cover, extent of surface detention) and the rainfall event characteristics (intensity, duration, spatial and temporal distribution pattern, storm direction).

The peak flow can be estimated by applying two main approaches: probabilistic and deterministic models. Probabilistic models are based on statistical inference which essentially estimates the design variables by fitting the observed data (De Risi et al., 2013). Deterministic models are based upon the peak flow estimation through analytical relationships and provide a point estimate without uncertainty assessment. Rainfall-Runoff models are applicable to estimate the peak flow. These are usually applied when flow observations are not available and, thus, they require the use of rainfall data (more easily available) to quantify the required data. The peak flow is generated by mechanisms conditioned by both human impacted environment and anthropogenic forcing. Due to the inability to model the related data (i.e. the difficulty in reproducing the geometry of the system) the peak flow estimation is affected by uncertainty, thus, the deterministic approaches significantly result ineffective in reproducing the required entity. Nevertheless, the probabilistic models should always be based on physical basic (in compliance with both the Newton's laws and the mass, energy and momentum conservation principles). The physically-based stochastic models assume that floods can be intended as random events, to be associated to random variables. Therefore, the peak flow is treated as a random variable, namely the association between the flood event and a real number. The physically-based stochastic model is able to estimate the peak flow, intended as a random variable, by applying a physically-based approach. The stochastic approach thus requires the estimation of a probability distribution to describe the occurrence frequency of peak flow data. The probability distribution of peak flows usually requires the estimation of the frequency occurrence of annual maxima. According to this procedure, the annual maximum return period T is the average interval between years containing a flood of flow of at least the assigned magnitude (Montanari, 2016). The most widely applied probability distribution is the Gumbel one. Its capability to provide a good fit can be tested by applying statistical tests (e.g. the Kolmogorov-Smirnov test). The annual maxima method thus needs sufficiently long series of annual maxima. The model requires the estimation of the mean value $E(x)$ and standard deviation $\sigma(x)$. Further widely used probability distributions are the Frechet and the Generalized Extreme Value (GEV) ones. The limit in using the annual maxima method is the disadvantage of considering a single value per each year. In order to overcome this limitation, the Peak-Over-Threshold (POT) method can be considered, based on taking into account all the peak values exceeding a fixed threshold.

Nevertheless, when data are not available for the considered section, estimation methods for ungauged catchments could be applied. Among them, referring to a nearby gauged location, for which the peak flow estimation could be obtained by using the annual maxima method can be applied and then rescaled to the section of interest.

The concept of hydrologic similarity can be extended to several sections, included into a "homogeneous region", so as to estimate the peak flow $Q(x,T)$ for the location x and the return period T as:

$$Q(x,T) = i(x)F(T) \tag{B.3}$$

where $i(x)$ is the site-dependent mean annual flood, namely the average of the annual maxima, and $F(T)$ is the regional frequency curve, resulting invariant over the homogeneous region. The regional frequency curve is estimated by fitting a suitable probability distribution to the sample of the specific peak flows (i.e. peak flow per unit catchment area). When observed data are not available, the index flood can be estimated by applying regression techniques, depending on key factors of contributing catchment, which may include meteoclimatic and/or geomorphological features (Giugni et al., 2015; De Risi et al., 2015; Montanari, 2016). When available data are scarce, the rainfall-runoff models can be applied, able to reproduce the rainfall-runoff transformation by explicitly or implicitly using the law of physics. The concept of these methods is to combine the available rainfall data with additional properties of the considered site. To this category, the Rational Formula estimates the peak flow Q [L^3/T] for a catchment with area A [L^2], as a function of the rainfall intensity i [L/T] and the runoff coefficient C [-]:

$$Q = C \cdot i \cdot A \tag{B.4}$$

Under certain assumptions, it can be intended that the rainfall duration causing the most severe response by the catchment, in terms of peak flow, is equal to the time of concentration of the catchment. The time of concentration represents the time required for a fluid particle to travel from the most hydraulically distant part of a watershed to its outlet section. It is usually estimated through empirical relationship (e.g. Giandotti's formula in Italy);

- PEAK VOLUME: represents volume of water corresponding to the peak flow. Flood volumes are related to 1) the time scales of the meteorological inputs (rainfall, snowmelt) and 2) the time scales of the storage and delay of this input in the catchment (Gaàl et al., 2015). The volumes are strictly related to the peak flow, depending on the catchment properties, the rainfall durations and the catchment processes. The flood volume is intended as the total volume between the time of the apparent sudden rise of the hydrograph and the time when the descending limb again reached the initial discharge (Kovàcs, 1978).

- FLOODED AREA: area submerged by discharge during the flooding event. Susceptible flooding area maps are available, using different colours to mark out zones exposed to different level of risk from fluvial and tidal flooding. The US Federal Emergency Management Agency (FEMA, 2009) developed Flood Insurance Rate Maps (FIMs) to delimit the area subjected to flooding high-risk, moderate-to-low risk, and areas with undetermined risk, according to the following categories:
  - **HIGH-RISK AREAS: SPECIAL FLOOD HAZARD AREAS:** high-risk areas having at least 1% annual change of flooding, defined Base Flood;
  - **MODERATE-TO-LOW RISK AREAS: NON-SPECIAL FLOOD HAZARD AREAS:** in moderate-to-low risk areas, the risk of being flooded is

reduced, but not completely removed. These areas are outside the 1% annual chance floodplain, therefore flood insurance is not required. However, insurance can be obtained at a reduced cost for property owners and renters. These moderate-to-low risk areas are shown on the flood maps;

- **UNDETERMINED RISK AREAS:** No flood-hazard analysis has been conducted in these areas, but a flood risk still exists. Flood insurance rates reflect the uncertainty of the flood risk. These areas are shown on the flood maps.

HIGH-RISK AREAS: SPECIAL FLOOD HAZARD AREAS	
ZONE A	Areas with a 1% annual chance of flooding and a 26% chance of flooding over the life of a 30 year mortgage. Because detailed analyses are not performed for such areas; no depths or base flood elevations are shown within these zones
ZONE AE	The base floodplain where base flood elevations are provided
ZONE AH	Area with 1% annual chance of shallow flooding, usually in the form of a pond, with an average depth ranging from 1 to 3 feet. These areas have a 26% chance of flooding over the life of 30-year mortgage. Base flood elevations derived from detailed analyses are shown at selected intervals within these zones
ZONE AO	River or stream flood hazard areas, and areas with a 1% or greater chance of shallow flooding each year, usually in the form of sheet flow, with an average depth ranging from 1 to 3 feet. These areas have a 26% chance of flooding over the life of a 30-year mortgage. Average flood depths derived from detailed analyses are shown within these zones
ZONE AR	Areas with a temporarily increased flood risk due to the building or restoration of a flood control system (such as a levee or a dam). Mandatory flood insurance purchase requirements will apply, but rates will not exceed the rates for unnumbered A zones if the structure is built or restored in compliance with Zone AR floodplain management regulations
ZONE A99	Areas with a 1% annual chance of flooding that will be protected by a Federal flood control system where construction has reached specified legal requirements. No depths are base flood elevation are shown within these zones
ZONE V	Coastal areas with a 1% or greater chance of flooding and an additional hazard associated with storm waves. These areas have a 26% chance of flooding over the life of a 30-year mortgage. No base flood elevations are shown within these zones
ZONE VE, V1 - 30	Coastal areas with a 1% or greater chance of flooding and an additional hazard associated with storm events. These areas have a 26% chance of flooding over the life of a 30-year mortgage. Base flood elevations derived from detailed analyses are shown at selected intervals within these zones

Table B.1 FEMA High-Risk Areas of FIMs

MODERATE-TO-LOW RISK AREAS: NON-SPECIAL FLOOD HAZARD AREAS	
ZONE B and X (shaded)	Area of moderate flood hazard, usually the area between the limits of the 100-year and 500-year floods. B Zones are also used to designate base floodplains of lesser hazards, such as area protected by levees from 100 year flood, or shallow flooding areas with average depths of less than one foot or drainage areas less than 1 square mile
ZONE C and X (shaded)	Area of minimal flood hazard, usually depicted on FIRMs as above the 500-year flood level. Zone C may have ponding and local drainage problems that don't warrant a detailed study or designation as base floodplain. Zone X is the area determined to be outside the 500-year flood and protected by levee from 100-year flood

Table B.2 FEMA Moderate-to-Low Risk Areas of FIMs

UNDETERMINED RISK AREAS	
ZONE D	Areas in which flood hazards are undetermined, but possible No flood hazard analysis has been conducted Flood insurance rates are commensurate with the uncertainty of the flood risk.

Table B.3 FEMA Undetermined Risk Areas of FIMs

- Alternative approaches are based on the implementation of numerical simulations, which combining GIS-based software and hydraulic solvers, are able to detected the flooding areas, as a function of the set forcing, through one-dimensional (e.g. HEC-RAS of the US Army Corps of Engineers), two-dimensional (e.g. FLO-2D of the FLO-2D software Inc.) or tri-dimensional (e.g. ANUGA Hydro developed by the Australian National University).

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Peak Flow	Model	Model	Model
Peak Volume	Model	Model	Model
Flooded Area	Model/GIS	Model/GIS	Model/GIS

Table B.4 Sub-criterion Indicators: Flooding Risk Resilience

B1.1.3 SUB-CRITERION: Snow Avalanches Risk Resilience

SUB-CRITERION	Indicators will assess....
Snow Avalanche Risk Resilience	the site response to Snow avalanche phenomena based on susceptibility indicators: topography, wind, temperature

Table B.5 Sub-Criterion Table: Snow Avalanches Risk

A snow avalanche is a mass of snow, ice and debris flowing and sliding rapidly down a steep slope. The forces generated by moderate or large avalanches can damage or destroy most manmade structures. The debris from even small avalanches is enough to block a highway or railroad. Avalanche occurrence is directly related to topography, climate, vegetation and aspect of the area (Martinelli Jr., 1974). The Group of European

Avalanche Warning Services intended an avalanche as a snow mass with typically a volume greater than 100 m^3 and a minimum length of 50 m that slides rapidly downhill (EAW).

Avalanche formation is the result of a complex interaction between terrain, snow pack and meteorological conditions (e.g. slope steepness, depth of snow cover, volume of weak layers in the snow (ice) cover, water saturation, and other effects (wind, seismic activities, etc.).

The vulnerability for avalanches can be calculated based on two data sets: first, a map of snow cover duration; and second, a digital elevation model (DEM).

The snow cover was classified by the mean duration of snow cover for each raster cell. A snow cover of less than 10 days was assumed to be a no-risk zone: as the duration relates to the whole year, the snow accumulation is not expected to become unstable and build up avalanches. Areas with more than 10 days of snow cover were classified into three classes (Dige et al., 2015), as shown in Table B.10.

Table 4.7 Hazard potential 'Avalanches'

Class	Length of snow cover AND slopes > 15° per 1 km cell	Hazard potential
Outside area	0–10 days	Snow outside mountains (no avalanches assumed)
Low	10–90 d (< 3 months)	Low
Medium	90–180 d (3–6 months)	Medium
High	180–365 d (6 months–1 year)	High

Table B.6 Hazard of Avalanches Classes (Dige et al., 2015)

The land relief was used as second Indicator for avalanche vulnerability. Values in literature define a slope of ± 30° as threshold in starting zones of avalanches (Schweizer & Jamieson, 2000). Due to strong generalization, the threshold for the occurrence of avalanches was assigned at a lower slope value of 15°, to take into account the steeper slope on a smaller scale. A mask was calculated to exclude regions with slope values smaller than 15°. Cells with a slope > 15° were assumed to be in danger of avalanches. The output of the calculation is a raster indicating areas where avalanches could appear, based on snow cover duration and morphology.

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Snow Cover Map	GIS/Statistical Data	GIS/Statistical Data	GIS/Statistical Data
Digital Terrain Model (DEM)	GIS	GIS	GIS
Land Relief	GIS	GIS	GIS/Model

Table B.7 Sub-Criterion Indicators: Snow Avalanches Risk

B1.1.4

B1.1.5 SUB-CRITERION: Drought Risk Resilience

SUB-CRITERION	Indicators will assess....
Drought Risk Resilience	the site response to drought phenomena based on susceptibility indicators: land use cover, temperature, moisture, wet weather

Table B.8 Sub-Criterion Table: Drought Risk Resilience

Drought is a continuous period of dry weather, when an area gets less than its normal amount of rain, over months or even years. Crops and other plants need water to grow and animals need it to live. Droughts can become dangerous to people and other land animals causing famine and even creating deserts. A drought is a natural event, caused by other weather events and high-pressure systems. Drought can also be triggered by deforestation, by global warming, and by diverting rivers or emptying lakes. It can have a significant impact on the ecosystem and agriculture of the affected region and harm to the local economy.

Fig. B.6 Land cracked by drought (https://civildigital.com/water-resources-management-in-drought-conditions)

- STANDARDIZED PRECIPITATION INDEX (SPI): the Standardized Precipitation Index (SPI) is a widely used index to characterize meteorological drought on a range of timescales. On short timescales, the SPI is closely related to soil moisture, whereas at longer timescales, the SPI can be related to groundwater and reservoir storage. The SPI can be compared across regions with markedly different climates. It quantifies observed precipitation as a standardized departure from a selected probability distribution function that models the raw precipitation data. The raw precipitation data are typically fitted to a Gamma or a Pearson Type III distribution, and then transformed to a Normal Distribution. The SPI values can be interpreted as the number of standard deviations by which the observed anomaly deviates from the Long-Term mean. The SPI can be estimated with reference to differing periods of 1-to-36 months, using monthly input data. For the operational community, the SPI has been recognized as the standard index that should be available worldwide for quantifying and reporting meteorological drought. Concerns have been raised about the utility of the SPI as a measure of changes in drought associated with climate change, as it does not deal with changes in evapotranspiration (https://climatedataguide.ucar.edu/).

- EFFECTIVE DROUGHT INDEX (EDI): Byun & Wilhite (1999) developed the Effective Drought Index (EDI), which is an intensive measure that considers daily water accumulation with a weighting function for time passage. The EDI can be calculated as:

$$EP = \sum_{n=1}^{i}\left[\left(\sum_{m=1}^{n} P_m\right)\Big/ n\right] \quad \text{(B.5)}$$

$$DEP = EP - MEP \quad \text{(B.6)}$$

$$EDI = DEP \big/ SD\left(DEP\right) \quad \text{(B.7)}$$

In the Eq. (B.5), *EP* represents the valid accumulations of precipitation, P_m the precipitation level for a day, *m* the number of days prior to a specific date, whereas the index *i* starts from 365. Thus, *EP* becomes the valid accumulation of precipitation for 365 days from a particular date. *DEP* in the Eq. (B.6) is the deviation of *EP* from *MEP* (30-year average EP for the calendar date). When *DEP* is negative for two consecutive days, *i* becomes 366 (=365+2-1) and the calculation begins once again. Therefore, the drying effect of the soil from a drought that occurred several years ago is reflected in the EDI. The “drought range” of the EDI is summarized in the following Tab. B.11. The Eq. (B.7) allows to estimate the EDI as the ratio between the *DEP* and the standard deviation of the DEP.

EDI	DROUGHT LEVEL
≤ -2.0	Extreme Drought
-2.0 ÷ -1.5	Severe Drought
-1.5 ÷ -1.0	Moderate Drought
-1.0 ÷ 1.0	Near Normal Condition

Table B.9 EDI Categories

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Standardized Precipitation Index (SPI)	Model	Model	Model
Effective Drought Index (EDI)	Model	Model	Model

Table B.10 Sub-Criterion Indicators: Drought Risk Resilience

B1.2 CRITERION: Exposure

People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses. Measures of exposure can include the number of people or types of assets in an area. These can be combined with the specific vulnerability of the exposed elements to any particular hazard to estimate the quantitative risks associated with that hazard in the area of interest (UNISDR Terminology, 2009).

B1.2.1 SUB-CRITERION: Potential Areas Exposed to Risks

SUB-CRITERION	Indicators will assess....
Potential Areas Exposed to Risk	the potential areas exposed to risk

Table B.13. Sub-Criterion Table: Potential Areas Exposed to Risks

- URBAN/RESIDENTIAL AREAS ($A_{U/R}$): an urban area or urban agglomeration is a human settlement with high population density and infrastructure of built environment. Urban areas are created through urbanization and they are categorized by urban morphology as cities, towns, conurbations or suburbs. In urbanism, the term contrasts with rural areas such as villages and hamlets and in urban sociology or urban anthropology, it contrasts with natural environment. The creation of early predecessors of urban areas during the urban revolution led to the creation of human civilization with modern urban planning, which along with other human activities, such as exploitation of natural resources, leads to human impact on the environment. A residential area is a land used in which housing predominates, as opposed to industrial and commercial areas. Housing may significantly vary between, and through, residential areas. These include single-family housing, multi-family residential, or mobile homes. Zoning for residential use may permit some services or work opportunities or may totally exclude business and industry. It may permit either high density land use or only low density uses. Residential zoning usually includes a smaller FAR (Floor Area Ratio or the ratio of a building's total floor area and the size of the land piece which it is built) than business, commercial or industrial/manufacturing zoning. The area may be large or small;

- PRODUCTIVE AREAS (AGRICULTURE, GRAZING, INDUSTRIES) (A_{AGI}): the areas utilized for the agricultural, grazing and industrial productions. Agricultural production data refers to vegetable and fruit production that is made available for human consumption. Grazing and pasture production are meat, milk and other products available for the human consumption obtained by the method of feeding in which a herbivore feeds on plants such as grasses, or other multicellular organisms such as algae. Industrial production is a measure of output of the industrial sector of the economy. The industrial sector includes manufacturing, mining, and utilities;

- NATURAL AREAS, SITE OF COMMUNITY IMPORTANCE (SCI), SPECIAL PROTECTION AREAS (SPA): The Indicator describes the extension, measured in hectares, of Site of Community Importance (SCI) and Special Protection Areas (SPA) in the study area. The Indicator will hardly change in the Design and long-term scenario, even if it could be assessed if the NBSs implementation have produced such a beneficial impact on biodiversity to activate EU procedures in order to enlarge SCI and/or SPA perimeter.

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Urban/Residential Areas	GIS	GIS	GIS
Productive Areas (Agriculture, Grazing, Industries)	GIS	GIS	GIS
Natural Areas, Site of Community Importance (SCI), Special Protection Areas (SPA)	Model/Survey	Model/Survey	Model/Survey

Table B.11 Sub-Criterion Indicators: Potential Areas Exposed to Risks

B1.2.2 SUB-CRITERION: Potential Population Exposed to Risks

SUB-CRITERION	Indicators will assess....
Potential Population Exposed to Risk	the potential population exposed to risk

Table B.12 Sub-Criterion Table: Potential Population Exposed to Risks

- INHABITANTS: number of people that inhabit a place, especially as permanent residents;

- OTHER PEOPLE: number of workers, tourists, homeless etc.;

- ELDERLY, CHILDREN, DISABLED: number of people old or aging, young human people being below either the age of puberty or the legal age of majority, people with an impairment that may be cognitive, developmental, intellectual, mental, physical, sensory, or some combination of these.

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Inhabitants	Statistical Data	Model/Statistical Data	Model
Other People (Workers, Tourists, Homeless)	Statistical Data	Model/Statistical Data	Model
Elderly, Children, Disabled	Statistical Data	Model/Statistical Data	Model

Table B.13 Sub-Criterion Indicators: Potential Population Exposed to Risks

B1.2.3 SUB-CRITERION: Potential Species Exposed to Risk

SUB-CRITERION	Indicators will assess....
Potential Species Exposed to Risk	the potential animal species exposed to risk

Table B.14 Sub-Criterion Table: Potential Species Exposed to Risks

- DOMESTIC AND WILD FAUNA: livestock and protected species.

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Domestic and Wild Fauna (livestock and protected species)	Statistical Data	Model	Survey

Table B.15 Sub-Criterion Indicators: Potential Species Exposed to Risks

B1.2.4 SUB-CRITERION: Potential Buildings Exposed to Risks

SUB-CRITERION	Indicators will assess....
Potential Buildings Exposed to Risk	the potential buildings exposed to risk

Table B.16 Sub-Criterion Table: Potential Buildings Exposed to Risks

- HOUSING: density of buildings where people live in, or the providing of places for people to live;
- AGRICULTURAL AND INDUSTRIAL BUILDINGS: density of factories and other premises used for manufacturing, altering, repairing, cleaning, washing, breaking-up, adapting or processing any article, generating power or slaughtering livestock;
- STRATEGIC BUILDINGS: density of buildings allocated to civil protection activities of local authorities, public and private sanitary facilities equipped with first aid, Regional, Provincial, Municipal and Mountain Communities administrative offices.

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Housing	Statistical Data	Model	Model
Industrial Buildings	Statistical Data	Model	Model
Strategic Buildings (Hospital, School,…)	Statistical Data	Model	Model

Table B.17 Sub-Criterion Indicators: Potential Buildings Exposed to Risks

B1.2.5 SUB-CRITERION: Potential Infrastructures Exposed to Risks

SUB-CRITERION	Indicators will assess....
Potential Infrastructures Exposed to Risk	the potential infrastructures exposed to risk

Table B.18 Sub-Criterion Table: Potential Infrastructures Exposed to Risks

- ROADS: length per km^2 of a wide way leading from one place to another, especially one with a specially prepared surface which vehicles can use;
- RAILWAYS: length per km^2 of a track made of steel rails along which trains run;
- LIFELINES (WATER MAIN, SEWERAGE, PIPELINE,...): distributive systems and related facilities necessary to provide electric power, oil and natural gas, water and wastewater, and communications.

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Roads	Statistical Data	Model	Model
Railways	Statistical Data	Model	Model
Lifelines (Water main, Sewerage, Pipeline,...)	Statistical Data	Model	Model

Table B.19 Sub-Criterion Indicators: Potential Infrastructures Exposed to Risks

B1.3 CRITERION: Vulnerability

Vulnerability represents the capacity to resist to the damaging effects of a hazard or to respond when a disaster occurs. Vulnerability varies significantly within a community and over time, resulting from different physical, social, economic, and environmental factors. This definition identifies vulnerability as a property of the element of interest (community, system or resource) that is independent of its exposure. Vulnerability depends on several factors, such as the entity of the forcing event, the people's age and state of health, as well as on the quality and state of buildings and infrastructures and their location with respect to any hazards (UNISDR Terminology, 2009).

B1.3.1 SUB-CRITERION: Potential Population Vulnerable to Risks

SUB-CRITERION	Indicators will assess....
Potential Population Vulnerable to Risks	the potential population vulnerable to risk

Table B.20 Sub-Criterion Table: Potential Population Vulnerable to Risks

- POPULATION: Vulnerability of population (inhabitants of a particular place). For instance, the vulnerability of people is strictly connected to the vulnerability of buildings where they live.

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Population	Statistical Data	Model	Model

Table B.21 Sub-Criterion Indicator: Potential Population Vulnerable to Risks

B1.3.2 SUB-CRITERION: Potential Economic Effects due to Risks

SUB-CRITERION	Indicators will assess....
Potential Economic Effects due to Risks	the potential economic effects due to risk

Table B.22 Sub-Criterion Table: Potential Economic Effects due to Risks

- ECONOMIC VALUE OF THE PRODUCTIVE ACTIVITIES VULNERABLE TO RISKS: vulnerability of productive activities, such as the economic value of agricultural fields, workers number, etc. For instance, agricultural productivity along rivers is more vulnerable to floods than industrial productivity.

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Economic Value of the Productive Activities Vulnerable to Risks	Statistical Data	Model	Model

Table B.23 Sub-Criterion Indicator: Potential Economic Effects due to Risks

B1.3.3 SUB-CRITERION: Potential Infrastructures Vulnerable to Risks

SUB-CRITERION	Indicators will assess....
Potential Infrastructures Vulnerable to Risks	the potential infrastructures and buildings vulnerable to risk

Table B.24 Sub-Criterion Table: Potential Infrastructures Vulnerable to Risks

- BUILDINGS: vulnerability of housing, industrial buildings and strategic buildings. For instance, a wooden house is sometimes less likely to collapse in an earthquake, but it may be more vulnerable in the event of a fire or a hurricane;
- TRANSPORTATION INFRASTRACTURES AND LIFELINES: Vulnerability of transportation infrastructures like roads and railways, and vulnerability of lifelines (water distribution systems, sewerage, pipelines, energy lifelines,...).

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Buildings	Statistical Data/GIS	Model/GIS	Model/Statistical Data/GIS
Transportation Infrastructures and Lifelines	GIS	GIS	GIS

Table B.25 Sub-Criterion Table: Potential Infrastructures Vulnerable to Risks

B2 AMBIT: Technical & Feasibility Aspects

B2.1 CRITERION: Technical Feasibility (Affordability)

Technical feasibility is the complete study of the project in terms of input, processes, output, fields, programs and procedures. It is a highly effective tool for long term Design and trouble-shooting that can be used to evaluate investments from various perspectives, e.g. technical, social, legal, financial, market, and organizational. The technical feasibility study should most essentially support the financial information of an organization.

B2.1.1 SUB-CRITERION: Cost-Benefit Analysis of the Intervention

SUB-CRITERION	Indicators will assess....
Cost-Benefit Analysis of the Intervention	Cost-Benefit Analysis of the Intervention

Table B.26 Sub-Criterion Table: Cost-Benefit Analysis of the Intervention

Financial feasibility is often a predominant factor in feasibility analysis, as most investments are not relevant if they do not generate profit or social benefits. The financial assessment must ensure that enough money is available for paying ongoing costs over the life of the project:

- INITIAL COSTS: project's initial costs are those occurring during the design and construction phases;
- MAINTENANCE COSTS: maintenance expenses are the costs incurred to keep an item in good condition or good working order;
- REPLACEMENT COSTS: replacement costs or replacement values refer to the amount that an entity would have to pay to replace an asset at the present time, according to its current worth;
- AVOIDED COSTS: avoided costs are essentially the costs of the damages which a catastrophic event could provoke without the expected intervention;
- PAYBACK PERIOD: the length of time required for the expected intervention to recover the cost of an investment. The payback period of a given investment or project is an important determinant of whether to undertake the position or project, as longer payback periods are typically not desirable for investment positions.

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Initial Costs	Model	Model	Model
Maintenance Costs	Model	Model	Model
Replacement Costs	Model	Model	Model

Avoided Costs	Model	Model	Model
Payback Period	Model	Model	Model

Table B.27 Sub-Criterion Indicators: Cost-Benefit Analysis of the Intervention

B2.1.2 SUB-CRITERION: Application of Suitable Materials and Technologies

SUB-CRITERION	Indicators will assess....
Application of Suitable Materials and Technologies	the application of suitable materials and technologies

Table B.28 Sub-Criterion Table: Application of Suitable Materials and Technologies

- MATERIAL USED COHERENCE: it assesses whether the building materials used are coherent or not with local natural materials and if they produce negative impacts on landscape perception;
- TECHNIQUES USED COHERENCE: it assesses whether the typology of used techniques is invasive or not for landscape (e.g. huge excavation, cave, deforestation to build new road for caterpillars). In a long-term scenario, those above mentioned Indicators could be re-assessed, monitoring, through a direct survey, if the materials/techniques used have produced impact on landscape.

INDICATOR	Scenarios		
	Baseline	**Design**	**Long-term**
Material Used Coherence	Survey/Living Labs	Dichotomic Scale	Dichotomic Scale
Techniques Used Coherence	Survey/Living Labs	Dichotomic Scale	Dichotomic Scale

Table B.29 Sub-Criterion Indicators: Application of Suitable Materials and Technologies

B3 AMBIT: Environment & Ecosystems

B3.1 CRITERION: Water

Water quality is determined by physical, chemical, microbiological and biological properties of water and by properties of whole river ecosystems.

