# DELIVERABLE 2.5

## Configuration of local climate risk outcomes with climate-resilient NBS integration and permitting pathways


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# Deliverable 2.5

## Configuration of local climate risk outcomes with climate-resilient NBS integration and permitting pathways

## Project description

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## Abbreviations

| | |
|---|---|
| LAND4CLIMATE | Utilization of private land for mainstreaming nature-based solution in the systemic transformation towards a climate-resilient Europe |
| CBA | Cost-Benefit Analysis |
| CEA | Cost-Effectiveness Analysis |
| CER | Cost-Effectiveness Ratio |
| $CO_2$ | Carbon Dioxide |
| CRA | Climate Risk Assessment |

| | |
|---|---|
| EU | European Union |
| FRR | Frontrunning Region |
| GA | Grant Agreement |
| GCEA | General Cost-Effectiveness Assessment |
| HMH | Hydro-Meteorological Hazard |
| HMR | Hydro-Meteorological Risk |
| IPCC | Intergovernmental Panel on Climate Change |
| LAD | Leaf-Area Density |
| NBS | Nature-Based Solution |
| OAL | Open-Air Laboratory |
| OECD | Organization for Economic and Development |
| OPERANDUM | OPEn-air laboRAtories for Nature baseD solUtions to Manage environmental risks |
| PET | Physiological Equivalent Temperature |
| PMV | Predicted Mean Vote |
| PHUSICOS | "According to Nature" in Greek |
| RR | Replicating Region |
| SES | Socio-Ecological System |
| WP | Work Package |
| 2D | Two-Dimensional |
| 3D | Three-Dimensional |

# Executive Summary

Deliverable 2.5 builds upon the methodology for the assessment of NBS effectiveness introduced in Deliverable 2.1 and connects it with the results of the modelling analyses on hazard mitigation (Deliverable 2.3) and multi-criteria decision analyses on co-benefits and trade-offs (Deliverable 2.4). The following report extends the application of the methodology to include the assessment of risk reduction resulting from the implementation of selected no-regret NBS, as well as qualitative insights on NBS acceptance in the FRR. The evidence collected in WP2 is used to reflect on replication and upscaling processes that could amplify and speed up the adoption of NBS interventions. Finally, the legacy of WP2 is summarised in lessons learnt and recommendations to support both the ongoing implementation in FRR regions (WP4) and future replication efforts in the replicating ones (WP5).

## Keywords

Hydro-Meteorological Hazards and Risks, Modelling and Monitoring Methodology, Nature-Based Solution Effectiveness

# 1. Introduction

Risk is the potential for adverse consequences for society and ecosystems (Masson-Delmotte et al., 2021), triggered by the occurrence of a hazard, i.e., any event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, environmental resources, and social and economic disruption. The relationship between hazard and risk is modified by exposure and vulnerability. Exposure is defined as the presence of people, livelihoods, species or ecosystems, environmental functions, services, resources, infrastructure, and economic, social, and cultural assets in places and settings that could be adversely affected by the hazard, while vulnerability is the propensity or predisposition of these elements to be adversely affected. Risks may occur only if hazard, exposure, and vulnerability are not simultaneously null (Crichton's Risk Triangle; Crichton, 1999).

Land-use transformations, ecosystem degradation, and greenhouse gas emissions due to human activities are significantly affecting the dynamics of the Earth system leading to possible changes in the risk function, especially for those arising from Hydro-Meteorological Hazards (HMHs), i.e., atmospheric, hydrological, or oceanographic phenomena and processes (UNDRR, 2017). For instance, floods can be exacerbated by sealing the soil with impervious materials in urban areas (Scalenghe et al., 2009), channeling the rivers and converting floodplains in agricultural areas (Rajib et al., 2023), and removing natural buffer zones for the construction of human settlements (Van Coppernolle et al., 2018). Water cycle variability and related extremes are projected to increase faster than mean changes due to the increase of near-surface atmospheric moisture capacity in a warming climate (Masson-Delmotte et al., 2011). This increase in extreme precipitation can exacerbate flash and urban floods, while the confidence in fluvial-flood projections is low because river responses highly depend on land cover and human-water management. Furthermore, sea-level rise will increase the frequency of occurrence of coastal floods in low-lying areas with high confidence. This increase can be exacerbated by observed changes in tides due to human activities that modify the dynamics in estuaries (e.g., wetland reclamation; Talke et al., 2020). Human activities are also the main contributors to coastal erosion (Mentaschi et al., 2018) by reducing the capacity of estuaries to retain sediments with the construction of dams (Milliman, 1997) and the degradation of natural ecosystems (e.g., mangroves; Barbier et al., 2008). The effects of sea-level rise are already observable in sandy beaches located in subsident areas (Marfai et al., 2007).

Drought is another extreme condition maximised by anthropogenic climate change and activities (e.g., water demand for crop production). Masson-Delmotte et al. (2021) and Vicente et al. (2022) report that changes in precipitation are not the main driver of global-scale drought with medium confidence. Drought is mainly affected by the increase in Atmospheric Evaporative Demand (AED), which is the maximum quantity of water that would evaporate under unlimited water availability and null or constant resistance factors from soil and vegetation (Katerji et al., 2011). However, uncertainties derive from the poor estimate of some variables of the hydrological systems (e.g., groundwater, snow melting, soil moisture; Blahuvsiakova et al., 2020) and the $CO_2$ fertilizing effect (Ault, 2020). The larger $CO_2$ concentrations may increase the efficiency of photosynthesis, reducing water loss by leaf transpiration. Drought conditions can be exacerbated by the co-occurrences of heat waves, whose magnitude, duration, and frequency of occurrence are increasing worldwide with high confidence (Masson-Delmotte et al., 2021). The higher the warming rate is, the higher this increase will be (Fischer et al., 2021). Moreover, a heat-wave event may be locally intensified by urbanization and the subsequent urban-heat island effect (Lin et al., 2018; Ward et al., 2016).

Climate change and hydro-meteorological hazards can be addressed through adaptation measures that enhance the adaptive capacities of the exposed elements (Pörtner et al., 2022) and mitigation measures that prevent the emission or remove greenhouse gases from the atmosphere (Shukla et al., 2022). An example of these measures is Nature-Based Solutions (NBS; Cohen-Shacham et al., 2016). Since NBS include green and blue elements, NBS are ecosystemic elements that interact with the surrounding ecosystems in which they are implemented. This ability to act as part of the ecosystem provides the advantages to act over several other environmental and socio-economic variables in addition to the hazardous ones (i.e., the primary objectives). The positive and negative additional effects of NBS are named co-benefits and trade-offs (Ommer et al., 2022), respectively, and can contribute to modifying the risk function (Martin et al., 2020). The provision of co-benefits is one of the main NBS characteristics that can increase their adoption and public acceptance (Pauleit et al., 2017). Public and landowner acceptance is essential for the success of an NBS intervention (Giordano et al., 2020) and refers to a broad spectrum of attitudes and behaviors of individuals towards adaptation and mitigation measures (Anderson et al., 2021). However, NBS are usually perceived as less reliable than traditional engineering solutions due to the limited evidence on long-term effectiveness. The few frameworks for the assessment of NBS effectiveness in risk reduction include CLIMADA (CLIMate ADAptation; Aznar-Siguan and Bresch, 2019), the Vulnerability and Risk Assessment Framework in the Context of NBS (VR-NBS; Shah et al., 2020; 2023), and the framework for hydro-meteorological hazards proposed by Brogno et al. (2024).

**This report aims to integrate the outcomes of previous WP2 deliverables to provide useful insights into the effects of NBS interventions in the FRR regions on local climate risk configurations, thereby supporting both the same FRR regions and the replicating ones in the upscaling and replication processes.** Upscaling and replication refer to the reproduction of an NBS over a larger area at the same site and in new sites, respectively. The report follows the LAND4CLIMATE methodology for the assessment of NBS effectiveness (Deliverable 2.1; Brogno et al., 2025). This methodology states that an NBS is effective if it mitigates hazards, reduces risks, provides co-benefits, is cost-effective, and is accepted (and co-developed) with public stakeholders. In this regard, Section 2 summarises results on the mitigation of hazard characteristics (e.g., magnitude, duration, frequency of occurrence) expected by the implementation of no-regret NBS in the six FRR regions (Deliverable 2.3; Gargiulo et al., 2025), as well as the consequent provision of co-benefits (Deliverable 2.4; Schindelegger and Thaler, 2025). Section 3 integrates the hazard-mitigation results with exposure and vulnerability indicators for risk assessment, while Section 4 introduces the concept of NBS acceptance, a methodology for its assessment and preliminary results regarding its contextualization in the implemented sites. Then Section 5 discusses processes to amplify NBS effectiveness and build suitability maps to identify areas suitable for replication and upscaling processes. Finally, Section 6 draws lessons learnt and recommendations to spread and speed up these processes.

## 2. Lessons learnt from previous deliverables

This section integrates the main findings from the previous work-package deliverables with a special focus on the subset of no-regret NBS selected and modeled in Brogno et al. (2025) and Gargiulo et al. (2025), respectively:

- Green infrastructures included in a sponge city approach to reduce heat stress in the Lafnitz Catchment (FRR Austria);

- Infiltration ponds for groundwater recharge for drought periods in the National Park Bohemian Switzerland (FRR Czechia);
- Tiny forest to cope with heat waves in the County of Euskirchen (FRR Germany);
- Sand dune as a natural barrier that blocks seaspray and seawater during storm surges in the Eastern Po Valley and Po Delta (FRR Italy);
- Reforestation as a buffer zone to offer protection against fluvial floods in the Upper Timiş River Catchment (FRR Romania);
- Retention ponds to store stormwater and mitigate the effects of drought periods in crop fields located in the Roňava River Catchment (FRR Slovakia).

These NBS were selected according to the preference of implementers within the FRR, who evaluated which NBS are most likely to be effective in risk reduction, feasible for implementation, and supported by sufficient data to allow for a comprehensive assessment of their effectiveness following the methodology described in Brogno et al. (2025). This methodology states that the assessment of NBS effectiveness needs to take into account hazard mitigation, risk reduction, the

*Table 1: Selected indicators for hazard mitigation (Gargiulo et al, 2025), co-benefits and trade-offs (Schindelegger and Thaler, 2025) for each no-regret NBS analysed in the six Front-Running Regions*

<table>
<tr><th>FRR</th><th>NBS</th><th>Hazard Mitigation: Actionable Variables</th><th>Hazard Mitigation: Impact Variables</th><th>Co-Benefits (i.e., positive effects)</th><th>Trade-Offs (i.e., negative effects)</th></tr>
<tr><td>Austria</td><td>Trees in Sponge City</td><td>Vegetation Cover ($m^3$)</td><td>Temperature (°C), Relative Humidity (%)</td><td colspan="2" rowspan="6">Environmental:<br>positive/negative effects on Water Quality, Air Quality, Biodiversity, Ecological Connectivity, Soil Health, Groundwater Recharge, Carbon Storage, Drought Prevention, Erosion Prevention<br><br>Economic:<br>positive/negative effects on Settlement Area, Forest Area, Agricultural Area, Primary Production, Land Value, Water Supply, Job Opportunities, Tax Revenues<br><br>Social:<br>positive/negative effects on Heat Mitigation, Fluvial Flood Mitigation, Pluvial Flood Mitigation, Recreation, Aesthetics, Human Health, Social Inclusion, Community Organisation</td></tr>
<tr><td>Italy</td><td>Dune</td><td>Beach elevation (m)</td><td>Wave fraction that surpasses the dune (%), Pressure peak (hPa), Total Deposed Mass of Sea Spray ($\mu g\ m^{-2}\ day^{-1}$)</td></tr>
<tr><td>Germany</td><td>Tiny Forest</td><td>Vegetation Cover ($m^3$)</td><td>Temperature (°C), Relative Humidity (%)</td></tr>
<tr><td>Czechia</td><td>Infiltration Ponds</td><td>Water Storage Capacity ($m^3$)</td><td>Groundwater Level (m)</td></tr>
<tr><td>Romania</td><td>Reforestation</td><td>Vegetation Cover ($m^3$)</td><td>River Discharge ($m^3\ s^{-1}$), Delay of the Flood Peaks (day), Surface runoff ($m^3$), Plant Transpiration ($mm\ day^{-1}$)</td></tr>
<tr><td>Slovakia</td><td>Retention Ponds</td><td>Water Storage Capacity ($m^3$)</td><td>Catchment Area ($m^2$)</td></tr>
</table>

provision of co-benefits, occurring trade-offs, and an evaluation of both cost-benefit and landowner acceptance.

The methodology was partially applied in the previous deliverables, namely Task 2.3 for hazard mitigation and Task 2.4 for the provision of co-benefits and trade-offs. Table 1 reports the indicators selected for these assessments for each no-regret NBS. Indicators for hazard mitigation are classified into actionable and impact variables. Actionable variables are bio-geophysical quantities that are both directly affected by the NBS and affect in turn the targeted natural hazard processes, while impact variables quantify the local impact of an extreme hazardous event. The goal of an NBS intervention is the modification of impact variables by acting on the actionable ones, and in principle, these two variables can coincide. Indicators for indirect benefits are instead classified as co-benefits and trade-offs. Co-benefits and trade-offs are, respectively, other positive and negative effects of NBS in addition to their primary objectives.

The following subsection provides a summary of the lessons learnt from the analyses conducted so far, which will be further expanded in the subsequent sections.

## 2.1 FRR Germany

The County of Euskirchen (~200,000 inhabitants in the state of North Rhine-Westphalia) is considering various small-scale NBS to achieve two objectives:

- Soil water conservation practices for both pluvial-flood mitigation and drought prevention in agricultural fields through structural NBS (e.g., agroforestry, multifunctional hedges) and changes in cultivation practices (e.g., miscanthus);
- Water management and local heat mitigation in the built environment due to measures of sustainable urban drainage systems (e.g., unsealing of pavements, bioswales), and the creation of green spaces (e.g., tiny forests, climate parks).

All considered soil water conservation NBS were evaluated as effective concerning hazard mitigation by the multi-criteria decision analysis (MCDA) reported in Schindelegger and Thaler (2025). Although structural NBS require higher implementation and maintenance costs than changes in cultivation practices, these measures provide more environmental (e.g., biodiversity, ecological connectivity, soil health) and social (landscape aesthetics) co-benefits. On the other hand, crop changes can provide new opportunities for jobs and tax revenues (economic co-benefits) and do not reduce primary production.

Similarly, NBS in the built environment are evaluated as costly but effective measures that can provide environmental (biodiversity, air quality, carbon storage) and social (recreation, aesthetics) co-benefits with marginal trade-offs if their implementation does not modify the already-existing urban structure.

A tiny forest has been selected for further analyses since it offers the opportunity to provide insights on an already-implemented intervention (~370 $m^2$). The modelling experiment (Gargiulo et al., 2025) aims to verify the reduction of near-surface temperature by this compact and densely-planted area of native vegetation. ENVI-met model has been used to analysed the effects on a typical heatwave day with minimum (maximum) temperature of 20°C (35°C), minimum (maximum) relative humidity of 40% (95%) with a resolution of 2 m in three different scenarios: baseline, mature scenario (5 years after plantation), fully-grown scenario (20 years after plantation).

Positive effects of the tiny forest are already expected after 5 years from the implementation. The comparison between baseline and NBS scenarios shows an average decrease of 0.5-0.8°C in the implementation area and 0.2-0.4°C in the surroundings, during both daytime and nighttime. Spatial local differences depend on the prevailing wind conditions. This enhancement of heat stress conditions is also confirmed by the calculation of the Physiological Equivalent Temperature (PET). A cost-effectiveness ratio (CER, Boardman et al., 2011) equal to 55.000 €/°C has been obtained by dividing the sum of implementation and maintenance costs by the resulting PET reduction.

## 2.2 FRR Austria

Several NBS are currently under consideration for implementation in the Lafnitz River catchment (located in eastern Austria). These NBS include:

- Soil water conservation practices in agricultural areas. These practices are classified into land use and management measures (e.g., no-till farming, strip till, strip farming) and structural measures (e.g., agroforestry, multifunctional hedges, sedimentation and infiltration ditches);
- A sponge city concept covering approximately 4,000 m² in the small town of Rudersdorf (population ~2200). This NBS aims to enhance rainwater infiltration and mitigate heat stress through a combination of green and blue infrastructures (e.g., unsealing pavements, planting additional trees, green strips) alongside an underground retention body to collect runoff.

The MCDA analysis presented in Schindelegger and Thaler (2025) confirms that the soil water conservation practices are both effective and cost-efficient in preventing drought and erosion. Structural NBS offers more co-benefits, including improvements in biodiversity, air quality, soil health, ecological connectivity, and landscape aesthetics. However, these measures typically require converting agricultural land, reducing available farmland and primary agricultural production. In contrast, land use and management measures do not result in such trade-offs. Given the existing network of farmers already implementing these practices and sharing best practices based on their experience, the Austrian FRR partners decided to focus modelling efforts in work package 2 on the sponge city concept. According to the MCDA analysis, the sponge city is effective in heat and pluvial flood mitigation and provides environmental (e.g., air quality and biodiversity reconnection), economic (e.g., water quantity) and social (e.g., recreation and human well-being) co-benefits with no significant trade-offs on settlement areas. Therefore, the sponge city concept is selected as a no-regret NBS to be assessed because this measure is an opportunity to test the implementation of NBS in a combination of to date extensively-sealed public and private land in the town centre of Rudersdorf.

The developed modelling chain (Gargiulo et al., 2025) tests the effectiveness of the green-infrastructure component of the sponge city concept concerning heat mitigation:

- The analysis of the SPHERA dataset (2.2 km resolution) (Giordani et al., 2023) for selecting the most intense heatwave that occurred in Rudersdorf in the period 1995–2020;
- The dynamical downscaling of ERA5 reanalysis hourly data with the WRF model by three nested domains (grid spacing of 9, 3, and 1 km, respectively);

- The quality check of the results with four ground stations located around Rudersdorf, namely in Güssing, Feldbach, Fürstenfeld, and Wörterberg;
- The use of WRF output to initialise ENVI-met simulation (i.e., a CFD model) for an area of 230 m x 180 m with a resolution of 2 m x 2 m. The scenario with the implementation of green infrastructure (i.e., 24 trees in an unsealed parking lot) as part of the sponge city is compared with the baseline without NBS (current simulation) in terms of temperature (T) and relative humidity (RH).

The selected most intense event had the heat-stress peak on July 28th, 2013, when the heat index in Rudersdorf exceeded 37°C. ENVI-met output shows a negligible effect of trees during daytime, with cooling limited to a few meters from the trees (variations in T and RH up to -0.4°C and 1.2%, respectively). The effect of trees is more evident at street level during nighttime with local variations of T and RH up to -1.3°C and 5.4%, respectively. Despite the increase in RH, the latter values correspond to a heat-index reduction equal to 1.3°C. These local variations could extend for tens of meters depending on wind conditions, reducing heat stress during the resting time with positive effects on human health.

## 2.3 FRR Slovakia

The Slovakian FRR considers implementing different small-scale NBS for agricultural, forest and built environments within their region, to revitalize the Ronava river basin. The MCDA conducted in Schindelegger and Thaler (2025) for the Slovakian FRR offers insights into possible co-benefits and trade-offs occurring when implementing the planned NBS. In agriculture, NBS like retention ponds/wetlands are effective for drought, erosion, and flood prevention, with co-benefits like enhanced biodiversity. However, they require large land areas, competing with agricultural use. Check dams have a minimal impact on the surrounding land. In forest areas, retention ponds provide environmental benefits but reduce productive forest land; closing drainage ditches has less impact. In the built environment, measures address drought, heat, and flood risks effectively, with underground water tanks providing limited benefits beyond water retention. Most built environment solutions have low trade-offs as they occupy minimal land. Overall, the co-benefits of NBS in Slovakia are location-dependent, with trade-offs like land use reduction in agricultural areas. The no-regret NBS are effective but offer lower co-benefits when considering the design and scale of implementation.

The Slovakian FRR intends to implement several NBS at different locations within its region. One of the locations is a centrally located farm, Ranc Banc, situated in Byst, which was the center of the modelling case for the Slovakian FRR. Specific interventions have not yet been finalized, but the primary objective of the measure is to enhance landscape-scale water retention capacity to mitigate the effects of drought periods within the region. This will be achieved through the deployment of water-retention measures (e.g., retention ponds or tanks). Three fields on the privately owned property have been identified as candidate locations for implementation. The site is characterized by open fields with sparse residential structures and scattered trees. As the exact NBS measures are not yet determined, a preliminary spatial analysis was conducted to identify the field location with the highest potential for capturing surface runoff. This analysis supports strategic siting of future interventions by targeting areas with the greatest hydrological relevance.

To identify optimal locations for surface runoff collection, the following methodological approach was applied (Gargiulo et al., 2025):

- Hydrological modelling was carried out through flow path analysis and drainage basin delineation, providing detailed insights into terrain-influenced runoff behavior and highlighting areas where surface water naturally converges.
- Spatial data processing and geospatial analysis were performed using the open-source GIS software QGIS.

The analysis focused on identifying the longest continuous flow paths within and surrounding the three designated fields. These flow paths were prioritized due to their association with the largest potential drainage basins, indicating the highest potential for surface runoff accumulation. To delineate the contributing catchment areas, eight locations for potential NBS implementation were established along the major flow paths. These points were strategically positioned near the perimeters of the fields, at locations where the main flow paths intersect, to ensure accurate representation of catchment extents and maximize runoff capture potential. The sizes of the eight catchment areas - the largest contributing catchment covering an area of approximately 2,686 $m^2$ - are determined solely by topography and are independent of climate changes. However, the optimal design and capacity of retention basins at these locations may vary depending on climatic factors such as rainfall intensity and frequency.

## 2.4 FRR Romania

The Romanian FRR is located in the Upper Timis River Catchment in the Banat region. Several NBS measures are under evaluation for the improvement of:

- Water-flow regimes of the Timis river by increasing flow retention and decreasing flood peaks with the creation of green-blue spaces (e.g., riparian buffer zones) and stream restoration measures (e.g., re-connection of floodplains);
- Heat-stress conditions and rainwater retention in built environments by the implementation of green (e.g., tree plantation), blue (e.g., retention ponds), and hybrid (e.g., green roofs) measures.

The MCDA analysis (Schindelegger and Thaler, 2025) found that all the proposed measures in the built environment can contribute to addressing heat waves and urban floods, with limited space subtracted from settlement areas. However, the benefits are limited by the implementation and maintenance costs. The planting of trees is an NBS that can provide more environmental (e.g., air quality and biodiversity), economic (e.g., land value), and social (e.g., land aesthetic, recreation, and human well-being) co-benefits.

The modelling experiment in Gargiulo et al. (2025) focuses on the creation of buffer zones by reforesting along the Timis River. This choice derives from the uncertainty in water-flow regulation because the outcomes in the river environment highly depend on the location of the implementation sites, the scales, and their combination. Since the NBS-design phase is still ongoing, these features are not yet available. It is worth mentioning that the creation of buffer zones can also provide both environmental (ecological connectivity, biodiversity, water quality) and social co-benefits (e.g., landscape aesthetics, recreation, and human well-being) co-benefits. However, reforestation in private land can subtract space for agriculture and decrease primary production.

The modelling chain selected for testing the effectiveness of reforestation in fluvial-flood mitigation and improvement of catchment-scale hydrological performance includes:

- The modelling initialization by taking into account altimetry (Digital Elevation Model, resolution of 7 m; sourced from Banat Water Basin Administration BWBA), hydrological observations (BWBA), land use (satellite imagery collected in 2025 and CORINE, 2018), soil characteristics (high-resolution local inputs combined with European soil database), precipitation (17 weather stations, period 2008-2017), and other weather variables (SWAT Global Weather generator, period 2001-2024);
- The application of a Multi-Criteria Decision Analysis to identify the suitable areas for reforestation in 17 subbasins divided into hydrological response units. The criteria of the analysis are current land use, slope, and soil characteristics;
- The analysis of reforestation effects on monthly mean high discharge values (MMHQ), daily river discharge, flood peaks, and surface runoff by the SWAT+ (2020, Soil and Water Assessment Tool Plus) model for the period 2015-2017. The total model area is 2723 $km^2$.

The Multi-Criteria Decision Analysis found that approximately 4.4% of the total catchment surface is suitable for reforestation, while about 65% of the catchment is already covered by forests.

Monthly mean high discharge values (MMHQ) and runoff peaks increase during the wettest months (i.e., spring) and decrease during the driest ones (i.e., summer and autumn) in the NBS scenario. However, daily flow peaks are mostly reduced in comparison with the baseline, and peaks are delayed by one or two days. Some peaks occurred only in the NBS scenario, especially in correspondence with precipitation events upstream. Reforestation improves the water balance within the catchment with an increase in percolation (+1.0%), plant transpiration (+3.5%), and surface runoff volume retained before reaching the mainstream (+6.9%).