B3.1.1 SUB-CRITERION: Effects on Water Quality

SUB-CRITERION	Indicators will assess....
Effects on Water Quality	the effects on water quality

Table B.30 Sub-Criterion Table: Effects on Water Quality

- EXTENDED BIOTIC INDEX (EBI): The Extended Biotic Index (EBI) is based on the analysis of macroinvertebrate communities that colonize river ecosystems. These communities live in the substrate and are composed of populations characterized by different levels of sensitivity to environmental modifications and with different ecological roles. Since macroinvertebrates have relatively long life cycles, the index provides integrated information over time on the effects caused by different causes of disruption (physical, chemical and biological). In monitoring the quality of running waters it must therefore be considered a complementary method to the chemical and physical control of water. http://www.isprambiente.gov.it/

- FLUVIAL FUNCTIONALITY INDEX: the main objective of the Fluvial Functionality Index consists of the overview of the comprehensive state of the river environment and in the evaluation of its functionality, understood to be the result of synergy and integration of an important series of biotic and abiotic factors present in the water ecosystem and in the connected terrestrial one. Through the analysis of morphological, structural and biotic parameters of the ecosystem, interpreted following the principles of river ecology, the functions associated with it as well as the distances from the condition of greatest functionality, identified following a reference model, can be highlighted. The critical and integral understanding of the environmental features allows the definition of a global index of functionality in terms of retention and cycling capacity of the fine and coarse particulate organic matter (short FPOM and CPOM) (Elwood et al., 1983), of buffer potential of the riparian ecotones as well as of morphological structure. Secondary objectives - but however important - are the FFI results which can be used in order to plan, forecast and verify the policy and strategy applicable for the river and land management. Through the description of morphological, hydraulic and biological parameters interpreted in the light of the principles of the river ecology, the associated functionality is evaluated. This integrated reading of the riverine environment is used, to define the river comprehensive functionality (Negri et al., 2007);

- PHYSICAL PARAMETERS (temperature, colour, taste and odour, turbidity, solids,...): Physical parameters of water, together with chemical and microbiological properties, determine the water quality. Main quality characteristics of water are:
  - TEMPERATURE: the temperature of water affects some of the important physical properties and characteristics of water: thermal capacity, density, specific weight, viscosity, surface tension, specific conductivity, salinity and solubility of dissolved gases and etc. Chemical and biological reaction rates

increase with increasing temperature. Reaction rates usually assumed to double for an increase in temperature of 10 °C. The temperature of water in streams and rivers throughout the world varies from 0 to 35 °C. http://echo2.epfl.ch/VICAIRE/mod_2/chapt_2/main.htm

- COLOUR: colour in water is primarily a concern of water quality for aesthetic reason. Coloured water gives the appearance of being unfit to drink, even though the water may be perfectly safe for public use. On the other hand, colour can indicate the presence of organic substances, such as algae or humic compounds. More recently, colour has been used as a quantitative assessment of the presence of potentially hazardous or toxic organic materials in water. http://echo2.epfl.ch/VICAIRE/mod_2/chapt_2/main.htm
- TASTE AND ODOUR: taste and odour are human perceptions of water quality. Human perception of taste includes sour (hydrochloric acid), salty (sodium chloride), sweet (sucrose) and bitter (caffeine). Relatively simple compounds produce sour and salty tastes. However sweet and bitter tastes are produced by more complex organic compounds. Human detect many more tips of odour than tastes. Organic materials discharged directly to water, such as falling leaves, runoff, etc., are sources of tastes and odour-producing compounds released during biodegradation. http://echo2.epfl.ch/VICAIRE/mod_2/chapt_2/main.htm
- TURBIDITY: turbidity is a measure of the light-transmitting properties of water and is comprised of suspended and colloidal material. It is important for health and aesthetic reasons. http://echo2.epfl.ch/VICAIRE/mod_2/chapt_2/main.htm
- TOTAL SOLIDS TS: the Total Solids content of water is defined as the residue remaining after evaporation of the water and drying the residue to a constant weight at 103 °C to 105 °C. Total solids include Total Suspended Solids (TSS) and Total Dissolved Solids (TDS);
- CONDUCTIVITY E.C.: the conductivity (specific conductance) is the numerical expression of the water's ability to conduct an electric current. It is measured in micro Siemens per cm and depends on the total concentration, mobility, valence and the temperature of the solution of ions. Electrolytes in a solution disassociate into positive (cations) and negative (anions) ions and impart conductivity. Most dissolved inorganic substances are in the ionised form in water and contribute to conductance. The conductance of the samples gives rapid and practical estimate of the variation in dissolved mineral content of the water supply. Conductance is defined as the reciprocal of the

resistance involved and expressed as mho or Siemens. Pollutants from urban, agricultural and industrial sources usually increase the electrical conductivity of water and make it unsuitable for usage. http://wgbis.ces.iisc.ernet.in/energy/monograph1/Methpage1.html

- PH: the pH of a sample of water is a measure of the concentration of hydrogen ions. pH is defined as -log[H+], and measured as intensity of acidity or alkalinity on a scale ranging from 0-14. If free H+ are more it is expressed acidic (i.e. pH < 7), while more OH- ions is expressed as alkaline (i.e. pH > 7). At higher pH, there are fewer free hydrogen ions, and a change of one pH unit reflects a tenfold change in the concentrations of the hydrogen ion. The pH scale ranges from 0 to 14. A pH of 7 is considered to be neutral. Substances with pH of less than 7 are acidic; substances with pH greater than 7 are basic. The pH of water determines the solubility (amount that can be dissolved in the water) and biological availability (amount that can be utilized by aquatic life) of chemical constituents such as nutrients (phosphorus, nitrogen, and carbon) and heavy metals (lead, copper, cadmium, etc.). For example, in addition to affecting how much and what form of phosphorus is most abundant in the water, pH may also determine whether aquatic life can use it. In the case of heavy metals, the degree to which they are soluble determines their toxicity. Metals tend to be more toxic at lower pH because they are more soluble;

- CHEMICAL POLLUTION PARAMETERS

- BIOCHEMICAL OXYGEN DEMAND (BOD_5): BOD is the amount of oxygen required by microorganisms for stabilizing biologically decomposable organic matter (carbonaceous) in water under aerobic conditions. The test is used to determine the pollution load of wastewater, the degree of pollution and the efficiency of wastewater treatment methods. 5-Day BOD_5 test being a bioassay procedure (involving measurement of oxygen consumed by bacteria for degrading the organic matter under aerobic conditions) requires the addition of nutrients and maintaining the standard conditions of pH and temperature and absence of microbial growth inhibiting substances. http://wgbis.ces.iisc.ernet.in/energy/monograph1/Methpage1.html

- CHEMICAL OXYGEN DEMAND (COD): measure of oxygen equivalent to the organic content of the sample that is susceptible to oxidation by a strong chemical oxidant. The intrinsic limitation of the test lies in its ability to differentiate between the biologically oxidisable and inert material. It is measured by the open reflux method. http://wgbis.ces.iisc.ernet.in/energy/monograph1/Methpage1.html

- DISSOLVED OXIGEN (DO): Indicator of the physical, chemical and biological activities of the water body. The two main sources of dissolved oxygen are diffusion of oxygen from the air and photosynthetic activity. Diffusion of oxygen from the air into water depends on the solubility of oxygen, and is influenced by many other factors like water movement, temperature, salinity, etc. Photosynthesis, a biological phenomenon carried out by the autotrophs, depends on the plankton population, light condition, gases, etc. Oxygen is considered to be the major limiting factor in water bodies with organic materials. Dissolved oxygen is calculated by many methods.
  http://wgbis.ces.iisc.ernet.in/energy/monograph1/Methpage1.html
- NUTRIENTS–TOTAL NITROGEN (TN) AND TOTAL PHOSPHORUS (TP): total amount of nitrogen and phosphorus present in the water body. Nitrogen can be present in different forms (e.g. organic nitrogen in plant material, ammonia, nitrate and nitrite). Phosphorus can also be present in different forms (e.g. organic phosphorus, phosphate). High concentrations of phosphorus and nitrogen can result in excessive growth of aquatic plants such as cyanobacteria, phytoplankton, macrophytes and filamentous algae

• https://www.epa.sa.gov.au/data_and_publications/water_quality_monitoring/lower_lakes/lower_lakes_water_quality_parameters

- PHOSPHATES: existing in three forms, orthophosphate, metaphosphate (or polyphosphate) and organically bound phosphate each compound contains phosphorous in a different chemical arrangement. Orthophosphate forms are produced by natural processes, but major man-influenced sources include: partially treated and untreated sewage, runoff from agricultural sites, and application of some lawn fertilizers. Orthophosphate is a readily available to the biological community and typically found in very low concentrations in unpolluted waters. The organic phosphate is the phosphate that is bound or tied up in plant tissue, waste solids, or other organic material. After decomposition, this phosphate can be converted to orthophosphate. Phosphate stimulates the growth of plankton and aquatic plants which provide food for larger organisms, including zooplankton, fish, humans, and other mammals. Plankton represents the base of the food chain. Initially, this increased productivity causes an increase in the fish population and overall biological diversity of the system. But as the phosphate loading continues and there is a build-up of phosphate in the lake or surface water ecosystem, the aging process of lake or surface water ecosystem will be accelerated. The overproduction of lake or water body can lead to an imbalance in the nutrient and material cycling process (Ricklefs, 1993).

- https://www.water-research.net/index.php/phosphate-in-water
- - SULPHATES: appreciably found in all natural waters, particularly those with high salt content. Besides industrial pollution and domestic sewage, biological oxidation of reduced sulphur species also add to sulphate content. Soluble in water, it imparts hardness with other cations. Sulphate causes both scaling in industrial water supplies, and odour and corrosion problems due to its reduction to hydrogen sulphide. It can be estimated by applying the turbidimetric method.
  - http://wgbis.ces.iisc.ernet.in/energy/monograph1/Methpage1.html
- - CLORIDES: the presence of chlorides in natural waters can be mainly attributed to dissolution of salt deposits in the form of ions (Cl-). Otherwise, high concentrations may indicate pollution by sewage, industrial wastes, intrusion of seawater or other saline water. It is the major form of inorganic anions in water for aquatic life. High chloride content has a deleterious effect on metallic pipes and structures, as well as agricultural plants. They are calculated by Argentometric method. http://wgbis.ces.iisc.ernet.in/energy/monograph1/Methpage1.html
- - ESCHERICHIA COLI: abbreviated E. coli, is a bacterium that is found in the large intestine or faeces of healthy warm-blooded animals and humans. Most E. coli strains are harmless and serve a useful function in the body by stopping the growth of harmful bacteria species and by making necessary vitamins. After someone ingests a sufficient quantity of E. coli O157:H7 (the infective dose being as low as 10 infectious particles), the bacteria travels through the stomach and small intestine, attaches itself to the inside surface of the large intestine and causes inflammation of the intestinal wall.

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Extended Biotic Index (EBI)	Model/Survey	Model/Survey	Model/Survey
Fluvial Functionality Index (FFI)	Model/Survey	Model/Survey	Model/Survey
Quality Parameters (Temperature, Colour, Taste & Odour, Turbidity, TS, Conductivity E.C., PH)	Model/Survey	Model/Survey	Model/Survey

Chemical Pollution Parameter (BOD5, COD, DO, TN, TP, Phosphate, Sulphate, Chlorides, E. coli)	Model/Survey	Model/Survey	Model/Survey

Table B.31 Sub-Criterion Indicators: Effects on Water Quality

B3.1.2 SUB-CRITERION: Effects on Water Quantity

SUB-CRITERION	Indicators will assess....
Effects on Water Quantity	the effects on water quantity

Table B.32 Sub-Criterion Table: Effects on Water Quantity

- WATER STORAGE CAPACITY ENHANCEMENT: The Indicator describes the water storage capacity in terms of volume of NBSs and Green Solutions.

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Water Storage Capacity Enhancement	Model/Survey	Model/Survey	Model/Survey

Table B.33 Sub-Criterion Indicators: Effects on Water Quality

B3.2 CRITERION: Soil

Some index properties like total predicted soil loss are utilized to estimate the soil physical resilience.

B3.2.1 SUB-CRITERION: Soil Physical Resilience

SUB-CRITERION	Indicators will assess....
Soil Physical Resilience	if the Design Scenarios enhance the ability of a soil to resist or recover their healthy state in response to de-stabilising influences.

Table B.34 Sub-Criterion Table: Soil Physical Resilience

- TOTAL PREDICTED SOIL LOSS (RUSLE): widely applied to estimate the rate of soil loss by water. The landscape profile is defined by a slope length, which is the length from the origin of overland flow to the point where the flow reaches a major flow concentration or a major area of deposition. The soil loss is an average erosion rate for the landscape profile. Erosion can widely vary even on a uniform slope, depending on slope position and configuration of the slope profile. RUSLE factors are listed below:

- $$A = R \cdot K \cdot LS \cdot C \cdot P \qquad \text{(B.8)}$$

where:

- A Annual soil loss from sheet and rill erosion in tons/acre

- *R* Rainfall erosivity factor
- *K* Soil erodibility factor
- *LS* Slope length and steepness factor
- *C* Cover and management factor
- *P* Support practice factor

Each factor has been either updated with recent information and new factor relationships have been derived based on modern erosion theory and data.

- *R* Factor represents the erosivity powers of rainfall energy and it varies with geographic location
- *K* Factor describes the susceptibility of a type of soil to erosion in some geographic areas
- *LS* factor takes into account the slope length and steepness, they are also called topographic factors
- *C* Factor is an additional sub-factors for evaluating the cover and management
- *P* Factor is a new conservation practice value for cropland and rangeland (Jones et al., 1996);

- ERODIBILITY: soil erodibility is a parameter of the soil profile reaction to the process of soil detachment and transport by raindrops and surface flow. The soil erodibility is expressed as the *K*-factor in the widely used soil erosion model, the Universal Soil Loss Equation (USLE) and its revised version (RUSLE). The *K*-factor, which expresses the susceptibility of a soil to erode, is related to soil properties such as organic matter content, soil texture, soil structure and permeability. With the Land Use/Cover Area frame Survey (LUCAS) soil survey in 2009 a pan-European soil dataset is available for the first time, consisting of around 20,000 points across 25 Member States of the European Union;
- SOIL WATER HOLDING CAPACITY: Soil water holding capacity is the amount of water that a given soil can hold for crop use. Field capacity is the point where the soil water holding capacity has reached its maximum for the entire field. The goal for agricultural producers is to maintain the field at or near capacity. When the amount of water in the soil is in deficit, the soil profile needs to be replenished by precipitation or irrigation. For farmers, the key is to

understand the nuances of soil water holding capacity and how to manage it so that the farm does not need to irrigate or suffer from a drought;

- LAND TAKE INDEX (LTI): The Land Take Index is calculated as the following ratio:
- $$LTI = SS / TS \quad (B.9)$$

where:

- *SS* is the surface in the study area occupied by Sealed Soils such as housing, industrial, commercial settlements, public services, infrastructures, mines, dumps (EEA);
- *TS* is the whole Total Surface of the study area.

- POLLUTED SOILS: This Indicator describes the quantity of soils in the study area, measured in hectares, used for highly polluting industries, brownfields, drosscapes, mines, dumps, construction sites. It provides a quick evaluation of soil quality since the less polluted soils there are in the study area, the higher its overall soil quality is. In a long-term scenario, those above mentioned Indicators could be re-assessed, monitoring, through a direct survey, if the NBSs implementation have produced impact on soil resilience.

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Total Predicted Soil Loss (RUSLE)	Model/Survey	Model/Survey	Model/Survey
Erodibility	Model/Survey	Model/Survey	Model/Survey
Soil Water Holding Capacity	Model/Survey	Model/Survey	Model/Survey
Land Take Index (LTI)	GIS	Model/GIS	Survey
Polluted Soils	GIS	Model/GIS	Survey

Sub-Criterion Indicators: Soil Physical Resilience

- ***SUB-CRITERION: Stability of the Soil Communities and Derived Environmental Services***

SUB-CRITERION	Indicators will assess....
Stability of the Soil Communities and Derived Environmental Services	the stability of the soil communities and derived environmental services

Sub-Criterion Table: Stability of the Soil Communities and Derived Environmental Services

- SOIL FOOD WEB STABILITY: is the community of organisms living all (or part of them) in the soil. It describes a complex living system in the soil and how it interacts with the environment, plants, and animals.

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term

Soil Food-Web Stability	Model/ Survey	Model/ Survey	Model/ Survey

Sub-Criterion Indicators: Stability of the Soil Communities and Derived Environmental Services

- ***SUB-CRITERION: Soil Fertility***

SUB-CRITERION	Indicators will assess....
Soil Fertility	the soil fertility

Sub-Criterion Table: Soil Fertility

- SOIL AVAILABLE NUTRIENTS AND TEXTURE: soil is a major source of nutrients needed by plants for grown. The three main nutrient are nitrogen (*N*), phosphorus (*P*) and potassium (*K*). (NSW government – Department of Primary Industries).

  Soil texture indicates the relative content of particles of various sizes, such as sand, silt and clay in the soil. Texture influences the ease with which soil can be worked, the amount of water and air it holds, and the rate at which water can enter and move through the soil. www.fao.org

- SOIL STRUCTURE: defined by the way individual particles of sand, silt, and clay are assembled. Single particles when assembled appear as larger particles. There are called aggregates. Aggregation of particles can occur in different patterns, resulting in different soil structures. The circulation of water in the soil varies greatly according to structure. www.fao.org

- MODELLED C AND N CYCLING: nutrient cycling is one of the most important processes of nutrients that occur in an ecosystem: their use, movement, and recycling in the environment. Valuable nutrients like carbon, oxygen, hydrogen, phosphorus, and nitrogen are recycled in the ecosystem to allow the life of organisms. Nutrient cycles are inclusive of both living and non-living components and involve biological, geological, and chemical processes, that's why these nutrient circuits are known as biogeochemical cycles.

  Carbon cycling is essential to all life as it is the main constituent of living organisms. It serves as the backbone component for all organic polymers, including carbohydrates, proteins, and lipids. Carbon compounds, such as carbon dioxide (CO_2) and methane (CH_4), circulate in the atmosphere and influence global climates. Nitrogen cycling is a necessary component of biological molecules. Some of these molecules include amino acids and nucleic acids. https://www.thoughtco.com/all-about-the-nutrient-cycle-373411

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term

Soil Available Nutrients and Texture	Sampling	Model	Model
Soil Structure	Sampling	Model	Model
Modeled C and N Cycling	Sampling	Model	Model

Sub-criterion Indicators: Soil Fertility

- ***SUB-CRITERION: Carbon Sequestration in Soil***

SUB-CRITERION	Indicators will assess....
Carbon Sequestration in Soil	the carbon sequestration in soil

Sub-Criterion Table: Belowground C Cycle

- DECOMPOSITION RATE: Decomposition of Carbon is a part of the Carbon cycle and is essential for recycling the finite matter that occupies physical space in the biosphere. Decomposition is the process by which organic substances are broken down into simpler organic matter. One can differentiate abiotic from biotic decomposition (biodegradation). The former means "degradation of a substance by chemical or physical processes, e.g., hydrolysis" (Water Quality Vocabulary. IShaO 6107-6:1994). The latter means "the metabolic breakdown of materials into simpler components by living organisms" "Biotic decomposition". Water Words Dictionary (WWD), typically by microorganisms;
- MODELLED C CONTENT IN THE UPPER SOIL LAYER: in soils and sediments, there are three basic forms of carbon that may be present. They are: elemental C, inorganic C, and organic C. The quality of organic matter in sediments is critical to the partitioning and bioavailability of sediment-associated contaminants. Elemental carbon forms include charcoal, soot, graphite, and coal. The primary sources for elemental carbon in soils and sediments are as incomplete combustion products of organic matter (i.e., charcoal, graphite, and soot), from geologic sources (i.e., graphite and coal), or dispersion of these carbon forms during mining, processing, or combustion of these materials. Inorganic carbon forms are derived from geologic or soil parent material sources. Inorganic carbon forms are present in soils and sediments typically as carbonates. Naturally-occurring organic carbon forms are derived from the decomposition of plants and animals. In soils and sediments, a wide variety of organic carbon forms are present and range from freshly deposited litter (e.g., leaves, twigs, branches) to highly decomposed forms such as humus. In addition to the naturally-occurring organic carbon sources are sources that are derived as a result of contamination through anthropogenic activities. http://webcache.googleusercontent.com/search?q=cache:http://bcodata.whoi.edu/LaurentianGreatLakes_Chemistry/bs116.pdf.

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Decomposition Rate	Sampling/Survey	Model	Model
Modeled C content in the upper soil layers	Sampling/Survey	Model	Model

Sub-Criterion Indicators: Carbon Sequestration in Soil

- **CRITERION: Vegetation**

- ***SUB-CRITERION: Aboveground C Cycle***

SUB-CRITERION	Indicators will assess....
Aboveground C Cycle	the forest carbon storage and sequestration

Sub-Criterion Table: Aboveground C Cycle

- ABOVE-GROUND TREE BIOMASS (AGB): one of seven key agriculture, forestry, and land-use carbon pools. It includes trees defined as generally five cm or greater diameter at breast height (4.3 feet above ground). (Finance and Carbon Markets Lexicon prepared by the Forest Carbon, Markets and Communities (FCMC) Program and Tetra Tech ARD and reviewed by the United States Agency for International Development (USAID);
- TREE BIOMASS STOCK CHANGE: Numerous studies analysed carbon stocks in forest ecosystems using forest inventory data (Cannell et al., 1992; Kauppi et al., 1992; Liski et al., 2000; Nabuurs et al., 2001; Liski et al., 2003; Janssens et al., 2003), using data directly from national inventories (e.g. Baritz & Strich, 2000), or from data reported to the FAO (TBFRA, 2000), which are originally based on national inventories. At regional and larger scales, changes in carbon stocks are commonly assessed by comparing the stocks from several inventories over time (Wutzler et al., 2011).

INDICATOR	SCENARIOS		
	Baseline	**Design**	**Long-term**
Decomposition Rate	Survey	Survey	Survey
Modeled C content in the upper soil layers	Survey	Survey	Survey

Sub-Criterion Indicators: Aboveground C Cycle

- ***SUB-CRITERION: Structural Diversity***

SUB-CRTIERION	Indicators will assess....
Structural Diversity	the structural diversity

Sub-Criterion Table: Structural Diversity

Maintaining a permanent soil cover is important in conservation agriculture, it protects the top soil from soil erosion, maintains soil moisture, smothers weeds and aids in

nutrient cycling. https://www.infonet-biovision.org/EnvironmentalHealth/Soil-cover
A method to estimate soil cover is via photo or GIS modelling, through which it is possible to distinguish:

- WOODY VEGETATION COVER: Soil covered by trees, bushes and shrubs;
- NON-WOODY VEGETATION (HERB) COVER: Soil covered by_plants with savoury or aromatic properties used for flavouring and garnishing food, in medicine, or as fragrances;
- TOTAL VEGETATION COVER: Soil covered by assemblage of plant species and the ground, without specific reference to particular taxa, life forms, structure, spatial extent, or any other specific botanical or geographic characteristics

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Woody Vegetation Cover	GIS	Project Data	GIS
Non-Woody Vegetation (HERB) Cover	GIS	Project Data	GIS
Total Vegetation Cover	GIS	Project Data	GIS

Sub-Criterion Indicators: Structural Diversity

- ***SUB-CRITERION: Stages of Forest Stand Development***

SUB-CRITERION	Indicators will assess....
Stages of Forest Stand Development	the stages of forest development

Sub-Criterion Table: Stages of Forest Stand Development

- NUMBER OF DIAMETER CLASSES: a classification of trees based on diameter outside bark, measured at breast height 4.5 feet (DBH) (1.37 m) above the ground or at root collar (DRC). Diameter classes are commonly in 2-inch (5 cm) increments, beginning with 2-inches (5 cm). Each class provides a range of values with the class name being the approximate mid-point. For example, the 6-inch class (15-cm class) includes trees 5.0 through 6.9 inches (12.7 cm through 17.5 cm) DBH, inclusive. https://www.nrs.fs.fed.us/fia/data-tools/state-reports/glossary/default.asp
- TREE REGENERATION: Forest regeneration is the act of renewing tree cover by establishing young trees naturally or artificially-generally, promptly after the previous stand or forest has been removed. http://www.ipcc.ch/ipccreports/sres/land_use/index.php?idp=235
- CANOPY GAPS: a space occurring in the general forest crown cover caused by the fall or death of one or more trees forming it. https://definedterm.com/canopy_gap

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Number of Diameter Classes	Sampling/GIS	Model/GIS	Model/GIS
Tree Regeneration	Sampling/GIS	Model/GIS	Model/GIS
Canopy Gaps	Sampling/GIS	Model/GIS	Model/GIS

Sub-Criterion Indicators: Stages of Forest Stand Development

- ***SUB-CRITERION: Typical Local Species Promotion and Development***

SUB-CRITERION	Indicators will assess....
Typical Local Species Promotion and Development	the stages of forest development

Sub-Criterion Table: Typical Local Species Promotion and Development

- TYPICAL VEGETATION SPECIES COVER:

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Typical Vegetation Species Cover	Sampling/GIS	Model/GIS	Model/GIS

Sub-Criterion Indicators: Typical Local Species Promotion and Development

- ***SUB-CRITERION: Moisture***

SUB-CRITERION	Indicators will assess....
Moisture	the moisture

Sub-Criterion Table: Moisture

- MOISTURE INDEX: that portion of total precipitation used to satisfy plant (vegetation) needs. As used by Thornthwaite in his 1948 climatic classification: an overall measure of precipitation effectiveness for plant growth that takes into consideration the weighted influence of water surplus and water deficiency as related to water need and as they vary according to season. For a given station, the Moisture Index is calculated by the formula:

- $$I_m = Humidity\ Index - 0.60(Aridity\ Index) \quad \text{(B.9)}$$

which becomes

$$I_m = \frac{100s - 60d}{n} \quad \text{(B.10)}$$

where I_m is the moisture index, s the water surplus, d the water deficiency, and n the water need. The calculation of s and d is made on a normal month-to-month basis, with s being the total surplus from all months having a water surplus, and d the total of all monthly deficiencies; each is represented by the difference between monthly precipitation and monthly potential evapotranspiration (in centimetres or inches). Here *n* is the annual potential evapotranspiration. The moisture index replaced Thornthwaite's previously used (1931) precipitation-effectiveness index. http://glossary.ametsoc.org/wiki/Moisture_index

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Moisture Index	Living Labs/Model	Living Labs/Model	Living Labs/Model

Sub-Criterion Indicators: Drought Risk

- ***SUB-CRITERION: Flammability***

SUB-CRITERION	Indicators will assess....
Flammability	the flammability

Sub-Criterion Table: Flammability

- FLAMMABILITY INDEX: the ability of a landscape to burn or ignite, causing fire or combustion.

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Flammability Index	GIS/Survey	GIS/Survey	GIS/Survey

Sub-Criterion Indicators: Flammability

- **CRITERION: Landscape (Green Infrastructure)**

- ***SUB-CRITERION: Green Infrastructures***

SUB-CRITERION	Indicators will assess....
Green Infrastructures	the landscape connectivity and the mosaic diversity

Sub-Criterion Table: Green Infrastructures

- HANSKI'S CONNECTIVITY INDEX (CI): the index CI_i can be calculated by measuring edge-to-edge distances between study site (separately for large and small study sites) and all other habitat patches within the 2-km radius of each landscape (Fig. B.4) using the equation:

$$CI_i = \sum_{i \neq j} \exp\left(-\alpha d_{ij}\right) A_j^b \quad \text{(B.11)}$$

- (in km) from neighbouring calcareous grasslands *j* to the study site *i* (Hanski, 1994). The parameter *α* is a measure of the dispersal ability (1⁄average migration distance in km) and *b* is a parameter, which scales the size of the surrounding habitat patches. https://besjournals.onlinelibrary.wiley.com/doi/pdf/10.1111/j.1365-2664.2010.01828.x

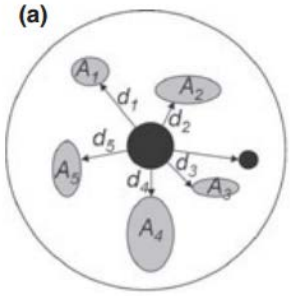

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Fig. B.7 Hanski's connectivity index (https://besjournals.onlinelibrary.wiley.com/doi/pdf/10.1111/j.1365-2664.2010.01828.x)

- <u>ABUNDANCE OF ECOTONES/SHANNON DIVERSITY</u>

The Shannon diversity index *H'* is calculated in the following way:

$$H' = -\sum p_i \ln\left(p_i\right) \quad \text{(B.12)}$$

where p_i is the proportion of individuals found in species *i*. For a well-sampled community, we can estimate the proportion as $p_i = n_i/N$, where n_i is the number of individuals in species *i* and *N* is the total number of individuals in the community. The Shannon index increases as both the richness and the evenness of the community increase.

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Hansky Connectivity Index	Model	Model	Model
Abundance of Ecotones/Shannon Diversity	Model	Model	Model

Sub-Criterion Indicators: Green Infrastructure

- **CRITERION: Biodiversity**

- ***SUB-CRITERION: Functional Diversity***

SUB-CRITERION	Indicators will assess....
Functional diversity	the plant soil genetic diversity of microbial and invertebrate (metagenomic map), soil functional diversity of microbial and invertebrate (abundance of functional groups), plant functional diversity (diversity of functional groups) and animal functional diversity (diversity of functional groups).

Sub-Criterion Table: Functional Diversity

- <u>METAGENOMICS MAP</u>: metagenomics is the study of genetic material recovered directly from environmental samples. The broad field may also be referred to as environmental genomics, ecogenomics or community genomics.

- ABUNDANCE OF FUNCTIONAL GROUPS
- DIVERSITY OF FUNCTIONAL GROUPS (PLANT FUNCTIONAL DIVERSITY)
- DIVERSITY OF FUNCTIONAL GROUPS (ANIMAL FUNCTIONAL DIVERSITY)

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Metagenomic Map	GIS/Model	GIS/Model	GIS/Model
Abundance of Functional Groups	Survey/Model	Survey/Model	Survey/Model
Diversity of Functional Groups (Plant)	Survey/Model	Survey/Model	Survey/Model
Diversity of Functional Groups (Animal)	Survey/Model	Survey/Model	Survey/Model

Sub-Criterion Indicators: Functional Diversity

- ***SUB-CRITERION: Forest Habitat Fragmentation***

SUB-CRITERION	Indicators will assess....
Forest Habitat Fragmentation	if the Design scenarios ensure the removal of physical barriers that block forest habitat connectivity

Sub-Criterion Table: Forest Habitat fragmentation

- EFFECTIVE MESH DENSITY: Effective mesh density (s_{eff}) quantifies the degree to which wildlife movement is interrupted by barriers in the environment. It expresses the degree of fragmentation of a landscape and measure the effective number of patches per 1 km^2 (EEA). It can be calculated using the following expression:

$$s_{eff} = {}^{1}/_{m_{eff}} \qquad \text{(B.13)}$$

given:

$$m_{eff} = \frac{1}{A_{tot}} \cdot (A_1 + A_2 + \cdots + A_i + \cdots A_n) \qquad \text{(B.14)}$$

where:

- n is the number of patches
- A_{tot} is the total area of the study area
- A_i is the size of patch i ($i = 1,\ldots, n$)

In a long-term scenario, those above mentioned Indicators could be re-assessed, monitoring, through a direct survey, if the NBSs implementation have produced impact on forest habitat fragmentation.

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Effective Mesh Density	GIS	Project data	Direct survey

Sub-Criterion Indicators: Forest Habitat Fragmentation

- ***SUB-CRITERION: Protected Areas***

SUB-CRITERION	Indicators will assess....
Protected Areas	if the study area is acknowledged as a protected area or is within a protected area belonging to Natura 2000 network

Sub-Criterion Table: Protected Areas

- SITE COMMUNITY IMPORTANCE (SCI) AND SPECIAL PROTECTED AREAS (SPA): The Indicator describes the extension, measured in hectares, of Site of Community Importance (SCI) and Special Protection Areas (SPA) in the study area. The Indicator will hardly change in the Design and long-term scenario, even if it could be assessed if the NBSs implementation have produced such a beneficial impact on biodiversity to activate EU procedures in order to enlarge SCI and/or SPA perimeter.

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Site Community Importance (SCI) and Special Protected Areas (SPA)	GIS	Model/GIS	Model/GIS

Sub-Criterion Indicators: Protected Areas

- AMBIT: Society

The complex of socio-economic and environmental phenomena that specifically characterize the territorial contexts where PHUSICOS is applied to (rural and mountainous areas) is considerably different from the set of problems that usually affect urban settlements where NBSs have been chiefly implemented and their effects thoroughly analyzed. Therefore, rural and mountainous areas need different tailored solution since they can achieve benefits from NBSs application that could be noticeably different from the ones attainable in urban contexts.

It is evident how in rural and mountainous areas we do not usually have to face undoubtedly important effects of phenomena, which have their maximum intensity in urban areas, such as air or water pollution, Urban Heat Islands, floods from run-off ineffective drainage, overpopulation.

Anyway, from the socio-economic point of view, some other issues, that characteristically affects rural and mountainous areas, should be dealt with, such as:

- the risk of abandonment due to depopulation;
- the economic stagnation due to the lack of well-structured economic activities;
- the risk of loss of traditional knowledge and cultural resources.

These territories typically belong to peripheral areas that were cut off by the main economic development dynamics. Sometimes they have gradually been marginalised due to depletion of the local economy and demographic decline. Remote rural areas, far from major transport routes and with a high degree of slope or height, became marginal territories, where traditional farming systems had been abandoned because of depopulation due to migration outflows and population ageing.

Criteria and sub-criteria selected point out some co-benefits that the implementation of NBSs could induce on these territories. Some of the benefits outlined (e.g. new jobs creation, tourism development, ageing contrast) will be quantified only in the long-term period.

Sub-criteria and Indicators were selected by main literature on NBSs, identifying those appropriate for rural areas.

- **CRITERION: Quality of Life**
- ***SUB-CRITERION: Leisure and Connections Increasing***

SUB-CRITERION	Indicators will assess....
Leisure and Connections Increasing	*RECREATIONAL OPPORTUNITY*: how much the Design scenarios can increase the enjoyment of leisure activities in the area, making new areas available for recreational use and enhancing the accessibility of natural resources *SUSTAINABLE MOBILITY*: how much the Design scenarios can increase connections in the area, in particular enhancing the use of sustainable transportation mode (e.g. cycling, walking, etc.)

Sub-Criterion Table: Leisure and Connections Increasing

- NUMBER OF VISITORS IN NEW RECREATIONAL AREAS: A new infrastructure (both NBSs, Hybrid solutions and Grey infrastructures), implemented in a rural landscape in order to achieve a risk reduction, could, at the same time, enhance the life quality in the area, making new areas available for leisure, recreation or other cultural activities (Raymond et al., 2017; Byrd et al., 2017; Sandstrom 2002). For instance, the stabilization of a river bank through a NBSs could give these areas back to the community for different leisure purposes (e.g. creation of a promenade, cycling paths, panoramic viewpoints, etc.), attracting visitors in these new recreational areas. This Indicator will be equal to 0 in the Baseline Scenario and will be assessed in the Design scenarios (e.g. NBSs Scenario or Hybrid Scenario) computing the number of new visitors;

- DIFFERENT ACTIVITIES ALLOWED IN NEW RECREATIONAL AREAS: In the new areas available for leisure and recreation, a different range of leisure activities could be carried out (e.g. walking, cycling, refreshment in picnic areas, watching cultural performances in natural arenas, etc.). The more the Design Scenarios will ensure a high variety of activities allowed in the area where the new infrastructure will be built, the more effective will be the benefits in terms of quality of life for the community (Kronenberg, 2017). This Indicator will be equal to 0 in the Baseline Scenario and will be assessed in the Design Scenarios (e.g. NBSs Scenario or Hybrid Scenario) computing the number of leisure activities that people can carry out in the areas created by the project;
- AVERAGE DISTANCE OF NATURAL RESOURCES FROM URBAN CENTRES/TRAIN STATIONS/PUBLIC TRANSPORTATION: The implementation of the design Scenario can result in the reduction of the average distance of natural resources from urban centres/trains stations/public transportation;
- NEW PEDESTRIAN, CYCLING AND HORSE PATH: The implementation of the design scenario can result in the creation of new pedestrian, cycling and horse paths. The measure of the length of these new paths can be used as an Indicator of the improvement in terms of quality of life induced by the project;
- SUSTAINABLE TRANSPORTATION MODES ALLOWED: The project scenario should enhance the use of sustainable transportation modes. The number of sustainable transportation modes allowed by the project can be used as an Indicator;
- NEW LINKS BETWEEN URBAN CENTRES AND ACTIVITIES: NBSs or Hybrid solutions should enhance the connectivity between rural areas and urban centres, train stations and activities. The number of new links can be adopted as an Indicator of the benefits provided by NBS and Hybrid scenarios.

In a Long-Term scenario, those above mentioned Indicators could be re-calculated, monitoring, through a direct survey and verifying if the leisure spaces planned are actually used for the purpose they were projected. The Design scenario could contribute to increase the connection between urban centres in a rural or mountainous area, providing safe opportunities for walking and biking. For instance, the development and the permanent maintenance of a well-connected and safe bike and/or pedestrian network, could not only provide the opportunity for the enjoyment of natural resources, due to a higher accessibility, but also an actual possibility to increase the connections between urban settlements and/or activities through sustainable and low impacts means of transport.

In a Long-Term scenario, those above mentioned Indicators could be re-calculated, monitoring, through a direct survey, if the walking/cycling/horses network eventually planned have been actually used for the purpose they were projected and their efficiency in promoting sustainable mobility.

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Number of visitors in new recreational areas	-	Model/GIS	Model/Survey
Different activities allowed in new recreational areas	-	Model/GIS	Model/Survey
Average distance of natural resources from the urban centres, train stations and activities	-	Model/GIS	Model/Survey
New pedestrian, cycling and horse paths	-	Model/GIS	Model/Survey
Sustainable transportation modes allowed	-	Model/GIS	Model/Survey
New links between urban centres/activities	-	Model/GIS	Model/Survey

Sub-Criterion Indicators: Leisure and Connections Increasing

- ***SUB-CRITERION: Social Justice***

SUB-CRITERION	Indicators will assess....
Social Justice	the beneficial effects ensured by the Planning scenarios in terms of social equity

Sub-Criterion Table: Social Justice

- <u>AREA EASILY ACCESSIBLE FOR PEOPLE WITH DISABILITIES</u>: An NBS can open up opportunities to increase social justice, providing people the possibility to meet and interact with other groups and interests. Design Scenarios which will create multi-target infrastructures, combining risk reduction with the provision of public spaces, could improve sociability of places. In detail, Green Surge point out the necessary requirements of a project "it needs to be designed and governed to provide people from different backgrounds with similar life opportunities and access to services, including green spaces. At highest risk of social exclusion are those who are different from the majority of the population, whether through income level, ethnicity, nationality, language, religion, age or health status; or who are otherwise vulnerable" (Byrd et al., 2017). To this purpose, the extensions of new areas accessible to people with disabilities can provide a measure of the benefit induced by the project in terms of social justice;

- RATE OF INCREASE IN PROPERTIES INCOMES: implementation of NBSs can increase the value of land and real estate by increasing the overall quality of the surrounding environment. The rate of increase in properties incomes can be used as an Indicator of the performance of the Design Scenario in terms of social justice.

INDICATOR	SCENARIOS		
	Baseline	Planning	Long-term
Area easily accessible for people with disabilities	-	Model/GIS	Model/GIS
Rate of increase in properties incomes	-	Model/GIS	Model/GIS

Sub-Criterion Indicators: Social Justice

- ***SUB-CRITERION: Ageing Contrast***

SUB-CRITERION	Indicators will assess....
Ageing Contrast	the beneficial effects ensured by the Design scenarios on the demographic structure in the area, contributing to increase total population and decrease, at the same time, the elderly rate

Sub-Criterion: Ageing Contrast

Rural and mountainous areas are often lacking in accessibility, have scarce economic visibility and low levels of enterprise and have difficulties in becoming part of effective economic hubs. The global economy favors the concentration of assets in big cities resulting in isolation of peripheral areas with limited infrastructure links. Young and working people are compelled to migrate leaving their native places triggering population decrease. This reduction of people is combined with lower birth rates and an increase in the elderly population (Eurostat, 2017). The main proportion of inhabitants in these landscapes is people over 65 years of age. Inhabitants of these areas are economically disadvantaged regarding the supply of essential services for daily life such as schools, health services care and basic goods stores. This combination of reduced communities with limited facilities and economic options can cause the abandonment of these areas by young people. If the depopulation trend continues, the impact on ageing population will be felt more and more dramatically; as the maintenance of basic services declines further and there are fewer younger people to help in the care of these dependents (Gellrich & Zimmermann, 2007; Molina Ibanez & Farris, 2011; Mottet et al., 2006).

If NBSs are conceived and designed to provide multiple socio-economic benefits, combining natural risk mitigation with the creation of new attractive spaces and services, natural heritage enhancement with accessibility to resources, they could give new job opportunities to young people and reverse negative population trends.

Monitoring of population trends could be realized through two basic Indicators

- POPULATION INCREASING (NATALITY + IMMIGRATION): Population increasing ΔP, due to both natural population balance (difference between births and deaths) and social one (different between immigrants and emigrants), can be expressed by the following formula:
    - $$\Delta P = P_{BS} - P_{LTS} \tag{B.15}$$

Where

- P_{BS} is the total population living in the area at the Baseline Scenario;
- P_{LT} is the total population living in the area at the Long Term Scenario.

In the Baseline Scenario Population increasing should be calculated taking into account population trend in the previous 30 years, in order to understand if a decreasing rate in the last 10 years point out a structural or a temporary problem. Population trend is likely to increase (and elderly rate is likely to decrease) if new jobs opportunities will be created.

To esteem increase or decrease of such demographic indexes in relationship with the realization of a project or another, it is possible to use a probabilistic scale.

In the Long-term scenario Population increasing should be calculated considering statistical data made available some years after NBSs/Grey/Hybrid solutions have been implemented.

- ELDERLY RATE: Elderly rate ER can be expressed by the following formula:
    - $$ER = \frac{P_{>65}}{P} \tag{B.16}$$

where

- $P_{>65}$ is the population over 65 years old;
- P is the total population.

INDICATOR	SCENARIOS		
	Baseline	Planning	Long-term
Population Increasing	Statistical data	Statistical data	Statistical data
Elderly Rate	Statistical data	Statistical data	Statistical data

Sub-Criterion Indicators: Ageing Contrast

- **CRITERION: Community Involvement and Governance**

- ***SUB-CRITERION: Participatory Processes and Partnership***

SUB-CRITERION	Indicators will assess....
Participatory Processes and Partnership	the quality of participation during NBSs implementation process and the ability of local authorities to promote NBSs

Sub-Criterion Table: Participation and Design Capacity Building

- CITIZEN INVOLVED: The amount of local actors in the Design Scenarios implementation should be taken into account in order to evaluate the quality of participation process. It should be assessed counting the number of citizen involved;
- STAKEHOLDERS INVOLVED: Analogously, the quality of participatory processes can be assessed counting the number of stakeholders involved;
- PUBLIC-PRIVATE PARTNERSHIP ACTIVATED: The quality of the participatory processes is also assessed by the number of partnership activated between public and private agencies;
- POLICIES SET UP TO PROMOTE NBSs: The quality of the participatory processes is also assessed by the number of policies set up by local administration to promote NBSs in their territories.

A good level of participation and co-design of solution is the best guarantee for finding solutions respectful at the same time of local site specific views and safety needs.

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Citizen Involved	-	Statistical Data/Model	Statistical Data/Model
Stakeholders Involved	-	Statistical Data/Model	Statistical Data/Model
Public-Private Partnership Activated	-	Statistical Data/Model	Statistical Data/Model
Polices Set-Up to Promote NBSs	-	Statistical Data/Model	Statistical Data/Model

Sub-Criterion Indicators: Participatory Processes and Partnership

- **CRITERION: Landscape & Heritage**

- ***SUB-CRITERION: Identity***

SUB-CRITERION	Indicators will assess....
Identity	the ability of NBSs to preserve traditional knowledge and to enhance the sense of belonging of local community

Sub-Criterion Table: Identity

The broken link between generations, between young and old people, interrupts the natural transmission of traditional knowledge which is based on previous experiences and drives the loss of intangible heritage composed of traditional skills, social organization forms, awareness, understanding and ability to use natural resources.
The survival of the intangible heritage is a necessary precondition to ensure the maintenance and care of tangible heritage (UNESCO, 2003; Council of Europe, 2000). It is the values, attitudes and beliefs of the indigenous people which form the intangible heritage and it is these principles that ensure the safeguarding and promotion of the tangible assets and result in recovery, upgrading and maintenance actions (Filipe & de Mascarenhas, 2011). Without the transmission of local knowledge and traditional skills, the tangible heritage could perish since a result of lack of know-how about suitable interventions and maintenance will inevitably lead to its decline. Consequently, without protection of intangible heritage, the tangible heritage may be destroyed (Stephenson, 2008).

The Indicators assess the ability of NBSs to reclaim traditional knowledge and techniques and to offer new spaces for traditional events. Moreover, an important role is played by local associations in the preservation of identity. In many cases, associations are the custodians of local knowledge and traditions. Therefore, the more social active associations there are in the area, the higher will be the probability to ensure traditional knowledge and uses reclamation.

The resulting Indicators are:

- TRADITIONAL KNOWLEDGE AND USES RECLAMATION
- TRADITIONAL EVENTS ORGANIZED IN THE NEW AREAS
- SOCIAL ACTIVE ASSOCIATIONS

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Traditional Knowledge and Uses Reclamation	Statistical Data/Survey	Statistical Data/Survey	Survey

Traditional Events Organized in the New Areas	Statistical Data/Survey	Statistical Data/Survey	Survey
Social Active Associations	Statistical Data/Survey	Statistical Data/Survey	Survey

Sub-Criterion Indicators: Identity

- *SUB-CRITERION: Heritage Accessibility*

SUB-CRITERION	Indicators will assess....
Heritage Accessibility	how much NBSs will make available natural and cultural heritage in the area, previously not accessible

Sub-Criterion Table: Heritage Accessibility

- NATURAL AND CULTURAL SITES MADE AVAILABLE: A new infrastructure, implemented in a rural landscape in order to achieve a risk reduction, could also ensure the accessibility to natural and cultural sites previously isolated. This Indicator will be equal to 0 in the Baseline Scenario and will be assessed in the Design Scenarios (e.g. NBSs Scenario, Hybrid Scenario, Grey Scenario) computing the size of spaces, in terms of square kilometers, free from any risk, that the infrastructure project dedicates to recreational activities.

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Natural and Cultural Sites Made Available	-	Statistical Data/Model	Survey

Sub-Criterion Indicators: Heritage Accessibility

- *SUB-CRITERION: Landscape Perception*

SUB-CRITERION	SUB-CRITERION: Indicators will assess....
Landscape Perception	how much NBSs will make landscape perceivable, through new scenic sites and paths, and contribute to create new landmarks in the area

Sub-Criterion Table: Landscape Perception

Some NBSs could contribute to enhance landscape enjoyment increasing the amount of perceivable scenic sites and creating new landmarks that could represent new elements of local identity. If the project foreseen the built of new natural trails, the scenic enjoyment of new viewsheds could be a co-benefit for population and tourists. The following Indicators are defined:

- VIEWSHED
- SCENIC SITES AND LANDMARK CREATED
- SCENIC PATHS CREATED

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Viewshed	GIS	GIS	GIS
Scenic Sites and Landmark Creation	-	Model/GIS	Survey
Scenic Paths Created	-	Model/GIS	Survey

Sub-Criterion Indicators: Landscape Perception

- AMBIT: Local Economy

- CRITERION: Revitalization of Marginal Areas

- *SUB-CRITERION: Promotion of Socio-Economical Development of Marginal Areas*

SUB-CRITERION	Indicators will assess....
Promotion of Socio-Economical Development of Marginal Areas	the ability of NBSs to promote socio-economic development in the area through the creation of jobs related to the creation and the maintenance of NBS itself and tourism sector

Sub-Criterion Table: Promotion of Socio-Economical Development of Marginal Areas

Some NBSs projects could have a potential to generate new jobs and new economic opportunities (Raymond et al., 2017; Byrd et al., 2017; European Commission, 2013). Literature reports many examples (OPPLA Case Studies). In detail, extended NBSs projects are likely to create new jobs in the construction and maintenance of these interventions. Furthermore, other opportunities could arise through the development of activities related to natural environment enjoyment (i.e. trail guides, bike rental and repair, education to nature, equipment rentals, service outlets, events and instructor led activities) or in activities related to tourism. If NBSs project realization could attract new visitors in the Region, new jobs related to sojourn and food services could be foreseen.

The Indicator "Jobs created in the NBSs construction and maintenance" could be inferred by the different executive projects to be evaluated (if they contain an esteem of needs regarding number of workers to be employed); otherwise it could be measured, as the Indicator "Jobs created in the nature-based sector" through a probabilistic scale and inferred by statistical data in the Long-Term scenario.

In addition, in Europe, frequently rural and mountain areas conserve uncontaminated natural environments with a rich cultural and historical heritage composed of a network of small historical centres, abundant high quality agricultural products and knowledge and skills utilized in traditional ways of working (Davies & Michie, 2011; Filipe & de Mascarenhas, 2011; Waterton, 2010). This heritage could be lacking in accessibility or abandoned and not usable for risk conditions.

Some NBSs projects could promote a new touristic development of rural and mountainous area in many different ways: by creating a new qualified natural attraction (a riverside, a green infrastructure, a new sport trial in natural context); increasing accessibility to and/or connecting existing cultural heritage sites or landscape viewpoints. This could enhance touristic attractiveness and promote new activities and jobs in tourism sector (B&B, restaurants, café, touristic guides) increasing gross profit from nature-based tourism.

The following Indicators are defined:

- JOBS CREATED IN THE NATURE-BASED SECTOR
- JOBS CREATED IN THE NATURE-BASED SOLUTION CONSTRUCTION AND MAINTENANCE
- NEW EMPLOYMENT IN THE TOURISM SECTOR
- NEW ACTIVITIES IN THE TOURISM SECTOR
- GROSS PROFIT FROM NATURE-BASED TOURISM
- TOURISTIC ACTIVENESS ENHANCING

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Jobs created in the nature-based sector	-	Model/Statistical Data	Model/Statistical Data
Jobs created in the nature-based solution construction and maintenance	-	Model/Statistical Data	Model/Statistical Data
New Employment In The Tourism Sector	Statistical Data	Model/Statistical Data	Model/Statistical Data
New Activities In The Tourism Sector	Statistical Data	Model/Statistical Data	Model/Statistical Data
Gross Profit From Nature-Based Tourism	Statistical Data	Model/Statistical Data	Model/Statistical Data
Touristic Activeness Enhancing	Statistical Data	Model/Statistical Data	Model/Statistical Data

Sub-Criterion Indicators: Promotion of Socio-Economical Development of Marginal Areas

- **CRITERION: Local Economy Reinforcement**

- ***SUB-CRITERION: New Areas for Traditional Resources***

SUB-CRITERION	Indicators will assess....
New Areas for Traditional Resources	how much area NBSs will be made available for traditional activities in rural mountain landscape (e.g. agriculture, livestock, fishing, etc.), previously not usable because dangerous or unreachable

Sub-Criterion Table: New Areas for Traditional Resources

This criterion evaluates if a project reducing hazard condition could make available, for traditional productive uses, areas that were previously at risk. Traditional uses considered are agriculture, fishing, pastures or the sustainable exploitation of woodland resources. Indicators considered could be inferred by projects or by spatial analysis in the Long-Term scenario. The following Indicators are defined:

- <u>NEW AREAS MADE AVAILABLE FOR TRADITIONAL ACTIVITIES (AGRICULTURE, LIVESTOCK, FISHING,….)</u>
- <u>FOREST AREA PLANTED</u>

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
New Areas Made Available for traditional activities (agriculture, livestock, fishing,….)	-	Model/GIS	Model/GIS
Forest Area Planted	-	Model/GIS	Model/GIS

Sub-Criterion Indicators: New Areas for Traditional Resources

- ***SUB-CRITERION: Enhancement of Local Socio-Economic Activities***

SUB-CRITERION	Indicators will assess....
Enhancement of Local Socio-Economic Activities	the increase and enhancement of local socio-economic activities induced by NBSs, such as the productivity of rural areas

Sub-Criterion Table: Enhancement of Local Socio-Economic Activities

- RURAL PRODUCTIVITY INDEX: NBS implementation can improve the productivity of rural areas, in term of agricultural products quality and quantity. This Indicator takes into account the variation of productivity of rural areas.

INDICATOR	SCENARIOS		
	Baseline	Design	Long-term
Rural Productivity Index	-	Model/GIS	Model/GIS

Sub-Criterion Indicators: Enhancement of Local Socio-Economic Activities

B4 References

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Appendix C

The Case study of Quindici (AV)

Contents

C1 Case Study

C1.1 Introduction

In the framework of PHUSICOS project, the Municipality of Quindici in the Province of Avellino was chosen as a preliminary case-study to test the reliability of the implemented framework for NBSs assessment (Figure C.1). In this Appendix an overview of the case-study area with a focus on the area-specific hazards is provided together with the description of its geological, hydraulic and topographic characteristics. In addition, with reference to two different Design Scenarios (a NBSs Scenario labelled as B1 and a Hybrid one labelled as B2), the methodology for the estimation of selected Performance Indicators of the Framework Matrix and its application for the Design Scenario performance assessment are illustrated.

In this application of the Framework Assessment Tool, on the basis of the site-specific characteristics and the available data, the analysis was performed considering a sub-set of the Indicators defined in APPENDIX A. The most of the PI were selected among the following Ambits: Risk Reduction, Technical & Feasibility Aspects, Society and Local Economy.

This application aims at demonstrating: (1) how NBSs are robust, sustainable and cost-effective measures to reduce the risk of extreme weather events in the mountain Municipality of Quindici (AV); (2) the suitability of the Framework Assessment Tool for the evaluation of the performance of different Design Scenarios.

Figure C.1 Location of Quindici (AV) Municipality

C2 The Baseline Scenario

The Quindici (AV) Basin, with an extension of about 85 km^2, was selected as the area for the application and testing of the proposed NBSs conceptual framework. The study area is part of Pizzo D'Alvano basin, located in Southern Italy. Figure C.2 shows the aerial photograph of Pizzo D'Alvano basin, including Quindici sub-basin. Slopes are characterized by shallow pyroclastic soil deposits, originating from the Vesuvio activities, underlying on limestone bedrock. Geological data are reported in the "Italian Geological Map" (scale 1:100.000) and are represented below in Figure 3.

The collection of the digital topographic data is summarized in the following Figures C.4-C.10, where the maps reporting the topographic properties of the Basin, the Landslide and Flooding Hazard and Risk Maps, as defined by the Basin Authority of Campania Centrale, are showed.