## 2.5 FRR Italy

A combination of three NBS has been selected to enhance the resilience of a privately owned site located along the Emilia-Romagna coastline in Ravenna (RA) within the Delta-Po Regional Park. The site includes a diverse array of ecosystems, such as low-lying agricultural fields, wetlands, remnant natural dunes, maritime-pine forests, and Mediterranean-shrub grasslands. The chosen NBS aims to protect portions of these ecosystems from various hydro-meteorological hazards:

- Construction of a dune using exclusively natural materials (e.g., rocks, wood, coconut fibers) to mitigate storm surges, prevent coastal erosion (i.e., avulsion) from sea waves, and reduce atmospheric deposition of seaspray on vegetation located behind the dune;
- Planting of halophyte vegetation to reduce saltwater intrusion through the absorption of salt in leaves and stems;
- Reinforcement of embankments at the River Reno delta with deep-rooted vegetation to prevent erosion during fluvial-flooding events.

The MCDA analysis (Schindelegger and Thaler, 2025) shows that all three measures contribute to reducing the impact of hydro-meteorological events while also providing environmental co-benefits.

Additionally, Salicornia could create new employment opportunities, as this plant is edible, and the dune contributes positively to landscape aesthetics.

Partners from FRR Italy chose to focus the modelling analysis (Gargiulo et al., 2025) on the dune as its implementation is more resource-intensive than the other measures. The dune is conceptualised as a solid, vertical trapezoidal barrier, measuring 200 m in length, 10-20 m in width, and 1-3 m in height. Given its potential to mitigate multiple hazards, two modelling analyses were conducted. The first analysis investigates the dune's effectiveness in mitigating storm surges. The modelling chain includes:

- Buoy station offshore data in Cesenatico (FC), approximately 40 km south of the site, to determine typical conditions of wave height and wind speed in severe maritime conditions;
- An idealised CFD model (OpenFOAM v12) based on Large-Eddy Simulation (LES) to simulate a finite water column flowing across flat terrain impacting the dune. The model has a horizontal resolution of 0.4 m and a vertical one of 0.1 m.

Results show the dune acts as an efficient physical obstacle that deflects the storm-surge flow up to 95% (77%) of the seawater with a wave height of 2 m (3 m). Therefore, only a small portion of the water column affects vegetation located behind the dune. The model shows the formation of a highly turbulent recirculation zone at the windward foothill of the dune. The high water-pressure stress in this zone highlights the necessity to increase the dune solidity with wooden reinforcements, as already planned in the designed prototype. Results are similar substituting the trapezoidal dune with a square barrier, i.e., the typical shape of engineering barriers.

The second modelling experiment analysed the sea spray atmospheric deposition in typical sea-breeze conditions (i.e., from East and North-East, consistent with the Atlante Eolico made by ARPAE, 2024). Breezes can suspend and transport sea spray. However, the dune can act as a barrier that partially intercepts sea spray, reducing the amount of salt deposited on the vegetation located behind it. The modelling chain includes:

- SPHERA dataset for wind-speed monthly averaged data for the period 1995-2020 in the offshore Adriatic area with a resolution of 2 km. The averaged minimum and maximum wind speeds ($U_{min}$ and $U_{max}$, respectively) are reported on the Atlante Eolico for the first 350 m of the atmosphere and then fitted with a logarithmic function. The obtained values at 25 m ($U_{min}$=4.50 m/s and $U_{max}$=6.89 m/s) are selected for wind-speed forcing conditions;
- 24-hour ENVI-met simulations with and without NBS under constant conditions of minimum and maximum wind speed and clear sky. The dune is integrated as a change in terrain height in a flat area with horizontal and vertical resolutions equal to 4 m and 1 m, respectively. Sea is considered as an areal source of sea spray with a rate of 0.2 μg/($m^2$s) (Schwier et al., 2015). Seaspray is assumed to be a particulate-matter PM molecule with 1 μm of effective radius (Liu et al., 2024; Freney et al., 2021) and 8.37 g/$cm^3$ of density (Dedrick et al., 2022). Sea-spray mass deposition *(μg $m^{-2}$)* is analysed over a transect located 50 m behind the dune.

Deposition is higher under $U_{min}$ conditions because light winds are less efficient in keeping sea spray suspended over longer distances. NBS scenarios show a reduction in deposited mass up to 9% (14%) with $U_{min}$ ($U_{max}$) conditions. Interception is higher at the centre of the dune. Due to wind flow deviation caused by the dune, the reduction becomes negligible at the dune edges under $U_{min}$ conditions, and a slight increase (2%) in deposition is even predicted on the sides of the dune.

## 2.6 FRR Czech Republic

Regarding the Grant Agreement, the Czech FRR aims to achieve to revitalise a natural stream in Krasna Lipa to improve the climate resilience in the urban environment, as well as revitalise forest landscapes in the national park Bohemian Switzerland. In order to realise these objectives, the application of NBS is being considered within the Czech FRR. In the MCDA the Czech FRR examines the co-benefits and trade-offs for NBS for both built and forest environments (Schindelegger and Thaler, 2025). In urban areas, measures like unsealing surfaces, retention ponds, and bioswales address heat and flood risks but are costly. Co-benefits include biodiversity, groundwater recharge, drought prevention, and improved aesthetics, but none of the measures offer significant co-benefits across the board. The trade-offs are low, with minimal loss of developable land. In forest areas, measures such as closing drainage ditches and river restoration effectively tackle drought and pluvial flooding. They require a high initial investment but low ongoing costs. Co-benefits include biodiversity, ecological connectivity, soil health, and recreational value. River restoration also aids in flood mitigation and enhances landscapes. Trade-offs involve reduced productive forest areas, depending on the project's specifics. Overall, the no-regret NBS in forest areas deliver important co-benefits, though they come at the cost of reduced productive areas.

The modelling activity for the Czech FRR was focused on the effectiveness of the NBS to be implemented by the national park authority (Gargiulo et al., 2025). One potential measure proposed by the FRR is the implementation of an infiltration pond to support groundwater recharge. This was investigated in the model using an idealised representation of such a pond. The proposed intervention site is situated north of Ustí nad Labem, near the German border. The area is underlain by a fractured silicate aquifer characterized by low hydraulic conductivity (ranging from $10^{-9}$ to $10^{-7}$ m/s), with gneiss as the predominant bedrock. The overlying soil consists of sandy-loamy colluvial brown earth.

Since no finalized pond specifications or comprehensive Czech hydrogeological datasets were available, the study relied on German cross-border datasets and assumed parameters. Modelling (Gargiulo et al., 2025) was conducted using the software LoFloDes and its associated QGIS plugin, developed under the German BMBF-funded DryRivers project. The integrated hydrodynamic module (HYD) was used to simulate coupled surface–subsurface interactions, focusing on groundwater level dynamics and infiltration fluxes.

Two groundwater model setups were developed to evaluate the impact of an infiltration pond:

- Model A represents the study area prior to infiltration pond implementation, while Model B represents the scenario including a highly idealized infiltration pond. Due to the lack of defined pond design parameters, assumptions were made; the pond was modelled as having a surface area of 1 hectare (10 m × 10 m).
- Both models were simulated under two climatic scenarios: a baseline scenario represent-ting the current situation and using observed precipitation and evaporation data (2001 to 2010), and a possible future scenario (2031 to 2040) based on the MPI-ESM-LR global climate model coupled with REMO2009, following the RCP8.5 emissions pathway.
- The effective precipitation rate was calculated monthly by subtracting the evapotranspi-ration rate from the precipitation rate (German Weather Service, DWD) and applying a

runoff coefficient of 0.2, reflecting agricultural land use, which was identified through CORINE Land Cover data.

- The model domain spans 100 m × 100 m, discretized into 400 grid cells of 5 m × 5 m each. Observation points were established at distances of 7.25 m, 17.25 m, and 27.25 m from the pond's center to monitor groundwater level changes. The pond water level was fixed at 496 meters above sea level (a.s.l.), with the aquifer base set at 455 meters a.s.l. and the initial groundwater table 30 m above the aquifer base.
- The hydraulic conductivity in the domain was assumed to be uniform at $1\times10^{-7}$ m/s, and the porosity was modelled with 0.25. These assumptions are based on the Hydrogeological Overview Map of Germany at 1:200,000 scale (HÜK 200).
- Groundwater recharge was applied as a time-variable Neumann boundary condition, while Dirichlet conditions at model boundaries allowed groundwater outflow and prevented artificial accumulation.

The results show that the presence of the infiltration pond can consistently increase groundwater levels across all points, with the effect strongest near the pond and diminishing with distance, for both the current and future scenarios. Due to a lack of site-specific and validation data, key model parameters were estimated, limiting the certainty of results. Nonetheless, findings suggest that, under idealized conditions, infiltration ponds can enhance local groundwater recharge.

# 3. Risk assessment

Risk assessment is a key step in evaluating the effectiveness of NBS. This step estimates their contribution to reducing potential damages when a hazardous event occurs in a specific area, affecting the exposed elements located there (i.e., the exposure component). The response of exposed elements to the hazard depends on their predisposition to being damaged (i.e., the vulnerability component). Risk is generally estimated as the product of these three components: hazard, exposure, and vulnerability.

Few existing risk assessment frameworks are designed to integrate the contribution of adaptive measures such as NBS. Figure 1 shows the Vulnerability and Risk Assessment Framework in the Context of NBS (VR-NBS; Shah et al., 2020; 2023), which takes into account NBS as elements of socio-ecological systems (SES, Berkes et al., 2000). This framework, developed during the OPERANDUM project, integrates typical SES indicators for exposure and vulnerability with hazard indicators derived from modelling and monitoring activities. The scores for each component are then combined according to Crichton's risk triangle, resulting in risk maps ranging from low to high. This approach is suitable for comparing baseline and NBS scenarios across a range of hydrometeorological hazards and spatial scales.

Figure 2 shows the framework proposed by Brogno et al. (2024). This framework retains the main features of VR-NBS but allows for a more detailed analysis of the implications of hazardous events and NBS interventions within socio-ecological systems. It introduces the evaluation of climate-related contributions in terms of equivalent $CO_2$ emissions and provides a final quantitative risk

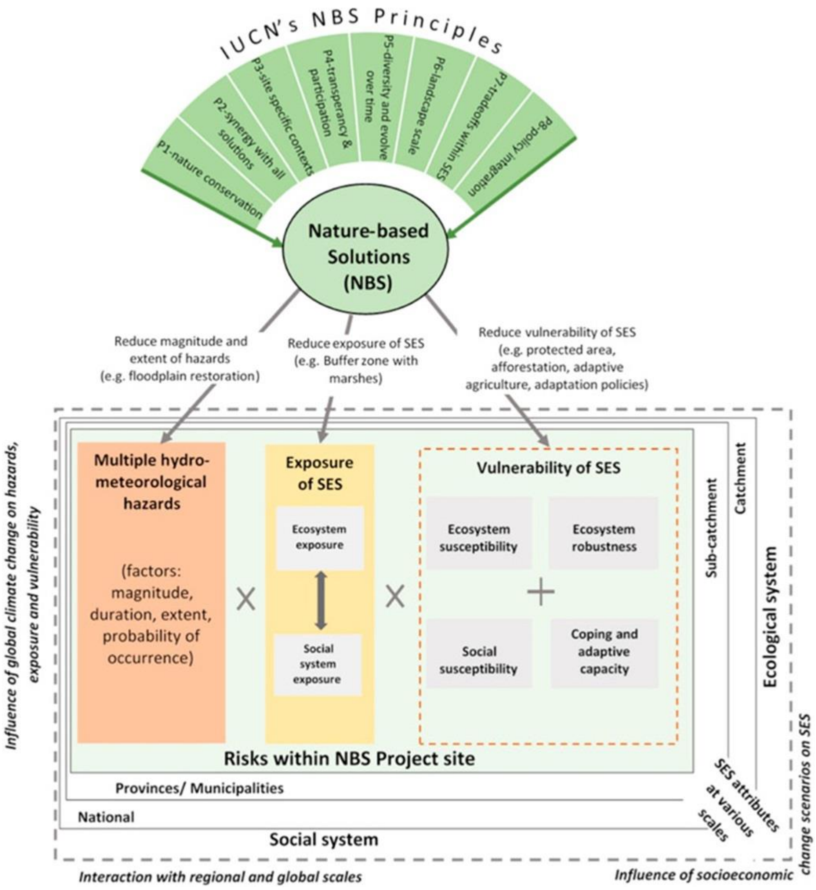



*Figure 1: VR-NBS framework for the assessment of vulnerability and risks in the context of NBS interventions. Source: Shah et al. (2020, 2023).*

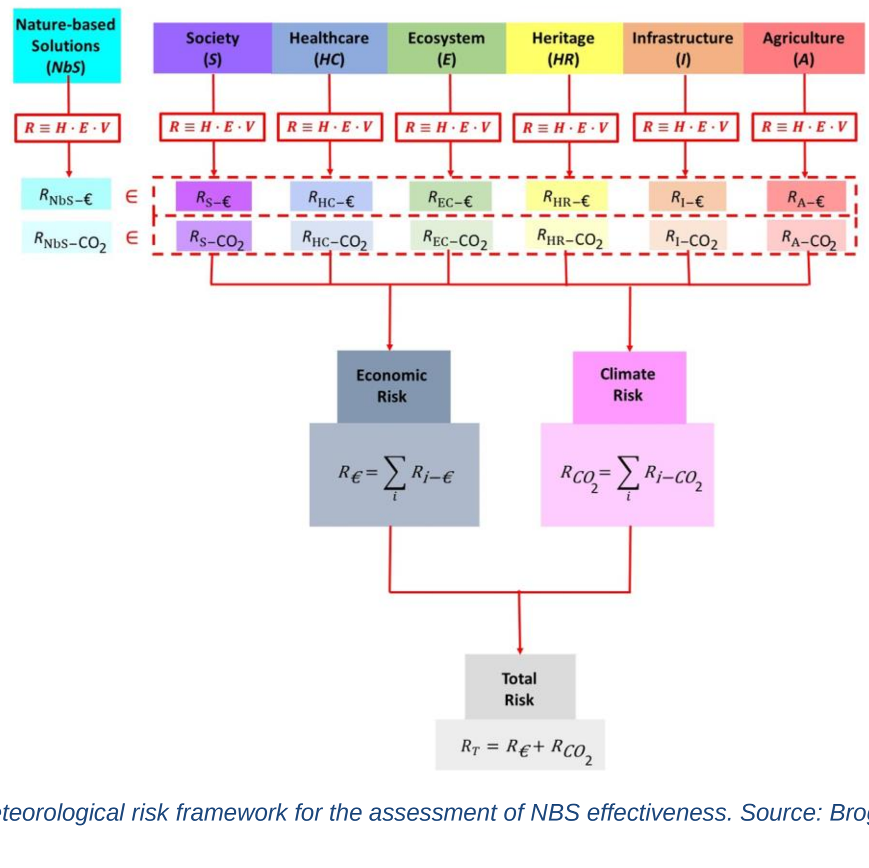



*Figure 2: Hydro-meteorological risk framework for the assessment of NBS effectiveness. Source: Brogno et al. (2024).*

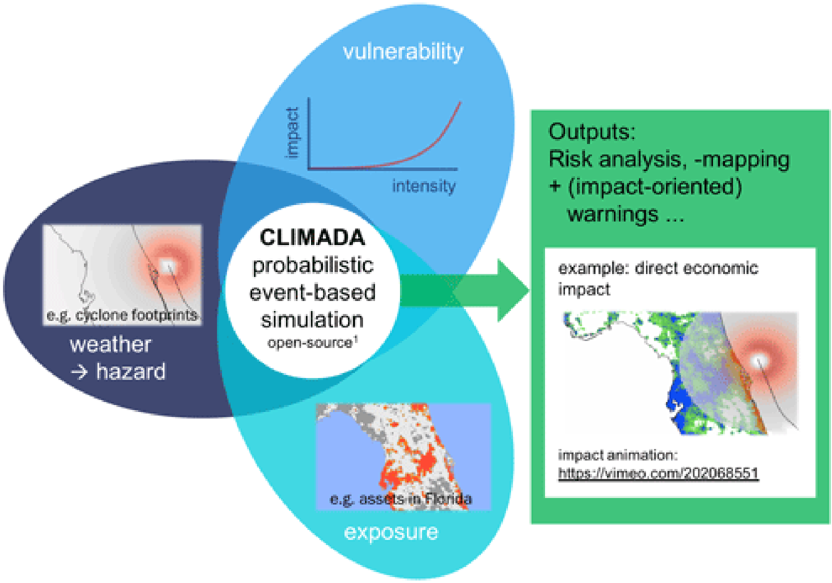



*Figure 3: CLIMADA concept for probabilistic event-based simulations. Source: Aznar-Siguan and Bresch (2019).*

assessment expressed as a cost per day, instead of a qualitative risk score. The cost-per-day metric was selected as a pragmatic output that facilitates comparison of risk contributions across several sectors: healthcare, society, agriculture, ecosystems, infrastructure, and cultural and natural heritage. Due to its economic structure, this framework can also incorporate typical cost–benefit information such as NBS implementation, maintenance, restoration costs, and associated $CO_2$ emissions.

Figure 3 shows CLIMADA (CLIMate ADAptation, Aznar-Siguan and Bresch, 2019), which is an open-source platform for risk assessment and climate adaptation to various natural hazards (e.g., tropical cyclones, floods, earthquakes, heatwaves), supporting both deterministic and probabilistic analyses. This framework considers a broad range of exposed elements such as population, physical assets, croplands, and their associated economic value. Vulnerability functions relate hazard magnitude to expected impacts by estimating the proportion of physical damage to assets and the resulting economic losses, the likelihood of injuries and fatalities, as well as sector-specific vulnerabilities, including agricultural yield losses and power outages. The output is designed to support decision-making for climate adaptation by providing probabilistic risk metrics, such as expected annual damages or losses, loss exceedance curves, and scenario-based impact assessments.

The structure of these frameworks has inspired the following analyses, aimed at evaluating the effectiveness in risk reduction of a no-regret NBS for each FRR by building upon the lessons learnt from previous deliverables and summarised in Section 2.

## 3.1 FRR Germany

FRR Germany has implemented a tiny forest of 370 $m^2$ at Zülpicher Straße (Euskirchen municipality) to reduce heat stress. Since the implementation site is an urban ecosystem, people are the main exposed elements to heat waves that would benefit from this NBS intervention. Heat can trigger several multi-organ diseases contributing to excess mortality, especially affecting people in already unhealthy conditions (e.g., Gosling et al., 2007). Affected people include the elderly, who are particularly susceptible to heat stress due to several impairments of cutaneous vasodilatation, i.e., the main adaptive response of the human body (Lõhmus, 2018). The lower efficiency in vasodilation is even worsened by a lower production of sweat and density of surface thermoreceptors (Chang et al., 2022). Mortality rates are increasing due to global warming, which leads to more severe and frequent heat waves (Lüthi et al., 2023). The main hazard feature correlated to excess mortality is the heat-wave magnitude (e.g., Gasparrini and Armstrong, 2011). The following subsection 3.1.1 describes the methodology for the risk-assessment analysis, while subsection 3.1.2 shows the results. The analysis aims to understand the reduction of heat-stress mortality risk thanks to the implementation of the tiny forest, by integrating the modelling experiment regarding hazard mitigation reported in Gargiulo et al. (2025) with exposure and vulnerability data according to the framework proposed by Brogno et al. (2024).

## 3.1.1 Methodology

The framework proposed by Brogno et al. (2024) aims to estimate several economic and climate contributions to risk due to the occurrence of hydro-meteorological events, taking into account adaptive measures such as NBS. The framework is partially applied to the tiny-forest case study to assess the reduction of excess mortality as a cost per year based on Crichton's risk triangle theory (Crichton, 1999). This theory states that the risk (R) is null if hazard (H), exposure (E), and vulnerability (V) do not spatially and temporarily coexist, i.e.,

$$R = H \times E \times V \qquad (1)$$

In the following application, the NBS is introduced as a modification in the hazard component $\Delta H$ between the NBS scenario and the baseline (i.e., modelling output without the NBS) that leads to changes in risk $\Delta R$:

$$\Delta R = \Delta H \times E \times V \qquad (2)$$

To take into account the reduction of air temperature reported by Gargiulo et al. (2025), the difference in hazard component has been estimated as follows:

$$\Delta H = \left.\frac{\frac{T_{day}}{T_{t-day}} + \frac{T_{night}}{T_{t-night}}}{2}\right|_{NBS-baseline} \quad if\ T_{day} \geq T_{t\_day} \text{ and } T_{night} \geq T_{t\_night} \qquad (3)$$

in which $T_{t-day} = 30°C$ and $T_{t-night} = 20°C$ are the tropical day and night temperatures, respectively. These temperatures are selected for normalizing modelled temperatures because they are widely used meteorological thresholds that can indicate potentially harmful stress conditions. It is worth mentioning for other applications that the ratios $\frac{T_{day}}{T_{t-day}}$ and $\frac{T_{night}}{T_{t-night}}$ are supposed to be null if $T_{day} < T_{t-day}$ and $T_{night} < T_{t-night}$, respectively, because the heat-stress condition is no longer verified.

The exposure component that benefits from the NBS implementation is estimated from census data as follows:

(4) $$E = E_{tot}\frac{A_{NBS}}{A_{urb}},$$

where $E_{tot}$ and $A_{urb}$ are, respectively, the total elderly population and the extent of urban area in Euskirchen in 2025.

In agreement with Brogno et al. (2024), the vulnerability component due to excess mortality is estimated as the product of a vulnerability factor that links the exposed elements to their predisposition to be harmed by hazardous events (i.e., the premature death rate $PD$) times an associated cost that quantifies the possible damage from an economic perspective (i.e., the cost of a life lost $C_l$). The obtained equation is

(5) $$V = PD \cdot C_l.$$

The quantity $C_l$ is assumed to be equal to the national value of a statistical life *VSL*, i.e., how much the people are willing to pay to reduce mortality due to high temperatures for a reduction of mortality equal to one person over $1 \times 10^5$ (Adélaïde et al., 2022).

### 3.1.2 Results

The heat-wave modelling experiment (Gargiulo et al., 2025) reports a reduction of 2-m air temperature equal to 0.3°C during both daytime and nighttime over an area of $A_{NBS} = 6765\ m^2$ around the tiny forest. By introducing this result in Equation (3), the obtained change in the hazard component is $\Delta H = 1.3 \times 10^{-2}$. Census data from Destatis (i.e., the Federal Statistical Office of Germany) are consulted for estimating the number of elderly that benefit from the tiny forest. Equation (4) provides an estimate equal to $E = 4.1\ elderly$. Vulnerability data are obtained from the OECD (Organization for Economic Co-operation and Development) dataset on “Mortality, morbidity and welfare cost from exposure to environment-related risks”. These dataset reports values up to 2019. The quantity $C_l = 4.5\ \times 10^6 €\ elderly^{-1}$ has been projected to 2025 by assuming a linear trend in time ($R^2$=0.99), while $PD = 1.4\ \times 10^{-6} year^{-1}$ has been averaged between 2010 and 2019. The obtained value by Eq. (5) is $V = 6.3\ \ €\ elderly^{-1} year^{-1}$.

The final reduction of risk thanks to the implementation of the tiny forest is found by applying Eq. (2), and it is equal to $\Delta R = 0.33\ €\ year^{-1}$. This value consists of a 1.2% risk reduction in the area $A_{NBS}$ that benefits from the NBS intervention. Although these values may appear small at first glance, they confirm that the tiny forest has the potential to represent a first step towards the development of an urban adaptation plan aimed at building an urban green infrastructure network. Given the overlap of multiple variables that can locally affect atmospheric temperature, the combination of multiple NBS may lead to a non-linear risk reduction and requires dedicated modelling studies to refine the expected outcomes.