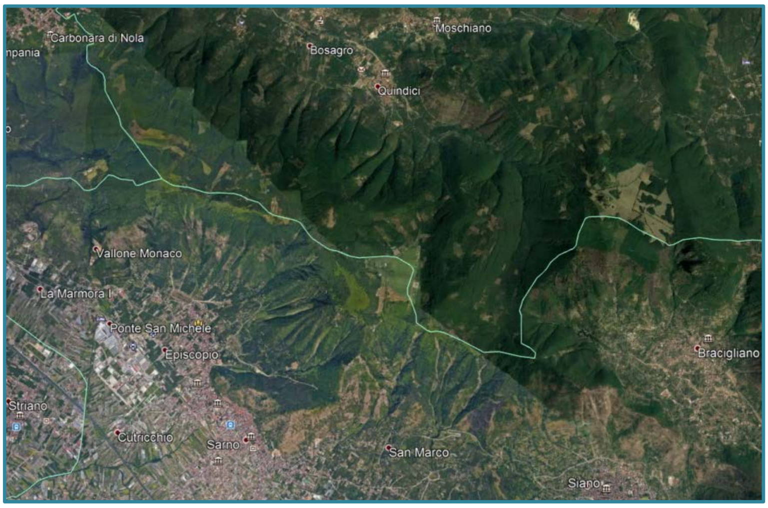

Figure C.2 Aerial photograph of Pizzo D'Alvano basin

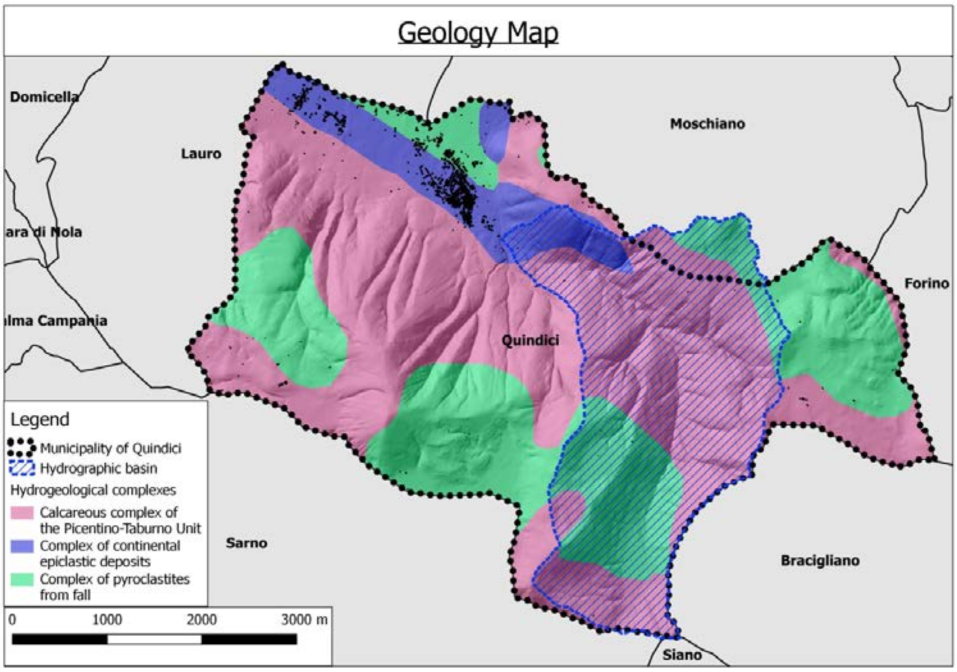

Figure C.3 Geological Map of Quindici (AV) Basin

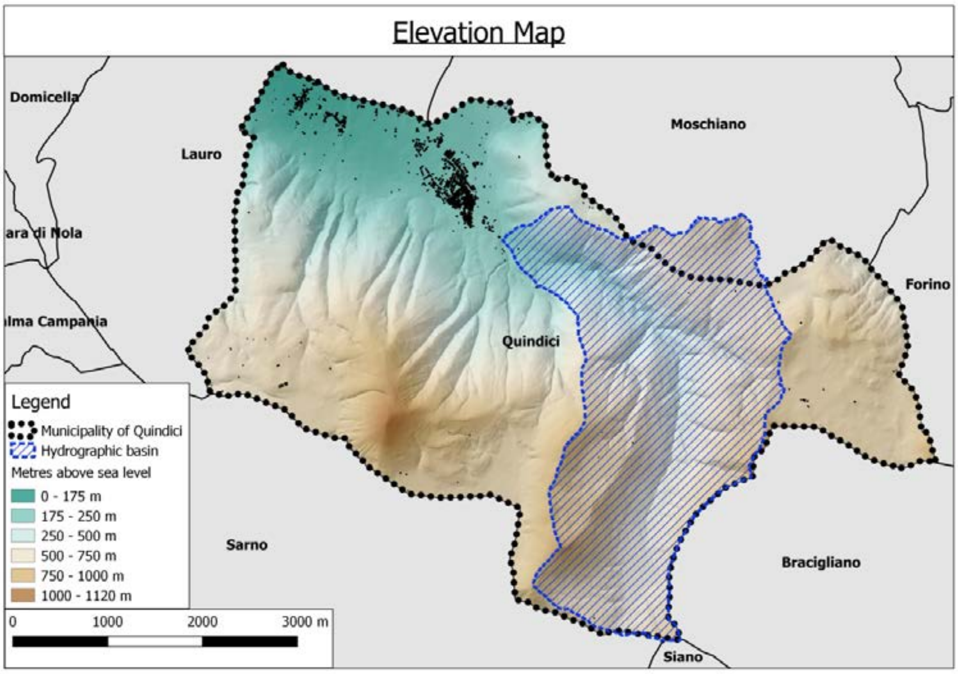

Figure C.4 Elevation Map of Quindici (AV) Basin

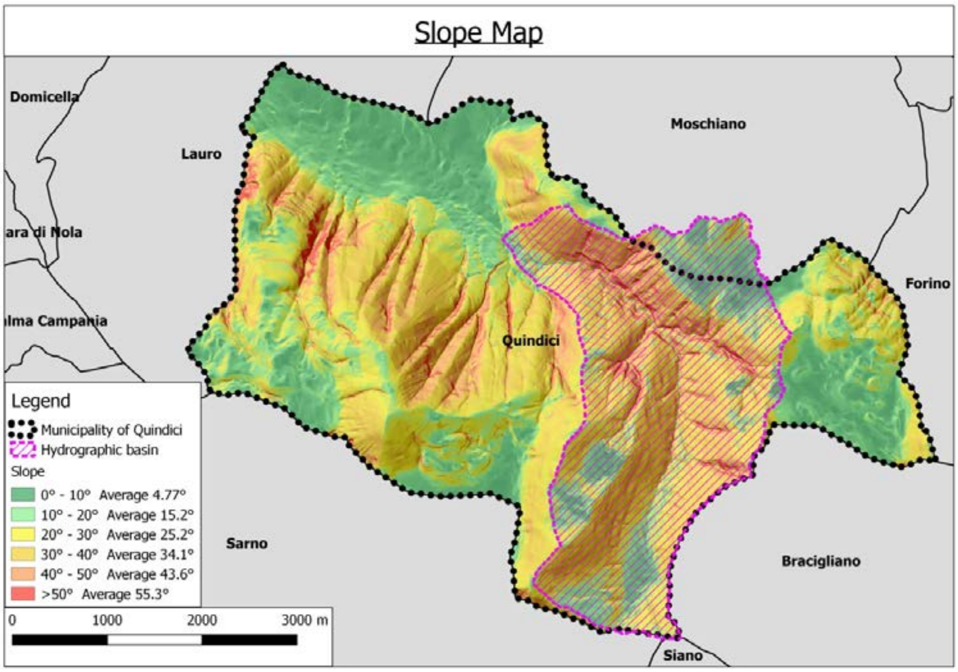

Figure C.5 Slope Map of Quindici (AV) Basin – Baseline Scenario

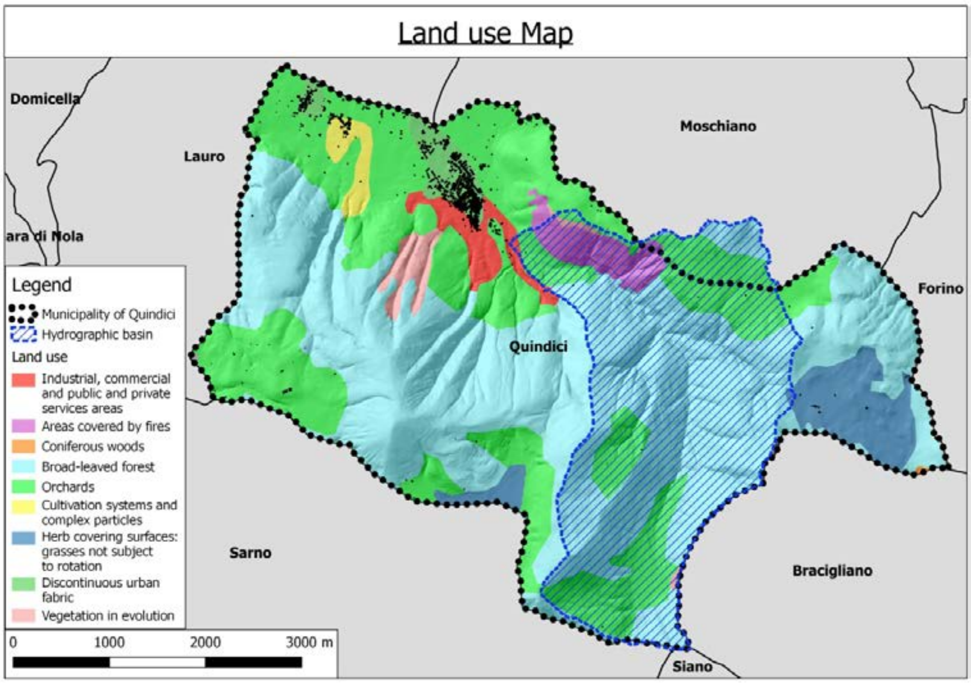

Figure C.6 Land Use Map of Quindici (AV) Basin – Baseline Scenario

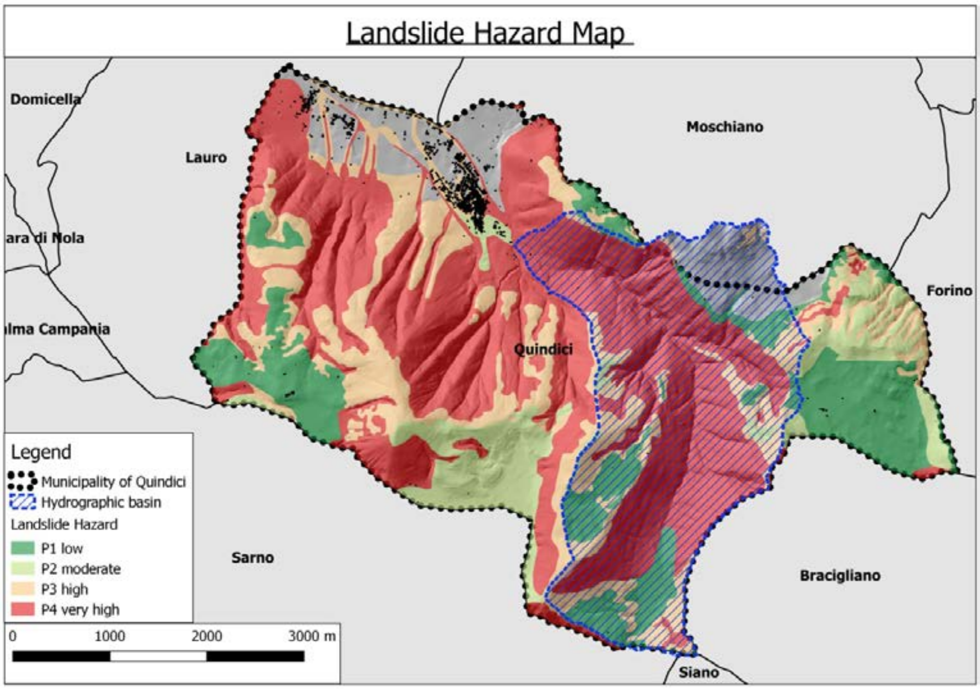

Figure C.7 Landslide Hazard Map of Quindici (AV) Basin – Baseline Scenario

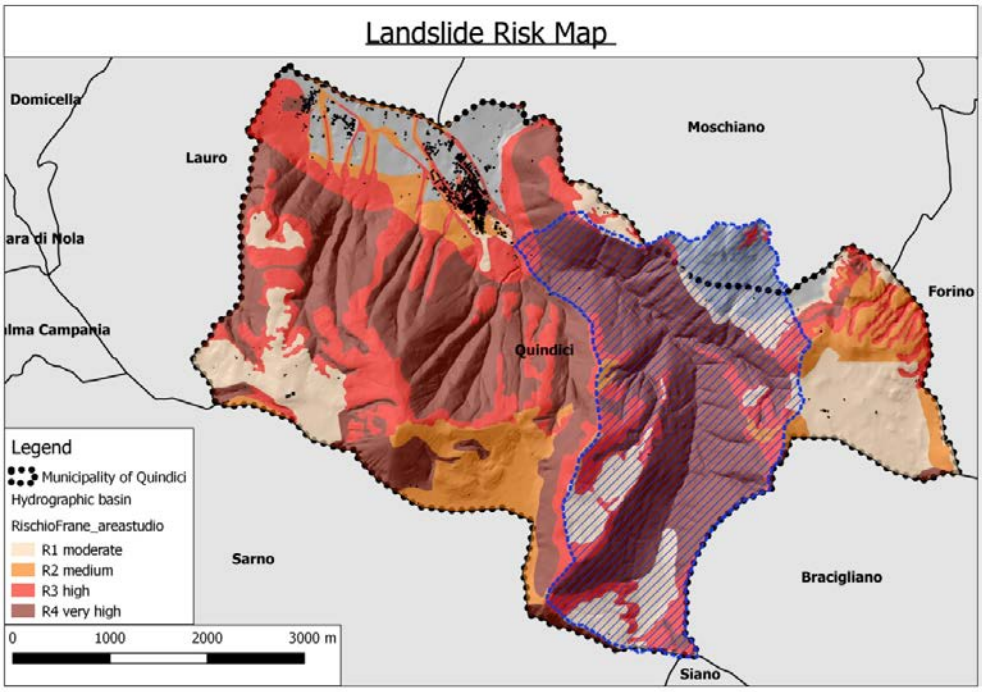

Figure C.8 Landslide Risk Map of Quindici (AV) Basin – Baseline Scenario

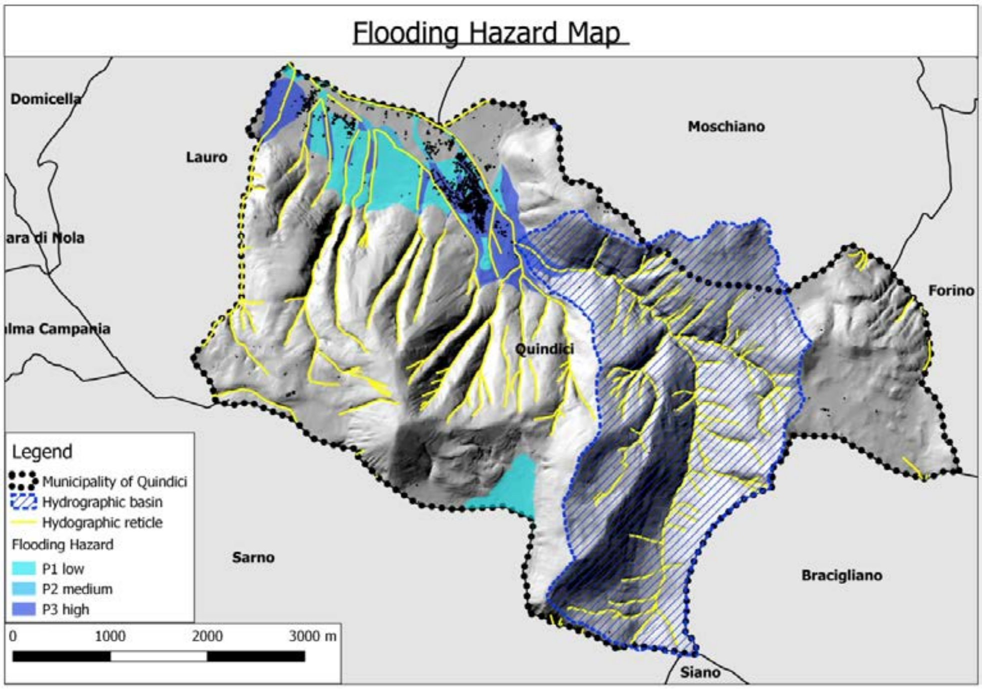

Figure C.9 Flooding Hazard Map of Quindici (AV) Basin – Baseline Scenario

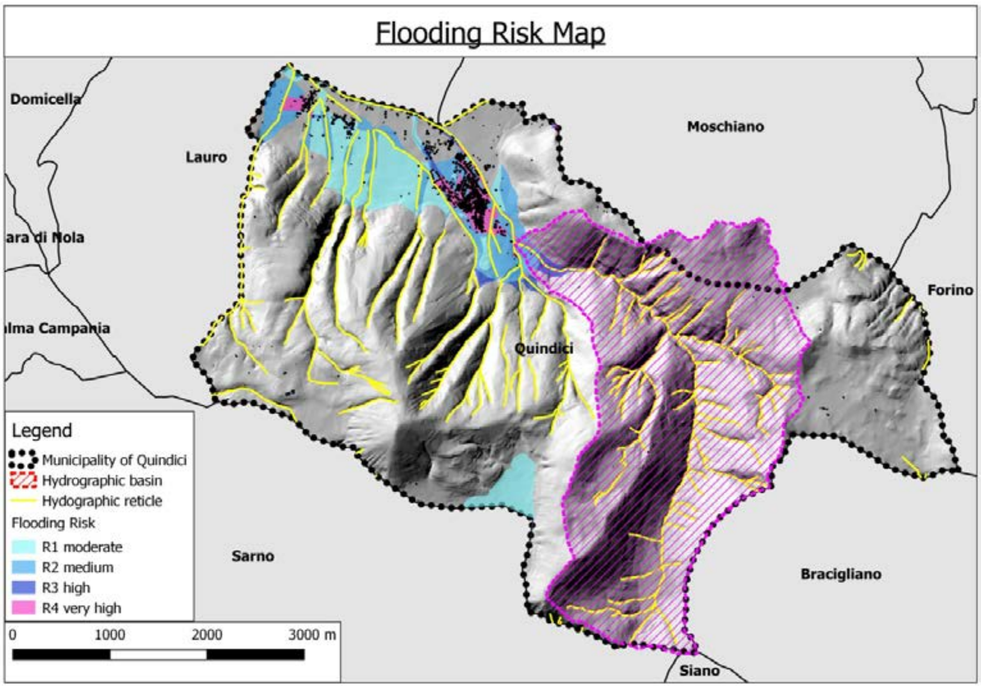

Figure C.10 Flooding Risk Map of Quindici (AV) Basin – Baseline Scenario

The most recent calamitous events occurred in this area on May 1998: intense and prolonged rainfalls determined over 140 landslides; about 3 million cubic meters invaded the urban areas with an estimated velocity ranging from 1 to 20 m/s (Bilotta et al., 2005). Several flow landslides, triggered by intense rainfall, occurred along Pizzo D'Alvano slopes (extension of ≈60 km^2), causing 159 casualties and seriously damaging four small towns (Bracigliano, Quindici, Sarno and Siano, shown in Figures C.2 and C.11). The energy of the mud wave was such to seriously damage structures (Figure C.12). Also structures in reinforced concrete were blanked or irreparably compromised (Cascini, 2004).

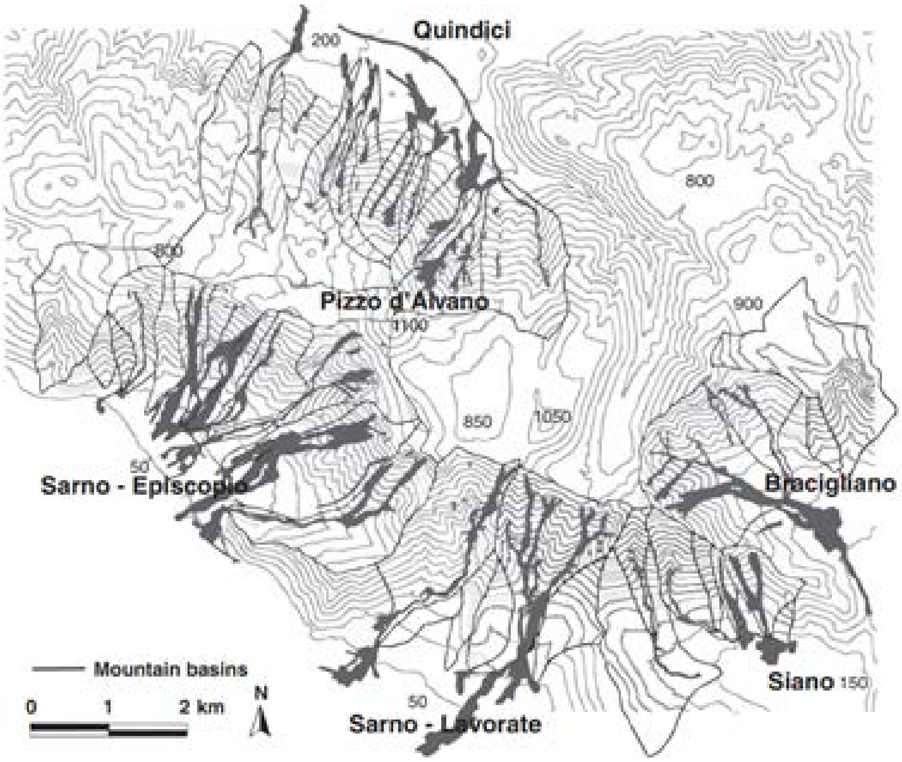

Figure C.11 Pizzo D'Alvano massif: overview of the main flow type landslides occurred in May 1998 (Cascini et al., 2004)

Figure C.12 Sarno and Quindici (AV) debris flow event on May 1998

From the catastrophic event of May 1998, several interventions were designed and implemented, with the aim of both reducing the tendency to detachment in the trigger areas along the slopes and ensuring the potential outflow of rainwater.

To achieve these objectives, different types of interventions were combined to create more complex defence systems, developing integrated interventions through active and passive measures. Active measures aimed at reducing the likelihood of detachments in those areas most susceptible to mobilization; passive measures aimed at mitigating, or cancelling, the potential damage caused by the debris flow events.

In greater detail, in the Municipality of Quindici (AV), the following interventions were implemented:

- the constructions of a detention basin (Pietra di Valle detention basin) (Figure C.13), useful to accumulate volumes of sludge coming from the uphill basins;
- the construction of a diversion channel (Connola diversion channel), allowing to reduce the risk of debris and mud pouring over the inhabited centre of Quindici, near the S. Francesco riverbed;
- the construction of retaining walls in the fractions of Beato and Bosagro.

Figure C.13 Pietra di Valle Detention Basin of Quindici (AV) Municipality

In the framework of this Appendix, the implementation of different Design Scenarios is simulated. The two different Design Scenarios were defined considering that the chaotic development of inhabited centres over the centuries has led to the loss of the paths naturally followed by the muddy flows characterizing the area. Thus, the two Scenarios were accurately designed in order to restore and realize naturalistic settlements on the slopes, by implementing NBSs, such as living grids and/or live fencings and fascines, which present, if correctly located and designed, a perfect and harmonious environmental insertion.

C2.1 Geotechnical characterization

Periodically rapid flow type movements occur in Campania Region (Southern Italy) caused by critical rainfall events. Essentially mudflows and debris flows can occur at the same time on several slopes characterized by shallow pyroclastic soil deposits, originating from the volcanic activity of Vesuvio, underlying on carbonate bedrock (Figure C.14).

The activation of a rapid landslide caused by the high grade of slopes and sometimes by the fluidification of the material, results in the high speed downstream propagation of the detached material in the foothills area. Due to its inertia, the soil movement continues to move quickly, being able to cover long distance. The kinetic energy of the soil movement represents the destructive potential of the landslide body. This energy is transferred to any obstacle placed along the path, generating significant impact forces (Budetta & de Riso 2004; Calcaterra et al., 1997; Guadagno 1991; Del Prete et al., 1998; Scotto di Santolo 2000; Fiorillo et al., 2000; Cascini et al., 2000; Picarelli & Olivares, 2001).

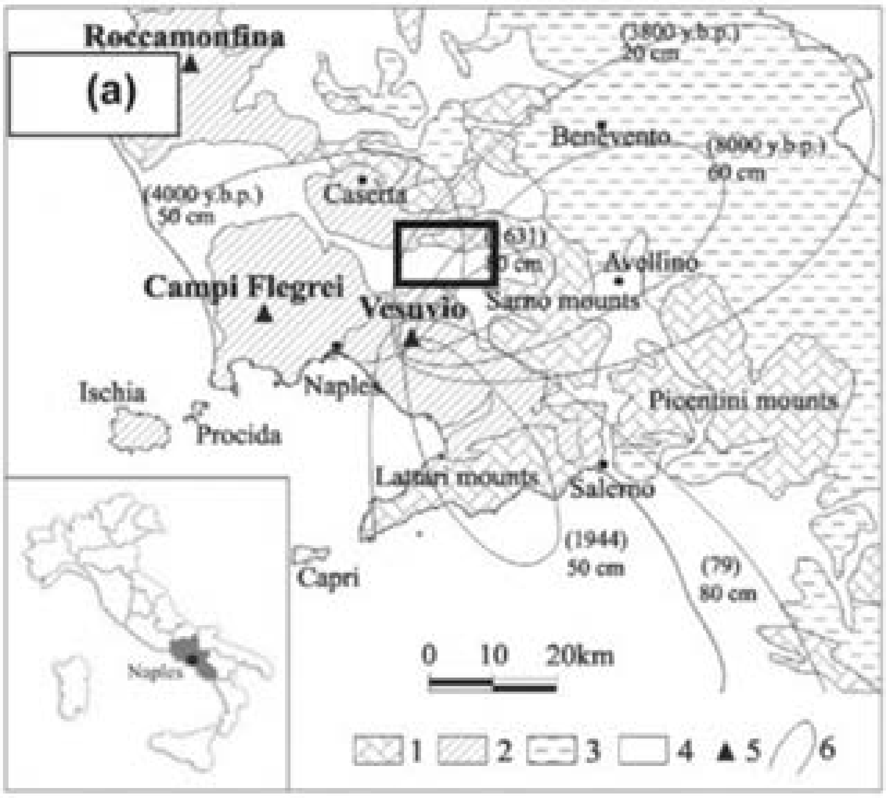

Figure C.14 Air fall pyroclastic deposits in the Campania region (modified after Cascini et al., 2008): 1 carbonate bedrock; 2 tuff and lava deposits; 3 flysh and terrigenous bedrock; 4 alluvial and continental deposits; 5 volcanic complexes; 6 isopachs of the pyroclastic products from the main eruptions

The stratigraphic profile of Pizzo D'Alvano basin is homogeneous and consists of a few meters thick of unsaturated pyroclastic soil (ranging from 0,5 to 5.0 m) underlying the limestone bedrock. The slope has an average angle of 25-30°, with local range of 35-40° (Figure C.6).

Several investigations were carried out in the Pizzo D'Alvano site. In-situ investigations were executed including topographical surveys, stratigraphic investigations and soils suction monitoring using portable and in-place tensiometers (Cascini & Sorbino, 2002). Moreover, an extensive laboratory test program was performed on undisturbed and remolded specimens by means of Suction Controlled Oedometer, Volumetric Pressure Plate Extractor, Richard Pressure Plate and Suction Controlled Triaxial Apparatus, allowing the collection of a noticeable data set of physical and mechanical properties of the involved ashy and pumice soils (Bilotta et al., 2005). The pyroclastic cover, generated by the explosive activity of the Vesuvio, is characterized by a high stratigraphic variability. Figure 15 shows typical stratigraphic conditions of pyroclastic soil covers, which are almost everywhere characterized by layers succession of pumiceous soils and ashy soils (discerned in class A generally on the top and class B on the bottom), sometimes with paleosoil horizons (Sorbino et al., 2013). Physical and mechanical properties for the pyroclastic soils along Pizzo D'Alvano slopes are summarized in the Table 1 below (Cascini et al., 2010):

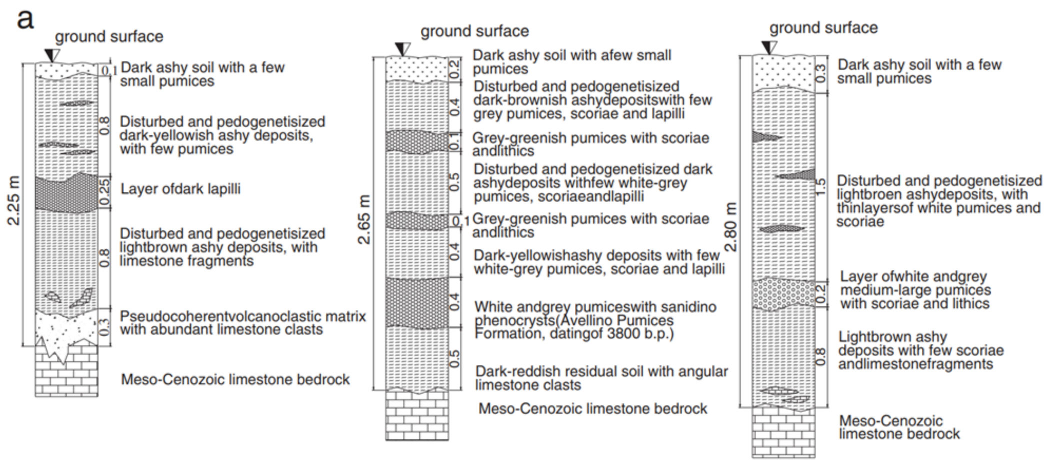

Figure C.15 Typical stratigraphic conditions of pyroclastic soil covers at Pizzo D'Alvano (Sorbino et al., 2013)

	Ashy soil (class A)	Pumice soils	Ashy soil (class B)
Dry unit weight [kN/m³]	9.10	6.20	7.30
Saturated unit weight [kN/m³]	15.70	13.10	13.10
Porosity [-]	0.66	0.69	0.58
Saturated hydraulic conductivity [m/s]	$1x10^{-6}$	$1x10^{-4}$	$1x10^{-5}$
Cohesive intercept [kPa]	5-15	0	0-5
Friction angle associated to the net normal stress [°]	32-35	37	36-41
Friction angle associated to matric suction [°]	20	20	20
Poisson ratio [-]	n.a.	n.a.	0.29
Elastic Modulus [MPa]	n.a.	n.a.	3-7
Dilatancy angle [°]	n.a.	n.a.	0-20

Table C.1 Physical and mechanical properties assumed for the pyroclastic soils along Pizzo D'Alvano slopes (Cascini et al., 2010)

C2.2

C2.3 Landslide

A2.3.1 Methodology

Hypothetical physical models of landslides can estimate slope instability by taking geometrical and geotechnical characteristics into account. The physically based model is recognized as one of the most effective susceptibility analysis methods since it takes into account the failure mechanism (Fell et al., 2008). In contrast physically based approaches can provide stability analysis at small scale (usually slope scale).