Furthermore, several considerations can enhance the risk assessment reported in this subsection:

- **Simulation of multiple heat-wave events** to evaluate whether the tiny forest's response varies with the magnitude, duration, and seasonal timing of such events;

- **Broadening the health impacts** taken into account. Excess mortality is the main risk contribution in the health sector due to heat stress (e.g., Adélaïde et al., 2022). However, a more comprehensive assessment can include excess morbidity and economic losses due to patients' inability to work or restriction of activity days. Health impacts are not restricted to the elderly but can also affect other population groups, such as children (Xu et al., 2012), workers (Foster et al., 2020), and the homeless (Schwarz et al., 2022);

- **Integration of acclimatization effects** in the estimate of the hazard component (Eq. (3)) (e.g., Nairn and Fawcett, 2015). Identical heat-wave events may have different impacts depending on their timing within summer due to human acclimatization. Mortality and morbidity often peak during the first summer event (e.g., Liss et al., 2017; Sun et al., 2020);

- **Refinement of temperature thresholds**. The current analysis assumes that excess mortality is null below the tropical daytime and nighttime temperature thresholds, and increases linearly from 1 once these thresholds are exceeded. These temperatures are generally associated with the beginning of heat-stress conditions. However, a more accurate estimate would require the identification of the median daytime and nighttime temperatures during heat-wave events at which the national OECD death rates are observed;

- **The use of local clinical data** can further refine both hazard and vulnerability components. For instance, latitude can affect both heat-related death rates and the threshold temperature at which such deaths begin to occur (e.g., Curriero et al., 2002; Gosling et al., 2007). Local clinical data allow for understanding the relationship between death rate and temperature (i.e., heat-wave magnitude). Despite the linear assumption adopted in this analysis for the lack of data, the relationship is usually exponential, showing U- or V-shaped dose-response curves (Gasparrini and Armstrong, 2011);

- **Improvement of the exposure estimate** by knowing how many elderly live in the surroundings of the tiny forest. Equation (4) assumes a uniform distribution of the elderly across the municipality's area. This assumption may not be verified at a very local scale as the area that benefits from the NBS;

- **Integration of the other adaptive measures** adopted by the local population, such as air-conditioning systems. These other measures can significantly affect the correlation between atmospheric temperatures and the ones experienced indoors, where the elderly probably spend most of their time during heat-wave events;

- **Integration of the co-benefits** provided by the tiny forest. Green infrastructures may yield indirect health benefits by encouraging recreational and physical activities. However, the quantification of these indirect effects on mortality is not straightforward and requires sophisticated clinical experiments.

The application of the proposed framework to future climate scenarios is theoretically possible but presents several methodological challenges that prevent a straightforward extension of the present analysis. First, it is important to acknowledge that the implementation of NBS in future climate scenarios involves uncertainties that go beyond the sole modeling of local temperature reduction. Future climatic conditions are expected to differ not only in terms of increased temperatures, but also in the frequency, duration, and intensity of heat waves (e.g., Masson-Delmotte et al., 2021; Jacob et al., 2018). However, the biophysical response of an NBS under these altered conditions is not yet well understood. Factors such as vegetation stress, soil moisture deficits, or increased evapotranspiration demands may significantly modify the NBS's effectiveness. Moreover, climate projections do not account for NBS implementation unless explicitly modelled, which is rarely feasible at the local scale due to the spatial resolution limits of regional climate models. Therefore, introducing a localized, future NBS into a regional climate projection would require dedicated high-resolution modeling that dynamically couples land-use changes and vegetation growth with future meteorological drivers—something not readily available in current datasets. In addition, the vulnerability and exposure components in future climate contexts are also affected by demographic, social, and infrastructural changes, which are difficult to predict. For example, elderly population distributions, building stock characteristics, prevalence of air conditioning, and urban morphology will evolve in time and may interact with climate hazards in complex ways. Despite these limitations, several studies (e.g., Fischer and Schär, 2010; Russo et al., 2014) converge on the expectation that heat waves in Central Europe will become more frequent, intense, and long-lasting in the coming decades. This amplifies the importance of adaptive strategies, such as NBS.

Even though the NBS simulated here affects a small urban area, the simulated reduction of near-surface temperature (0.3°C) during extreme heat conditions may still provide a relevant health benefit under future climate conditions. We cannot clearly assume that reductions in surface temperature will be similar for future heat waves. However, if similar local cooling effects can be maintained under climate change, they could help partially compensate for the increasing hazard, bringing localized conditions closer to current climate levels during heat extremes. This would represent an important contribution to risk reduction, especially for vulnerable groups such as the elderly.

## 3.2 FRR Austria

The selected no-regret NBS for FRR Austria is a sponge city that may be implemented in the municipality of Rudersdorf to address flood and heat-wave events. The first design of this NBS includes the pavement unsealing of a parking lot and the plantation of trees. The modelling experiments made in Gargiulo et al. (2025) analysed the contribution of these trees in improving stress conditions during the worst heat-wave event that occurred in the period 1995-2020. The following subsection 3.2.1 shows the methodology to integrate the modelling outcomes with exposure and vulnerability data for assessing risk. Since the urban environment, the analysis is similar to FRR Germany, with the elderly selected as elements exposed to heat-related excess mortality. Then, subsection 3.2.2 reports the results.

### 3.2.1 Methodology

Excess-mortality risk due to heat stress has been assessed in agreement with the framework proposed by Brogno et al. (2024) based on Crichton’s risk triangle theory (Eq. (1)) by comparing the NBS scenario with the baseline (Eq. (2)).

## 3.2.2 Results

The heat-wave modelling experiment (Gargiulo et al., 2025) highlights the effects of trees in improving the microclimate only during nighttime. However, these effects are limited to the implementation area and local spots that depend on wind conditions. The reduction of 2-m nighttime air temperature $T_{night}$ is equal to 0.1°C by averaging over an area $A_{NBS} = 5600\,m^2$ around the parking lot. This area has been selected to include the closest buildings in the analysis. The mitigation of the hazard component $\Delta H = 2.5 \times 10^{-3}$ has been obtained by applying Eq. (3) with the same general temperature thresholds adopted in FRR Germany.

The exposure component $E$=*2.3* has been estimated by Eq. (4) from census data provided by Statistik Austria (i.e., the National Statistical Office of Austria). The total elderly population $E_{tot} = 4.5 \times 10^2\ elderly$ in Rudersdorf has been obtained by multiplying the total population in 2025 (i.e., $2.2 \times 10^3$ people) for the national ratio of people over 64 years old (i.e., $2.0 \times 10^{-1}$). The total area of Rudersdorf that hosts the total population $A_{urb} = 1.1 \times 10^6\ m^2$ has been estimated from Google Earth, which shows a roughly rectangular shape of this village (i.e., $8.0 \times 10^2\ m \times 1.4 \times 10^3\ m$).

The vulnerability components $V = 7.1\ €\ elderly^{-1} year^{-1}$ results from Eq. (5) by taking data from the same OECD dataset (i.e., $PD = 1.5 \times 10^{-6} year^{-1}$ and $C_l = 4.8 \times 10^6 €\ elderly^{-1}$).
The final reduction of risk $\Delta R = 0.04\ €\ year^{-1}$ due to the tree plantation is obtained by applying Eq. (2), corresponding to a 0.2% risk reduction in the area $A_{NBS}$ that benefits from the implementation of the NBS. In addition to all the considerations already discussed for FRR Germany, it is worth noticing that the sponge-city concept represents a multi-hazard adaptation measure. As requested by FRR partners, this study has investigated the role of the sponge-city vegetation in mitigating stress during heat-wave events. However, the sponge city has two other primary objectives, namely:

1. The mitigation of urban pluvial flooding by slowing down and collecting surface runoff;
2. The improvement of water quality by filtering stormwater before it reaches water bodies.

The analysis presented here should therefore be seen as a contribution, which would benefit from being complemented by broader multi-hazard risk assessments to provide a more complete understanding of the overall effectiveness of the proposed adaptation measure.

Similar to FRR Germany, future climate conditions are expected to exacerbate the frequency, intensity, and duration of heatwaves also in Austria. However, due to the limited spatial extent and intensity of the local NBS intervention in Rudersdorf, the simulated temperature reductions remain small even under more severe climate scenarios. Nonetheless, simulations show that the implemented NBS can still provide a modest cooling benefit, mostly during nighttime, leading to a reduction of around 0.1°C within the intervention area.

While this mitigation may appear limited in absolute terms, it still contributes to reducing risk, especially in critical environments such as elderly housing or healthcare facilities. Although small-scale NBS cannot fully offset future climate impacts on their own, they remain a low-regret strategy, especially when integrated within broader, multi-functional adaptation plans.

As discussed in Section 3.2.1, the sponge-city intervention also contributes to flood and water quality improvements, whose benefits are not quantified in this analysis but are expected to increase under climate change due to more frequent extreme rainfall events.

## 3.3 FRR Slovakia

The Slovakian FRR intends to implement different small-scale measures to revitalize the Ronava river basin to water crops on the adjacent field in months of water scarcity. The aim is to keep the water in the landscape to be used at a later moment. In Gargiulo et al. (2025), eight locations were analysed as possible implementation locations. Figure 4 shows these locations that serve as water inlets to a potential retention measure, as well as the corresponding catchment areas. In a more detailed analysis, a water balance was established to assess whether crops on the adjacent fields can be irrigated during dry months using water retained in such a measure. For this purpose, the monthly water availability in the study area was evaluated over a 25-year period. The analysis investigates how much water could potentially be available at the examined locations and whether this would be sufficient to meet the monthly crop water requirements—even during months with limited precipitation.

### 3.3.1 Methodology

The investigation is based on precipitation and evaporation data derived from climate model simulations (MPI-ESM-LR global climate model coupled with REMO2009). For the historical scenario, data from the period 1981–2005 were used; for the future scenario, data from 2031–2055 were considered.

The following assumptions were made in developing the water balance:

- The water retention measures are assumed to irrigate only the adjacent fields. Accordingly, the potential locations for irrigating crops on the first field are sites 1–4, for the second field sites 5 or 6, and for the third field sites 7 or 8.

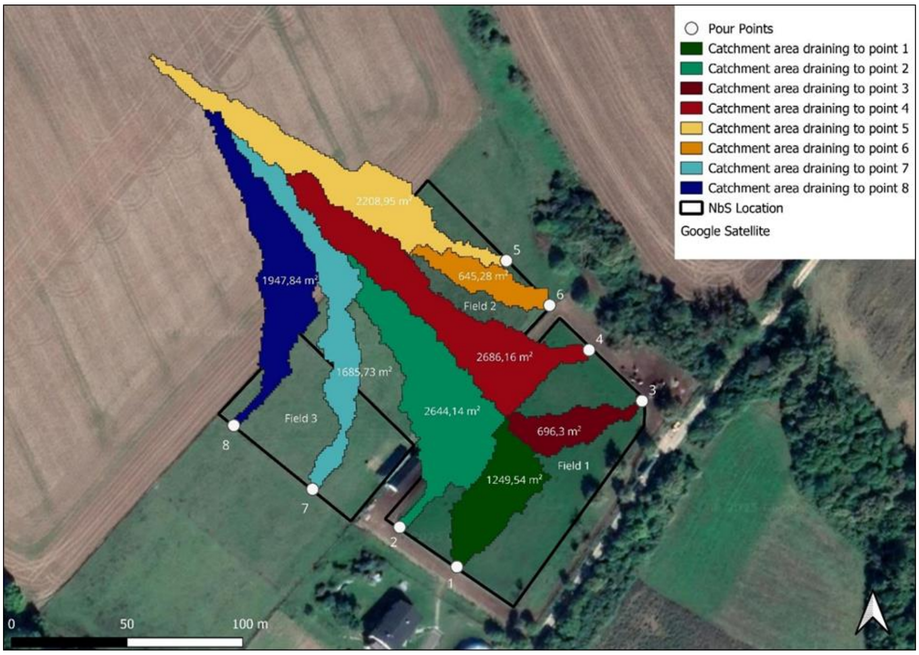



*Figure 4: Resulting potential locations for water retention measure per field with the calculated drainage areas [$m^2$]. Source: Gargiulo et al. (2025).*

- The water inflow from the catchment area into the retention measure and the crop water demand on the individual fields are considered separately. It is assumed that the catchments do not overlap with the agricultural fields, although partial overlap may occur in reality. This is an idealized approach.
- The catchment areas are assumed to be impervious. Only rainfall runoff and evaporation are considered, while infiltration into the soil is neglected due to a lack of site-specific data. This is an idealized approach.
- $ET_0$ is used for a first estimation of crop water demand, as no information is available about the specific crops cultivated in the study area. $ET_0$ represents the reference evapotranspiration of a standardized surface, typically well-watered grass, and serves as the basis for calculating crop-specific evapotranspiration (Allen et al., 1998).

The monthly water volume, in $m^3$, potentially available in the retention measures at each location was calculated by multiplying the effective precipitation—defined as the difference between precipitation and evaporation—with the respective catchment area.

To assess the water demand of the crops per field, the $ET_0$ value was estimated with the CROPWAT software, which was developed in 1991 by the Food and Agriculture Organisation (FAO). CROPWAT is a decision support tool developed by the Land and Water Development Division of FAO. The program is able to calculate crop water requirements and irrigation requirements based on soil, climate and crop data. When no local data is available, the program uses its own standard soil and crop data. Climate data can be obtained from a nearby station using the associated software CLIMWAT, which includes climate data from more than 5000 stations worldwide (*https://www.fao.org/land-water/databases-and-software/cropwat/en/*).

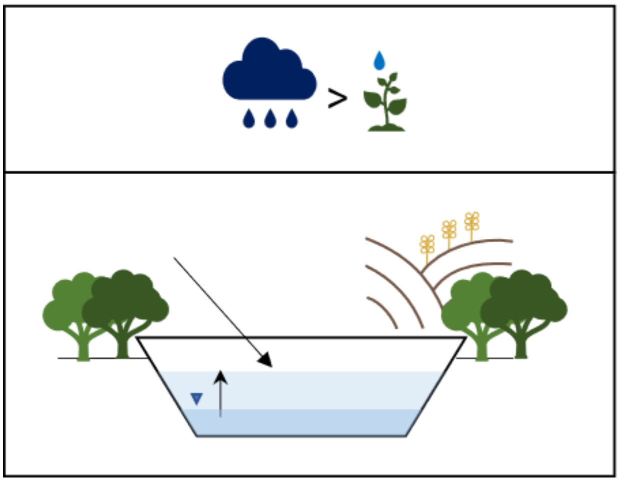
CROPWAT uses the FAO56 Penman-Monteith method to calculate the daily reference evapotranspiration ($ET_0$) per month, combining the original Penman-Monteith equation with equations for aerodynamic and surface resistance of a grass reference crop (Allen et al., 1998):

(6) $$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

where

$ET_0$: reference evapotranspiration [mm $day^{-1}$],
$R_n$: net radiation at the crop surface [MJ $m^{-2}$ $day^{-1}$],
G: soil heat flux density [MJ $m^{-2}$ $day^{-1}$],
T: mean daily air temperature at 2 m height [°C],
$u_2$: wind speed at 2 m height [m $s^{-1}$],
$e_s$: saturation vapour pressure [kPa],
$e_a$: actual vapour pressure [kPa],
$e_s - e_a$: saturation vapour pressure deficit [kPa],
Δ: slope vapour pressure curve [kPa $°C\Delta^{-1}$],
$\gamma$: psychrometric constant [kPa $°C\gamma^{-1}$].

The FAO56 Penman-Monteith method is a standardized scheme recommended for hydrological and irrigation applications under different climate conditions at locations where all the required data is available. In the past, there have been various studies based on this method, analyzing its sensi-



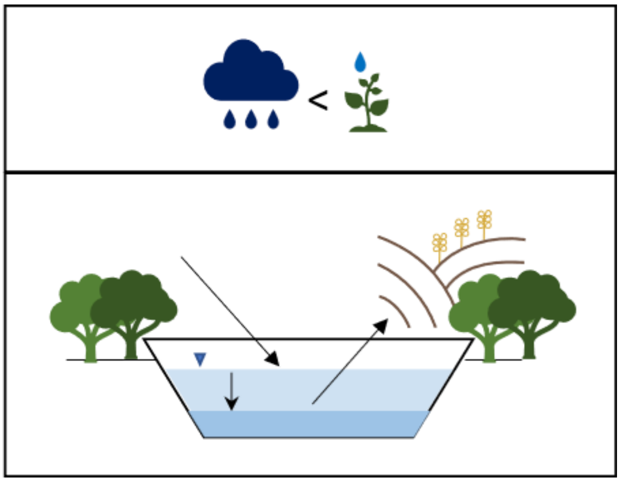



*Figure 5: Schematic illustration of the water balance in relation to crop water demand and the retention measure (NBS) a) the precipitation exceeds the water demand of the crops water volume in NBS rises through water from the drainage area; b) precipitation is not sufficient to meet the crop water demandà water from the NBS is used to supplement irrigation.*

tivity for varying climate regions and developing simplified forms of the equation (Valiantzas, 2013; Debnath et al., 2015).

Since the required climate data is not available for the Košice region, the closest weather station, available with CLIMWAT at a similar altitude was used instead. This station, located in Miskolc, Hungary, is situated at an altitude of 233 metres, approximately 90 kilometres south-west of Košice (altitude 210 m). The following parameters were used as input for the calculation: maximum and minimum monthly temperatures, wind speed, relative humidity, and average number of hours of sunshine per day, as well as the latitude (48.10°N), longitude (20.78°E), and altitude of the station. The climate parameters are the averaged values over the entire recording period, and time series are not provided. Therefore, the same water demand per month was assumed every year, even in historical as well as future calculations. This is an idealized approach.

The monthly crop water requirement per field was calculated by multiplying the crop water demand (in mm/month) by the respective field area (in $m^2$), resulting in the total monthly water volume (in $m^3$) needed for irrigation. If the precipitation in a given month is sufficient to meet the crop water demand on the respective field, the water volume in the retention measure increases, as no additional irrigation is required. This situation is illustrated on the left side of Figure 5. If, however, the monthly precipitation is insufficient, water from the retention measure is used to supplement irrigation, as shown on the right side of Figure 5. Although the retention measure can be depleted, negative water volumes are not assumed. Thus, in any given month, the maximum possible water deficit corresponds to the amount needed to fully meet the crop water demand. Water deficits are treated as monthly values and are not carried over or accumulated across months.

## 3.3.2 Results

The results of the water balance indicate that the water stored in the retention measure is not always sufficient to meet the crop water demand on the adjacent fields. This is particularly evident during the summer months, when precipitation levels are lower and water deficits occur. The following diagram presents the results for Location 4, which is adjacent to Field 1, under the historical climate scenario. Green bars represent the volume of water available in the retention measure, while red bars indicate the volume of water lacking to fully satisfy the crop water requirements. In months where a deficit is observed, the retention measure is assumed to be depleted. Figure 6 serves as an example for the graphical representation of the results; additional diagrams for other locations are provided in Annex 1.

Table 2 presents the results for all locations under both historical and future climate scenarios. For each field, a reference case without the implementation of an NBS was also analyzed. This baseline reflects the number of months during which crop water demand is not met through rainfall alone, without any supplementary irrigation from a retention measure. Under the historical climate scenario, 50% of all months over the 25-year investigation period exhibit a water deficit in the absence of any retention measure. In the future scenario, this share decreases slightly to 45%. Furthermore, the table includes the absolute water deficit required to ensure sufficient irrigation for both historical and future scenarios.

The results indicate that Location 4 is the most suitable site for implementing a retention measure for Field 1, in both the historical and future scenarios. The number of deficit months can be reduced from 150 to 72 (historical) and to 57 (future), respectively. The total water deficit decreases from 39215 m³ to 20656 m³ in the historical scenario and from 39541 m³ to 16476 m³ in the future scenario. For Field 2, Location 5 proves to be the most suitable, reducing the number of deficit months from

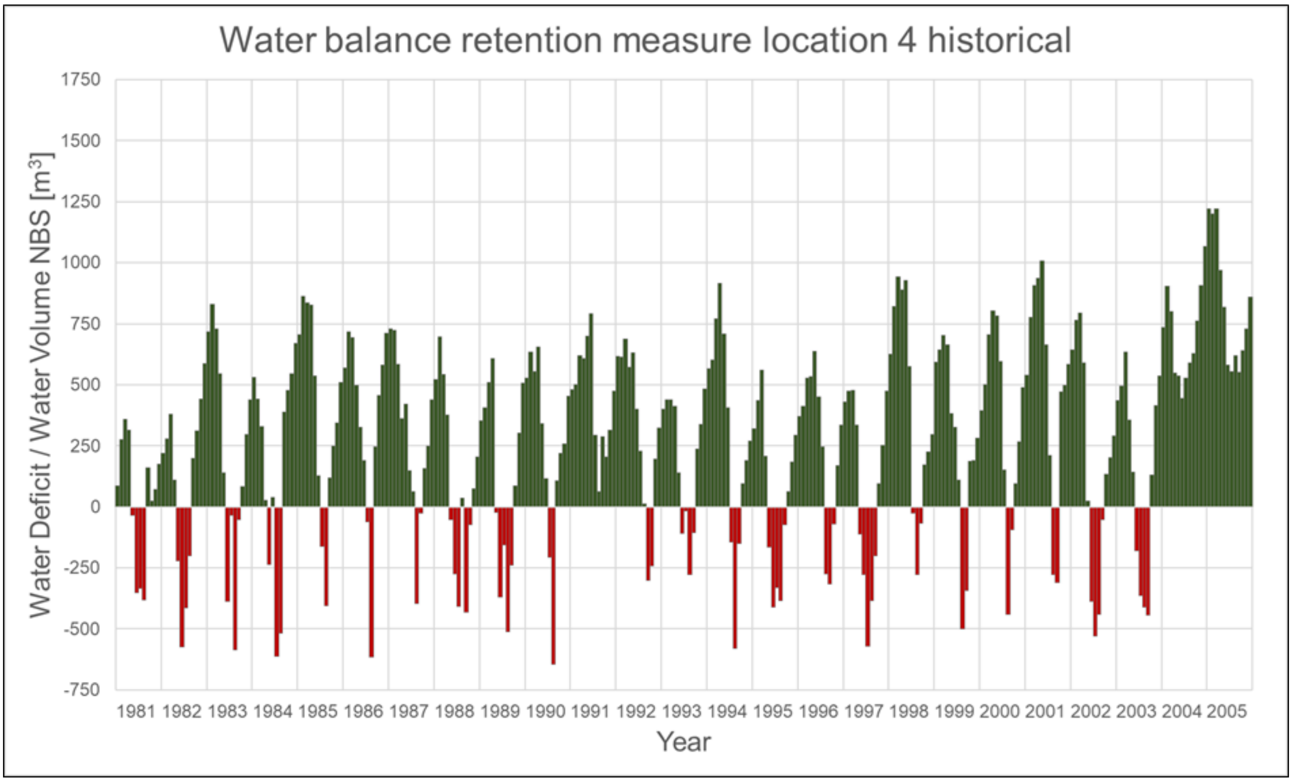



*Figure 6: Resulting water balance for location 4 in the historical scenario.*

*Table 2: Overview of water deficit months and absolute water deficit for the historical and future scenarios that span 25 (300 months) years each.*

| | | Historical | | Future | |
|---|---|---|---|---|---|
| | | Water Deficit Months | Absolute Water Deficit [m3] | Water Deficit Months | Absolute Water Deficit [m3] |
| Field 1 | No NBS | 150 | 39215 | 136 | 39541 |
| | Location 1 | 106 | 30308 | 98 | 28794 |
| | Location 2 | 75 | 21421 | 58 | 16834 |
| | Location 3 | 122 | 34251 | 114 | 33557 |
| | Location 4 | 72 | 20656 | 57 | 16476 |
| Field 2 | No NBS | 150 | 17649 | 136 | 17796 |
| | Location 5 | 28 | 2837 | 1 | 89 |
| | Location 6 | 103 | 13051 | 91 | 12246 |
| Field 3 | No NBS | 150 | 19165 | 136 | 19325 |
| | Location 7 | 59 | 7720 | 37 | 4835 |
| | Location 8 | 45 | 6033 | 18 | 2723 |

150 to 28 (historical) and even down to 1 (future). The absolute water deficit is reduced from 17649 $m^3$ to 13051 $m^3$ in the historical case, and from 17796 $m^3$ to 89 $m^3$ in the future case. For the third

field, the implementation of a measure at Location 8 can reduce the number of deficit months from 150 to 45 for the historical and to 18 in the future scenario. The absolute water deficit is decreased from 19165 $m^3$ to 6033 $m^3$ (historical) and from 19325 $m^3$ to 2723 $m^3$ (future). These results show that the larger the catchment area, the greater the potential water availability for supplementary irrigation, resulting in fewer months with water deficits.

When interpreting the results, it is important to consider that the water availability within the retention measure is likely overestimated. This is primarily due to the absence of soil data, which means that infiltration and groundwater recharge—i.e., the portion of precipitation lost to the subsurface—is not accounted for in the water balance.

Furthermore, the catchment areas contributing water to the retention measure and the crop fields requiring irrigation were treated separately. However, as shown in Figure 1, these areas partially overlap. For a more accurate assessment, this spatial overlap should be considered in future calculations. It was also assumed that crop water demand remains constant from year to year. In reality, this demand is influenced by climatic conditions, which vary over time. More accurate and site-specific data on crop types and their water needs would therefore improve the reliability of the analysis. As no detailed crop data were available, the estimates used represent only a rough approximation.

The study's results focus solely on the potential availability of water. However, practical constraints related to the design of retention measures must be emphasized. The design process is critical to ensure the system's effectiveness and sustainability. Retention measures cannot be planned as infinitely large due to spatial limitations and land availability. Moreover, the retention system must be appropriately dimensioned: if too small, it will overflow frequently; if too large, water may remain stagnant, leading to deterioration in water quality. Without proper aeration or management, stagnant water can become unsuitable for irrigation. Therefore, careful design—including consideration of size, location, hydrological inputs, and operational aspects—is essential to maximize benefits and ensure the retention measure functions as intended.

The results of this suitability map can be used to identify the most suitable locations for a retention measure. They also give a good estimation of the effectiveness of the primary goal to improve water availability for irrigation purposes during dry seasons.

## 3.4 FRR Romania

FRR Romania is evaluating the reforestation of private fields along the Timis River as buffer zones that would reduce streamflows during river floods. The following risk assessment is conducted with the CLIMADA framework by considering economic losses due to the damage of physical assets and crop losses. The NBS scenario is set up according to the reduction of surface runoff volume that contributes to peak flows found in Gargiulo et al. (2025). Section 3.4.1 provides more details about the methodology, followed by results in Section 3.4.2.

### 3.4.1 Methodology

The methodology for assessing risk reduction due to the restoration of forest areas integrates several steps listed as follows:

- Step 1) Extraction of annual maximum daily streamflow (AMAXQ) from EFAS historical data (https://ewds.climate.copernicus.eu/datasets/efas-historical?tab=download) for the region bounded by latitudes between 45.0-45.8 and longitudes between 20.5-22.5. The spatial and temporal resolution of the EFAS data employed for the analysis is 1x1 arcminute and 1999-2024, respectively;
- Step 2) Application of a 6.9% peak reduction factor representing the introduction of NBS as obtained by the modeling experiment summarized in Section 2.4. Different reduction factors are also tested in a simplified sensitivity analysis;
- Step 3) Extreme-value analysis of selected extremes using a Gumbel distribution fit and calculation of event return periods;
- Step 4) Estimation of flood height via linear interpolation between the return periods of historical extremes (Step 3) and 100m-resolution flood hazard maps (Dottori et al., 2022). The hazard maps provide flood height at return periods of 10, 50, and 100 years;
- Step 5) Risk modeling and impact calculation with CLIMADA. The LitPop dataset is used to estimate economic asset exposure in the selected region of Romania, and vulnerability curves by Scussolini et al. (2016) are used to estimate the damage function.

Steps 3-5 are applied to streamflow data with and without an NBS peak reduction factor to assess whether the presence of NBS affects the estimated annual impact of historical streamflow extremes in the Timis basin *(n = 26 events).*

## 3.4.2 Results

The difference between the estimated average annual impact calculated with CLIMADA (i.e., total economic loss in affected GDP) after introducing the NBS is highly negligible ~0.00000097%. This is likely due to insufficient sensitivity of the modeling chain (Steps 3-5) to the slight variation in peak flows (see Figure 7 showing the AMAXQ at Lugoj). Similarly, no difference in the average annual impact on the exposed population can be detected after introducing the NBS flow reduction factor.

No historical event between 1999-2024 has produced flooding at Lugoj. However, estimated basin-wide damages of 8.9, 7.1, and 9.9 million USD are associated with the events of 1999, 2000, and 2010, respectively.

Based on the statistical analysis described in Step 3, detectable differences in flood risk emerge when applying a basin-wide peak reduction factor of 20%. If NBS were implemented until this threshold was reached, the following changes in regional flood risk would occur:

- A 10-year event would result in a maximum flow of approximately. 344.33 m$^3$/s in the presence of NBS as opposed to 430.41 m$^3$/s in the absence of NBS;
- A 50-year event would result in a maximum flow of approximately. 470.25 m$^3$/s in the presence of NBS as opposed to 587.81 m$^3$/s in the absence of NBS;
- A 100-year event would result in a maximum flow of approximately. 523.75 m$^3$/s in the presence of NBS as opposed to 654.69m$^3$/s in the absence of NBS.

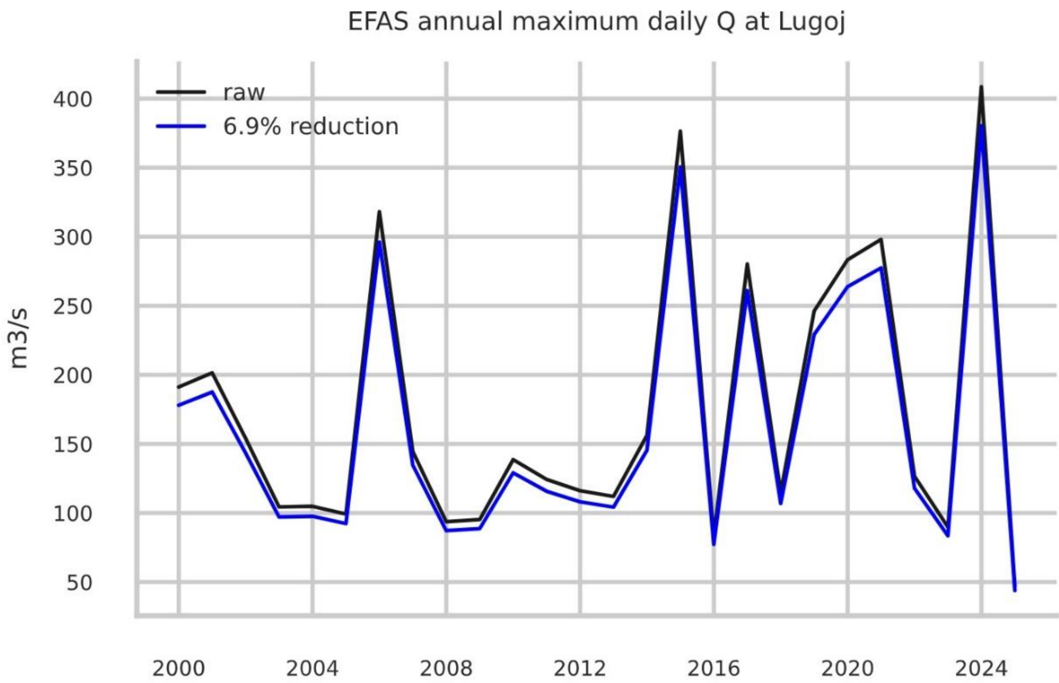



*Figure 7: Annual maximum daily streamflow at Lugoj. The black and blue lines show the baseline provided by EFAS data and the NBS scenario, respectively.*

An even larger NBS reduction factor of 30% would result in approximate reductions in the maximum streamflow of the order of:

- 129.12 $m^3$/s for a 10-year event
- 176.33 $m^3$/s for a 50-year event
- 196.41 $m^3$/s for a 100-year event

No change is detected regarding which historical events produce a flood in the Timis basin, defined as events with flood height above 1.5m. That is to say, the introduction of NBS with a 20% or 30% reduction factor is not sufficient to convert flood events into non-flood events, as the difference in the estimated return levels above does not translate into meaningful differences in the flood height of the historical annual maxima between 1999-2024.

Note that the threshold is identified with a simplified sensitivity analysis with fixed reduction factors of 6.9%, 20%, and 30% due to the limitations imposed by historical data scarcity. The few historical extremes available for frequency analysis substantially affect the statistical modeling of events and its robustness. Applying a uniform scaling factor on the gridded streamflow values produces very little change in the CDF values and return periods estimated by the Gumbel fit (Step 3) in the configurations with and without NBS. This means that the return period of a streamflow event does not change much even after a relatively large change in magnitude (20-30%). Moreover, a small variation in the return periods is associated with an even smaller change in the interpolated flood height, given that the flood height is interpolated between coarse return period steps (see Step 4). Nevertheless, the statistical analysis provides insight into the reduced severity of events with fixed return periods, as illustrated in the example using 20% and 30% NBS reduction factors above.

## 3.5 FRR Italy

The dune acts as a vertical passive barrier that partially blocks floods and the transport of sea spray by the atmosphere. Since the dune will be built within the Delta-Po Regional Park, the main exposed element protected by the dune is the vegetation located behind this structure. A methodology is developed in the following Section 3.5.1 to assess the reduction in excess vegetation morbidity and mortality due to soil saturation and salinization.

### 3.5.1 Methodology

The methodology for risk assessment in FRR Italy consists of a two-step approach: first, a refinement of the hazard-mitigation analysis reported in Gargiulo et al. (2025), followed by the integration of the results with exposure and vulnerability indicators on vegetation extents and potential morbidity and mortality. The first step integrates the idealised 2D OpenFOAM experiment (see Section 2.5) with further information on floods along the Emilia-Romagna coast (Figure 4.a). This information is provided by the EU-funded ECFAS project (European Coastal Flood Awareness System; G.A.: 101004211, years 2021-2022), which developed new products and tools for a fully integrated risk cycle monitoring service for coastal areas. This monitoring service includes an awareness system for coastal areas (preparedness phase) and impact assessment products (response phase), propaedeutic for effective recovery after the occurrence of hazardous events and the selection of preventive actions (recovery phase). The final project outcomes have contributed to two QGIS (Quantum Geographic Information System) databases.

The first database identifies local thresholds that may trigger the occurrence of a coastal-flood event (ECFAS Deliverable 4.3; Montes Pérez et al., 2022). The first threshold, named the duration threshold, is the minimum water level (in meters) above which a storm is active (Figure 4.b). This threshold indicates a state of attention, highlighting both the onset and the end of a storm event. The storm duration consists of the total time during which this threshold is exceeded. The exceedance of the second threshold, named the triggering threshold, signals a state of alert. This threshold represents the minimum water level (in meters) above which an event is potentially flooding (Figure 4.c), based on an Extreme Value Analysis (EVA) applied to time series. The database provides estimates of Total Water Level (TWL) peaks (i.e., the linear sum of mean sea level, astronomical tide, storm surge, and wave setup) along with storm duration, for events with return periods of 1, 2, 5, 10, 20, and 50 years.

The second database gathers flood and velocity maps along with the associated forcing parameters with a grid resolution of 100 m (ECFAS Deliverable 5.4; Duo et al., 2022). The maps are obtained with the LISFLOOD-FP model (Bates and De Roo, 2000; Bates et al., 2010) by simulating synthetic storms for five extreme water-level values (associated with the analyzed return periods between 2 and 50 years) and three durations (12, 24, 36 h), leading to 15 scenarios for each coastal sector. The analysis of these maps can provide an estimate of the inundation area for several scenarios.

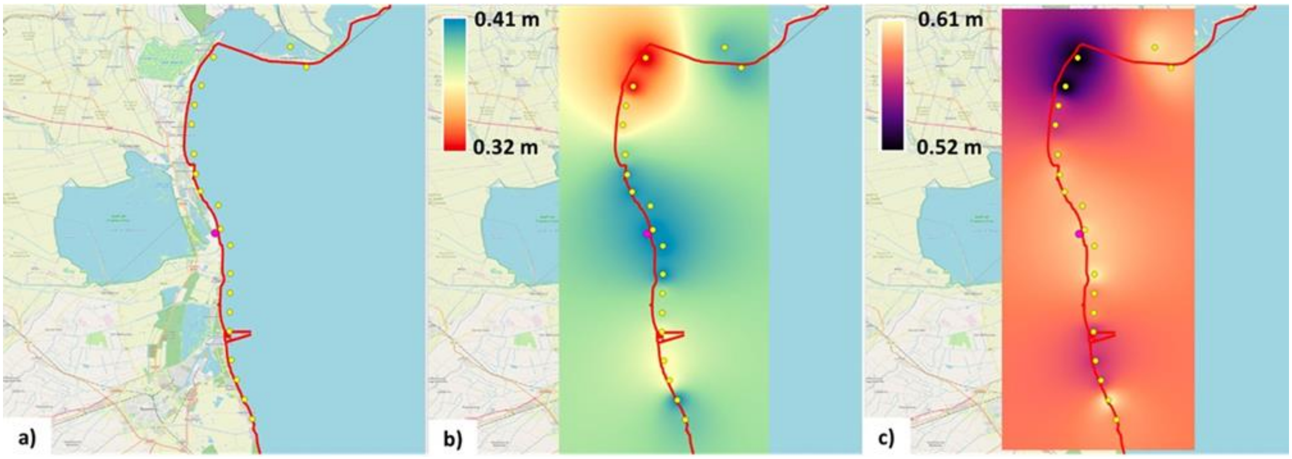



*Figure 8: a) Emilia-Romagna coastline (red line), including the dune site (pink dot) and the centre of coastal segments in which the variables are estimated (yellow dots), b) the estimated duration and c) triggering thresholds for the area of interest. Source: Duo et al. (2022); Montes Pérez et al. (2022)*

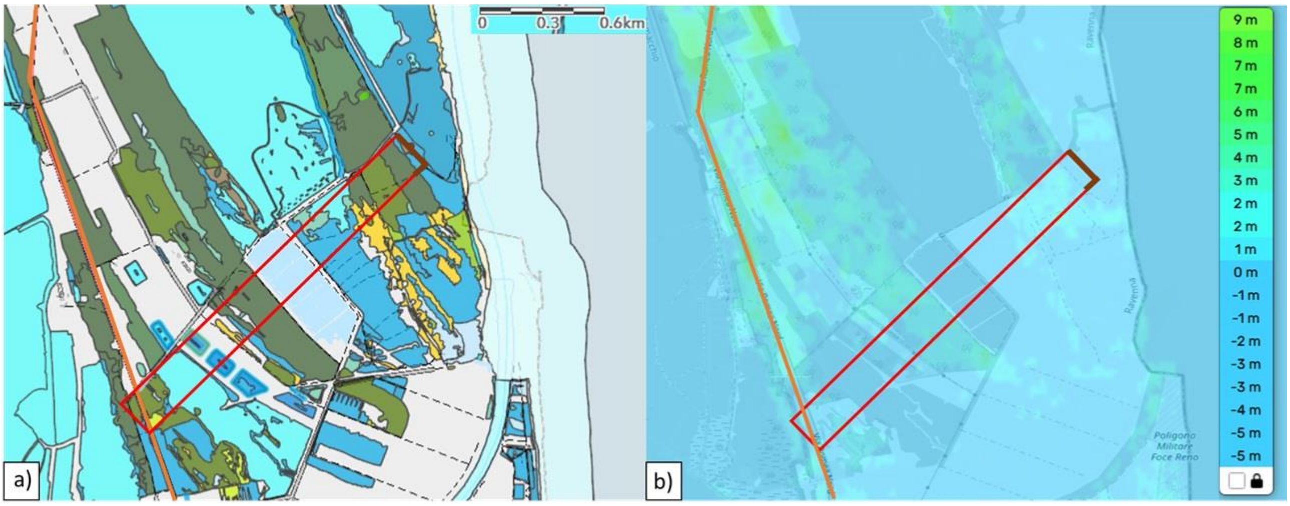



*Figure 9: a) Habitats and b) altitude at the FRR-Italy site. The L-shaped brown line is the dune, while the orange line is the Romea road up to the dune is expected to reduce risks. The red rectangle is the area selected for a first evaluation of the habitats that will benefits by the dune implementation. Source: habitats, Emilia-Romagna region, [https://servizimoka.regione.emilia-romagna.it/mokaApp/apps/parchi_01HTM5/index.html](https://servizimoka.regione.emilia-romagna.it/mokaApp/apps/parchi_01HTM5/index.html) ; altitude, topographic-map.com, [https://it-it.topographic-map.com/](https://it-it.topographic-map.com/)*

Then, this estimate will be integrated with the OpenFOAM results to understand how much water overflows the dune, affecting the vegetation.

The second step of the methodology is the provision of a risk assessment suitable for estimating the NBS effectiveness in vegetation protection. The hazard-mitigation results from the first step will be integrated with maps of the vegetation habitats located at the dune site (i.e., exposure component) and tolerance thresholds to soil saturation and salinization (i.e., vulnerability component). The ENVI-met outcomes on sea-spray atmospheric transportation will be used as a benchmark of salt concentrations to which the vegetation is exposed during non-flood days, both with and without the implementation of the dune.

Figure 9.a shows the habitats located at the FRR-Italy site behind the dune (L-shaped brown line). The Reno-River mouth is part of the Natura 2000 Network established by the European Union under the Habitats Directive (92/43/EEC) to protect natural habitats and wild species of community interest. Due to the flat terrain (Figure 9.b), seawater during flood events could extend a few kilometres inland,

reaching as far as the Romea road (orange line). The dune, in combination with the existing earth bund along the remaining coastline, aims to limit the inland intrusion of seawater. The most frequent habitats include: Mediterranean salt-influenced wet meadows (habitat code 1410), fixed coastal dunes with herbaceous vegetation (2130), and dunes with forests of Pinus pinea and/or Pinus pinaster (2270). More information on these habitats is available in the list of habitats of European interest in Emilia-Romagna available at the following link: https://ambiente.regione.emilia-romagna.it/it/parchi-natura2000/rete-natura-2000/habitat-e-specie-di-interesse-europeo/habitat .

Mediterranean salt-influenced wet meadows develop in retrodunal wetlands periodically or permanently inundated by brackish water and can provide optimal nesting conditions for bird species. Although resilient to saltwater intrusion, these meadows may be threatened by coastal erosion and changes in salinity linked to altered hydrological regimes. The meadows can include species of community interest such as Puccinellia festuciformis, Puccinellia distans, Crypsis schoenoides, Orchis laxiflora, Orchis palustris, and Triglochin maritimum.

Fixed coastal dunes with herbaceous vegetation consist of plant communities settled on the landward side of a partially or fully stabilized dunal system. The vegetation is dominated by non-hydrophilous plants, which are generally not reached by seawater. Species of community interest include Cladonia convoluta, Cladonia rangiformis, Schoenus nigricans, and Stachys recta. These communities may be threatened by coastal erosion and seawater intrusion into the aquifer.

Dunes with forests of Pinus pinea and/or Pinus pinaster are coastal dunes colonized by Mediterranean pines, often resulting from anthropogenic reforestation over various historical periods. However, these pinewoods can provide a suitable environment for other species of community interest (e.g., Rhamnus alaternus, Ruscus aculeatus) and valuable species (e.g., Erianthus ravennae), which are indicators of good conservation status. Although these habitats usually occupy the most inland and stable part of the dunal system, they are highly vulnerable to extreme weather events such as storm surges, saltwater intrusion, and coastal erosion.

## 3.6 FRR Czech Republic

A detailed risk analysis of current and future scenarios for the Czech FRR is not feasible at this stage, as the modelled NBS represents a highly generic concept and relies on numerous assumptions. Due to the absence of concrete design specifications or implementation plans, and given the limited availability of reliable data within the study area, further risk assessment cannot be meaningfully pursued at this time. Moreover, the Czech FRR does not intend to implement the specific NBS configuration as modelled in Gargiulo et al. (2025). Instead, alternative measures aimed at revitalizing the study area—unrelated to groundwater recharge—are currently under consideration. A more targeted modelling effort may become possible at a later stage, once planning processes for these alternative measures have advanced and more detailed information becomes available.

# 4. NBS acceptance by key stakeholders

In Deliverable 2.1 (Brogno et al., 2025), we discussed potential social impacts of NBS measures. The main social impacts deemed potentially relevant for the NBS measures in LAND4CLIMATE included changes in the following dimensions:

- Public acceptance by landowners;
- Aesthetic values;
- Perceptions of risk;
- Empowerment, knowledge, and learning;
- Social capital and trust;
- Better access to nature and health benefits; and
- Policy governance and process transparency.

In Deliverable 2.2 (Barbano et al., 2025), we unpacked the different types of social impact data, what they offer insight on, and how they can be collected. Table 13 in Annex 1, in particular, took a closer look at the various research approaches, methods, and activities that could be used to assess change and, hence, measure the social impacts of the NBS measures.

Given discussions across the consortium and findings from the MCDA presented in Schindelegger and Thaler, 2025, it became apparent that one key factor that needed further research was acceptance. More specifically, there was an interest to further unravel and understand the acceptance of NBS by landowners, given the implementation of NBS measures on private land. For this Deliverable, additional literature was consulted with a twofold intent. Firstly, to better define acceptance for the purpose of LAND4CLIMATE and, secondly, to identify the key elements that influence acceptance. This section covers:

- Definition of NBS acceptance (Section 4.1);
- Factors which influence NBS acceptance (Section 4.2);
- Proposed methodology to assess NBS acceptance (Section 4.3);
- Contextualisation of NBS acceptance by FFR (Section 4.4).

The contextualisation results from preliminary data on risk perception, engagement, and acceptance collected through interviews and/or email exchanges with FRR partners.

## 4.1 Definition of NBS acceptance

In Brogno et al., 2025, an increase in public acceptance was framed as a key social impact resulting from implementing NBS. This is often linked to the participatory process and/or stakeholder engagement that typically accompanies NBS implementation (Anderson et al., 2021). For this deliverable and future evaluation activities within LAND4CLIMATE, it is important to have a deeper understanding and a common definition of acceptance.

At its broadest, dictionary-definition acceptance is the “general agreement that something is satisfactory or right, or that someone should be included in a group” (Cambridge University Press & Assessment, 2025). In the literature consulted, acceptance is analysed with respect to the implementation or adoption of a proposed technology or measure, often in the context of energy transitions. Upham et al. (2015) describe social acceptance as the public's attitude or behavioural reaction to the introduction or adoption of a suggested technology within a particular country, region, or community.

The literature highlights the importance of distinguishing between public acceptance and social acceptance (Wolsink, 2018). According to Wolsink (2018), research on social acceptance, particularly in the energy sector, has often focused too narrowly on public attitudes, neglecting systemic, institutional, and political factors. The author argues that public acceptance is sometimes overemphasized and incorrectly used as a proxy for broader social acceptance.

Wolsink (2018) conceptualises social acceptance as having three interrelated dimensions: community, market, and socio-political. The author advocates for a process-oriented, multi-level, and institutional perspective to understanding acceptance. In contrast, public acceptance is commonly interpreted in terms of individual attitudes and general support for initiatives, such as nature-based solutions (NBS). When public acceptance is reduced to overcoming local opposition - often described by acronyms like NIMBYism ("Not In My Back Yard") or BANANAism ("Build Absolutely Nothing Anywhere Near Anything or Anyone") in the context of large infrastructure projects - it risks overlooking the deeper factors necessary for achieving long-term acceptance (Kauark-Fontes et al., 2023).

Building on this perspective, social acceptance is understood as a dynamic, multi-actor, and multi-level process through which individuals, communities, institutions, and markets evaluate, support, resist, or engage with innovations, measures, or policy interventions (Wolsink, 2019; Giordano et al., 2020; Ferreira, 2022). In this sense, public acceptance can be considered a necessary but not sufficient condition for social acceptance. While public acceptance might indicate a favourable general attitude towards NBS, social acceptance implies that the implementation process is inclusive, equitable, and sustainable over time and across different stakeholders.

Acknowledging this important correlation between public and social acceptance, **for LAND4CLIMATE, we adopt an expanded understanding of public acceptance - encompassing not only local communities and citizens but also local stakeholders and landowners. This approach goes beyond attitudinal perspectives to consider the roles of processes, governance, and trust** (see Section 4.2**).** Acceptance is recognised not as a binary outcome, but as a socially embedded and evolving negotiation among diverse actors (see Section 4.4).

## 4.2 Factors which influence NBS acceptance

Acceptance of NBS is shaped by a multidimensional constellation of factors spanning the social, cognitive, emotional, and institutional domains. Building on the brief scoping review conducted as part of Brogno et al. (2025), additional sources were consulted specifically to better understand the landscape of factors that influence NBS acceptance. Six interrelated themes that underpin support


*Figure 10: Factors that influence NBS acceptance.*

for NBS were identified. As illustrated in Figure 10, these include: **social capital and trust; perceptions; awareness, understanding, and knowledge; values and attitudes; behaviour; and governance and process.**

**Social capital and trust** are increasingly recognised not only as potential social outcomes of NBS implementation but also as critical preconditions for their acceptance, uptake, and long-term success. The implementation of NBS often requires cooperation across multiple sectors, levels of governance, and community stakeholders; as such, trust serves as a foundational element in facilitating dialogue, reducing resistance, and fostering collective ownership. Exploring bonding social capital so the stronger ties within a group which offers support and sense of belonging and bridging social capital with weaker ties connecting diverse groups (Putnam, 2000). The sense of attachment that landowners and citizens have towards their land plays into their sense of place and local identity. Giordano et al. (2020) identify how deep-rooted cultural or institutional mistrust, particularly in contexts characterized by centralised control or top-down decision-making, can significantly undermine support for NBS initiatives. This mistrust can limit both the endorsement of NBS by affected communities and their willingness to actively participate in or maintain such interventions, particularly when they feel excluded from planning processes or perceive benefits as unevenly distributed.