Geographic Information System (GIS) can analyse the landslide susceptibility over large areas using physical based approaches (Park et al., 2013). Moreover, physically based models can be combined with hydrological models to evaluate the effects of pore water pressure. However, when applying physically based models over large areas, data collecting and ground conditions give rise to high uncertainties.

In this case, the infinite slope model integrated with hydrological model was used. An idealized one soil layer slope was considered. The geotechnical characteristics of the soil were averaged considering the soils belonging to the Quindici site (Table C.2), a constant thickness of 2.0 m was considered. In order to achieve a Safety Factor F_s higher than 1, a slope angle β not greater than 33° is allowed. The obtained Safety Factor was applied to construct a spatial database for the potential slope instability using GIS software with grid resolution 5x5 m (Park et al., 2013).

γ_d [kN/m^3]	G_s	n	k_{sat} [m/s]	c' [kPa]	ϕ' [°]
7.58	1.89	0.6	10^{-6}-10^{-3}	0	32

Table C.2 Typical soil properties of the pyroclastic soil of Quindici (AV) Basin (Cascini et al., 2003)

A2.3.2 Infinite Slope Model and Hydrological Model

The Infinite Slope Model is a simple but highly useful tool for shallow sliding on a slip surface parallel to the slope of ground. The infinite slope model assumes that landslides are infinitely long with lower landslide depth than their length and width. Thus this model is most appropriate for analysing shallow landslides with planar failure surfaces. The failure surfaces for rainfall-induced landslides are often shallow (upper few meters) and parallel to the ground surface, the infinite slope model is usually used to assess the slope stability. The infinite slope model is applied to estimate the **Safety Factor** (**F_S**), based on limit equilibrium analysis that determines the balance between shear stress, inducing fracture along the supposed failure plane, and shear strength, which serves to resist shear fracture. Montrasio & Valentino (2007) analysed the Pizzo D'Alvano events, applying a simplified model, based on the following assumptions:

- infinite slope model;
- stability equilibrium guaranteed by the apparent cohesion of partial saturation of matrix;
- entire amount of rain infiltrates through the soil, neglecting the amount of run-off and evapotranspiration;
- the instant of collapse is characterized by the formation of a ground water table in the subsoil (mH);
- the thickness of saturated soil is strictly connected to the amount of water infiltrates into the topsoil;
- the decrease in mH following a negative exponential law of a discharge capacity controlled by the coefficient of drainage capability of the soil k_T.

F_S depends on the slope angle β, the thickness of the soil layer H, the soil porosity n, the degree of saturation S_r, the specific gravity G_s, the effective cohesion c', the friction angle φ', the unit weight of water γ_w, the water down flow condition (drainage capability of the soil defined by k_T) and on the rainfall depth h (Figure C.16):

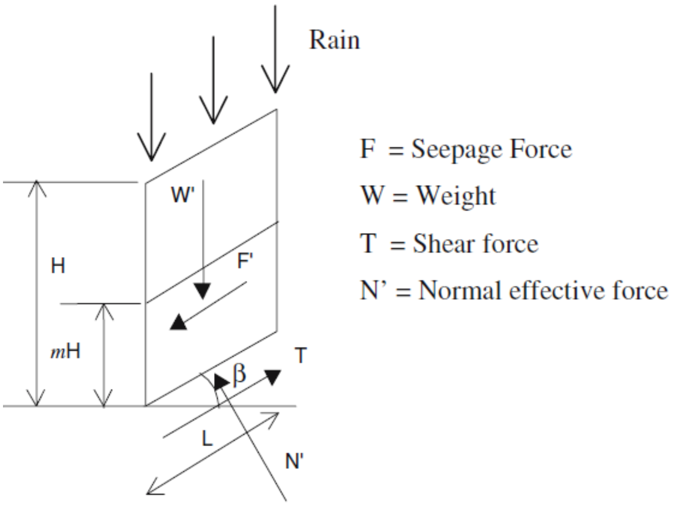

Figure C.16 The infinite slope model with forces acting on a slope slice

$$SF = \frac{N'\tan\varphi' + c'}{W'\sin\beta' + F'} \tag{C.1}$$

where

$$N' = \cos^2\beta \cdot H \cdot \gamma_w \left[m(n-1) + G_S(1-n) + nS_r(1-m) \right] \tag{C.2}$$

$$C' = c' + c_\psi = c' + AS_r(1-S_r)^\lambda (1-m)^\alpha \tag{C.3}$$

$$W' = \cos\beta \cdot H \cdot \gamma_w \left[m(n-1) + G_S(1+n) + nS_r(1-m) \right] \tag{C.4}$$

$$F' = \gamma_w \sin\beta \cdot \cos\beta \cdot mH \tag{C.5}$$

The cohesion *C'* for the unsaturated soils is composed by the effective cohesion *c'* and the apparent cohesion c_y, which can be expressed as a function of the saturation degree S_r, the parameters *A*, *λ*, *m* and *α* (Fredlund et al., 1996; Montrasio, 2000).
The value of *m* depends on time *t*:

$$m(t) = \sum_i e^{-K_T \frac{\sin\beta}{n(1-S_r)}(t-t_{0i})} \frac{h(t_{0i})}{nH(1-S_r)} \tag{C.6}$$

where t_{0i} is the instant when the rainfall event (expressed by rainfall depth $h(t_{0i})$) occurs. For the specific site the following parameters for the hydraulic model were calibrated (Montrasio & Valentino, 2007):

$A = 40$ $\lambda = 1.2$ $K_T = 4 \cdot 10^{-6}\ s^{-1}$

By analysing the data and the field measurements, it was reasonable to assume a constant value of $S_r = 0.7$. The Figure C.17 below shows how the model of Montrasio & Valentino (2007) well catches the Safety Factor F_S.

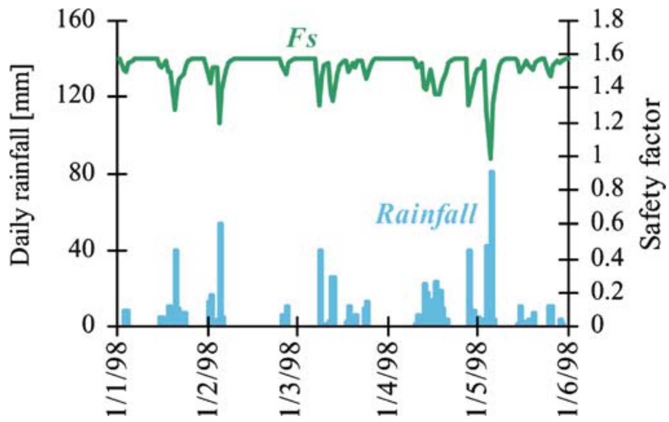

Figure C.17 Rainfall recorded at Pizzo D'Alvano in 1998 and *Fs* vs time

For the Baseline Scenario B_0, Landslides Risk Resilience Indicators of Quindici (AV) are referred to a characteristic daily rainfall $h = 80\ mm$ (the same daily rainfall which caused the catastrophic event on May 1998).

Figure C.18 shows the susceptibility map obtained by using GIS software. The adopted physical model results a Safety Factor $F_S \geq 1$ for slope angle $\beta \leq 33°$. The total potential slope failure area inside the basin was equal to 1.78 km^2 (Table C.3).

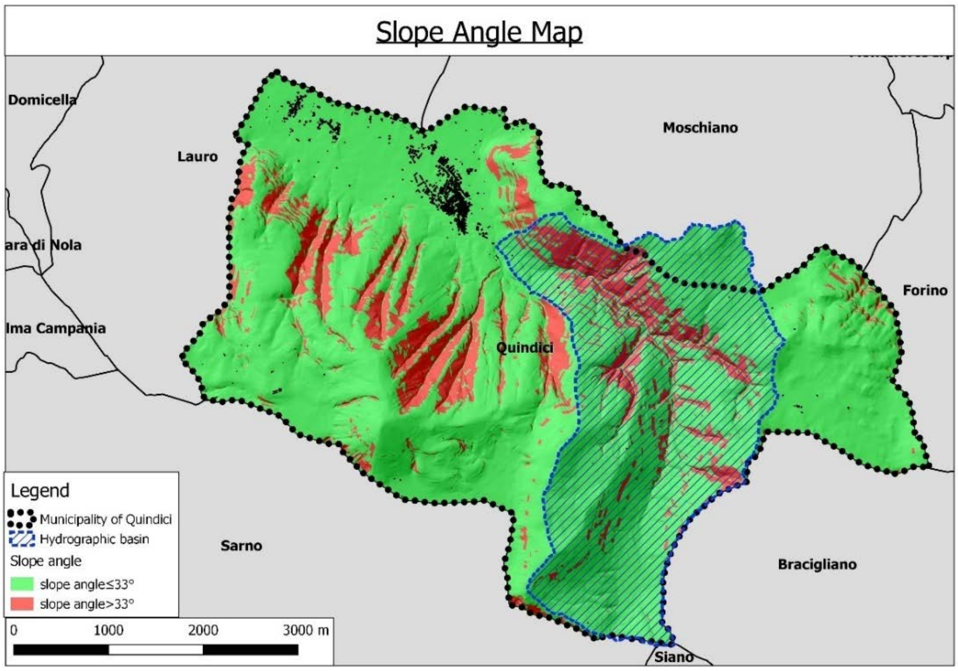

Figure C.18 Susceptibility map (assuming null soil cohesion) – Baseline Scenario

Scenario	Safety Factor (area with $F_S < 1$) [km^2]	
	Basin	Municipality
B0	1.78	4.70

Table C.3 Estimation of the Safety Factor indicator - Baseline Scenario

Note that this methodology is strongly influenced by the uncertainty of soil and soil topography. The above calculation is based on the conservative assumption of absence of cohesion corresponding to a return period approximately equal to 500/1000 years. Based on the experience of the recent events could be more plausible to assume a soil cohesion of 3kPa.

Assuming the soil cohesion value of 3 kPa, the landslide susceptibility map for the Baseline Scenario is reported in Figure C.19. In this case the Safety Factor $F_S \geq 1$ results for slope angle $\beta \leq 42.7°$.

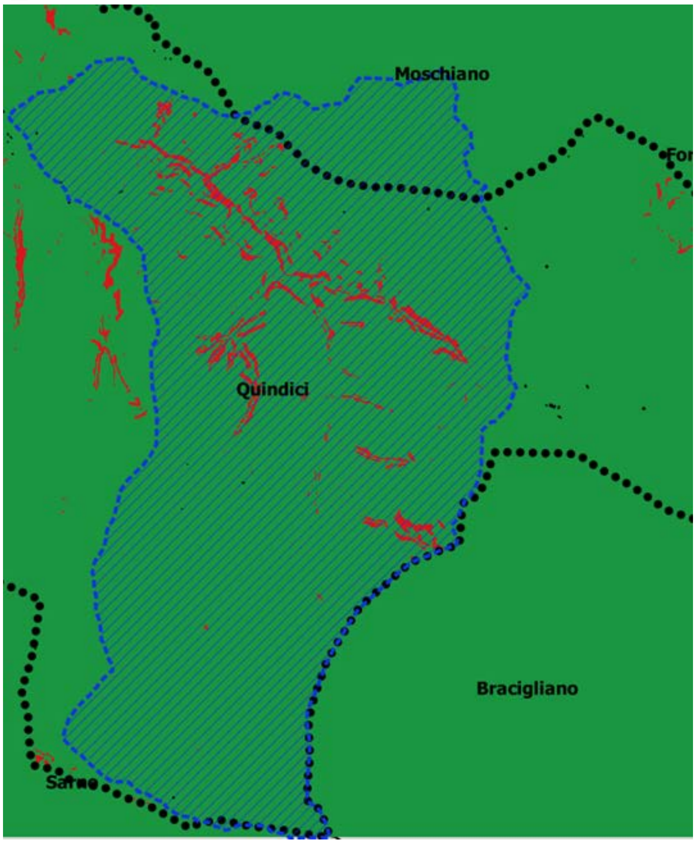

Figure C.19 Susceptibility map (assuming soil cohesion value of 3 kPa) – Baseline Scenario

C2.4 Evaluation of Occurred Landslide Invaded Area Indicator and Landslide Velocity

To define potentially invaded area from the landslide, the first step is to estimate the mobilizing potential soil volume.

De Falco et al. (2012) proposed an empirical method to estimate the potential volume that can be displaced during a flow type landslide. The method takes into account the information regarding the flow landslides occurred in Campania region in the recent years. The method is based on determining the thickness of the pyroclastic cover and the width of the detachment and erosion-transport zone.

The calculation of the volume that can potentially be displaced by the landslide refers to a single source and does not consider the case of multiple source areas merging in the same path (drainage way) within the basin.

The potential landslide area A_f can be calculated with a mathematical correlation as follows:

Carbonatic bedrock (regular slopes) $$A_f = {(H - 60.611)}/{0.007}$$ (De Falco et al., 2012)

where H is the probable height of the landsliding slope (Figure C.20).

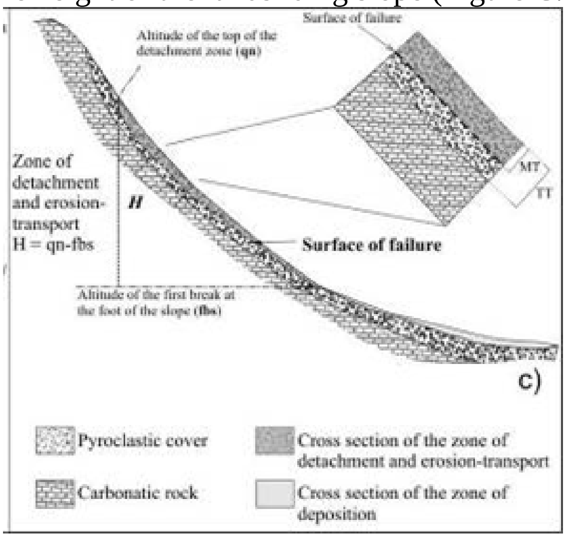

Figure C.20 A schematic representation of the main morphometric parameters (height of landslide H, total thickness of pyroclastic material TT and the actual thickness displaced MT)

The potential mobilizing soil volume is calculated as follow:

- *Step 1*: drawing up a susceptibility map. In this case the method used is explained in the previous paragraph (Figure C.19 for the Baseline Scenario B_0);
- *Step 2*: hierarchized drainage basins and regular slopes are individuated on the susceptibility map identified as A1, A2, A3 neglecting the area near to the river

(Figure C.21). The other basins have been reasonably neglected because significantly far from the urbanized area.

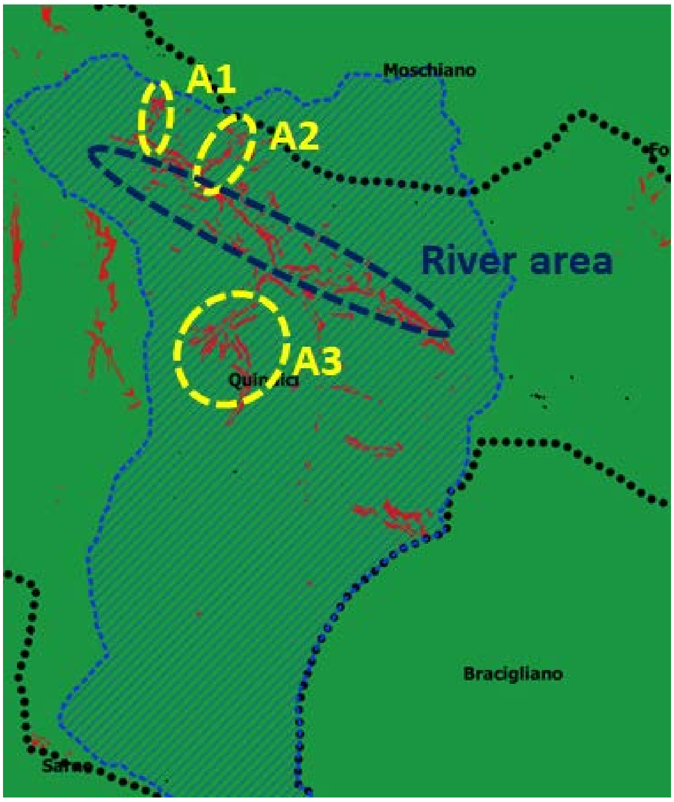

Figure C.21 Drainage basins A1, A2 and A3

- *Step 3*: The probable height of the landsliding slope (*H*) derives from the difference in height between the maximum height of slopes. For each basin, the potential landslide volume M is calculated as follows:

$$Volume \quad M = A_f \cdot tck \qquad (C.7)$$

Obviously, if the design scenario includes the construction of pond or reservoir, part of the volume can be intercepted before the propagation on the urbanized area. The Table C.4 summarizes the results.

Basin	Maximum altitude of detachment [m. a.s.l.]	Minimum altitude of detachment [m. a.s.l.]	Height of detachment [m]	Area of detachment [m^2]	N	Cover thickness [m]	Potential Mobilizing Volume M [m^3]	Detected Volume M [m^3]	Total Volume M [m^3]
A1	620	450	170	15627	1	1	15627	-	15627
A2	620	460	160	14198	1	1	14198	-	14198
A3	840	700	140	11341	1	1	11341	-	11341
TOT							41167	0	41167

Table C.4 Mobilized volumes for the Baseline Scenario

- *Step 4*: the peak discharge can be calculated with the empirical formula proposed by Rickenmann (1999):

$$Peak\ Discharge \quad Q_q = 0.1 \cdot M^{5/6} \tag{C.8}$$

A triangular mudgraph, associated to the empirical estimation of the peak flow obtained by the Rickenmann formula, is assumed. As a consequence, the duration $D(t)$ of the event is:

$$D(t) = 2M/Q_p = 0.041\ h \tag{C.9}$$

Moreover, as a check for the previously calculated mobilized volumes, the empirical formula of D'Agostino et al. (1996) was also applied. The adopted Eq. (C.10) was carried out from data on debris flow magnitude concerning basins of Eastern Italian Alps:

$$M = 70000 \cdot A \cdot S^{1.28} \cdot GI \tag{C.10}$$

where:

- M is the magnitude of the sediment volume yielded (m^3)
- A is the catchment area (km^2)
- S is the mean gradient of the stream (%)
- GI is a dimensionless geological index (-)

The obtained volume M from the formula above is equal to 39626 m^3, confirming the volumes previously calculated with the formula of De Falco et al. (2012) calibrated on Campania Region data.

The calculated values of mobilizing volume with De Falco's formula are the input for the simulation of flow landslides by using the analytical software FLO2D. This software is a 2D hydrological-hydraulic dynamic flood model that simulates flood, mud-flow and debris flow over complex topography. FLO-2D is a model that uses the full dynamic wave momentum equation and a central finite difference routing scheme with eight potential flow directions to predict the progression of a flood hydrograph starting from a closing section over a system of square grid elements estimating the hydraulic variables (depth, velocity and discharge) in a cell by cell basis.

Figure C.21 shows the propagation of the mobilizing soil volume calculated above on the urban area of Quindici (AV) for the Baseline Scenario where the urban area interested by the mud flow is about 0,705 km^2, and the calculated debris flow velocity is equal to 10.23 m/s. Table C.5 summarizes the main landslide properties of the Quindici (AV) Basin test case.

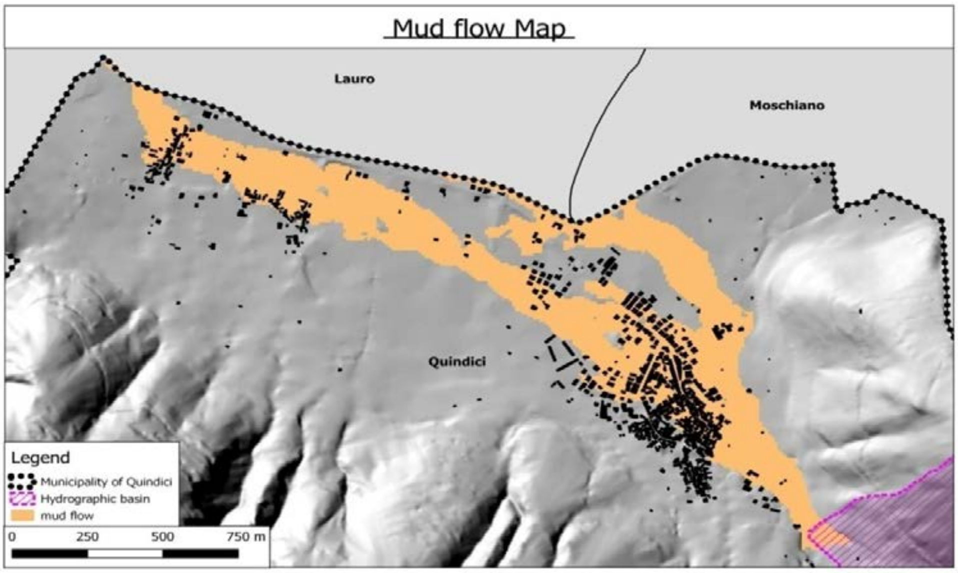

Figure C.21 Calculated propagation of the mobilizing soil volume – Baseline Scenario

Baseline Scenario B_0			
Landslides Risk Resilience	Site response to Landslide phenomena based on susceptibility indicators: slope angle, pore water pressure, groundwater depth, soil properties, land use, land cover	Safety Factor (Area with Fs < 1) [km^2]	0.276
		Occurred Landslide Area [km^2]	0.705
		Velocity of Occurred Landslide [m/s]	10.23

Table C.5 Landslides Risk Resilience Indicators of Quindici (AV) Basin – Baseline Scenario

C2.5 Flooding

A2.5.1 Hydraulic characterization

The main hydraulic properties of the Quindici (AV) Basin test-case are reported in Table C.6.

Hydraulic Properties of Quindici (AV) Basin	
Length of Main Stream *L* [km]	5.82
Basin Area *A* [km^2]	8.30
Elevation of the Basin Closure Section z_0 [m a.s.l.]	280
Average Elevation of the Basin z_m [m a.s.l.]	749
Maximum Elevation of the Basin z_{max} [m a.s.l.]	1067
Average Slope of the Basin *s* [%]	44.7
Concentration Time of the Basin by Giandotti's formula *tc* [h]	1.17
Average Curve Number of the Basin *CN* [-]	46.8

Table C.6 Main Properties of the Quindici (AV) Basin

In the following Figure C.22 the Quindici (AV) Basin is depicted, with related hydrographic reticulum.

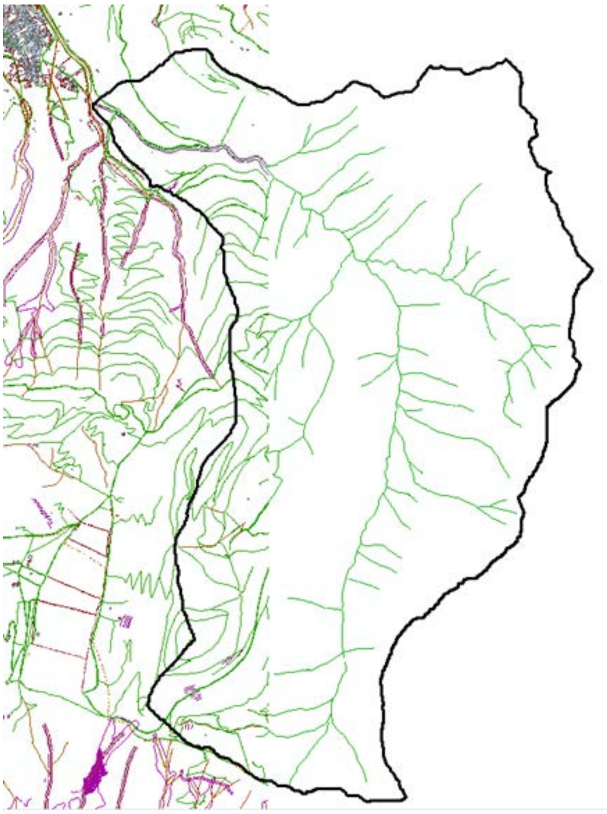

Figure C.22 Quindici (AV) Basin

A2.5.2 Evaluation of Flooding indicators

For the Baseline Scenario Flooding Risk Resilience, the following indicators have been evaluated with reference to a Return Period T = 100 years (Table C.7). Nevertheless, simulations for T = 30 years and T = 300 years have also been performed.

Baseline Scenario B_0 – Return Period T = 100 years (Medium Hazard)			
Flooding Risk Resilience	Site response to Flooding phenomena based on susceptibility indicators: land use cover, run-off coefficient, rainfall intensity and duration	Peak Flow [m^3/s]	17.57
		Peak Volume [m^3]	141647
		Flooded Area [ha]	75.1

Table C.7 Flooding Risk Resilience Indicators of Quindici (AV) Basin – Baseline Scenario B0; Return Period T = 100 years (Medium Hazard)

To assess both the Peak Flow Q_p and Peak Volume V_P the Soil Conservation Service (SCS) procedure was implemented in a hydrologic tool, with reference to the Mockus unit hydrograph. In Figure C.23 the derived hydrograph is shown.

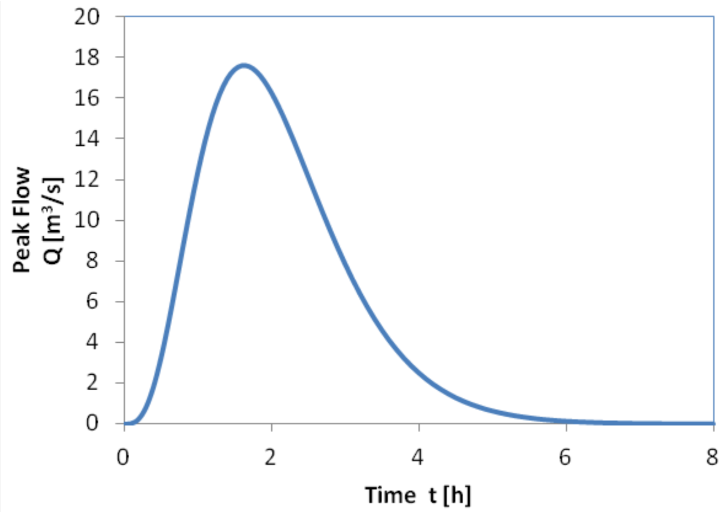

Figure C.19 Hydrograph of Quindici (AV) Basin – Baseline Scenario; Return Period T = 100 years

To detect the Flooded Area, the FLO2D software was used. A DEM with cell size resolution of 5 m was adopted (Figure C.24).

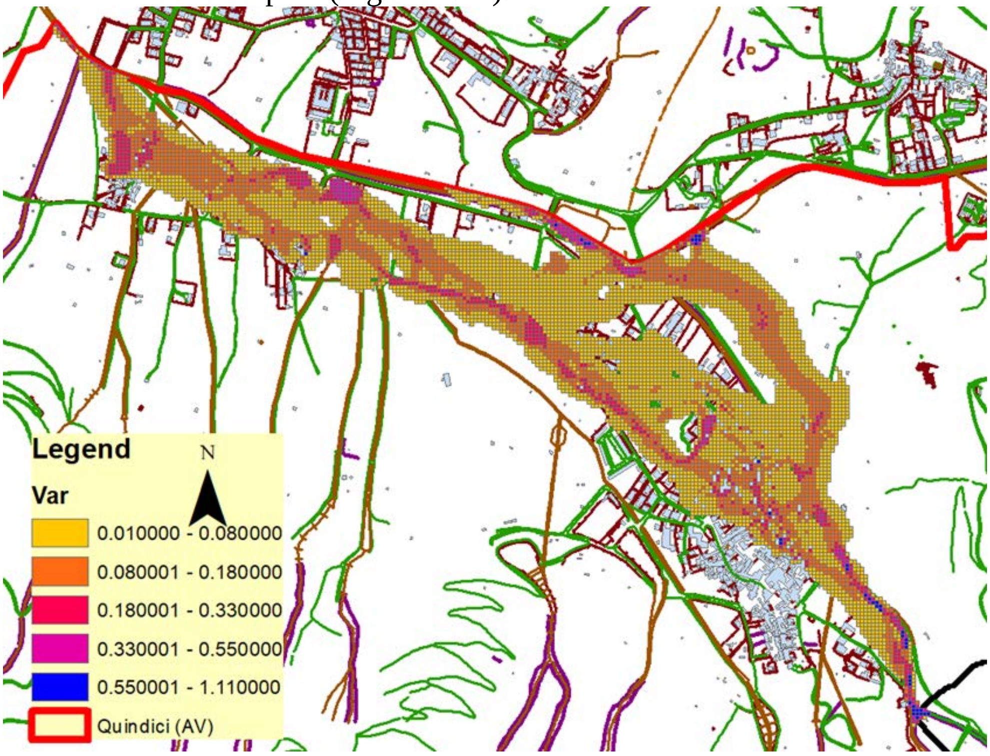

Figure C.20 Flooded Areas of Quindici (AV) Basin – Baseline Scenario; Return Period T = 100 years (Medium Hazard)

In Figures C.25 and C.26, the flooded area maps are shown, whereas in Figure C.27 the maximum flow depths *h* are shown in Figure C.27.

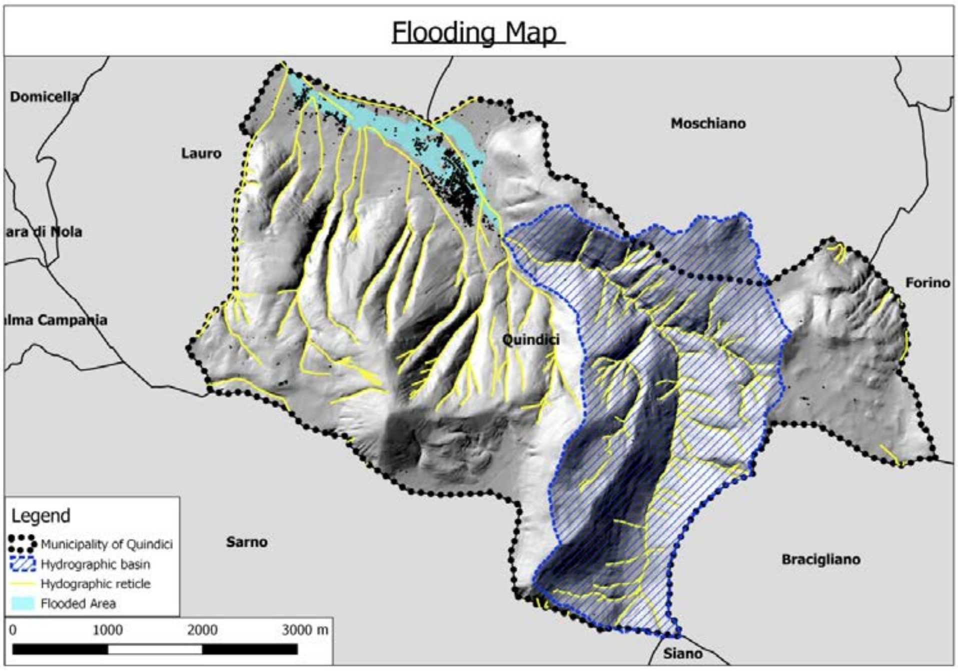

Figure C.215 Flooded Areas of Quindici (AV) Basin – Baseline Scenario; Return Period T = 100 years (Medium Hazard)

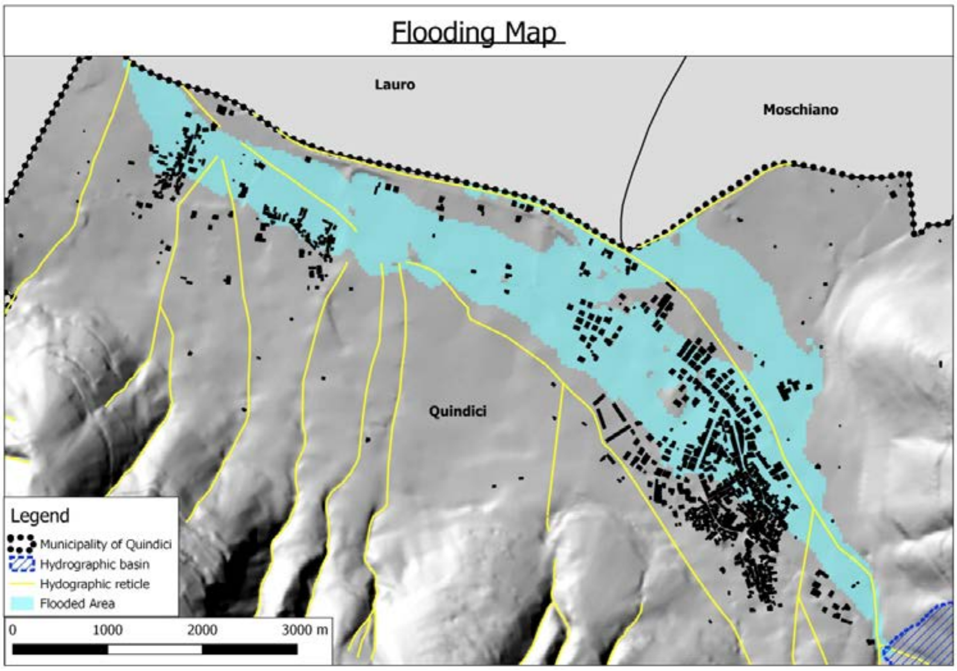

Figure C.26 Flooded Areas of Quindici (AV) Basin – Baseline Scenario; Return Period T = 100 years (Medium Hazard)

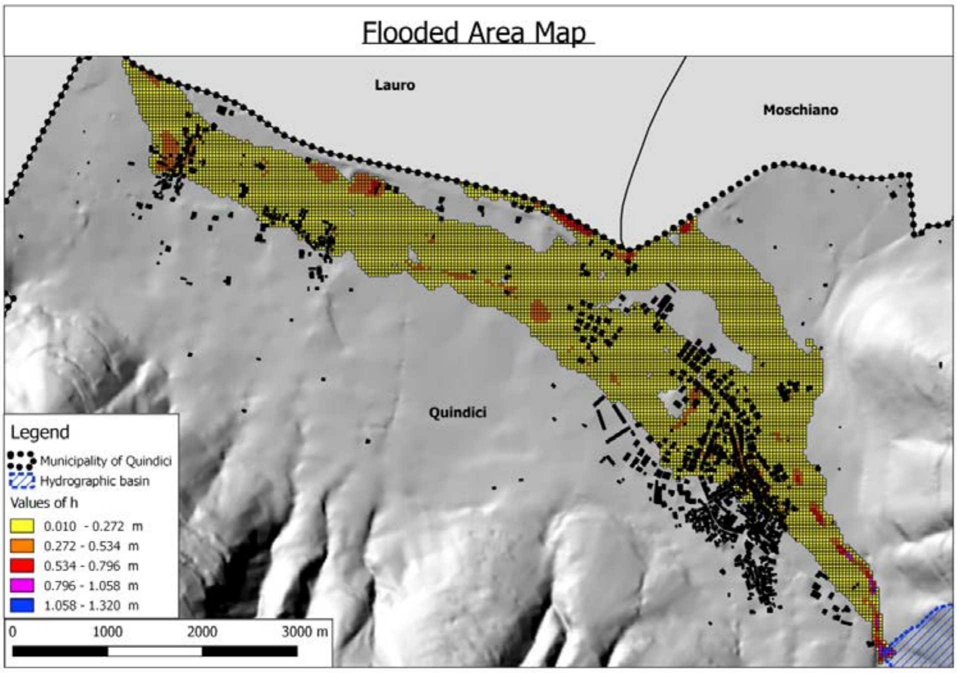

Figure C.22 Flooded Areas of Quindici (AV) Basin – Baseline Scenario; Return Period T = 100 years (Medium Hazard)

C2.6 Social and Economic Assets

Quindici (AV) is a small mountain municipality located in the innermost part of the Vallo di Lauro at the foot the of the homonymous mountains. In 1998, it was one of the municipalities most affected by the so-called "Sarno disaster", in which numerous debris flows struck five municipalities in Campania. Quindici was affected by two landslides, the second one, a violent wave of water and debris, invaded the centre of the town, causing 11 deaths and extensive damages to housing stock.

The tragedy constituted a turning point and the Municipality lost more than 40% of its inhabitants during the following decade. The cause of this strong demographic decrease was the combination of the effects of the natural disaster with a stagnant economy, mainly based on agriculture in an orographically rough area. The Municipality is affected by phenomena of both physical decay - there are still areas not reconstructed after the disaster - and social decay due to the presence of organized crime. The agricultural activity produces quality products such as walnuts and hazelnuts, but also olives and orchards. However, most part of the municipality surface is covered by forests, affected by a large fire that destroyed a great part of the wood on one of the slopes of the study basin during the month of August 2017.

On the other hand, the area is characterized by a large naturalistic and landscape heritage as evidenced by the vast Site of Community Importance area (Habitat Directive 92/43/EEC). Natural resources are completed by a minor historical-artistic heritage composed by numerous churches, some palaces and ancient water mills. As a matter of fact, the community has a strong identity character supported by many traditions mainly related to religious celebrations. Nevertheless, the natural heritage is crossed by a network of trails, currently in a bad state of maintenance.

On the basis of geospatial analysis implemented by using GIS software, the local socio-economic asset of the case study area (Figure C.28) was assessed, resulting in the definition of the following criteria for Society and Local Economy Ambits: Quality of Life, Landscape and Heritage, Local Economy Reinforcement and Revitalization of Marginal Areas. Specifically, solutions to foster the Recreational Opportunities, the Sustainable Mobility, the Heritage Accessibility and the Landscape Perception were taken into account, as summarized in Table C.8.

Figure C.28 Quindici (AV) viewshed - Baseline Scenario

Table C.8 Society and Local Economy Performance Indicators - Baseline Scenario

AMBIT	CRITERION	SUB-CRITERION	INDICATOR	METRIC	TIPOLOGY	DIRECTION	SOURCE	PI BASELINE SCENARIO
SOCIETY	*Quality of life*	Leisure and Connections Increasing	Number of visitors in new recreational areas	nr	QT	max	GIS	0
			Different activities allowed in new recreational areas	nr.	QT	max	S	0
			Average distance of natural resources from urban centres/train stations/public transportation	km	QT	min	GIS	2.3
			New pedestrian, cycling and horse paths	m	QT	max	GIS	0
			Sustainable transportation modes allowed	nr.	QT	max	S	0
	Landscape and Heritage	Identity	Traditional events organized in the new areas	nr.	QT	max	S	0
		Heritage Accessibility	Natural and cultural sites, made available	nr. Site	QT	max	GIS	0
		Landscape Perception	Scenic sites and Landmark created	nr.	QT	max	GIS	0
			Scenic paths created	km	QT	max	GIS	0
LOCAL ECONOMY	*Local Economy Reinforcement*	New Areas for Traditional Activities	New areas made available for traditional activities (agriculture, livestock, fishing,….)	ha	QT	max	GIS	0
			Forest area planted	km^2	QT	max	GIS	0

C3 Design Scenarios

A significant landslide and flooding risk level emerged from the Baseline Scenario analysis for the case study area. Thus, two Design Scenarios were developed in order to lower the aforementioned risks. Specifically, the first scenario considered only NBSs (B1), whereas hybrid solutions were applied for the second one (B2).

C3.1 NBSs Scenario (B1)

The NBS Scenario B1 aims at providing answers to the landslide and flooding natural risks. The interventions are located in an area that allows to link together some of the main resources of the Municipality. The B1 Scenario included only Natural Based Solutions, briefly listed below.

- *Vegetated timber crib (schematically reported in Figure C.29a, an example is shown in Figure C.29b for landslide risk reduction)*

(a) (b)

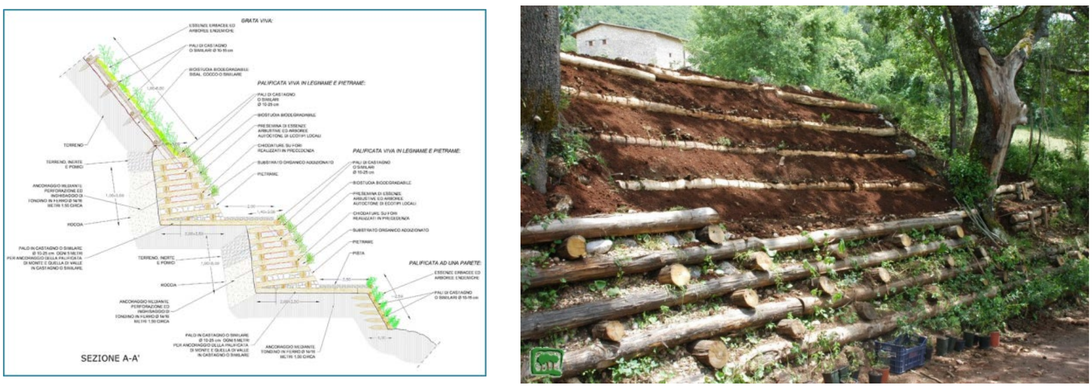

Figure C.23 Schematic description (a) and example (b) of vegetated timber cribs

- *Retention ponds (with total capacity of 20.000 m^3) (an example is reported in Figure C.30) for flooding risk reduction*

Figure C.30 Example of retention ponds

- *Reforestation (Figure C.31) for landslide and flooding risk reduction*

Figure C.31 Reforestation on a slope

- *River channel naturalization (Figure C.32) for flooding risk reduction*

Figure C.32 River channel naturalization

The location of the interventions within the study area is depicted in Figures C.33-C.34.

C4

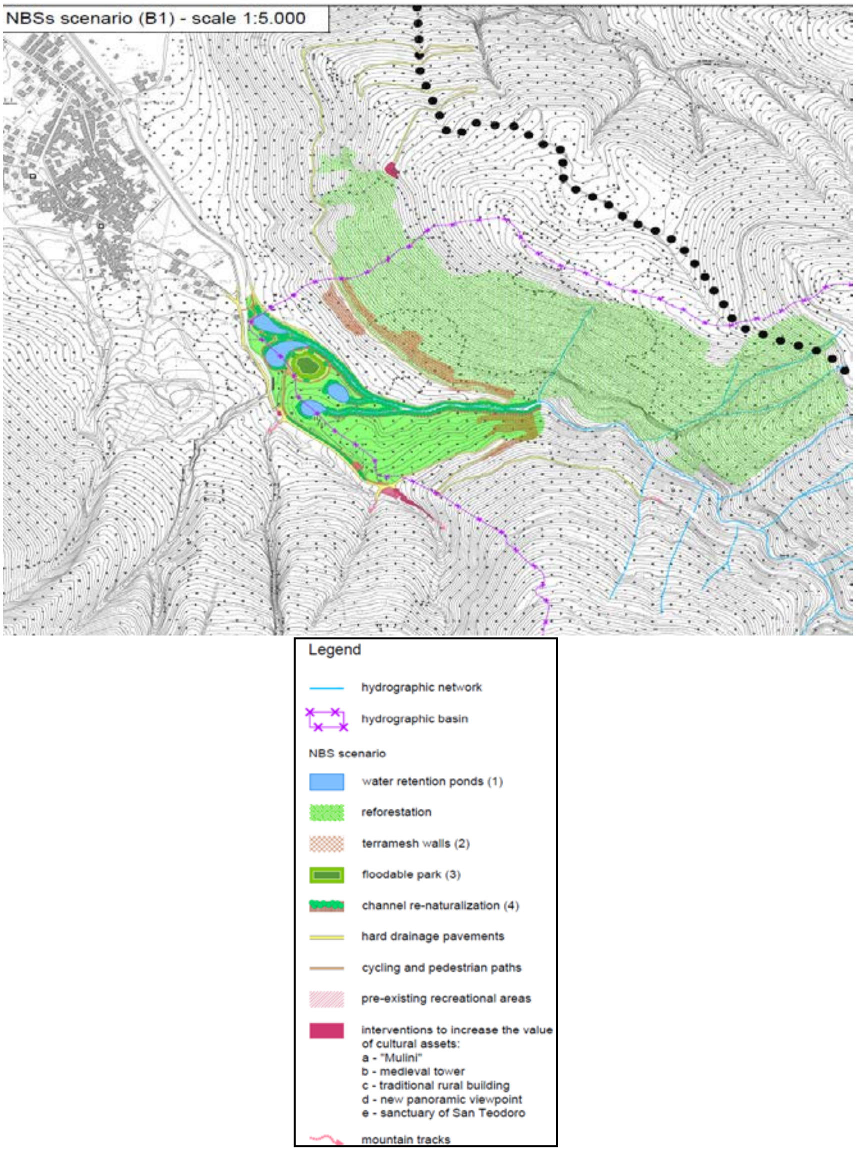

Figure C.24 Location of NBSs interventions for Scenario B1 (vegetated timber crib, retention ponds, reforestation, river channel naturalization)

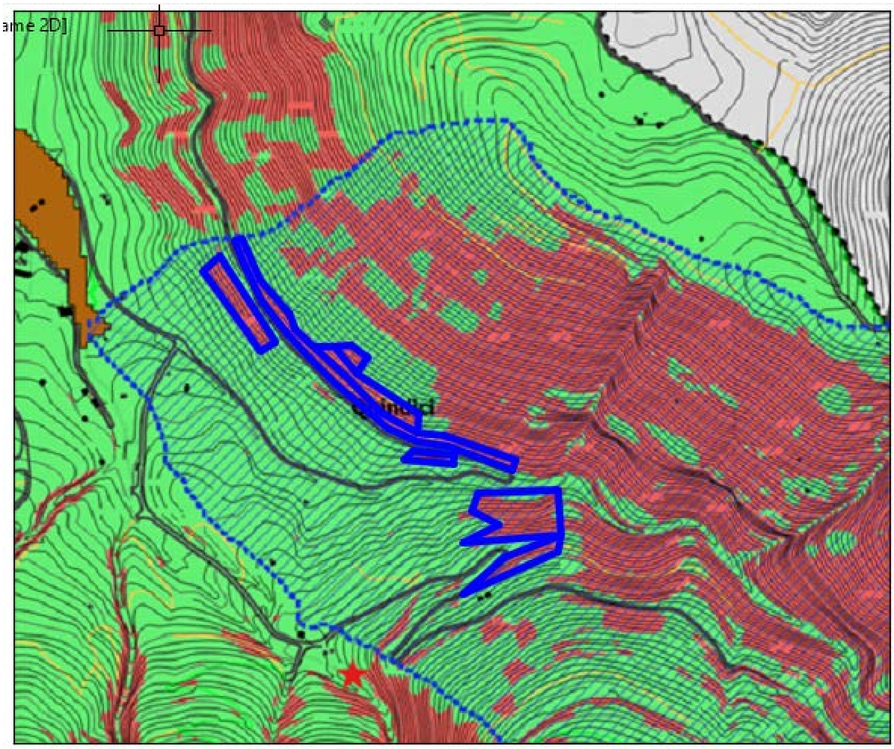

Figure C.25 Location of vegetated timber cribs within the study area

In B1, a system of 4 water **retention ponds** was proposed. The ponds, mutually interconnected, have a total area of 13300 m^2 and a total volume of 20000 m^3, having, on average, a 1.50 m depth. Furthermore, a **floodable park** of 9050 m^2 was planned.

The retention ponds, from the hydraulic viewpoint, are filled during rainy periods, when the torrent waterway, usually dry for the most of the year, start flowing nearby and fulfil them. In turn they reconnect to the existing artificial channel. For extreme events, when the retention ponds are totally filled, they can overflow into the adjacent floodable park. On the contrary, in dry weather conditions, the retention ponds and the floodable park can dry up, through infiltration into the base layer and evapotranspiration. Specifically, the Floodable Park becomes a recreational area that can host a multitude of leisure activities, such as social passive recreation activities (relax,…), cultural events and so on.

The following Figure C.35 shows the details of the described interventions.

(a) (b)

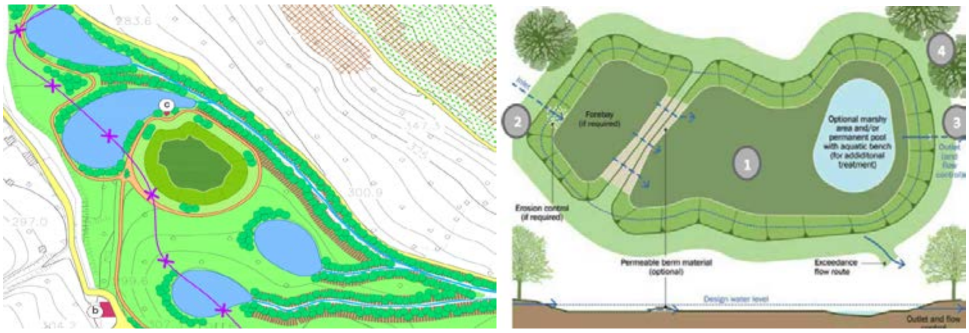

Figure C.26 The 4 retention ponds and the Floodable Park designed (a), Plan and profile view of a floodable park (b)

Moreover, the project foresees the watercourse channel naturalization through the **expansion** and the **re-profiling of the banks** along the path to the retention ponds and the floodable park, with a length of 2.06 km and a total volume of 61800 m^3. The re-profiling is made using a terramesh system, a modular system made of gabion type blocks with dimensions 0.3×1 m filled with stones (Figure C.36).

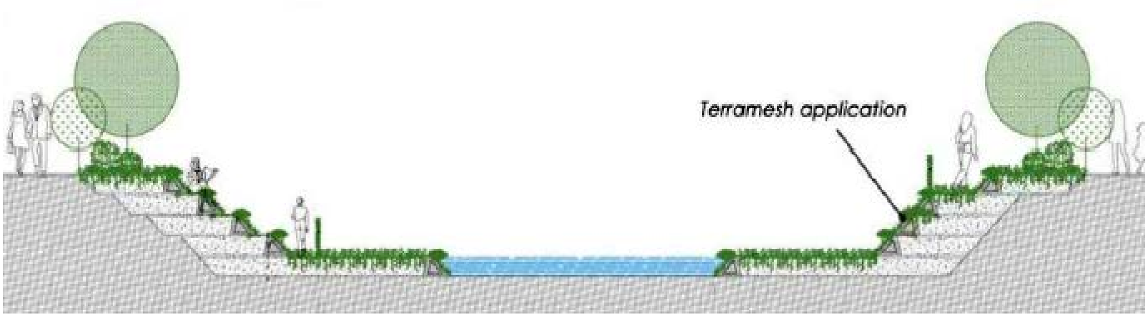

Figure C.36 Sample section of terramesh system for watercourse naturalization

From the landslide risk reduction viewpoint, active landslide defence measures constituted by vegetated timber cribs are considered. These interventions were located in areas close to roads, susceptible to landslide risk, as shown in the Figure C.37.

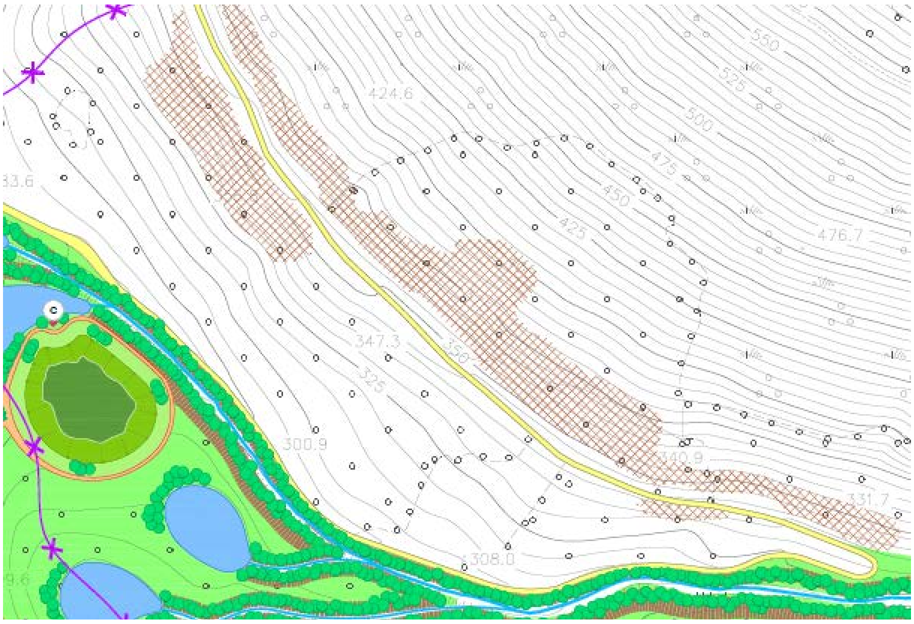

Figure C.27 Location of the vegetated timber cribs

As a complementary intervention, as shown in Figure C.37, also **hard drainage pavements** with length 24.20 km are foreseen, designed to improve the nature-based approach of the existing routes. Considering the cultural assets of the area, the proposed pavements could generate a diffusive green park able to reconnect and enhance a series of pre-existing resources: a small picnic area, a small historical-archaeological area with the remains of a medieval tower and the ancient water mills. These small recreational areas are shown in the Figure C.38.

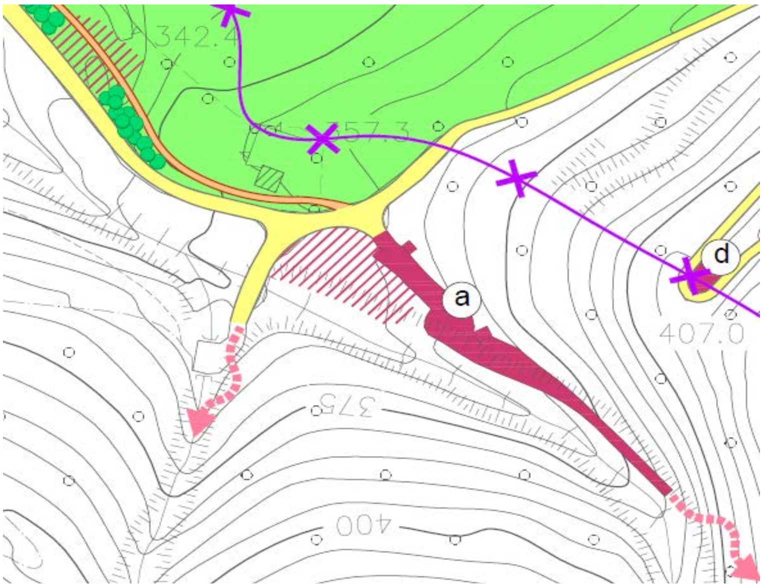

Figure C.28 Pre-existent recreational areas (crosshatch with red lines)

In addition, the use of hard drainage pavements allows to requalify the existing routes, providing additional cycling and pedestrian paths (1.35 km) connected to the existing route network, located around the retentions ponds and the floodable park. Concurrently, the considered measures are expected to increase the accessibility of the abovementioned heritage and natural sites, since new recreational areas (9050 m^2) are established, as shown in Figure C.39.