Similarly, Anderson et al. (2021) emphasise that trust in the organisations or individuals responsible for implementing NBS is a consistent and powerful determinant of public attitudes toward these approaches. When trust in implementers is low whether due to past experiences, lack of transparency, or perceived inefficacy, public support may weaken, even when NBS are technically sound. Demonstrating the tangible effectiveness of NBS for reducing risk, such as mitigating floods, landslides, or heatwaves, is therefore not only vital for validating these approaches but also essential for fostering and sustaining trust among stakeholders. As Anderson et al. (2021) note, until NBS become well-established and integrated into mainstream policy and planning frameworks, active and ongoing trust-building should be prioritised. This is particularly important in contexts of risk, where trust is both difficult to cultivate and highly susceptible to loss. These dynamics are closely tied to perceptions, which are often shaped by how trusted and credible the implementers and processes appear to be.

There was broad consensus among authors that individuals' perception of climate-related risks significantly influences their acceptance of NBS (Ferreira et al., 2022). Specifically, acceptance tends to increase when individuals perceive a clear and direct link between an environmental threat and the proposed NBS intervention. **Perceptions of risks, local solutions, and their benefits** are, therefore, crucial in gaining a better understanding of acceptance. Perceptions serve as a key lens through which people evaluate the relevance and urgency of proposed measures, underscoring their critical role in understanding patterns of acceptance. Research on infrequent hazards and climate change further supports this view, showing that when risks are perceived as distant in space or time, individuals are generally less willing to support or engage in mitigation efforts (Anderson et al., 2021).

The perceived fairness of NBS implementation and the ability of individuals to access benefits directly are also vital components in building public support. Wolsink (2018) notes that perceptions of procedural and distributive justice are central to achieving buy-in, particularly when benefits and costs are unevenly distributed. The temporal distribution of benefits can further complicate acceptance. For instance, while some outcomes, such as enhanced biodiversity, may only emerge over the long term, landowners may be faced with immediate and tangible costs, including land-use restrictions or reduced crop yields. Where individuals perceive that others benefit at their expense, support for NBS tends to decline (Giordano et al., 2020; Anderson et al., 2021).

The framing of NBS and the nature of their perceived benefits significantly shape public perception and, in turn, acceptance. Current narratives around NBS often emphasise ecological or environmental objectives, which may not align with the economic motivations typically held by landowners and other stakeholders (Giordano et al., 2020). Nevertheless, NBS are associated with a range of valued co-benefits, including opportunities for relaxation, leisure, aesthetic enjoyment, and improvements in wellbeing and health. Ferreira et al. (2022), along with Giordano et al. (2020) and Anderson et al. (2021), highlight that the perceived value of these benefits, as well as their fairness in distribution and timing, are critical factors in shaping acceptance. All these elements linked to perceptions influence the perceived need for the NBS and thus its acceptance.

While favourable perceptions and strong social capital and trust provide a supportive foundation, increasing awareness, understanding, and knowledge of NBS is also crucial for reinforcing NBS acceptance.

The literature reviewed also agreed that **awareness, understanding, and knowledge** are paramount in shaping public acceptance of NBS. A consistent finding is that acceptance tends to increase when individuals are informed about how NBS function and the range of long-term environmental, social, and economic benefits they can provide. Educational efforts and targeted awareness campaigns that clearly articulate the mechanisms and outcomes of NBS have been shown to foster greater support (Ferreira et al., 2022). Conversely, lower levels of knowledge are consistently associated with reduced acceptance, suggesting that gaps in understanding can lead to scepticism or indifference. Knowledge of both the technical aspects of NBS and their wider co-benefits thus plays a critical role in generating trust, reducing uncertainty, and enabling stakeholders to make informed evaluations of their value.

Acceptance is also closely tied to how well individuals grasp the nature, scale, and immediacy of climate-related risks such as flooding, drought, or heat stress. When stakeholders possess a strong understanding of these risks and recognise the capacity of NBS to mitigate them, acceptance tends to increase—even in cases where the benefits may only materialise over a longer timescale (Giordano et al., 2020). This highlights the importance of situating NBS within broader narratives of climate resilience and adaptive capacity. Moreover, enhancing knowledge not only supports initial acceptance but also strengthens long-term engagement and stewardship. Importantly, knowledge alone is not sufficient; acceptance is also influenced by underlying attitudes and values, which shape how individuals interpret information and assess the legitimacy and desirability of NBS (Anderson et al., 2021). Needless to say, satisfaction with NBS knowledge, benefits, and implementation increases acceptance levels.

**Attitudes and values** are strongly associated with commitment to nature and willingness to engage with, and consequently accept, NBS, particularly in terms of public acceptance (Anderson et al., 2021). Tapping into sub-dimensions like "the things we think," "how we feel," and "who we think we are" shapes residents' and landowners' propensity to support or resist NBS initiatives. The implication is that leveraging affective values such as those connected to aesthetics, leisure, health, well-being, and security can significantly enhance emotional buy-in, fostering deeper acceptance beyond purely rational or functional considerations (Ferreira et al., 2022). Such attitudes often manifest in tangible ways, including levels of satisfaction with recreational and green spaces, the appreciation of scenic beauty, and a heightened sense of pride or belonging tied to a place (Dumitru and Wendling, 2021; Ribe, 2022). By engaging these affective dimensions, practitioners and policy-makers can cultivate a stronger emotional connection between communities and NBS, which is critical for sustained support and stewardship. These attitudes and values not only shape acceptance but also influence the behaviours and actions individuals are willing to take in support of NBS.

Finally, **behaviours** are an indicator of the depth and breadth of acceptance. As Giordano R. et al.(2020) point out, acceptance increases when people can clearly identify and prioritize NBS-related benefits that align with their own interests, habits, and/or behaviours. Anderson et al. (2021) further support the notion that connection to place is a strong indicator of support for NBS. These behaviours can be measured through uptake of NBS, degree of current and future support, and future implementation. Behavioural acceptance is predicted by connectedness to place and the extent of expected future impacts (Anderson et al., 2021). Willingness to engage in changes in behaviour from landowners or community members could be indicative of willingness to address the value action gap (the observed disparity between people's reported concerns about key environmental concerns and how they act).

As discussed in Section 4.2, one of the key differences between public and social acceptance is that social acceptance is about the transformation of socio-technical systems, not just people's attitudes (Wolsink, 2019). Wolsinki argues that true social acceptance requires a shift in focus - from measuring public attitudes - to understanding governance, process, institutional resistance, systemic change, and justice. It is about how decisions are made, who is involved, and what power structures shape outcomes. This corroborates with what Anderson (2021) states: "A greater reliance on local stakeholders for cooperation with NBS during implementation, maintenance, management, and monitoring phases means public acceptance is crucial for their success" (Anderson et al, 2021, p.2). Therefore, public acceptance becomes a cornerstone of the implementation of NBS, and its success generates more acceptance, creating a positive reinforcement loop. Acceptance deepens when citizens and landowners are involved early, genuinely, and consistently in **governance and process**, including planning and implementation. Unpacking how landowners, local stakeholders, and citizens have engaged in the implementation and their experience of the process influences the degree of acceptance towards the NBS.

This also emerges from Giordano et al. (2020), according to whom involving stakeholders in NBS design and decision-making builds ownership, which strongly boosts acceptance. The local governance structure, the institutional and political contexts are important to understand the system-wide dynamics at play since they are correlated to the development of co-design and participatory decision-making actions. As explained in Section 4.1, acceptance cannot be treated as a binary outcome; it is a social process (Wolsink 2018). Acceptance is embedded in how people live, what people perceive and think, what people know and understand, how people behave, and the governing structures of their communities. In this way, the discussion comes full circle - starting from an initial focus on the social fabric and relational dynamics of communities and ending with an examination of the governing structures and institutional practices that both influence and are influenced by these social dimensions.

## 4.3 Proposed methodology to assess NBS acceptance

For LAND4CLIMATE, we propose that the six underlying factors (see Figure 10 above: social capital and trust; perceptions; awareness, understanding, and knowledge; values and attitudes; behaviour; and governance and process) are assessed through a series of sub-dimensions represented in Table 3. In this table, the six main dimensions have been unpacked into a series of measurable sub-dimensions informed by the literature consulted and reported in Section 4.2 above. For each sub-dimension, questions will be designed and developed to best elicit data and information related to the topic. These research activities will be planned as part of Task 4.2: "Cross-analysis of the implementation results and lessons learned."

*Table 3: Proposed methodological approach to assessing acceptance.*

| Dimension | Sub-dimension | Information providers or information related to… | Proposed research activity/Sources |
|---|---|---|---|
| Social capital and trust | Bridging and bonding – quality of interactions within and between social groups/ Collaboration with different bodies | FRR/ landowners | D4.10 Capacity Assessment Survey/ questionnaire/ interviews |
| | Sense of belonging/ sense of place | Landowners/ citizens | Questionnaire/ interviews |
| | Trust within the community | Landowners/ citizens | Questionnaire/ interviews |
| | Trust in institutions | Landowners/ citizens | Questionnaire/ interviews |
| | Trust in implementing organisation | Landowners/ citizens | Questionnaire/ interviews |
| Perceptions | Perception of environmental risks in general/ Risk exposure | FRR/ landowners/ citizens | EU Attitudes to Environment and Climate Change Eurobarometer/ questionnaire |
| | Perception of specific risk addressed by NBS | Landowners/ citizens | Questionnaire/ interviews |
| | Perception of local solutions (grey, hybrid & natural) | Landowners/ citizens | Questionnaire/ interviews |
| | Perceived relevance of NBS | Landowners/ citizens | Questionnaire/ interviews |

| | | | |
|---|---|---|---|
| | Perception of co-benefits (and trade-offs) | Landowners/ citizens | Questionnaire/ interviews/ focus group |
| | Perceptions of fair distribution of benefits | Landowners/ citizens | Questionnaire/ interviews/ focus group |
| **Awareness, understanding & knowledge** | Awareness of actual environmental risks | Landowners/ citizens | Questionnaire/ interviews |
| | Knowledge of NBS | Landowners/ citizens | D4.10 Capacity Assessment Questionnaire/ interviews/ questionnaire |
| | Understanding of capability of NBS to address environmental risks | Landowners/ citizens | D4.10 Capacity Assessment Questionnaire/ interviews/ questionnaire |
| | Satisfaction of NBS evidence | Landowners/ citizens | Questionnaire/ interviews |
| | Degree of understanding of benefits – primary (climate risk) vs secondary (socio-economic) | Landowners/ citizens | Questionnaire/ focus group |
| **Values and attitudes** | Changes in values (e.g., placement of climate change and nature deterioration), norms, and motivations | Landowners/ citizens | Climate Change Eurobarometer/ World Value Survey/ questionnaire |
| | NBS framing (economic, security, wellbeing/health, resilience, place identity, livability, and comfort) | Landowners/ citizens/ FRR | Questionnaire/ Task 5.2.1 Reflexivity Monitoring |
| | Satisfaction with recreational and green areas | Citizens | Questionnaire |
| | Feelings towards measures | Landowners/ citizens/ FRR | Questionnaire/ Task 5.2.1 Reflexivity Monitoring |
| | Likes vs dislikes of measures | Landowners/ citizens | Questionnaire |
| | Changes in the way of thinking of place - aesthetic values, sense of pride, sense of place, place-based values, etc. | Landowners/ citizens | Focus group/ interview |
| | Appreciation of and changes in usefulness/effectiveness of NBS | Landowners/ citizens | Questionnaire |
| | Ranking of benefits (aesthetics/landscape or scenic beauty, sense of belonging, better access to nature, wellbeing, health, security, etc.) | Landowners/ citizens | Questionnaire/ focus group |
| **Behaviour** | NBS uptake | Landowners | Questionnaire |
| | Degree to which NBS is actively supported or passively tolerated by social actors | Landowners/ citizens/local stakeholders/ FRR | Questionnaire/Task 5.2.1 Reflexivity Monitoring |

| | | | |
|---|---|---|---|
| | NBS future support | Landowners/ local stakeholders/ FRR | Questionnaire/Task 5.2.1 Reflexivity Monitoring |
| | NBS future implementation | Landowners/ local stakeholders/FRR | Questionnaire/ Task 5.2.1 Reflexivity Monitoring |
| **Governance and process** | Local governance structure and how it influences the implementation of the NBS | Landowners/ local stakeholders/FRR | Questionnaire/ Task 5.2.1 Reflexivity Monitoring |
| | Landowners and community participation - involvement in decision-making processes | Landowners/ citizens/ local stakeholders | Questionnaire |
| | Level of engagement in implementation | Landowners | Questionnaire |
| | Experience of process | Landowners/ FRR | Questionnaire |
| | Elements to improve | Landowners/ FRR | Questionnaire |

In autumn 2025, a battery of questions will be developed, drawing from existing literature and datasets where possible and relevant. Questions will unpack each sub-dimension listed and follow a coherent logic and conceptual framework. The feasibility and timing of when these research activities can be administered will be discussed and agreed upon with the FRR.

## 4.3.1 Data gathering

In collaboration with the FRR, different research activities will be planned to collect data for relevant sub-dimensions. This will be done through a combination of bespoke questionnaires, interviews, and focus groups, as well as drawing out contextual data from existing statistics (e.g., Eurobarometer). For each FRR, these methods will explore information provided by or related to the FRR (in their roles as implementing authorities), landowners (often farmers), citizens, and local stakeholders.

Where possible, data will be gathered for all NBS measures implemented in each FRR. Not all audiences will be researched to the same degree in each FRR, this will depend on the NBS measures implemented in each FRR. Particular attention will be paid to landowner acceptance. Where relevant, data will also be drawn from existing datasets like the Eurobarometer surveys, World Value Surveys, and, where present, FRR's own public opinion surveys. Data will also be collected from existing relevant deliverables and tasks such as D4.10 Capacity Assessment Survey and Task 5.2.1 Reflexivity Monitoring.

Ideally, when assessing social impact topics like acceptance, it is best practice to have two rounds of research activities, one before the implementation of the intervention or the engagement with land-owners or local community (baseline or ex-ante) and one after the implementation of the intervention or engagement (follow-up or ex-post). Given that some FRR have already started implementing and the various demands on time and resources, this ex-ante/ ex-post approach cannot be applied for LAND4CLIMATE.

We would suggest that for the RRs and other local stakeholders interested in researching NBS acceptance, this be done at least at these two intervals and, if resources and timing allow, at a midpoint as well. For LAND4CLIMATE, to overcome this missing data point, we will use retrospective questions asking respondents to recall their perceptions, attitudes, behaviours, etc., before the implementation of the NBS measure or engagement. This can be done either by asking respondents to anchor their recall to a specific time or to assess change since a certain time and now. In all cases, just consideration will be given to the respondent's survey experience and avoiding respondent fatigue. This will ensure high data quality in terms of accuracy and respondent engagement (e.g., length, repetition, tediousness; MRS, 2024).

For RRs and other stakeholders implementing NBS, conducting sentiment analysis and social network analysis may be useful to further understand certain dimensions linked to acceptance and social impact more broadly. Sentiment analysis is the process of analysing digital text to determine if the emotional tone of the message and hence the feeling of the times is positive, negative, or neutral around a specific topic. Social Network Analysis is the process of investigating social structures to visualise, understand, and assess the power of relationships between actors. Further information is reported by Home Office (2016) and Mao et al. (2024).

## 4.4 Contextualisation of NBS acceptance

This section, first, provides an overview of environmental attitudes at a macro level across the EU and each nation state from a selection of relevant Eurobarometer data and secondly, takes a deep dive into the reported experiences of the FRR, as authorities implementing NBS measures, at the micro level in their implementation areas. We gathered information on perceptions of environmental risks both of the public and landowners, changes in engagement techniques with landowners, and experience of NBS acceptance with the public and landowners. Their contextual input is reported in the sub-sections below for each FRR.

### 4.4.1 Eurobarometer data as national contextualisation

Besides the data that will be gathered by interviews and questionnaires with FFR representatives, landowners, citizens, and local communities in the future, at this stage, it is useful to characterise the regions by looking at statistical sources that can illustrate national contextual elements. In this sense, Eurobarometer data on environmental attitudes and climate change can be valuable.

For this contextualisation exercise, Eurobarometer data from March/April 2024 on environmental attitudes were consulted, and data for each FRR at the national level were extrapolated. To better understand public and landowner acceptance in each FRR, some preliminary data on perception of risks, motivations and experience of engagement, and acceptance were also gathered through interviews and/or email exchanges with each FRR.

As the graph in Figure 11 shows, across the EU, between a fifth (21% in Czechia) and two-fifths (41% in Slovakia) of respondents claim they totally agree that "environmental issues have a direct effect on your daily life and health". In both Slovakia (82%) and Italy (88%), overall agreement levels to this statement reach over four-fifths of respondents, while for all FFR countries overall agreement is higher than 60%. This would suggest a high value attributed to the environment as well as a high level of understanding of how environmental issues have an impact on everyday life and wellbeing.

When asked about the most effective way of tackling environmental problems, almost half (49%) of EU respondents state "restoring nature" though this cannot be understood to be a direct proxy for NBS, it does show an indication of the potential appreciation of effectiveness for NBS-like measures. In Romania, Slovakia, Germany, and Czechia between half and three-fifths of respondents place their faith in the effectiveness of "restoring nature" in their top four actions which would be the most effective way of tackling environmental problems.

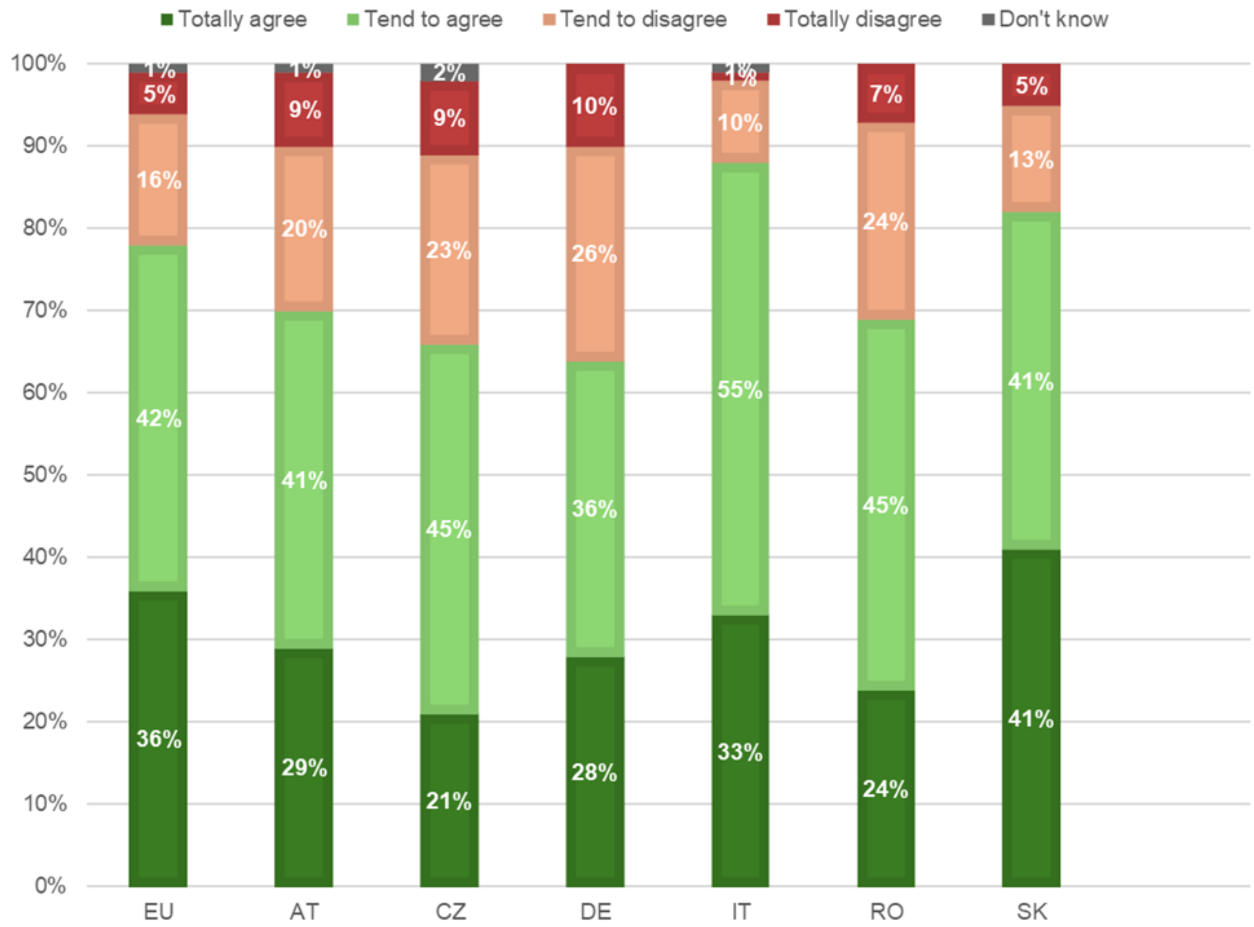



*Figure 11: QB1 Please tell me to what extent you agree or disagree with each of the following statements: Environmental issues have a direct effect on your daily life and health (%). Source: Eurobarometer, https://europa.eu/eurobarometer/screen/home .*

Conversely, between two-fifths and half of respondents across the EU and the FRR nation states see "investing in research and development to find technological solutions" as an effective solution for tackling environmental problems. Again this cannot be taken to mean grey-infrastructure alone but, undoubtedly, these technologies would be included in this option. In Italy and Germany, reliance on "technological solutions" was an option voiced by half of the respondents. In Italy, technological solutions featured higher than the "restoring nature" option - 49% compared to 38%. Figure 12 below presents the data in more detail. When looking at threats linked to water, pollution, as well as water overconsumption and wastage, were the main concerns. However, hazards like those the FRR are aiming to address featured highly too, including climate change, droughts, degradation of natural habitats, and floods. The graph in Figure 13 illustrates this selection of data. 61% of respondents across the EU stated that climate change was the main threat linked to water, this increased to 68% for Italy and fell to 41% for Czechia. All of the FRR are addressing droughts as part of the various NBS measures they are implementing. For example, the Czech FRR is implementing infiltration ponds for groundwater recharge for drought periods as one of their NBS measures. 60% of respondents in Czechia and Romania stated that droughts were a main threat linked to water.