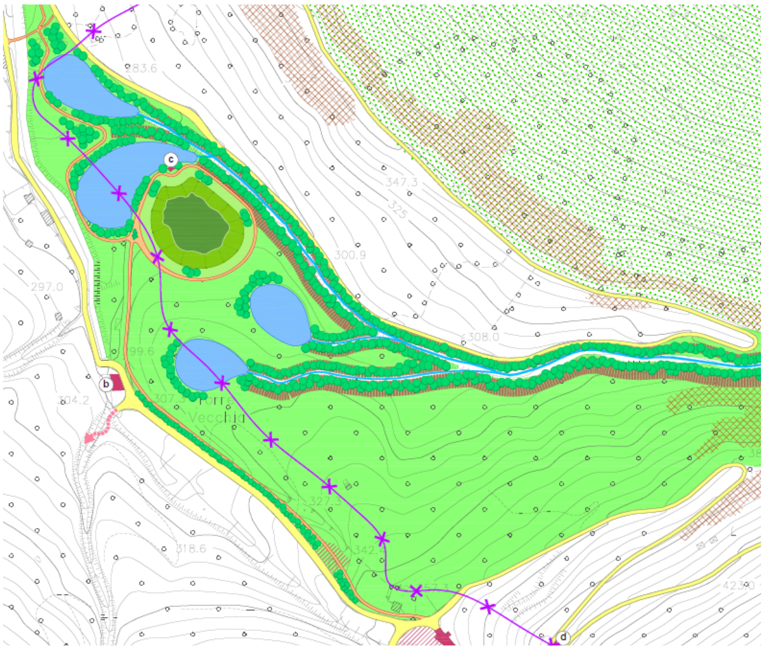

Figure C.29 Cycling and pedestrian paths in orange on the map and the new recreational areas in light green

Specifically, two existing paths are now available in the park, for which a partial redevelopment is planned. The first one, runs along the canal and climbs up the slope along the wood destroyed by fire, up to the sanctuary of San Teodoro (XIV century). The sanctuary is located in a panoramic point. The second path, located on the other side of the park, starts from the mill's area and reach the opposite hillside between orchards and woods.

Moreover, considering that part of the forest covering the mountain belonging to the study area was affected by a large fire in August 2017, in B1 Design Scenario, the **reforestation** of a large area (56.28 ha) was considered, using native trees, as shown in the picture below.

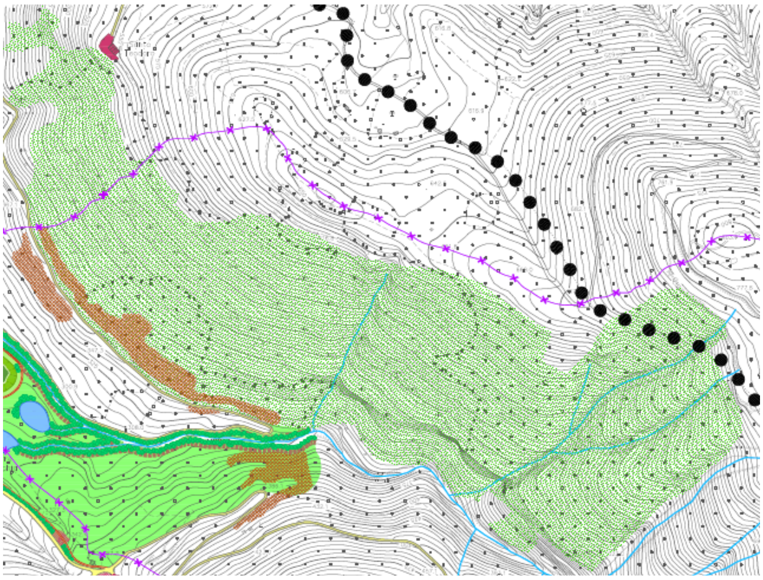

Figure C.40 The reforestation of NBSs Scenario B1

With reference to the landslides risk reduction, to calculate the indicators, the construction of vegetate timber cribs was opportunely taken into account for the susceptibility map (F_S) construction. The presence of ponds with a total detection volume of 20000 m^3 influences both the covered urban area by mobilized landslide soil volume and the landslide velocity, resulting in the values of Table C.9. In Figures C.41 the map of the urban area covered by mobilized landslide soil volume is shown.

NBSs Scenario B1			
Landslides Risk Resilience	Site response to Landslide phenomena based on susceptibility indicators: slope angle, pore water pressure, groundwater depth, soil properties, land use, land cover	Safety Factor (Area with Fs < 1) [km^2]	0.270
		Occurred Landslide Area [km^2]	0.472
		Velocity of Occurred Landslide [m/s]	9.9

Table C.9 Landslides Risk Resilience Indicators of Quindici (AV) Basin for NBSs Scenario B1

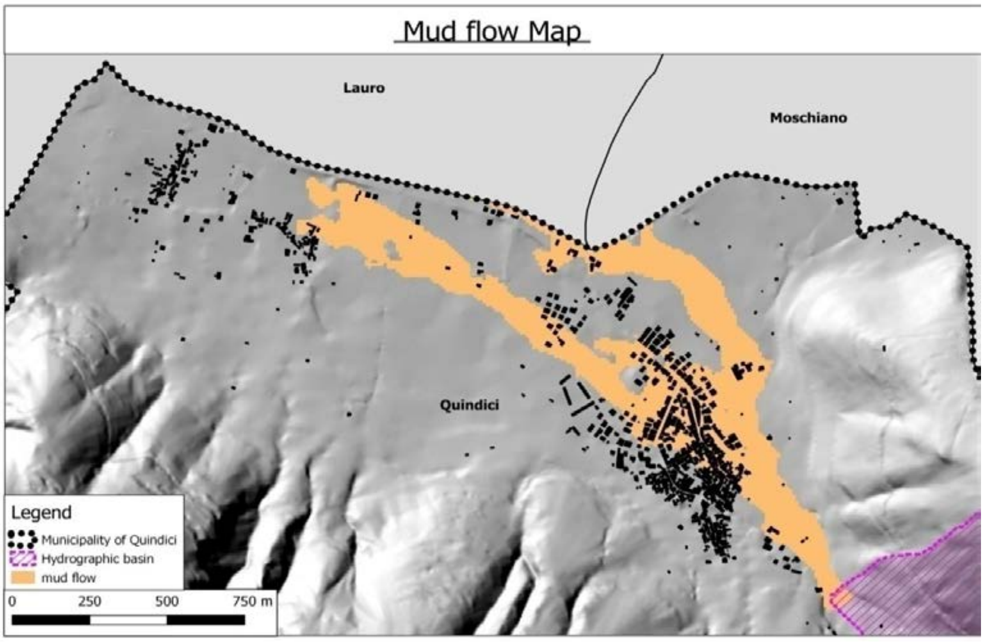

Figure C.41 Urban area covered by mobilized landslide soil volume - NBSs Scenario B1

With reference to the flooding risk reduction, to calculate both the Peak Flow Q_p and Peak volume V_p, the Soil Conservation Service (SCS) procedure was applied, adequately modifying the land use and simulating the presence of the aforementioned interventions, resulting in the values of Table C.10.

NBSs Scenario B1 – Return Period T = 100 years (Medium Hazard)			
Flooding Risk Resilience	Site response to Flooding phenomena based on susceptibility indicators: land use cover, run-off coefficient, rainfall intensity and duration	Peak Flow [m^3/s]	12.65
		Peak Volume [m^3]	104703
		Flooded Area [ha]	72

Table C.10 Flooding Risk Resilience Indicators of Quindici (AV) Basin for NBSs Scenario B1; Return Period T = 100 years (Medium Hazard)

In Figures C.42-C.43 the flooded area maps are depicted, whereas in Figure C.44 the the water depth map is reported.

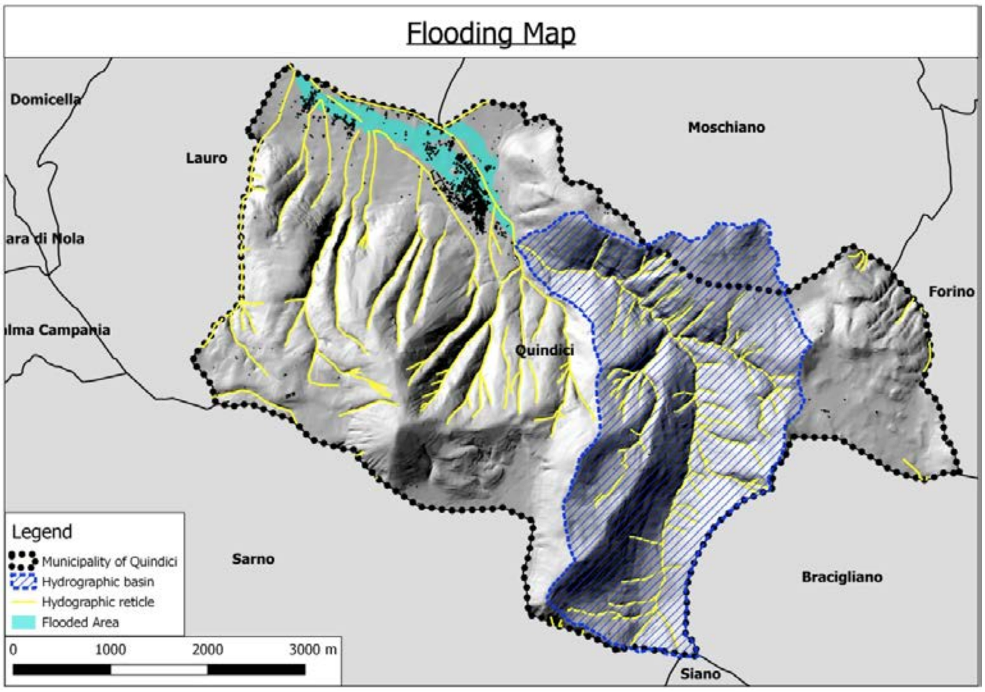

Figure C.42 Flooded Areas of Quindici (AV) Basin – NBSs Scenario B1; Return Period T = 100 years (Medium Hazard)

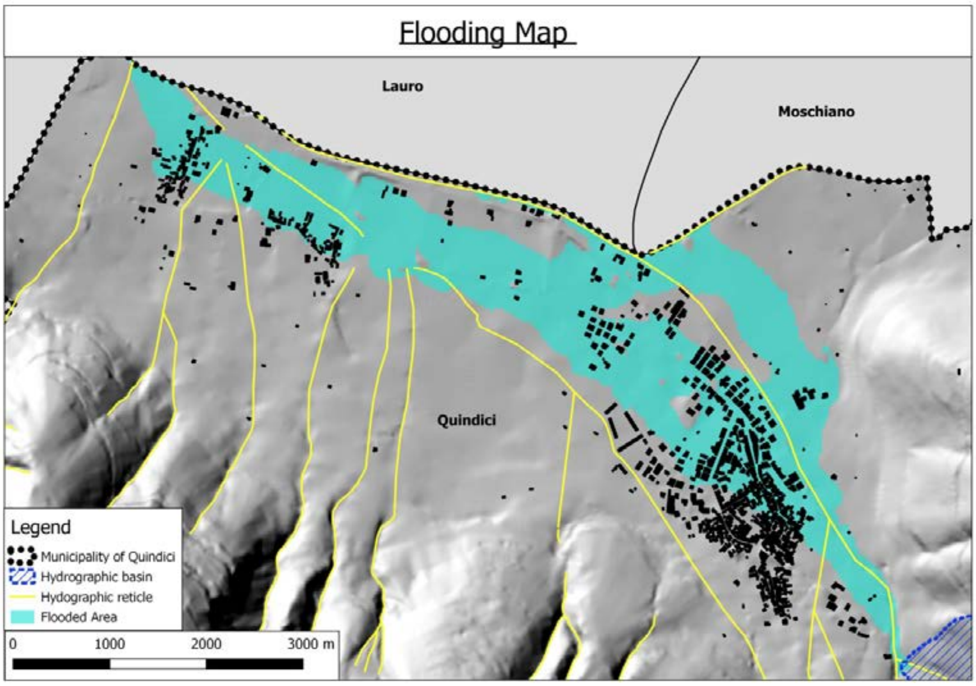

Figure C.43 Flooded Areas of Quindici (AV) Basin –NBSs Scenario B1; Return Period T = 100 years (Medium Hazard)

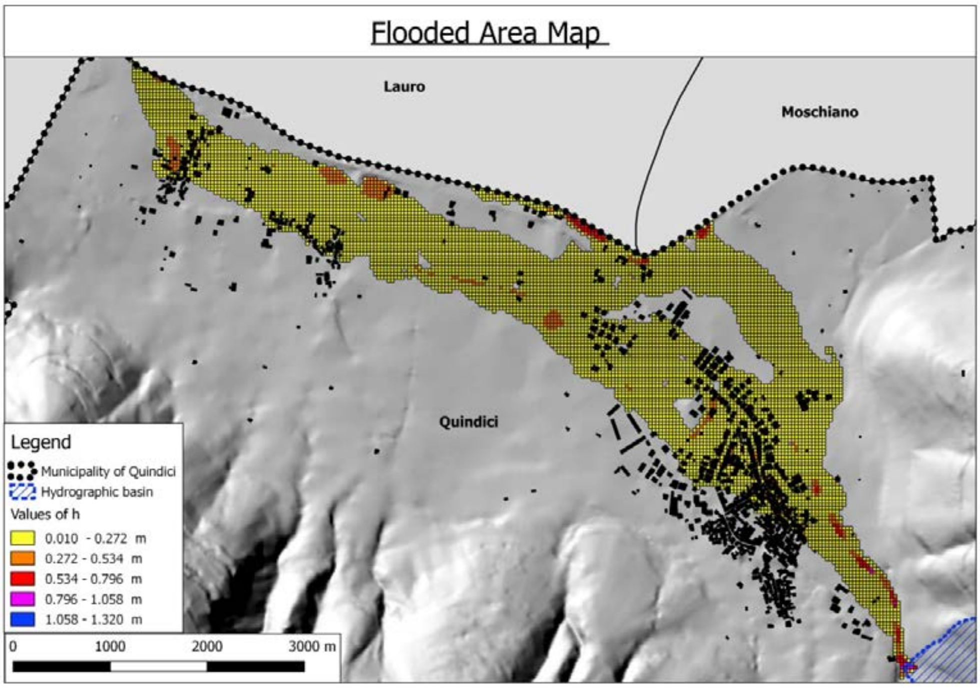

Figure C.44 Flooded Areas of Quindici (AV) Basin – NBSs Scenario B1; Return Period T = 100 years (Medium Hazard)

The Vulnerability Indicators were assessed by considering the $h \cdot V$ (product between water level and velocity) parameter according to the Wallingford Model (HR Wallingford, 2006).

In terms of landslide risk, the assessment of the basin area with Safety Factor lower than 1 for the current scenario is reported in Table C.11.

Scenario	Safety Factor (area with $F_S < 1$) [km^2]	
	Basin	Municipality
B1	0.26	0.784

Table C.11 Estimation of the Safety Factor indicator for the NBSs Scenario B1 (soil cohesion value of 3 kPa)

The design costs were estimated with reference to the following unit costs and sizing (Table C.12).

NBS	Estimated budget [€/u.m.]	Quantity	Initial Costs [M€]	Maintenance [% Initial Costs]	Maintenance Cost [M€]	Total cost [M€]
Grassed swales and water retention ponds	35.00	20000 m^3	0.70	8	0.06	0.76
Cycle and pedestrian green route	40	3500 m^2	0.14	8	0.01	0.15
Re-forestation	5350	56.28 ha	0.30	8	0.02	0.33
Channel re-naturing	100	61800 m^3	6.18	8	0.49	6.67

Floodable park	20	9050 m^2	0.18	8	0.01	0.19
Hard drainage pavements	17.5	24200 m^2	0.42	8	0.03	0.46
Vegetated Timber Cribs	163.7	8019 m	1.31	8	0.10	1.42

Table C.12 Unit costs, quantities and metrics adopted for NBSs costs for NBSs Scenario B1

The total initial cost was equal to 9.24 M€ and the total maintenance cost equal to 0.72 €.

With reference to the Society and Local Economy Ambits, PI from Quality of Life, Landscape and Heritage, Local Economy Reinforcement Criteria were selected. Namely, solutions to foster the Recreational Opportunities, the Sustainable Mobility, the Heritage Accessibility and the Landscape Perception were implemented, aimed at re-qualifying rural buildings (Figure C.45), mills (Figure C.46) and medieval belfries (Figure C.47).

Figure C.45 Rural building of Quindici (AV) [source: Google Earth]

Figure C.46 Mill of Quindici (AV) [source: Google Earth]

Figure C.47 Medieval Belfry of Quindici (AV) [source: Google Earth]

C4.1 Hybrid Scenario (B2)

The Hybrid Scenario B2 combines the following NBSs and Grey Solutions (Figure C.48):

- Vegetated timber cribs
- Concrete detention tank with total capacity of 30.000 m^3
- Reforestation
- River channel re-naturalization

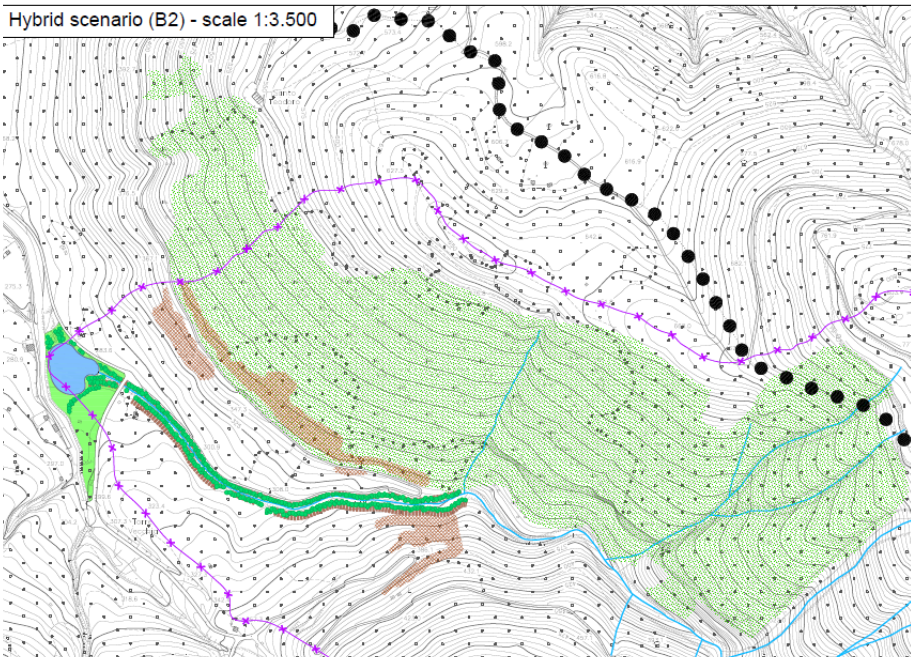

Figure C.30 Hybrid Scenario B2

In this scenario, a **reinforced concrete tank** with a volume of 30000 m^3 is foreseen. The tank, during rain events will host both flooding and mud volumes occurring after a landslide. Moreover, as in the NBSs Scenario B1, the **re-profiling of the river banks**, the geotechnical interventions and the reforestation, previously described, were considered. The reforestation produces a change in the land use map, compared to the Baseline Scenario, as shown in Figure C.49:

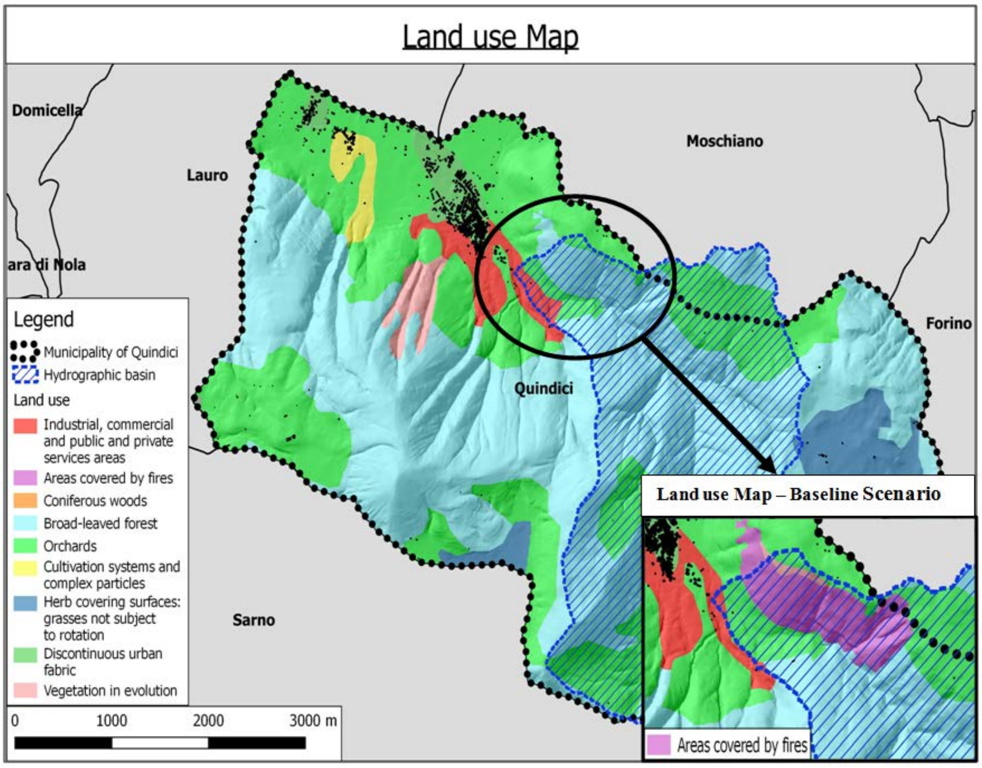

Figure C.31 Land use Map for the Hybrid Scenario vs. the Baseline Scenario

Since the reforestation intervention was foreseen in both the NBSs and Hybrid Scenarios, the new land use map was used in both Scenarios as input data for the hydrological model for flooding and landslide risk assessment.

With reference to the landslides risk reduction, to calculate the indicators, the construction of vegetated timber cribs was taken into account for the susceptibility map (F_S). The presence of the reinforced concrete tank with a total detection volume of 30000 m^3 is expected to influence both the urban area covered by mobilized landslide soil volume and the landslide velocity, resulting in the values of Table C.13.

In Figure C.50 the map of the urban area covered by mobilized landslide soil volume is shown.

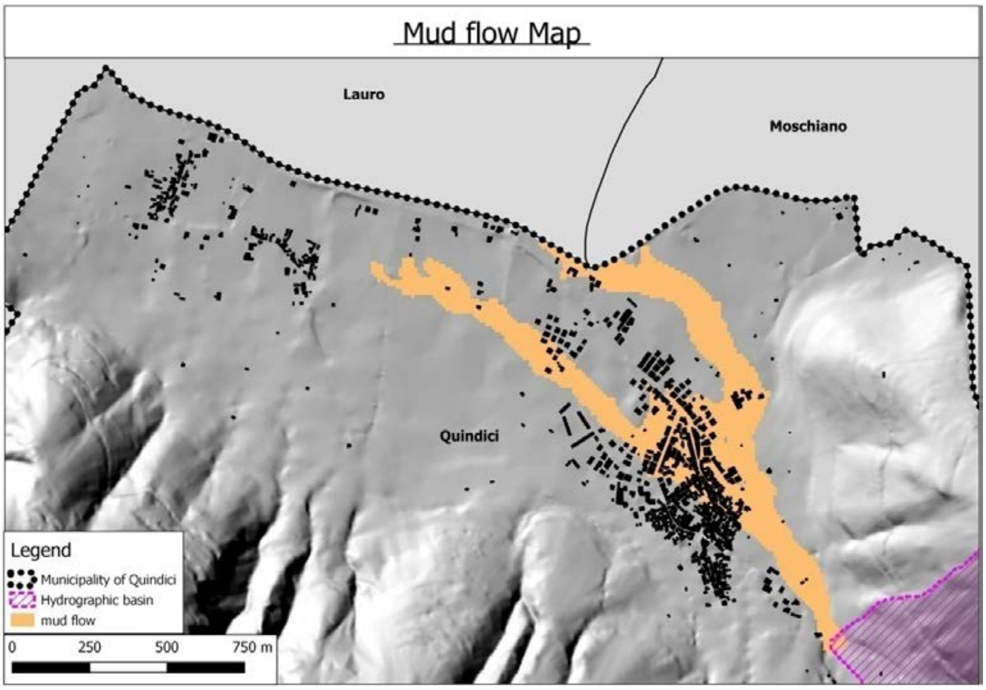

Figure C.50 Urban area covered by mobilized landslide soil volume maps - Hybrid Scenario B2

Hybrid Scenario B2			
Landslides Risk Resilience	Site response to Landslide phenomena based on susceptibility indicators: slope angle, pore water pressure, groundwater depth, soil properties, land use, land cover	Safety Factor (Area with F_S < 1) [km^2]	0.260
		Occurred Landslide Area [km^2]	0.340
		Velocity of Occurred Landslide [m/s]	9.27

Table C.13 Landslides Risk Resilience Indicators of Quindici (AV) Basin for Hybrid Scenario B2

Specifically, for flooding risk reduction for the Hybrid Scenario B2, the construction of a reinforced concrete tank with a surface of 6000 m^2 and a depth of 5 m (total volume of 30000 m^3) was considered. To calculate both the Peak Flow Q_P and Peak volume V_P, the Soil Conservation Service (SCS) procedure was applied, adequately modifying the soil use and simulating the presence of the aforementioned interventions. The results obtained are shown in Table C.14.

Hybrid Scenario B2 – Return Period T = 100 years (Medium Hazard)			
Flooding Risk Resilience	Site response to Flooding phenomena based on susceptibility indicators: land use cover, run-off coefficient, rainfall intensity and duration	Peak Flow [m^3/s]	11.14
		Peak Volume [m^3]	92238
		Flooded Area [ha]	71

Table C.14 Flooding Risk Resilience Indicators of Quindici (AV) Basin for Hybrid Scenario B2; Return Period T = 100 years (Medium Hazard)

In Figures C.51-C.52 the flooded area maps are depicted, whereas in Figure C.53 the the water depth map is reported.