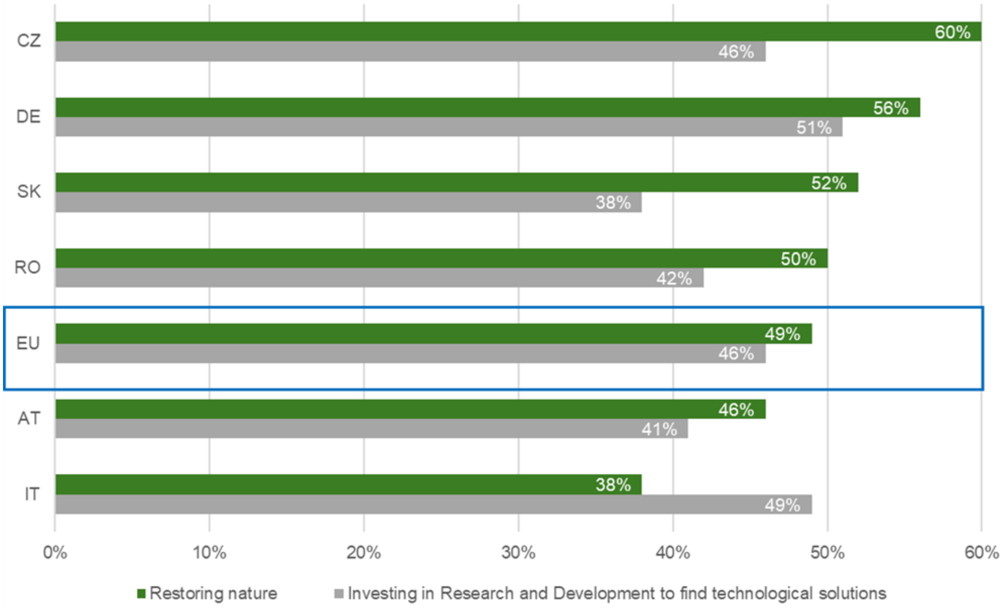



*Figure 12: QB2T In your opinion, which of the following actions would be the most effective way of tackling environmental problems? First? Second? Third? Fourth? (%)*[5] *Source: Eurobarometer, [https://europa.eu/eurobarometer/screen/home](https://europa.eu/eurobarometer/screen/home) .*

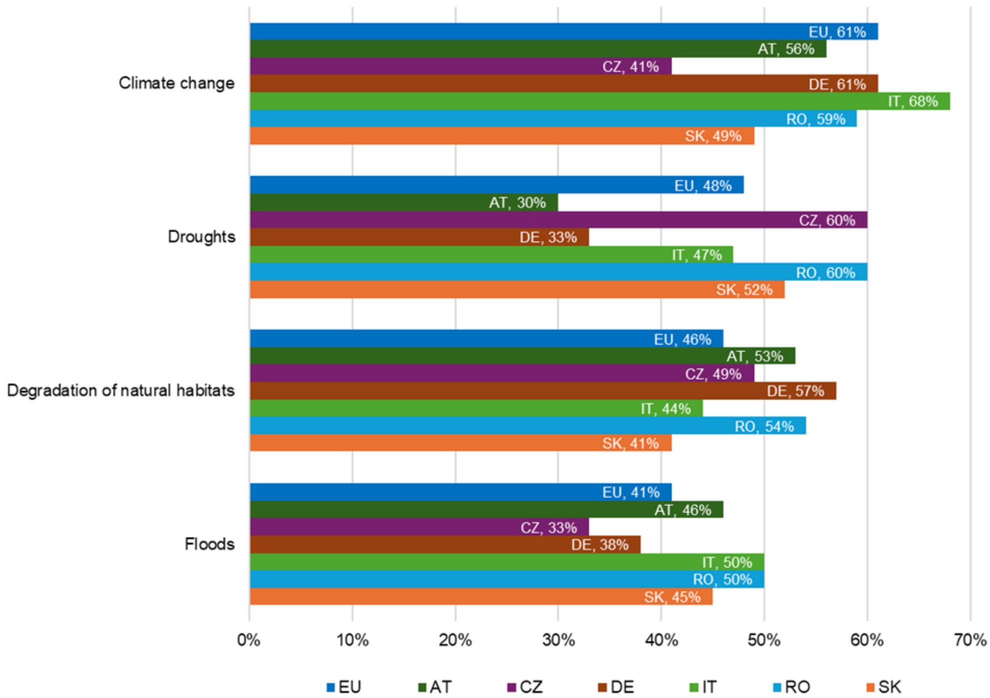



*Figure 13: QB15T What do you believe are the main threats linked to water in (OUR COUNTRY)? First? Second? Third? Fourth? (%)*[5] *Source: Eurobarometer, [https://europa.eu/eurobarometer/screen/home](https://europa.eu/eurobarometer/screen/home) .*

Degradation of natural habitats was a primary concern for between two-fifths and three-fifths of respondents across the EU and six nation states. Responses peaked at 57% for Germany, followed by 54% for Romania and 53% for Austria. All FRR are addressing floods as a climate risk, and half of the respondents in Italy and Romania stated this as one of the main threats to water. Concerns were slightly lower for floods in Czechia, where about a third of respondents stated it as a main threat linked to water.

The following sub-sections highlight some preliminary findings from discussions with FRR on the perception of risks, engagement strategies used, and experience of public and landowner acceptance. The idea is that the Eurobarometer Survey data provides some insight at the macro and micro levels of the NBS implementation areas. This will act as a starting point for future research activities as part of WP 4 starting in the autumn of 2025.

## 4.4.2 Austrian FRR context

In Austria there are two main actors implementing NBS measures in the river Lafnitz catchment area, and they are working with two local contractors to engage landowners. Burgenland Provincial Government's Water Department (BGLD) has partnered with the Chamber of Agriculture as their local contractor, and the State of Styria Department 14 Water Management, Resources and Sustainability (STMK) has partnered with **Humus+**, a farming specialist network. We interacted with colleagues at BGLD and STMK who, in turn, discussed our questions with the local contractors to ensure that the information provided was an accurate representation of local landowners and the community.

In the exchanges with the implementing partners, it emerged that, at a societal level, the local community tends to perceive environmental risks primarily when there is a direct or negative impact on individuals, a perception influenced partly by the role of the media. According to the Austrian FRR, this became evident in the past, for example, during events that caused significant damage, such as flooding or crop losses due to hail or drought.

Both contractors agreed that the perception of environmental risks among landowners (in this case, mainly farmers) participating in the LAND4CLIMATE project is high. Landowners' decision to take part is linked to wanting to find solutions to deal with one or more climate hazards, and because they want to contribute.

Funding is seen as key to increasing acceptance of NBS measures. In the BGLD implementation area, acceptance in the agriculture sector is divided: one part does not see the implementation of NBS as a worthwhile investment, and the other as ecologically valuable. Amongst those that see NBS as "good" measures to implement the overarching consensus is that these can only be implemented with financial support/incentives. In the STMK implementation area, many NBS would probably not be implemented if farmers must exclusively cover the costs themselves.

For BGLD, farmers experimenting with alternative methods are more open to NBS, while most still view NBS as a loss of productive land and do not yet recognize the added benefits. The relevance of the value dimension in acceptance emerges as relevant for this community – farmers exploring alternative methods. Adoption requires pioneers, strong local networks, and initial financial incentives – these aspects link to dimensions discussed earlier like social capital, values and norms, and perceived benefits. For STMK, NBS acceptance is higher in areas facing significant challenges like erosion or drought. Awareness and attitudes also play key roles in increasing acceptance (dimensions we will be researching further).

## 4.4.3 Czech FRR context

As in the case of Austria, the Czech FRR is running two intervention areas, one around Krásná Lípa town and the other in the National Park Bohemian Switzerland. In terms of reported perception of environmental risks at a societal level, there seems to be a divergence between the two intervention sites. In Krásná Lípa town, according to the implementing FRR, general societal awareness of environmental risks such as drought, biodiversity loss, and soil degradation is quite high, especially among young people and urban residents, which corresponds to Eurobarometer data discussed earlier in Section 4.4.1. However, in the National Park Bohemian Switzerland, societal-level environmental risk perception was deemed quite low, especially close to the national border with Germany. The implementing partners stated that there is lower awareness, with many climate change deniers; people tend to view climate change impacts mainly through economic lenses, such as rising food prices.

In Krásná Lípa, landowner views are mixed—those actively managing their land are more supportive of sustainable practices, while absentee owners or large/scale leaseholders tend to prioritize short-term economic gains and see environmental risks as secondary unless they directly affect yields or operations. Although many stakeholders initially associate NBS with financial incentives, a recent educational excursion (30 participants at the end of May 2025) showed high levels of engagement and positive feedback from participants, including municipal staff, farmers, and researchers. Public acceptance is generally strong, especially when events focus on shared values, local identity, and long-term benefits like water retention and flood prevention. However, large-scale farmers on leased land remain resistant to change unless clear economic advantages are presented, as their motivations are largely profit-driven despite their significant impact on the landscape. Without clear economic benefits, their willingness to support NBS remains very limited.

Public support for NBS, in Krásná Lípa, is generally strong in theory, as shown in a recent street survey of 150 residents, many of whom supported measures like meandering the outflow from a nearby pond. However, support drops significantly when NBS must be implemented on private land. Challenges include absentee or uncooperative landowners, unauthorized land use (such as fencing, illegal water extraction, or private installations on public land), and disputes over land boundaries (bringing to life the NIMBYism attitude mentioned in Section 4.2). While a few smaller, owner-operated farms have voluntarily adopted NBS, they remain the exception.

Landowners in the National Park often see the real impacts of extreme weather conditions, making them more open to cooperation and NBS, though attitudes still vary. The divide tends to be between more progressive farmers and more traditional ones - linking to the value dimension of acceptance. Landowners operating smaller farms, who tend to have a stronger personal connection to their land, are often more open to adopting new practices, technologies, and NBS to address climate change. For them, even a single poor harvest caused by extreme weather can have serious consequences. In contrast, larger producers typically work with multiple landowners, many of whom lack a direct emotional attachment to the land and view it primarily through the lens of financial profit or loss. This makes it more challenging to build consensus and implement innovative or sustainable measures.

In the National Park, the FRR explained that the problem is more linked to finding the right landowners and stakeholders who can look beyond short-term benefits and see NBS implementation in a broader context and longer horizon, rather than changing the attitude of other landowners and stakeholders. Negotiations with landowners are highly individual. One case failed due to strong resistance to NBS, but current negotiations are progressing more positively. This improvement is attributed to working with landowners who have a different perspective—those more open to non-traditional land management and more receptive to sustainable approaches.

### 4.4.4 German FRR context

The citizen survey conducted in the district of Euskirchen in April 2024 aimed to assess public perceptions of climate change impacts and identify preferred adaptation measures to inform the region’s climate strategy. The survey received 702 responses. A large majority of participants reported local environmental changes: 84% (586 people) observed drought and dry vegetation, 73% (510) noted an increase in extreme weather events, and 68% (479) reported rising summer heat. Over half, 52% (364), were directly affected by the 2021 flood disaster, and 42% (292) experienced health issues related to heat. These findings informed the choice of NBS measures implemented in the area.

Beyond perceptions of environmental risks, there is a clear demand for stronger adaptation efforts. Close to 8 in 10 respondents believe that climate change adaptation measures in the district should be intensified. When asked about preferred urban adaptation strategies, 78% (549) supported unsealing and greening public and private areas, 78% (548) favoured planting large-crowned shade trees, and 78% (546) endorsed near-natural redesigns of urban spaces. These results show not only a high level of concern and direct experience with climate impacts but also public backing for practical, nature-based solutions.

According to the FRR, the public seemed to have more concerns around health and wellbeing, while farmers' concerns were more focused on income and economic interests.

In terms of engagement approaches, slightly different techniques for the various NBS measures were used.

- Tiny Forest and Climate Parks: To overcome defensive attitudes linked to misinformation, information events were held, providing residents a safe space to voice concerns, especially about planning issues. These sessions, plus launch events and planting days, received very positive feedback, improving acceptance since the project’s start. Minor issues like littering remain but these are not seen as a major concern by the implementing authority. Maintenance is managed by the housing company Eugebau, with detailed instructions included in their contract.
- Unsealing: To find interested parties to take part in the unsealing of gravel gardens and parking lots, an open call was organised. Communication of the call relied mainly on press and information campaigns without interactive events. The unsealing call was open county-wide (~200,000 people), including tenants with landlord approval. The first round received 14 applications, all implemented; a second round expects more.
- Farmers and Miscanthus Planting: Farmer engagement included moderated talks with the University of Bonn experts providing scientific and practical knowledge, reassuring farmers, and building trust. Collaboration with a local farmers’ association helped relationship dynamics as it was seen as a trusted intermediary. It is interesting to see how the social capital element of public acceptance was positively activated to support the NBS implementation. By the second meeting, farmers were largely enthusiastic about the measures, including miscanthus planting, although they are mainly the altruistic and philanthropic landowners – pioneering farmers who take part in NBS measures even if benefits are not immediate or directly for them, they choose

to do it for the welfare of others and/or the environment. Positive feedback could be an indicator of good acceptance levels within the farming community.

In terms of experience to date with regards to acceptance across the three main target audiences of the local project:

- Farmers: Acceptance has been challenging due to political distrust of state and EU institutions and frustration over subsidy conditions. Many farmers feel their pride is affected by dependency on funding. However, engagement through expert-led talks and involvement of a local farmers' association helped build trust. Some farmers became enthusiastic once reassured about the economic viability of measures like Miscanthus planting. The approach focuses on early adopters, hoping positive experieces will encourage wider uptake.
- Local Residents: Residents showed initial defensiveness linked to misinformation but were engaged through information events providing safe spaces to voice concerns, especially around planning. Launch events and planting days received very positive feedback, improving acceptance over time. However, ingrained habits like maintaining gravel gardens remain a barrier, with efforts focusing on voluntary education campaigns to shift mindsets rather than quick widespread change.
- Housing Association: The housing association has been fully supportive and proactive from the start. They agreed to take responsibility for the maintenance of the NBS measures implemented and integrated detailed guidelines into their contracts, showing a high level of acceptance and cooperation from the onset.

### 4.4.5 Italian FFR context

According to the Italian FFR, the park authority of Parco del Delta del Po, the public and decision makers widely recognize the serious environmental risks posed by climate change, especially after recent extreme events like sea storms and major floods causing significant damage and fatalities (May 2023). However, both the general public and local landowners predominantly believe that technological and infrastructural solutions - such as concrete barriers, steel reinforcements, and other grey infrastructure - are the best way to manage these risks.

Local landowners are also very aware of the environmental risks but share this conventional view and are generally reluctant to consider alternative or nature-based approaches, even when presented with evidence of the limitations of traditional methods. It is very rare to find landowners willing to embrace new thinking, with only isolated exceptions who remain sceptical about non-traditional solutions despite participating in innovative projects like LAND4CLIMATE. The Italian FRR has been very active in running several initiatives to raise awareness on the issue in the local community.

According to the FFR, economics remains a key factor, with several EU-funded projects (Interreg, LIFE, EU Horizon) supporting NBS initiatives, making funding crucial. While some technicians or policy officers working in public authorities understand the role NBS could play, they are relatively rare, and interest often does not translate into concrete action.

The Civil Protection Agency is an exception because of its direct experience with NBS. They saw the success of the OPERANDUM project, which built a dune barrier at Lido delle Nazioni in Comacchio in the same park, to protect the land from sea storms. Since it worked well, they now plan to use similar NBS approaches on public land. This hands-on experience has strengthened their commitment to using NBS.

Experience of acceptance to date for the three NBS measures can be summarised as follows:

- Dune: Despite evidence of their effectiveness, such as in Lido Nazioni, natural dunes are still viewed with scepticism by both landowners and the public, who tend to prefer traditional grey infrastructure. The belief persists that artificial barriers offer stronger protection, reflecting deep-rooted misconceptions. Acceptance of natural dunes as a viable NBS requires visible proof and time, as most people are not yet ready to trust nature-based approaches.
- River Embankment Planting: River embankments face similar prejudices. They are still largely perceived to be more effective when constructed with concrete or other artificial materials. There is little awareness or acceptance of natural river management through renaturalisation or planting as a legitimate solution, underscoring the need for broad communication and demonstration to shift public and landowner attitudes.
- Salicornia Planting: As a novel agricultural practice for soil desalination and restoration of saline-degraded lands, Salicornia planting is met with doubts about both its long-term function and profitability. Though Salicornia is edible, there is not much of a market for it, and there are concerns about how the soil reacts when harvested and not replanted. To lower resistance, landowners are being asked to plant it on only part of their land, while continuing conventional farming on the rest. Its success hinges on offering practical benefits and time for adoption, much like other agroecological models.

### 4.4.6 Romanian FRR context

According to the Romanian FRR, environmental risks such as floods and droughts are recognised by the local community but do not rank among their primary concerns until extreme events occur. This limited awareness is similarly reflected among landowners and local authorities. In contrast, NGOs and academic institutions demonstrate a higher level of knowledge and engagement on these issues. Enhancing public awareness of environmental risks would significantly support the successful implementation of NBS in the region.

In the Romanian case study, the initial approach of relying on trusted intermediaries to engage landowners in accepting NBS proved less effective than anticipated. Instead, success was achieved through a more direct, bespoke strategy involving numerous bilateral meetings with individual landowners, combined with a public call inviting participation. This personalised engagement approach, rather than working through local trusted organisations, was key to securing the commitment of the four landowners involved. It would be interesting to investigate the characteristics of the local social capital network and how this played a role in influencing the process.

In the FRR's experience, securing landowner acceptance of NBS measures remains challenging. The focus has been on unused lands, such as old gravel pits, with implementation costs covered by the EU. Engaging landowners would have been considerably more difficult if the land had been actively used or if they had been required to shoulder these costs. Convincing landowners required significant effort, a challenge likely compounded by Romania's recent history of land nationalisation during the communist regime, which continues to influence attitudes toward land ownership and management.

### 4.4.7 Slovakian FRR context

In the Slovakian FRR, both the engaged public and participating landowners show a clear awareness of environmental risks, particularly related to climate change impacts like droughts and flash floods. However, this engagement is not fully representative of the broader population, as those attending meetings are typically already informed and concerned, and they already willingly engage in the topic. Among landowners, understanding environmental risks is a key precondition for cooperation with LAND4CLIMATE. The three involved landowners demonstrate strong commitment - one is even co-financing part of the project and implementing water-saving measures independently. Their active role in planning, alongside architects and the FRR, has been crucial, and it reflects a collaborative and locally grounded approach in identifying and addressing climate-related exposure and vulnerabilities.

It is difficult to determine whether local community opinions on environmental risks have shifted over the course of the project to date. Engagement on related issues, such as water conservation, began several years ago, so any changes in perception are hard to isolate. Stakeholders note that visible results are essential for changing minds - “seeing is believing” - and expect greater impact after the implementation phase. Regular meetings with local institutions, including the Water Board, help maintain momentum and build local interest. Feedback from the community has been largely positive, appreciating the investments and EU funding, but also questioning why interventions were not implemented on their land. This reflects both growing awareness and the importance of broader, more inclusive funding or alternative forms of financing to support wider adoption.

The FRR’s experience shows that landowner acceptance of NBS is challenged by concerns over complex participation processes, impacts on farming practices (like mechanisation and plot fragmentation), and economic concerns, especially the potential loss of income and Common Agricultural Practice subsidies since NBS benefits aren’t currently compensated. This highlights the need for policy changes to better support NBS in agriculture.

Public acceptance relies heavily on visible, tangible results. While many recognize environmental risks from extreme weather, wider support depends on demonstrating evidence of practical benefits. Local knowledge and willingness to participate are key, with the supportive attitude of philanthropic landowners also playing a role.

In post-communist regions like Slovakia, Czechia, and Romania, fragmented land ownership and weaker cultural ties to land reduce farmers’ motivation to adopt NBS. Overall, the FRR’s experience stresses the importance of clear benefits, policy support, and strengthening landowner-community connections to foster acceptance.

### 4.4.8 Preliminary insights on acceptance

It is premature to draw any definitive conclusions on the experience of acceptance of NBS measures with the public and landowners at this stage. It is imperative to consider that each region is adopting different strategies to involve landowners, there is no one-size-fits-all strategy. The local context, the nature of the local stakeholders, the social capital and fabric of the area, and their values are the dimensions that need to be considered when planning an NBS implementation like in LAND4 CLIMATE. These are the main tenets of NBS acceptance: **social capital and trust; perceptions; awareness, understanding, and knowledge; values and attitudes; behaviour; and governance and process.**

From the perspective of the FRR, looking across each of the six regions, the following emerging insights transpire. It is important to acknowledge that these insights will be true for different FRR to varying degrees. These have been summarised by a purposefully provocative strap line followed by a more considered explanation.

- **Economic loss, economic support.** Landowner acceptance of NBS hinges on direct experience of environmental risks and crucially, financial support - without which many farmers view NBS as a costly loss of productive land rather than a valuable solution (e.g., Austrian FRR, Italian FRR).
- **It's a personal affair.** Targeted educational events - like excursions involving municipal staff, farmers, and researchers - that build shared understanding and highlight long-term benefits. Additionally, individualised, case-by-case negotiations with receptive landowners who are open to sustainable land management have proven effective (e.g., Czech FRR, Romanian FRR).
- **Strong local networks and trusted actors.** Trusted intermediaries, expert-led talks, and collaborative events with farmers, residents, and housing associations have been key to building trust and securing active participation (e.g., German FRR, Austrian FRR, Czech FRR).
- **Recognition of environmental risks.** Environmental risks need to be and, in the most part, are recognised by engaged actors (e.g., Romanian FRR, Slovakian FRR, Czech FRR).
- **Show me, don't tell me.** Landowner and public acceptance of NBS depend on demonstrating clear, tangible benefits, and simplifying participation processes, especially within the context of fragmented land ownership and existing agricultural policies (e.g., Slovakian FRR, Italian FRR).
- **Technological galore.** Social acceptance of NBS is limited, with public and landowners often still favouring traditional grey infrastructure due to deep-rooted scepticism (e.g., Italian FRR).
- **Timing is crucial.** Timing is everything when engaging with landowners. An engagement deemed too early in the process makes onboarding difficult. However, engagement too late in the process risks losing landowners' trust as being genuinely part of the solution and process. If the solution is already too defined, it might not speak to/ be able to adapt to their needs .
- **Time for soft policies.** There seems to be a need to move beyond hard policies (taxation, financial incentives, public funding, etc.) to soft policies - building on connections with local communities, local context, and social capital.

# 5. Replication and upscaling

The path toward climate adaptation consists of numerous steps where the outcomes do not depend on a single NBS intervention but rather on their combination. While a single NBS often provides multiple ecosystem services and socio-economic benefits, the local scale of the intervention can limit the overall contribution. However, testing NBS through modelling and monitoring experiments allows for the maximization of the individual contributions and helps create the conditions needed for their spreading. Experiments are included in the amplification processes proposed by Lam et al. (2020) to describe transformative changes that can enhance the impact of sustainability initiatives. More specifically, the “amplifying within” category refers to all actions that support the demonstration of an NBS’s effectiveness (i.e., the stabilizing of an NBS), but also to all the efforts that make implement-tation more efficient (i.e., the speeding up of an NBS implementation), such as understanding and facilitating the permitting pathway required to move from design to real interventions.

Furthermore, modelling and monitoring experiments provide a broader perspective on the design of an NBS system, which in turn needs to be tested because the sum of individual contributions may not be linear. The main processes for building an NBS system are replication and upscaling, which refer to the reproduction of tested NBS in new sites or the expansion of these NBS at the same site, respectively. Both replication and upscaling involve processes categorised as “amplifying beyond” and “amplifying out” by Lam et al. (2020), reported in Figure 14.

“Amplifying beyond” processes enhance the implementation of NBS through changes in institutional structures, laws, values, or mindsets. These processes are classified as “scaling up” when tested NBS are integrated into governmental practices or inspire new regulations, whereas “scaling deep” implies changes in the perception, acceptance, and ways of thinking of the people who have benefited from the NBS interventions.

“Amplifying out” processes refer to the increase in the amount and coverage of NBS interventions that are expected to be effective in addressing hydro-meteorological hazards. This can occur through the implementation of tested NBS multiple times within the same context (“growing” process) or in different socio-economic and climatic conditions (“replicating” process). The “amplifying out” category also includes the sharing of technology, knowledge, and experience of the tested NBS with other actors who reproduce these NBS in similar contexts (“transferring” process) or dissimilar ones (“spreading” process).

A useful tool to identify suitable sites for replication and upscaling processes within the FRR is suitability maps, i.e., spatial representations of areas deemed appropriate for specific interventions according to defined criteria. The first step usually involves the construction of large-scale suitability maps based on land cover and use information (e.g., Corine Land Cover data) obtained by combining satellite remote sensing, visual inspection, and national auxiliary data. Then, the criteria

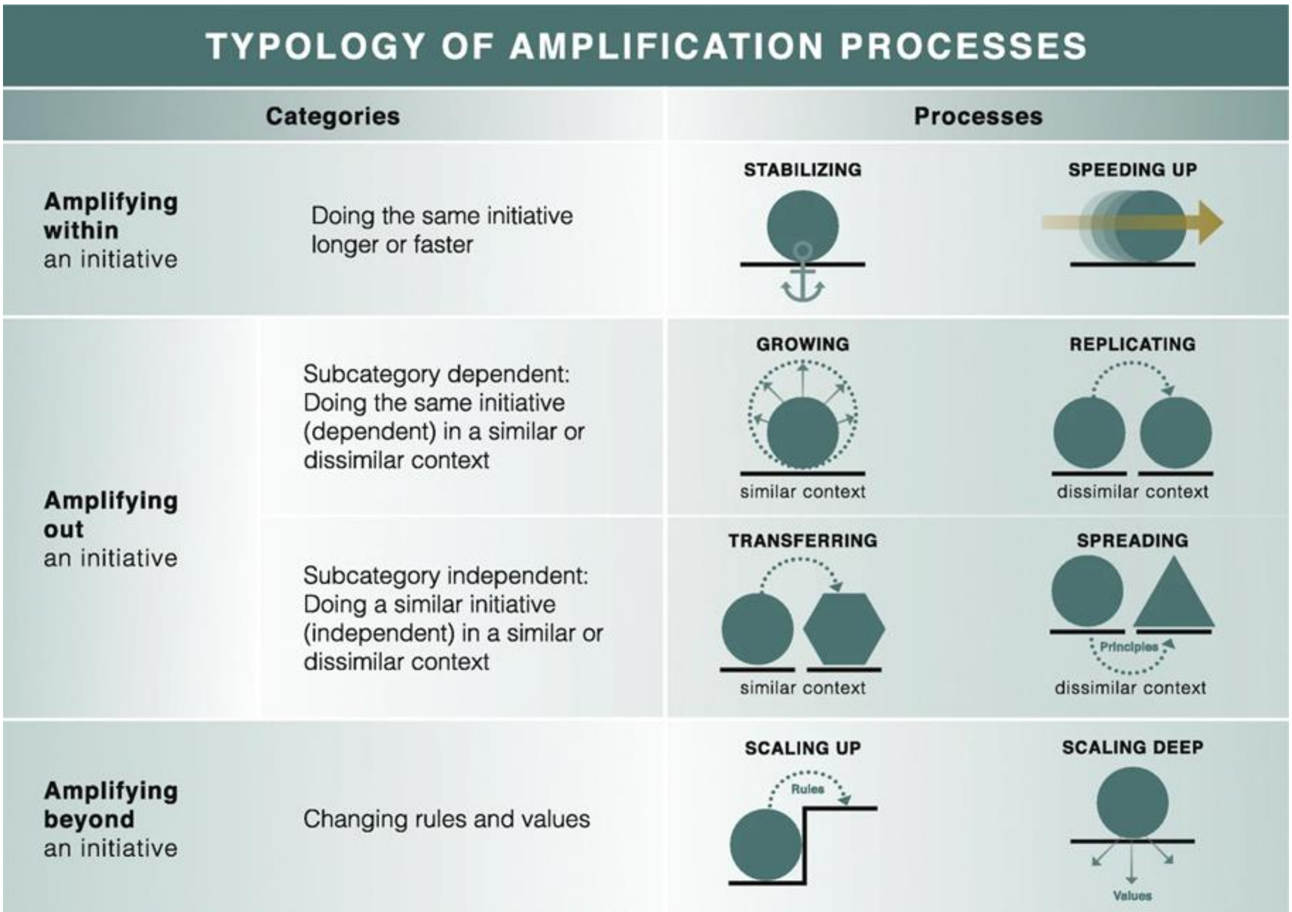



*Figure 14: The eight amplification processes classified in three categories: amplifying within, amplifying out, and amplifying beyond. Source: Lam et al. (2020).*

can be enriched by adding engineering constraints essential for the implementation of NBS. A key example of an engineering factor is slope. Some NBS require steep inclinations such as the terracing of agricultural fields, whereas other NBS need gentle slopes such as green roofs in which steep inclinations make difficult to anchor the substrate and vegetation. The second step consists of comparing the large-scale suitability maps with (1) hazard (Deliverable 1.3; Holtkötter et al., 2024) and risk maps (e.g., Shah et al., 2023) to prioritise areas where NBS interventions are most needed, and (2) the willingness of landowners to make their land available for NBS implementation. The third step involves small-scale refinement through modelling experiments and monitoring to identify the most suitable local sites and maximise NBS effectiveness. The following subsections will provide practical examples to clarify key aspects of these steps for building suitability maps.

## 5.1 FRR Romania: Suitability maps at large scale

Suitability maps are valuable tools to localize the sites suitable for a specific NBS intervention in a vast region as a catchment. This section shows an example from FRR Romania in which a suitability map is deployed to identify the optimal sites for reforestation in the Upper Timis River catchment area. The map has been built by aggregating spatial and physical criteria, starting from the CORINE land-cover dataset (2018) in agreement with Holtkötter et al. (2024). The CORINE dataset has a resolution of 100 m x 100 m and includes the classification of both natural and human environments.

Since the dataset refers to land cover in 2018, the classification has been locally updated with recent satellite imagery available on Google Maps. The other criteria include a soil-type shapefile provided by the Banat Water Basin Administration (BWBA) and checked with data from the European Soil Data Center (ESDAC), and averaged slopes of the terrains obtained by a Digital Elevation Model built by BWBA in 2021 with 3.5 m x 3.5 m of spatial resolution. Figure 15.a shows the suitability maps obtained by aggregating scores regarding land cover/use (LCU), soil type (ST), and slope (SL) for each pixel in QGIS software with the following formula:

(7) $$MCDA_{score} = 0.60LCU + 0.3SL + 0.1ST.$$

The weight has been selected through the judgment of experts who work in BWBA. The experts assigned the highest weight to land cover/use since changes could have economic consequences on landowners. Lower scores were adopted for slopes and soil type because trees usually grow on most slopes with no criticality on the soil types. The highest scores for land cover/use have been assigned to the pixels currently covered by natural grasslands ($LCU = 10$), range shrubland ($SL = 9$), and pastures ($LCU = 8$), which could be easily converted to forests with low economic losses, and are usually affected by higher surface runoff and consequent erosion. The lowest scores ($LCU = 1$) are assigned to urban areas, water, and sites already occupied by forests. These choices are in agreement with Gracelli et al. (2020). The pixels with an averaged slope lower than 5° obtained the lowest score ($SL = 1$) because flat terrains have less need for interventions to regulate local hydrology and reduce soil erosion, followed by the terrain with a slope higher than 35° ($SL = 5$), in which the tree growth could be more difficult. The highest scores have been attributed to slopes between 5° and 15° ($SL = 10$). The most suitable soil type for tree growth is loam ($ST = 10$), while the less suitable ones are both clay and silt loam ($ST = 1$). Figure 15.b shows the most suitable sites

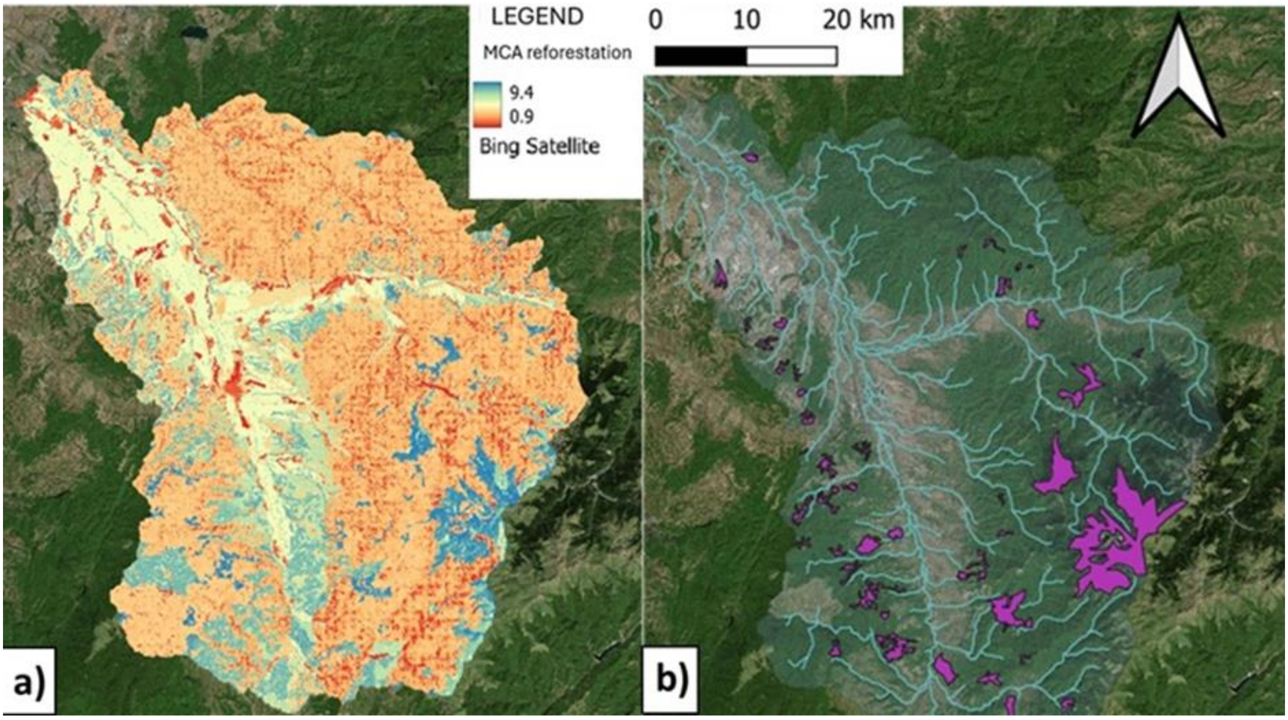



*Figure 15: a) suitability map for reforestation in the Upper Timiş River catchment area obtained as MCDA output, and b) most suitable sites for reforestation according to MCDA output (MCDA score > 9).*

for reforestation, in which $MCDA_{score} > 0.9$. These sites are 4.4% of the total basin, increasing the total forest cover from 67.9% to 72.3%, and are mainly located upstream of the Upper Timis Catchment.

To sum up, the suitability map has been built through an MCDA analysis by the following steps:

1) Selection of criteria (e.g., land cover/use, soil type, slope) and their classification (e.g., loam, clay loam, and silty loam for soil types);

2) Assignment of scores to all the possible categories included in the classification for each criterion

3) Assignment of weight and integration of all criteria in an MCDA score

4) Mapping of the sites with the highest scores.

The map allowed for the identification of the most optimal areas for reforestation at the catchment scale, helping to narrow the search for landowners potentially willing to reforest a portion of their property.

## 5.2 FRR Slovakia: Modelling activities for suitability maps at local scale

Modeling experiments can be used to develop small-scale suitability maps aimed at selecting the most appropriate locations for implementing NBS measures. This section shows an example from FRR Slovakia, where locations for retention ponds were investigated across three agricultural fields, with a total area of approximately 1000 m². The purpose of the retention ponds is to collect runoff water, creating a reserve for the irrigation of adjacent fields during drought periods.

The experiment (see Section 3.3) compared monthly water availability with crop water demand, using precipitation and evaporation data derived from climate model simulations (MPI-ESM-LR global climate model coupled with REMO2009) for the periods 1981–2005 (historical scenario) and 2031–2055 (future scenario). The comparison between water availability and demand allowed for the calculation of the water deficit (i.e., the amount required to fully meet crop water needs) for each possible location.

*Table 4: Suitability classification for retention-pond locations.*

| $S_i$-Values | Description |
|---|---|
| 0 – 0.33 | Suitable |
| 0.34 – 0.66 | Moderate |
| 0.67 – 1 | Unsuitable |

*Table 5: Calculated suitability values for each location in both historical and future scenarios.*

| | | $S_i$-Values | | Description | |
|---|---|---|---|---|---|
| | | Historical | Future | Historical | Future |
| Field 1 | Location 1 | 0.68 | 0.72 | Unsuitable | Unsuitable |
| | Location 2 | 0.06 | 0.02 | Suitable | Suitable |
| | Location 3 | 1 | 1 | Unsuitable | Unsuitable |
| | Location 4 | 0 | 0 | Suitable | Suitable |
| Field 2 | Location 5 | 0 | 0 | Suitable | Suitable |
| | Location 6 | 1 | 1 | Unsuitable | Unsuitable |
| Field 3 | Location 7 | 1 | 1 | Unsuitable | Unsuitable |
| | Location 8 | 0 | 0 | Suitable | Suitable |


*Figure 16: Suitability Map per field based on water deficit months and crop water demand.*

Based on the number of water deficit months, a suitability map was created using a min-max normalization approach. The suitability was calculated per field with the following equation:

$$S_i = \frac{(Water\ deficit\ months_i - Water\ deficit\ months_{min})}{(Water\ deficit\ months_{max} - Water\ deficit\ months_{min})}$$

The suitability was divided into three classification levels reported in Table 3. Then, Table 4 shows the calculated $S_i$ values for the eight locations for the historical as well as the future scenario.

Figure 16 shows the suitability map for both the historical and future scenario, indicating which locations are most appropriate for implementing a retention measure, based on the number of water deficit months. It highlights where an NBS would be most effective in providing supplemental irrigation during dry months, when precipitation alone is insufficient to meet crop water requirements. For Field 1, the normalized results were categorized into three classes: suitable, moderate, and unsuitable. For Fields 2 and 3, such categorization was not applicable, as only two potential locations were evaluated per field. Therefore, one location was classified as suitable and the other as unsuitable.

## 5.3 FRR Italy: Monitoring activities for suitability maps at local scale

The application of amplification processes to NBS requires careful assessment of similarities and differences between the implemented site and the potential replication/upscaling ones, in order to understand which ones are the most suitable and the possible changes in hazard mitigation and risk reduction. The consultation of public datasets often provides a preliminary indication of potential sites. For example, Figure 17 shows the bathymetry and elevation along the coast of Emilia-Romagna. The coastline maintains the same orientation over long stretches, consists of shallow sandy seabeds, and the elevation varies only by a few meters above sea level with some areas even lying below it. These characteristics make dune implementation highly replicable along the coast.

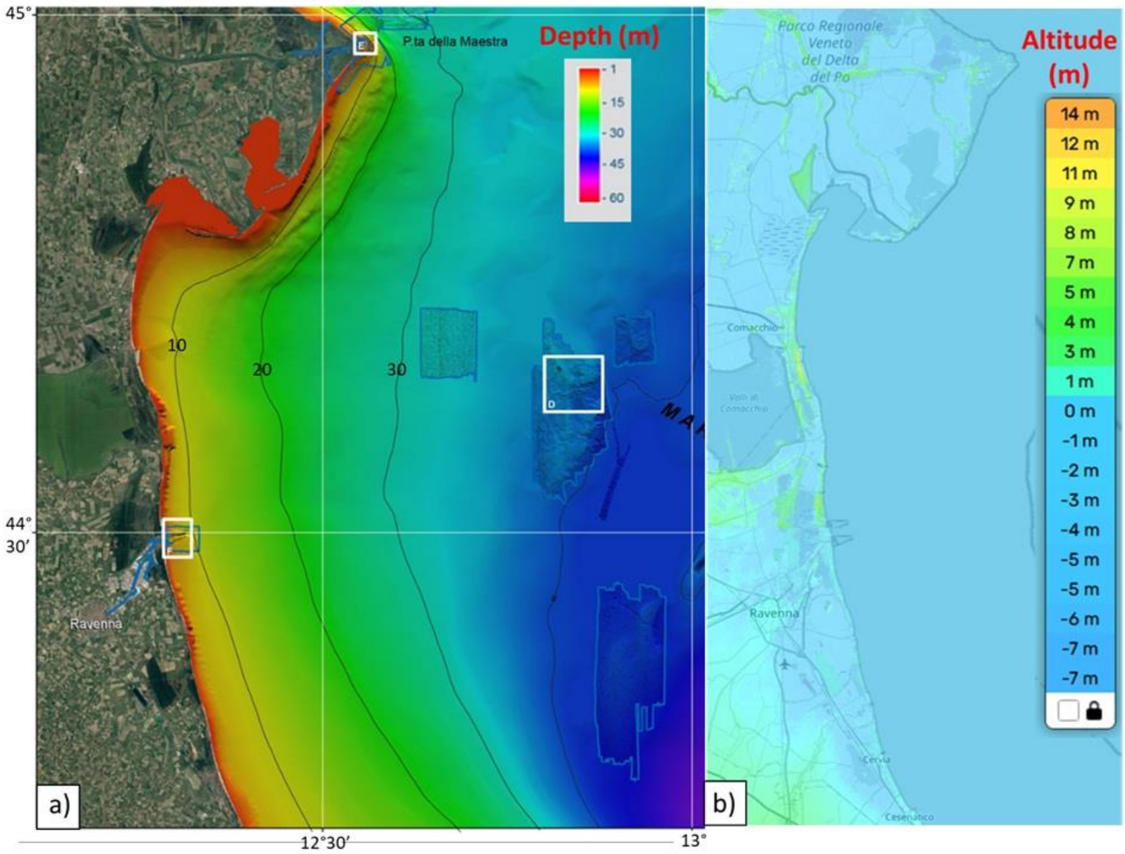



*Figure 17: a) bathymetry and b) altitude along the Emilia-Romagna coastline. Source: bathymetry, Foglini et al. (2020); altitude, topographic-map.com, [https://it-it.topographic-map.com/](https://it-it.topographic-map.com/) .*


*Figure 18: Other Natura-2000 sites in Ravenna Province: a) Ortazzo, Ortazzino, e Foce Bevano, b) Pialasse Baiona, Risega e Pontazzo. Source: [https://servizimoka.regione.emilia-romagna.it/mokaApp/apps/parchi_01HTM5/index.html](https://servizimoka.regione.emilia-romagna.it/mokaApp/apps/parchi_01HTM5/index.html), Emilia-Romagna region.*

High replicability is further supported by the presence of other sites with similar characteristics in terms of habitats. Other Natura-2000 sites are present, testifying to the high ecosystem value that needs to be preserved in the less urbanized areas. Figure 18, for instance, shows the habitats in a portion of two other Natura-2000 sites in the province of Ravenna, namely 1) Ortazzo, Ortazzino, and Foce Bevano, and 2) Pialasse Baiona, Risega, and Pontazzo. The site Ortazzo, Ortazzino, and Foce Bevano has the same main habitats as FRR Italy in the first kilometre from the coast, whereas the Pialasse Baiona, Risega, and Pontazzo site is dominated by dunes with Pinus pinea and/or Pinus pinaster forests, interspersed with natural eutrophic lakes (habitat code 3150) and coastal lagoons (1150), which are also affected by salinity variations.

Before proceeding with replication and upscaling, the initial evaluations provided by public datasets must be confirmed during the design phase through field inspections and monitoring experiments. These experiments aim to provide high-resolution information on seabed bathymetry, beach morphology, sediment types, wave and wind regimes, as well as the actual presence of valuable and community-interest species in the ecosystems to be protected.

These local-scale analyses are essential to better understanding where to place the dune, what dimensions it requires, and the points where it should be reinforced with wooden structures based on wave propagation, sediment transport, and the location of the most sensitive species. This is necessary to maximise the dune's effectiveness and extend its life cycle as much as possible. Like all NBS, a dune evolves over time by interacting and adapting its shape to the surrounding environment. The evaluation of its potential morphological evolution helps plan the required maintenance and anticipate how its contributions during hazardous events may change over time.

# 6. Conclusions, lessons learnt, and recommendations

This report shows the application of the LAND4CLIMATE methodology for the assessment of NBS effectiveness (Brogno et al., 2025) along with Work Package 2. Assessing the effectiveness of Nature-Based Solutions involves verifying whether a measure provides benefits for humans and ecosystems, by means of monitoring and modelling experiments that can adequately reproduce the complex system in which the solution is implemented. Since NBS consists of green and blue elements that interact with the surrounding ecosystems as part of them, the methodology states that an effective NBS leads to hazard mitigation, risk reduction, provision of co-benefits (with minimal trade-offs), in a cost-effective and publicly accepted way. In this regard, the current report summarizes the key findings from the previous WP2 deliverables on hazard mitigation (Gargiulo et al., 2025) and co-benefit provision (Schindelegger et al., 2025) in each FRR for selected no-regret NBS, i.e., measures that are expected to have more positive than negative effects on the livelihoods and ecosystems, regardless of the changing climate and other developments in the region (Freyer et al., 2024). These key findings pave the way for risk assessment on:

- human excess mortality due to heat stress (FRR Germany and Austria);
- crop losses due to water depletion (FRR Slovakia);
- property damages due to river flooding (FRR Romania);
- vegetation mortality due to soil saturation and salinization (FRR Italy).

Since the NBS implementation and maintenance depend on the willingness of people to be involved in the project, results from risk assessment are integrated with a methodology for acceptance and a preliminary contextualisation of each FRR context.

Results show that the no-regret NBS can provide a beneficial contribution to climate adaptation, especially if these measures are included in development plans that support the implementation of multiple NBS across the territory. Amplification processes to enhance the NBS effectiveness are the replication and upscaling, i.e., the reproduction of an NBS over a larger area at the same site and in new sites, respectively. A valuable tool for planning these processes is a suitability map that shows the areas that are expected to be suitable for specific interventions according to defined criteria regarding the hazard processes and engineering constraints (e.g., land cover and the slope of the terrain). Small-scale suitability maps can be combined with monitoring and modelling experiments to identify the priority areas and refine the NBS design.

The legacy of the Work Package 2 consists of a set of bullet points that summarize lessons learnt and recommendations to support the NBS implementation (WP 4) and their replication and upscaling (WP 5):

- The design of monitoring and modeling experiments starts with identifying the spatial and temporal scales at which hazard processes occur, and determining which indicators need to be evaluated to obtain a comprehensive description of how the NBS modifies the ecosystem where it is introduced and acts upon these processes.
- Modeling experiments are very effective for comparing different scenarios (e.g., climatic ones with and without the NBS), but monitoring experiments are also essential because they allow analyzing how an NBS and its response to hazardous events may change over time. These

changes may occur for several processes, such as the initial time required to become fully operational, degradation under the hazard pressure, lack of NBS maintenance to an optimal condition of functioning, weather dynamics, and the modification of boundary conditions (e.g., climate).

- Overall, MCDA is a robust and effective approach for assessing the co-benefits and trade-offs of NBS. Its structured, flexible, and participatory nature makes it well-suited for addressing the complex and context-specific challenges of NBS implementation. However, careful attention must be paid to mitigating its limitations, particularly the subjectivity in weighting criteria and the need for high-quality data.
- Assessing co-benefits and trade-offs is crucial for a comprehensive evaluation of NBS. It helps in decision-making by considering both the effectiveness of measures and their broader impacts, particularly for landowners.
- Taking a holistic view of acceptance, including the dimensions of social capital and trust; perceptions: awareness, understanding, and knowledge; values and attitudes; behaviour; and governance and process is important as they affect NBS acceptance.
- When assessing NBS acceptance, it is best practice to have two rounds of research activities, one before the implementation of the intervention or the engagement with landowners or local community (baseline or ex-ante) and one after the implementation of the intervention or engagement (follow-up or ex-post). We would suggest that for the RRs and other local stakeholders interested in researching NBS acceptance, this be done at least at these two intervals and, if resources and timing allow, at a midpoint as well.
- Most proposed NBS are no-regret measures. However, their effectiveness depends on specific locations and requires detailed assessment, including modelling and quantitative data. The assessed NBS primarily deliver environmental co-benefits like enhanced biodiversity and ecological connectivity, as well as social co-benefits including improved landscape aesthetics and recreational opportunities. The main trade-offs involve the loss of productive land (forests and agricultural areas) and reduced primary production, which is a key concern for landowners.
- Risk assessment is a crucial tool to understand the effects of an NBS intervention. However, this assessment requires the combination of several datasets that often do not include uncertainty estimates. The overall evaluation of an NBS intervention needs to take into account all the underlying assumptions, which components or processes have been neglected in the mathematical formulation of complex ecosystem systems, and the possible climatic and socio-economic pathways.
- An NBS intervention targeting risk reduction should be designed with careful consideration of the 5W2H framework:
  - Why is the NBS intervention needed?
  - Where can the NBS be implemented to maximize its effectiveness?
  - Who are the exposed elements that would benefit from the NBS intervention and from being involved in its implementation?
  - What are the factors that affect the vulnerability of elements exposed to the hazard?
  - How much is the balance between costs and benefits over the entire NBS life cycle?
  - What are the dimensions that affect NBS acceptance?

- When does the NBS require maintenance or restoration?
- How can effectiveness be amplified through replication and upscaling?

- Suitability maps are useful tools to identify sites for replicating and upscaling NBS measures. However, site selection should be confirmed by modeling experiments before implementation to verify the effectiveness of an NBS system. The overall effectiveness may not grow linearly, i.e., it is not simply the sum of the contributions given by each NBS.
- Suitability maps should be compared with hazard and risk maps to identify sites with the greatest need for intervention, and also with stakeholder willingness and both environmental and cultural constraints to understand which of these sites are available for implementation.