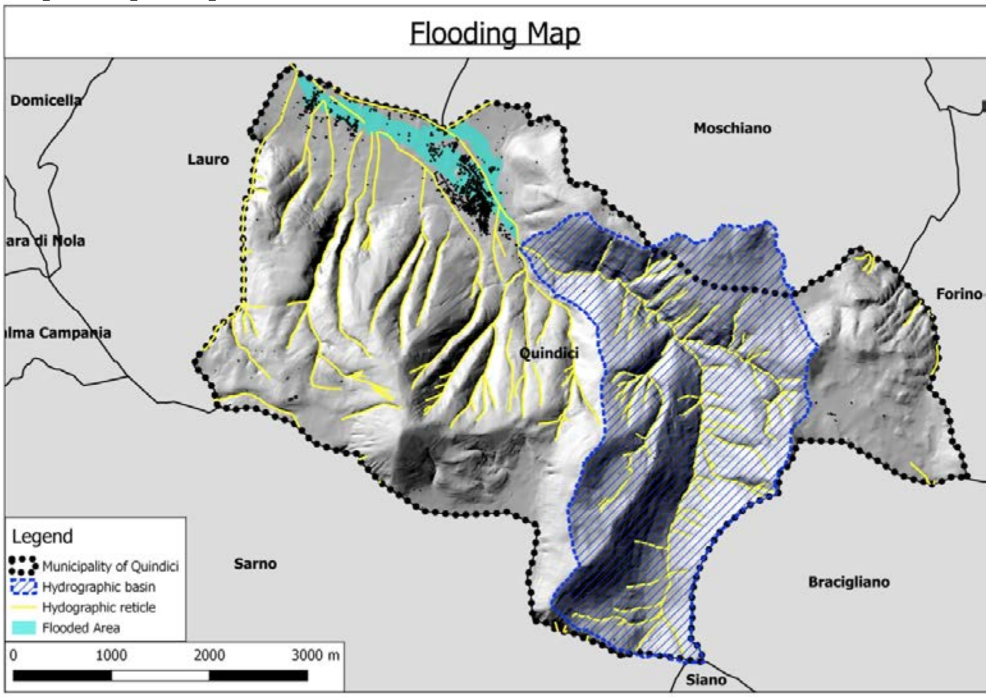

Figure C.51 Flooded Areas of Quindici (AV) Basin – Hybrid Scenario B2; Return Period T = 100 years (Medium Hazard)

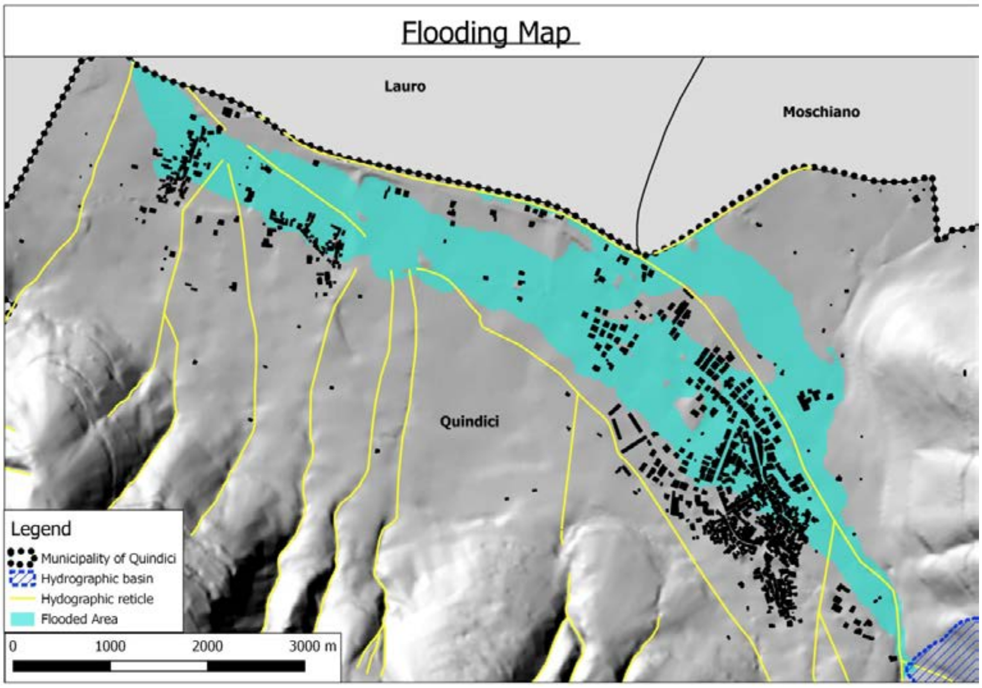

Figure C.32 Flooded Areas of Quindici (AV) Basin – Hybrid Scenario B2; Return Period T = 100 years (Medium Hazard)

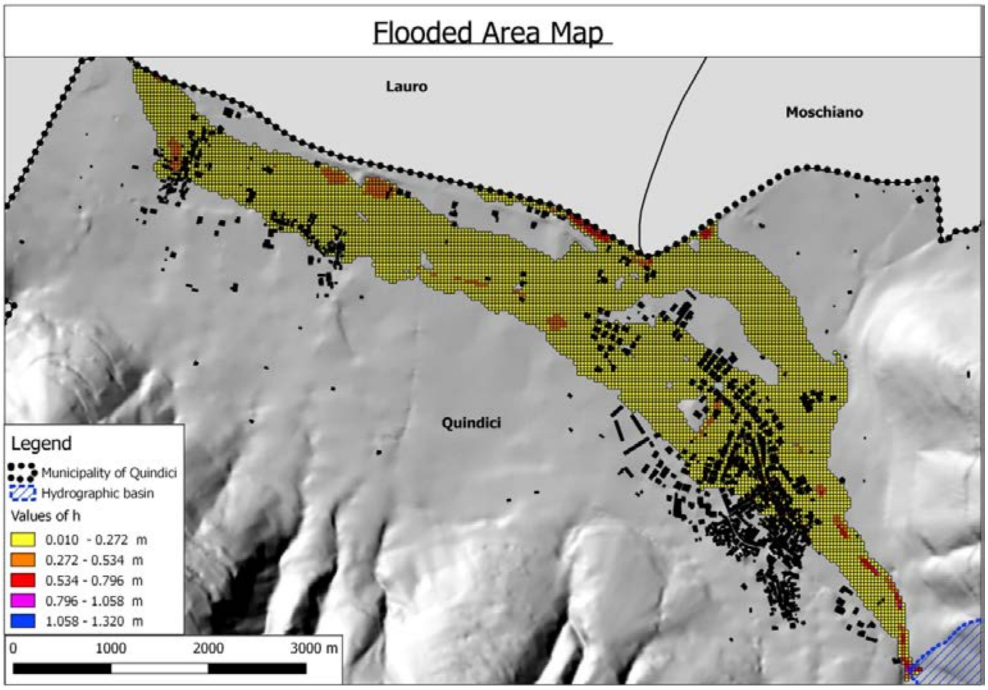

Figure C.53 Flooded Areas of Quindici (AV) Basin – Hybrid Scenario B2; Return Period T = 100 years (Medium Hazard)

In terms of landslide risk, the assessment of the basin area with Safety Factor lower than 1 for the current scenario is reported in Table C.15. No difference with the B1 scenario was observed.

Scenario	Safety Factor (area with $F_S < 1$) [km^2]

	Basin	Municipality
B2	0.26	0.784

Table C.15 Estimation of the Safety Factor indicator for the Hybrid Scenario B2 (soil cohesion value of 3 kPa)

The design costs were estimated with reference to the following unit costs and sizing (Table C.16).

NBS	ESTIMATED BUDGET [€/U.M.]	QUANTITY	INITIAL COSTS [M€]	MAINTENANCE [% INITIAL COSTS]	MAINTENANCE COST [M€]	Total cost [M€]
Grey Basin	40.00	30000 m^3	1.20	8.0	0.096	1.30
Re-forestation	5350	56.28 ha	0.30	8.0	0.024	0.33
Channel re-naturing	100	46968 m^3	4.70	8.0	0.375	5.07
Vegetated Timber Cribs	163.66	8019 m	1.31	8.0	0.105	1.42

Table C.16 Unit costs, quantities and metrics adopted for NBSs and Grey Solutions costs - Hybrid Scenario B2

The total initial cost was equal to 7.51 M€ and the total maintenance cost equal to 0.60 M€.

C5 Scenarios comparative analysis and weighting procedure

To assess the comprehensive benefits of the proposed design scenarios the NBSs Framework Tool, as defined in this D4.1, was used. Specifically, a multi-level weighting procedure was applied by considering several weighting approaches as to simulate the preferences of three different stakeholders.
The following weighting levels were applied: (1) *PI*; (2) *Criterion*; (3) *Ambit*.
For each level, the weights choice was performed considering three different hypothetical stakeholders *s*:

- **Neutral**, uniform weights were assumed for each level;
- **Technician**, providing higher weights for technical aspects;
- **Politician** providing higher weights for socio-economic and environmental aspects.

The NBSs Tool matrix was composed by 30 PIs categorized considering 5 Ambits and 8 Criteria as described in the following Table C.17.

AMBIT	CRITERION	INDICATOR
Risk Reduction	Hazard	Safety Factor; Peak Flow Peak Volume; Flooded Area
	Exposure	Urban/Residential Areas; Productive Areas (agriculture, grazing, industries); Inhabitants; Other people; Elderly, children, disabled; Housing; Roads
	Vulnerability	Population

Technical & Feasibility Aspects	Technical Feasibility (Affordability)	Initial costs; Maintenance costs; Avoided costs; Material and techniques used coherence
Environment & Ecosystems	Vegetation	Woody vegetation cover; Non-woody vegetation (herb) cover; Total vegetation cover
Society	Quality of life	Number of visitors in new recreational areas; Different activities allowed in new recreational areas; Average distance of natural resources from urban centres/train stations/public transportation; New pedestrian, cycling and horse paths; Sustainable transportation modes allowed
	Landscape and Heritage	Traditional events organized in the new areas; Natural and cultural sites, made available; Scenic sites and Landmark created; Scenic paths created
Local Economy	Local Economy Reinforcement including New Job Opportunities	New areas made available for traditional activities (agriculture, livestock, fishing,….); Forest area planted

Table C.17 Considered Performance Indicators PI

With reference to the first weighting level, a uniform approach was considered for all the PIs. Thus, the Equal Weights procedure was applied, assuming the PI weight equal to 1/m, where m indicates the number of considered PIs. For this specific application, for both the second and third weighting level, the *Pairwise Comparison* technique was adopted, calibrating the weights considering a 1 to 3 scoring scale.

In Tables C.18-C.20 the defined weights are indicated. Specifically, they were normalized to 1.

LEVEL I – PI WEIGHTING

PERFORMANCE INDICATOR
0.033

Table C.18 First weighting level: Performance Indicator

LEVEL II – CRITERION WEIGHTING

CRITERION	UNIFORM WEIGHTING	TECHNICAL STAKEHOLDER	POLITIC STAKEHOLDER
Hazard	0.13	0.18	0.11
Exposure	0.13	0.18	0.11
Vulnerability	0.13	0.18	0.08
Technical Feasibility (Affordability)	0.13	0.15	0.14
Vegetation	0.13	0.09	0.14
Quality of life	0.13	0.09	0.11
Landscape and Heritage	0.13	0.06	0.14
Local Economy Reinforcement	0.13	0.09	0.17
TOTAL WEIGHT	**1.00**	**1.00**	**1.00**

Table C.19 Second weighting level: Criterion

LEVEL III – AMBIT WEIGHTING

AMBIT	UNIFORM WEIGHTING	TECHNICAL STAKEHOLDER	POLITIC STAKEHOLDER
Risk Reduction	0.20	0.32	0.10
Technical & Feasibility Aspects	0.20	0.32	0.14
Environment	0.20	0.16	0.19
Society	0.20	0.03	0.29
Local Economy	0.20	0.16	0.29
TOTAL WEIGHT	1.00	1.00	1.00

Table C.20 Third weighting level: Ambit

According to the proposed procedure, the PI values were standardized by using the following equations: (C.11) for indicators to be maximized and (C.12) for indicators to be minimized.

$$I_{norm} = \left(\frac{I - I_{min}}{I_{max} - I_{min}} \right) \cdot 100 \qquad (C.11)$$

where I_{min} and I_{max} are set equal to the value of the indicator for the Baseline Scenario and the maximum achievable value, respectively.

$$I_{norm} = \left(\frac{I_{max} - I}{I_{max} - I_{min}} \right) \cdot 100 \qquad (C.12)$$

where I_{min} and I_{max} are set equal to the minimum achievable value of the indicator and the Baseline Scenario value, respectively.

Within the NBS Framework Tool, each standardized performance indicator is opportunely weighted considering the following equation:

$$W_{PI} = I_{norm} \cdot w_{PI,s} \cdot w_{A,s} \cdot w_{C,s} \qquad (C.13)$$

where:

- W_{PI} indicates the generic weighted standardized performance indicator;
- I_{norm} is the generic standardized performance indicator;
- $w_{PI,s}$ is the weight defined for the performance indicator, relative to the stakeholder s;
- $w_{A,s}$ is the weight defined for the ambit, relative to the stakeholder s;
- $w_{C,s}$ is the weight defined for the criterion, relative to the stakeholder s.

The results of the application of the NBS Framework Tool Assessment are reported in Tables C.21-C.23 for different weighting options.

		AMBIT WEIGHTING					
		NEUTRAL STAKEHOLDER		TECHNICAL STAKEHOLDER		POLITICAL STAKEHOLDER	
AMBIT	Nr. Indicators per Ambit	NBS	HYBRID	NBS	HYBRID	NBS	HYBRID
RISK REDUCTION	12	0.063	0.088	0.101	0.142	0.030	0.042

TECHNICAL & FEASIBILITY ASPECTS	4	0.052	0.047	0.084	0.075	0.037	0.033
ENVIRONMENT	3	0.040	0.040	0.032	0.032	0.038	0.038
SOCIETY	9	0.232	0.000	0.037	0.000	0.332	0.000
LOCAL ECONOMY	2	-0.057	-0.057	-0.046	-0.046	-0.082	-0.082
TOTAL SCORE	**30**	**0.330**	**0.117**	**0.208**	**0.203**	**0.355**	**0.031**

		AMBIT WEIGHTING					
		NEUTRAL STAKEHOLDER		TECHNICAL STAKEHOLDER		POLITICAL STAKEHOLDER	
CRITERION	Nr. Indicators per Criterion	NBS	HYBRID	NBS	HYBRID	NBS	HYBRID
HAZARD	4	0.049	0.065	0.069	0.091	0.044	0.058
EXPOSURE	7	0.008	0.010	0.011	0.014	0.007	0.009
VULNERABILITY	1	0.006	0.013	0.008	0.018	0.004	0.009
TECHNICAL FEASIBILITY (AFFORDABILITY)	4	0.052	0.047	0.061	0.055	0.058	0.052
VEGETATION	3	0.040	0.040	0.028	0.028	0.044	0.044
QUALITY OF LIFE	5	0.155	0.000	0.109	0.000	0.137	0.000
LANDSCAPE AND HERITAGE	4	0.078	0.000	0.037	0.000	0.086	0.000
LOCAL ECONOMY REINFORCEMENT	2	-0.057	-0.057	-0.040	-0.040	-0.076	-0.076
TOTAL SCORE	30	0.330	0.117	0.283	0.166	0.304	0.095

Table C.21 Total scoring resulting from Ambit weighting. Results are reported for Ambit and Criterion

		CRITERION WEIGHTING					
		NEUTRAL STAKEHOLDER		TECHNICAL STAKEHOLDER		POLITICAL STAKEHOLDER	
AMBIT	Nr. Indicators per Ambit	NBS	HYBRID	NBS	HYBRID	NBS	HYBRID
RISK REDUCTION	12	0.063	0.088	0.088	0.124	0.054	0.075
TECHNICAL & FEASIBILITY ASPECTS	4	0.052	0.047	0.061	0.055	0.058	0.052
ENVIRONMENT	3	0.040	0.040	0.028	0.028	0.044	0.044
SOCIETY	9	0.232	0.000	0.146	0.000	0.224	0.000
LOCAL ECONOMY	2	-0.057	-0.057	-0.040	-0.040	-0.076	-0.076
TOTAL SCORE	**30**	**0.330**	**0.117**	**0.283**	**0.166**	**0.304**	**0.095**
		CRITERION WEIGHTING					

		NEUTRAL STAKEHOLDER		TECHNICAL STAKEHOLDER		POLITICAL STAKEHOLDER	
CRITERION	Nr. Indicators per Criterion	NBS	HYBRID	NBS	HYBRID	NBS	HYBRID
Hazard	4	0.049	0.065	0.069	0.091	0.044	0.058
Exposure	7	0.008	0.010	0.011	0.014	0.007	0.009
Vulnerability	1	0.006	0.013	0.008	0.018	0.004	0.009
Technical Feasibility (Affordability)	4	0.052	0.047	0.061	0.055	0.058	0.052
Vegetation	3	0.040	0.040	0.028	0.028	0.044	0.044
Quality of life	5	0.155	0.000	0.109	0.000	0.137	0.000
Landscape and Heritage	4	0.078	0.000	0.037	0.000	0.086	0.000
Local Economy Reinforcement	2	-0.057	-0.057	-0.040	-0.040	-0.076	-0.076
TOTAL SCORE	**30**	**0.330**	**0.117**	**0.283**	**0.166**	**0.304**	**0.095**

Table C.22 Total scoring resulting from Criterion weighting. Results are reported for Ambit and Criterion

		AMBIT + CRITERION WEIGHTING					
		NEUTRAL STAKEHOLDER		TECHNICAL STAKEHOLDER		POLITICAL STAKEHOLDER	
AMBIT	Nr. Indicators per Ambit	NBS	HYBRID	NBS	HYBRID	NBS	HYBRID
RISK REDUCTION	12	0.063	0.088	0.143	0.200	0.026	0.036
TECHNICAL & FEASIBILITY ASPECTS	4	0.052	0.047	0.099	0.088	0.041	0.037
ENVIRONMENT	3	0.040	0.040	0.023	0.023	0.042	0.042
SOCIETY	9	0.232	0.000	0.024	0.000	0.320	0.000
LOCAL ECONOMY	2	-0.057	-0.057	-0.033	-0.033	-0.109	-0.109
TOTAL SCORE	30	0.330	0.117	0.255	0.278	0.320	0.006

		AMBIT + CRITERION WEIGHTING					
		NEUTRAL STAKEHOLDER		TECHNICAL STAKEHOLDER		POLITICAL STAKEHOLDER	
CRITERION	Nr. Indicators per Criterion	NBS	HYBRID	NBS	HYBRID	NBS	HYBRID
HAZARD	4	0.049	0.065	0.112	0.147	0.021	0.027
EXPOSURE	7	0.008	0.010	0.018	0.023	0.003	0.004
VULNERABILITY	1	0.006	0.013	0.013	0.029	0.002	0.004

TECHNICAL FEASIBILITY (AFFORDABILITY)	4	0.052	0.047	0.099	0.088	0.041	0.037
VEGETATION	3	0.040	0.040	0.023	0.023	0.042	0.042
QUALITY OF LIFE	5	0.155	0.000	0.018	0.000	0.196	0.000
LANDSCAPE AND HERITAGE	4	0.078	0.000	0.006	0.000	0.124	0.000
LOCAL ECONOMY REINFORCEMENT	2	-0.057	-0.057	-0.033	-0.033	-0.109	-0.109
TOTAL SCORE	30	0.330	0.117	0.255	0.278	0.320	0.006

Table C.23 Total scoring resulting from Ambit and Criterion weighting. Results are reported for Ambit and Criterion

For all the investigated configurations, the scores of the NBSs Scenario were higher than those of the Hybrid Scenario, except for the AMBIT+CRITERION WEIGHTING simulating the Technical Stakeholder.
Analysing the AMBIT scoring, higher relevance of the Society Ambit was observed for Neutral and Political Stakeholders. For the Technical Stakeholder, the Risk Reduction Ambit played a dominant role, except for the criterion weighting case.
About the Local Economy Ambit, negative scores resulted for all the cases, as a consequence of the reduction of new areas for traditional activities (such as agriculture, livestock, etc.) in comparison with the Baseline Scenario.
Specifically, with reference to the Neutral Stakeholder, a constant relative scatter of 65.4% was observed between the NBSs and Hybrid Scenario, independently from the weighting level. For the Technical Stakeholder a difference of 4.9, 42.3 and -7.2% was observed for the AMBIT, CRITERION and AMBIT+CRITERION weighting level respectively. Therefore, a significant variation related to the weighting procedure was highlighted. Finally, for the Political Stakeholder scatters equal to 91.8, 69.8 and 98.8% were evaluated for the three different weighting levels.
Aimed at assessing the relevance of weighting the PI, further investigation was performed by setting the PI weight as summarized in the following Table 24.

AMBIT	CRITERION	INDICATOR	PI WEIGHT
RISK REDUCTION	*Hazard*	Safety Factor	0.052
		Peak Flow	0.035
		Peak Volume	0.035
		Flooded Area	0.052
	Exposure	Urban / Residential Areas	0.035
		Productive Areas (agriculture, grazing, industries)	0.035
		Inhabitants	0.043
		Other people (workers, tourists, homeless)	0.026
		Elderly, children, disabled	0.035
		Housing	0.043
		Roads	0.026

	Vulnerability	Population	0.043
TECHNICAL & FEASIBILITY ASPECTS	*Technical Feasibility (Affordability)*	Initial costs	0.052
		Maintenance costs	0.052
		Avoided costs	0.017
		Material and techniques used coherence	0.017
ENVIRONMENT & ECOSYSTEMS	*Vegetation*	Woody vegetation cover	0.035
		Non-woody vegetation (herb) cover	0.017
		Total vegetation cover	0.017
SOCIETY	*Quality of life*	Number of visitors in new recreational areas	0.000
		Different activities allowed in new recreational areas	0.052
		Average distance of natural resources from urban centres/train stations/public transportation	0.017
		New pedestrian, cycling and horse paths	0.035
		Sustainable transportation modes allowed	0.035
	Landscape and Heritage	Traditional events organized in the new areas	0.017
		Natural and cultural sites, made available	0.017
		Scenic sites and Landmark created	0.052
		Scenic paths created	0.035
LOCAL ECONOMY	*Local Economy Reinforcement*	New areas made available for traditional activities (agriculture, livestock, fishing,….)	0.052
		Forest area planted	0.017

Table C.24 PI weights

The resulting total scoring are reported, for different weighting procedures, in Tables C.25-C.27.

		PI + AMBIT WEIGHTING					
		NEUTRAL STAKEHOLDER		TECHNICAL STAKEHOLDER		POLITICAL STAKEHOLDER	
AMBIT	Nr. Indicators per Ambit	NBS	HYBRID	NBS	HYBRID	NBS	HYBRID
RISK REDUCTION	12	0.069	0.097	0.111	0.157	0.033	0.046
TECHNICAL & FEASIBILITY ASPECTS	4	0.067	0.057	0.109	0.092	0.048	0.041
ENVIRONMENT	3	0.027	0.027	0.022	0.022	0.026	0.026

SOCIETY	9	0.230	0.000	0.037	0.000	0.328	0.000
LOCAL ECONOMY	2	-0.094	-0.094	-0.076	-0.076	-0.135	-0.135
TOTAL SCORE	**30**	**0.298**	**0.087**	**0.202**	**0.195**	**0.300**	**-0.022**

		PI + AMBIT WEIGHTING					
		NEUTRAL STAKEHOLDER		**TECHNICAL STAKEHOLDER**		**POLITICAL STAKEHOLDER**	
CRITERION	**Nr. Indicators per Criterion**	**NBS**	**HYBRID**	**NBS**	**HYBRID**	**NBS**	**HYBRID**
HAZARD	4	0.053	0.070	0.086	0.113	0.025	0.033
EXPOSURE	7	0.008	0.010	0.013	0.017	0.004	0.005
VULNERABILITY	1	0.007	0.017	0.012	0.027	0.004	0.008
TECHNICAL FEASIBILITY (AFFORDABILITY)	4	0.067	0.057	0.109	0.092	0.048	0.041
VEGETATION	3	0.027	0.027	0.022	0.022	0.026	0.026
QUALITY OF LIFE	5	0.161	0.000	0.026	0.000	0.230	0.000
LANDSCAPE AND HERITAGE	4	0.068	0.000	0.011	0.000	0.097	0.000
LOCAL ECONOMY REINFORCEMENT	2	-0.094	-0.094	-0.076	-0.076	-0.135	-0.135
TOTAL SCORE	**30**	**0.298**	**0.087**	**0.202**	**0.195**	**0.300**	**-0.022**

Table C.25 Total scoring resulting from PI + Ambit weighting. Results are reported separated for Ambit and Criterion

		PI + CRITERION WEIGHTING					
		NEUTRAL STAKEHOLDER		**TECHNICAL STAKEHOLDER**		**POLITICAL STAKEHOLDER**	
AMBIT	**Nr. Indicators per Ambit**	**NBS**	**HYBRID**	**NBS**	**HYBRID**	**NBS**	**HYBRID**
RISK REDUCTION	12	0.069	0.097	0.097	0.137	0.059	0.083
TECHNICAL & FEASIBILITY ASPECTS	4	0.067	0.057	0.079	0.067	0.075	0.063
ENVIRONMENT	3	0.027	0.027	0.019	0.019	0.030	0.030
SOCIETY	9	0.230	0.000	0.146	0.000	0.219	0.000
LOCAL ECONOMY	2	-0.094	-0.094	-0.067	-0.067	-0.126	-0.126
TOTAL SCORE	**30**	**0.298**	**0.087**	**0.275**	**0.157**	**0.258**	**0.051**

		PI + CRITERION WEIGHTING					
		NEUTRAL STAKEHOLDER		**TECHNICAL STAKEHOLDER**		**POLITICAL STAKEHOLDER**	

CRITERION	Nr. Indicators per Criterion	NBS	HYBRID	NBS	HYBRID	NBS	HYBRID
Hazard	4	0.053	0.070	0.075	0.099	0.047	0.062
Exposure	7	0.008	0.010	0.011	0.015	0.007	0.009
Vulnerability	1	0.007	0.017	0.010	0.024	0.005	0.011
Technical Feasibility (Affordability)	4	0.067	0.057	0.079	0.067	0.075	0.063
Vegetation	3	0.027	0.027	0.019	0.019	0.030	0.030
Quality of life	5	0.161	0.000	0.114	0.000	0.143	0.000
Landscape and Heritage	4	0.068	0.000	0.032	0.000	0.076	0.000
Local Economy Reinforcement	2	-0.094	-0.094	-0.067	-0.067	-0.126	-0.126
TOTAL SCORE	**30**	**0.298**	**0.087**	**0.275**	**0.157**	**0.258**	**0.051**

Table C.26 Total scoring resulting from PI + Criterion weighting. Results are separated for Ambit and Criterion

		PI + AMBIT + CRITERION WEIGHTING					
		NEUTRAL STAKEHOLDER		TECHNICAL STAKEHOLDER		POLITICAL STAKEHOLDER	
AMBIT	Nr. Indicators per Ambit	NBS	HYBRID	NBS	HYBRID	NBS	HYBRID
RISK REDUCTION	12	0.069	0.097	0.156	0.222	0.028	0.039
TECHNICAL & FEASIBILITY ASPECTS	4	0.067	0.057	0.128	0.108	0.053	0.045
ENVIRONMENT	3	0.027	0.027	0.016	0.016	0.029	0.029
SOCIETY	9	0.230	0.000	0.024	0.000	0.313	0.000
LOCAL ECONOMY	2	-0.094	-0.094	-0.054	-0.054	-0.180	-0.180
TOTAL SCORE	**30**	**0.298**	**0.087**	**0.269**	**0.291**	**0.244**	**-0.066**

		PI + AMBIT + CRITERION WEIGHTING					
		NEUTRAL STAKEHOLDER		TECHNICAL STAKEHOLDER		POLITICAL STAKEHOLDER	
CRITERION	Nr. Indicators per Criterion	NBS	HYBRID	NBS	HYBRID	NBS	HYBRID
HAZARD	4	0.053	0.070	0.122	0.160	0.023	0.030
EXPOSURE	7	0.008	0.010	0.018	0.024	0.003	0.004
VULNERABILITY	1	0.007	0.017	0.017	0.038	0.002	0.005
TECHNICAL FEASIBILITY (AFFORDABILITY)	4	0.067	0.057	0.128	0.108	0.053	0.045
VEGETATION	3	0.027	0.027	0.016	0.016	0.029	0.029
QUALITY OF LIFE	5	0.161	0.000	0.018	0.000	0.205	0.000

LANDSCAPE AND HERITAGE	4	0.068	0.000	0.005	0.000	0.108	0.000
LOCAL ECONOMY REINFORCEMENT	2	-0.094	-0.094	-0.054	-0.054	-0.180	-0.180
TOTAL SCORE	**30**	**0.298**	**0.087**	**0.269**	**0.291**	**0.244**	**-0.066**

Table C.27 Total scoring resulting from PI + Ambit + Criterion weighting. Results are separated for Ambit and Criterion

For all the investigated configurations, the scores of the NBSs Scenario were higher than those of the Hybrid Scenario, except for the AMBIT + CRITERION WEIGHTING simulating the Technical Stakeholder.
Specifically, with reference to the Neutral Stakeholder, a constant relative scatter of 72.2% was observed between the NBSs and Hybrid Scenario, independently from the weighting level. For the Technical Stakeholder a difference of 7.1, 44.7 and -5.2% was observed for the AMBIT, CRITERION and AMBIT+CRITERION weighting level respectively. Also considering the PI weighting, a significant variation related to the weighting level was highlighted. Finally, for the Political Stakeholder scatters equal to 108.3, 82.2 and 128.6% were evaluated for the three different weighting levels.
By comparing the two simulations performed considering uniform and weighted PIs, no significant differences were observed. Higher difference between the Political Stakeholder results, approximately equal to 13%, with reference to the Hybrid Scenario was highlighted, instead.

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