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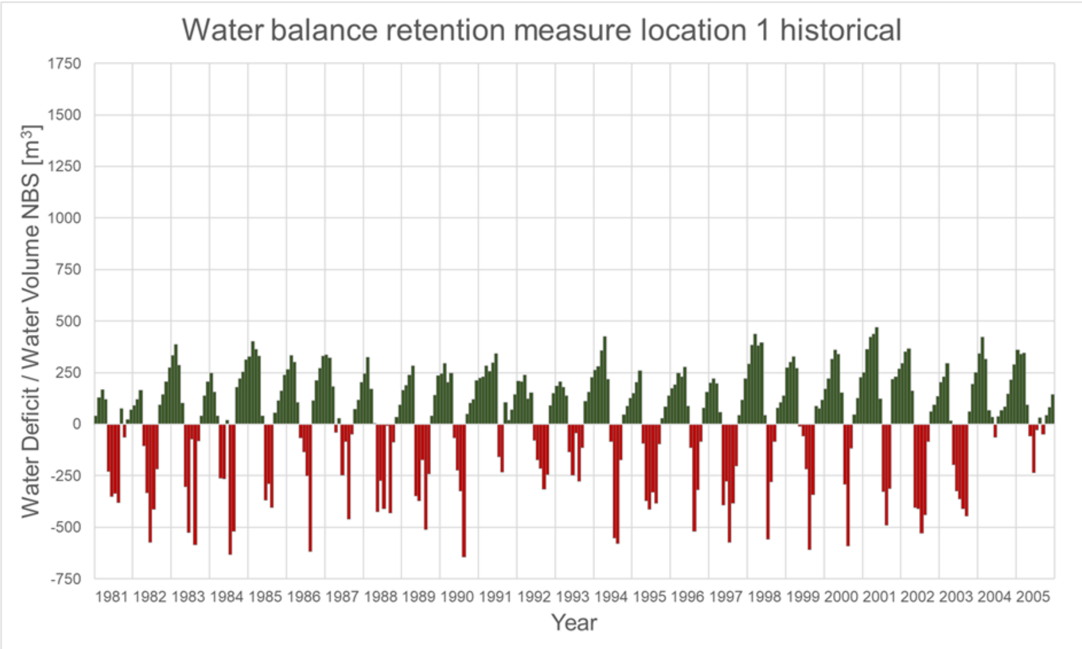
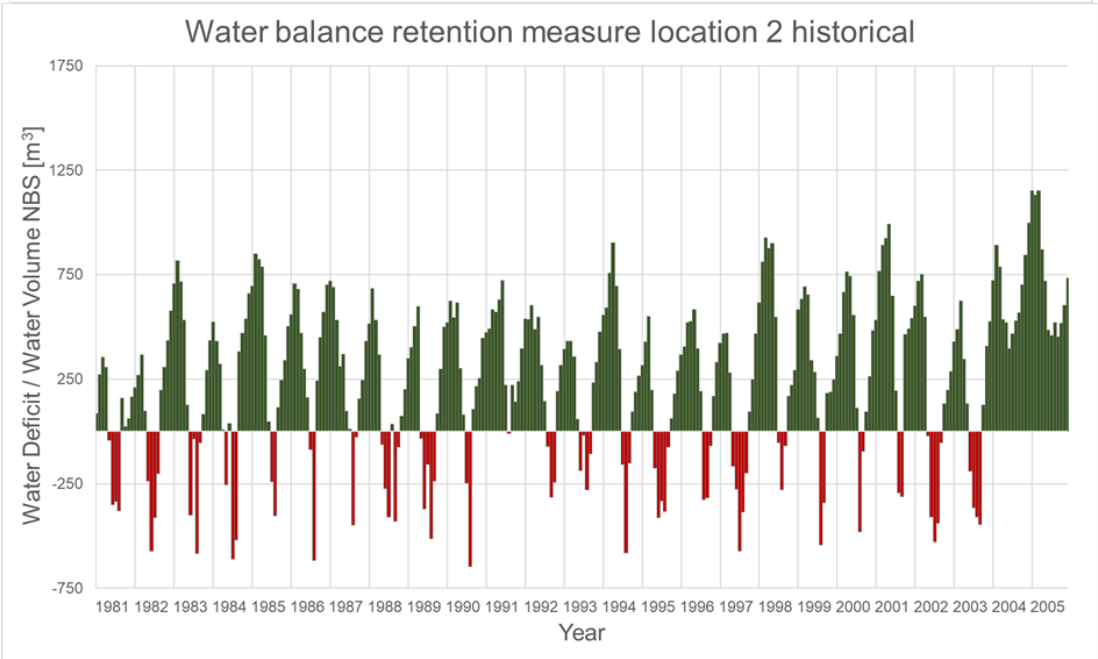
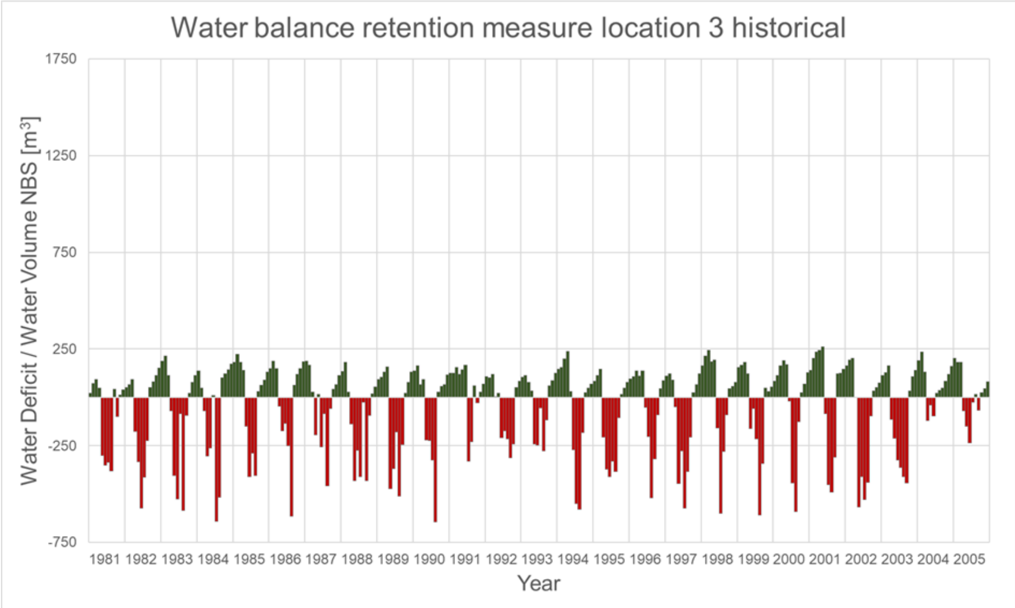
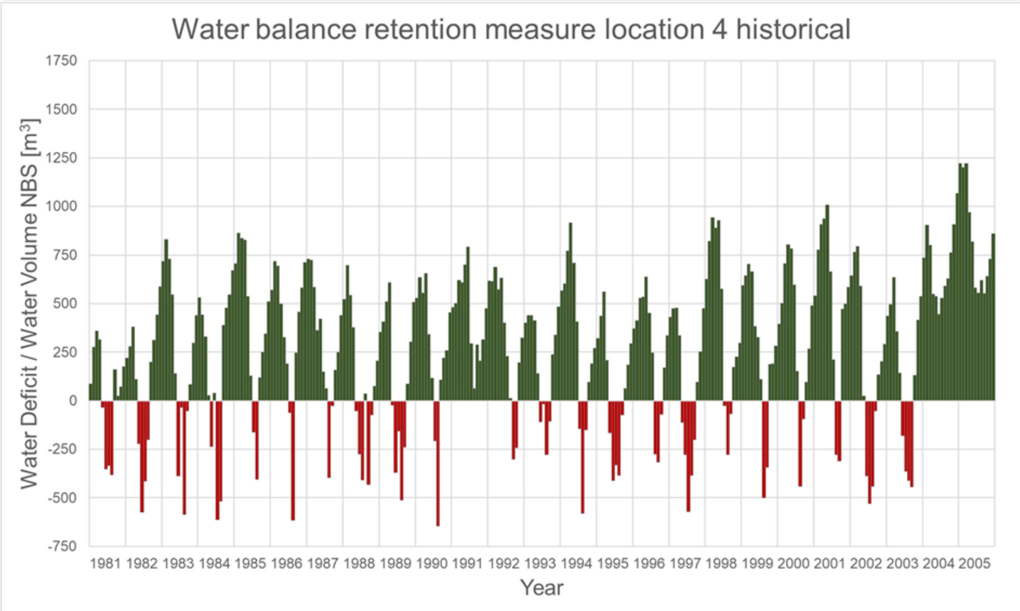
# Annex 1 – Water balance for historical and future scenarios

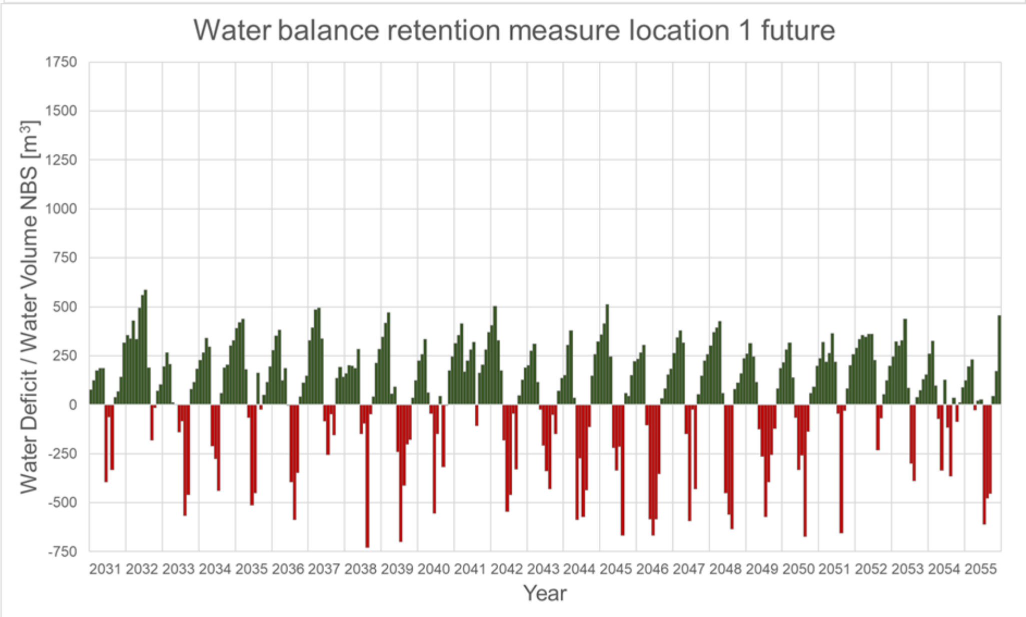
Water balance in Field 1 for historical and future scenarios:




Water balance retention measure location 3 historical
Water Deficit / Water Volume NBS [m³]
1750
1250
750
250
-250
-750
1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005
Year


Water balance retention measure location 4 historical
Water Deficit / Water Volume NBS [m³]
1750
1500
1250
1000
750
500
250
0
-250
-500
-750
1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005
Year


Water balance retention measure location 1 future
Water Deficit / Water Volume NBS [m³]
1750
1500
1250
1000
750
500
250
0
-250
-500
-750
2031 2032 2033 2034 2035 2036 2037 2038 2039 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049 2050 2051 2052 2053 2054 2055
Year

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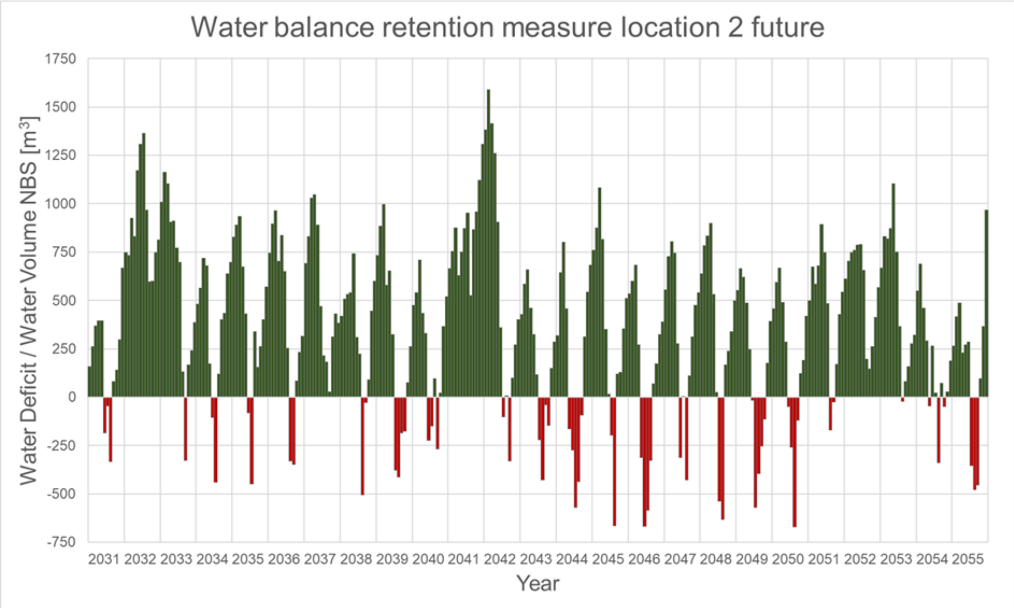
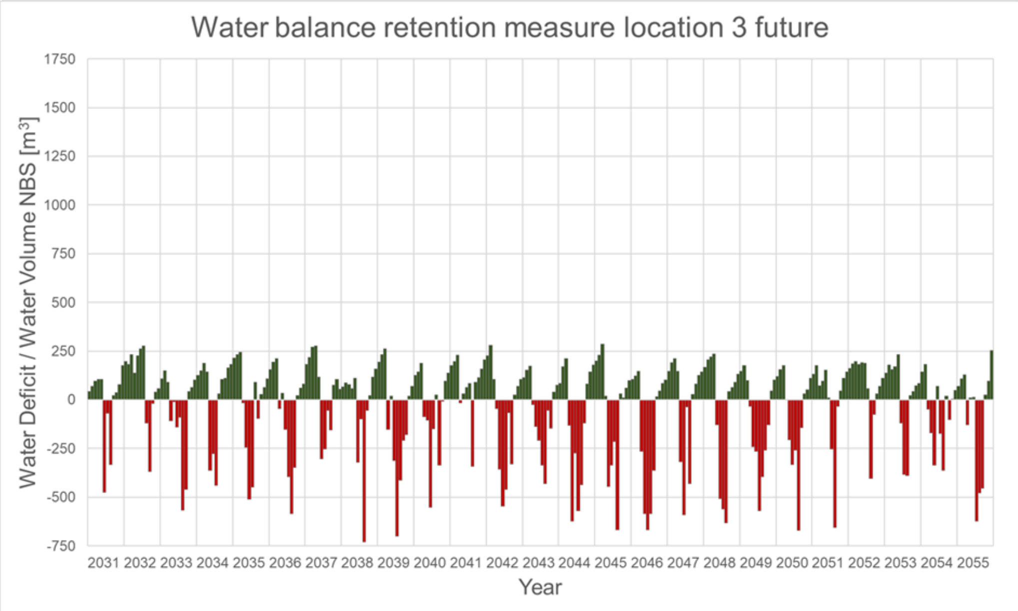
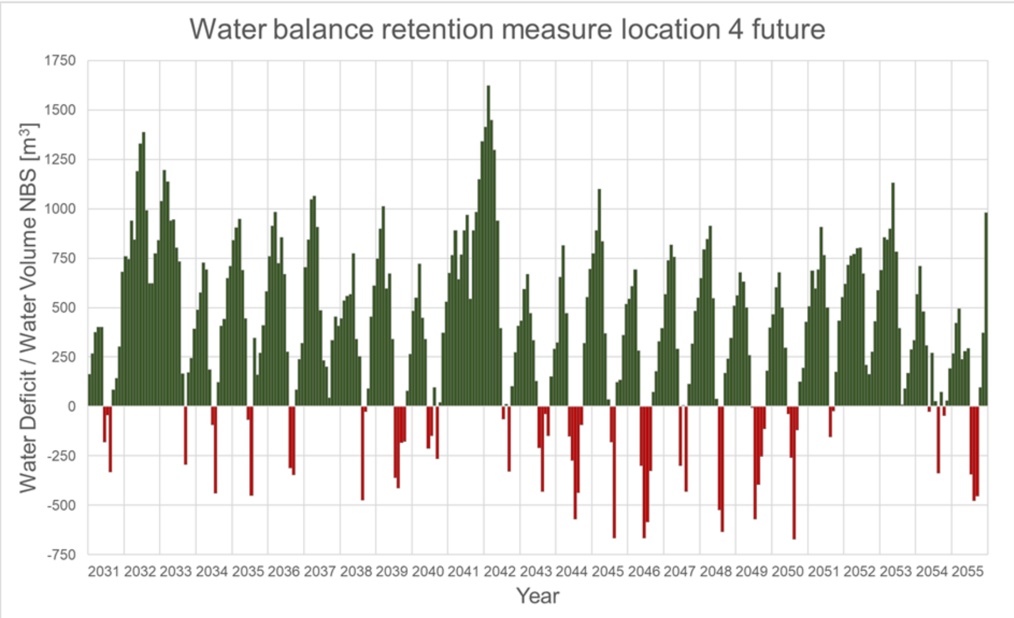
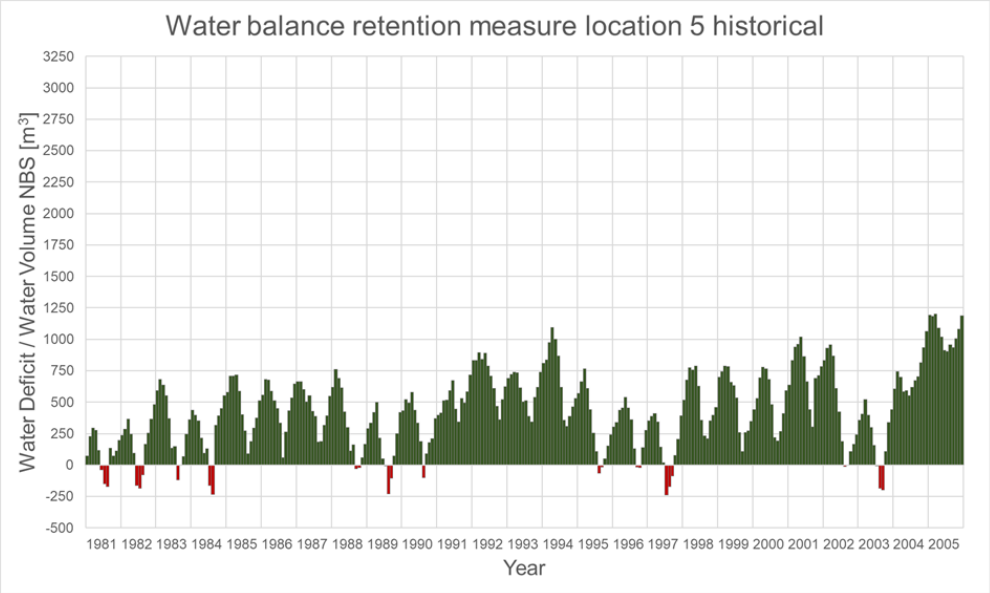
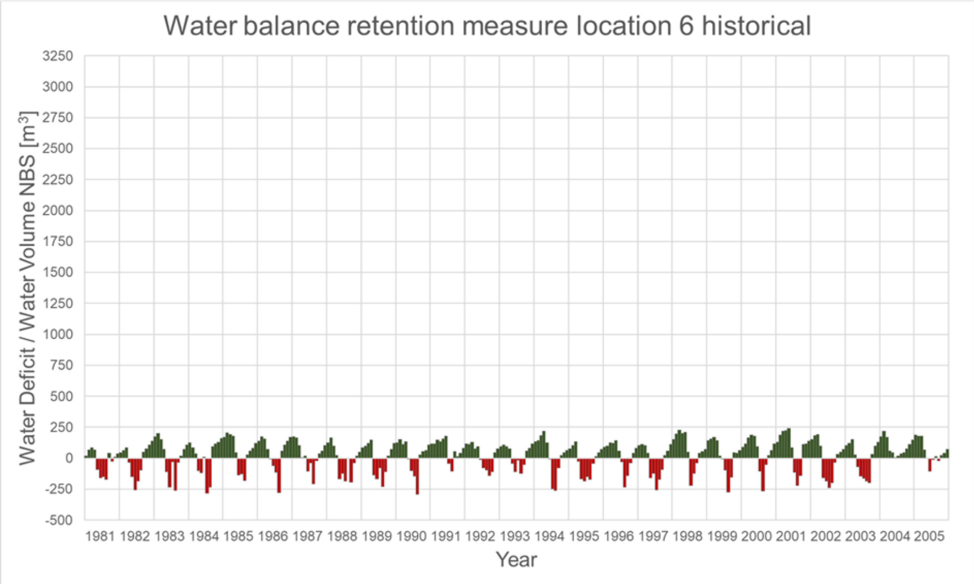


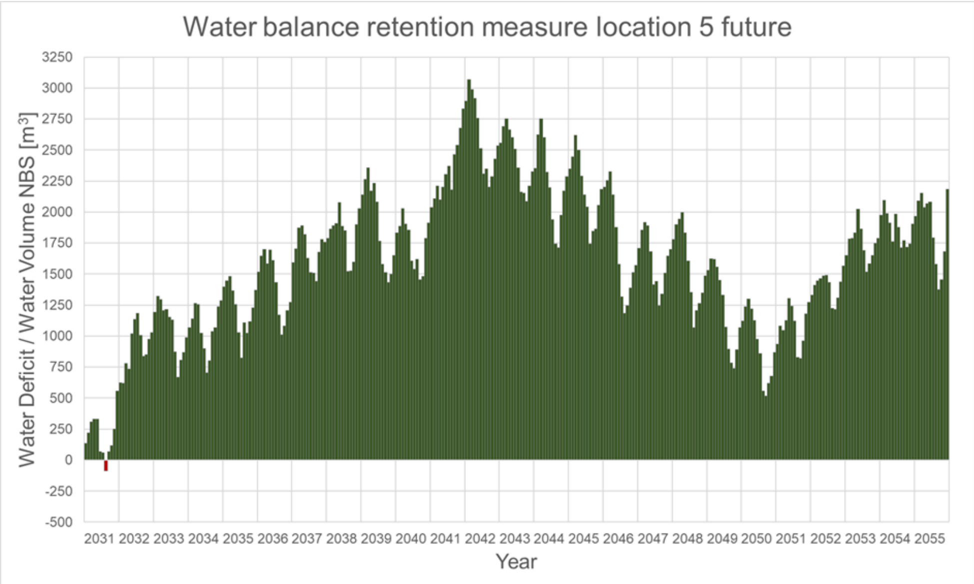



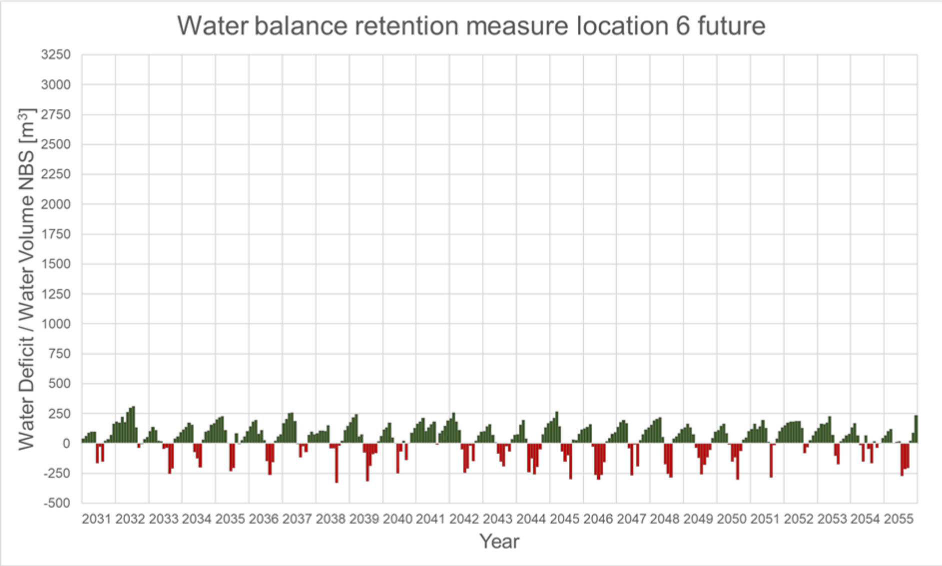



Water balance in Field 2:

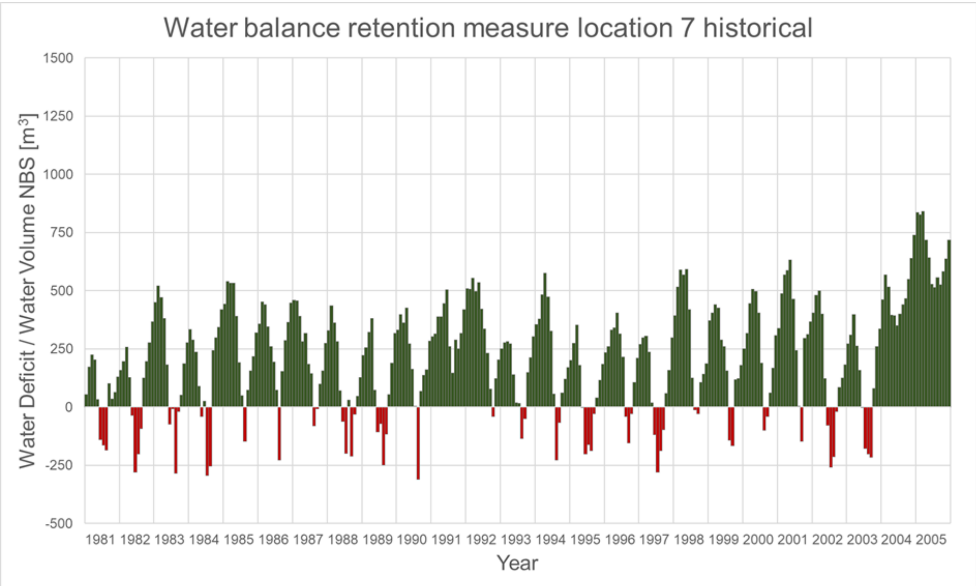


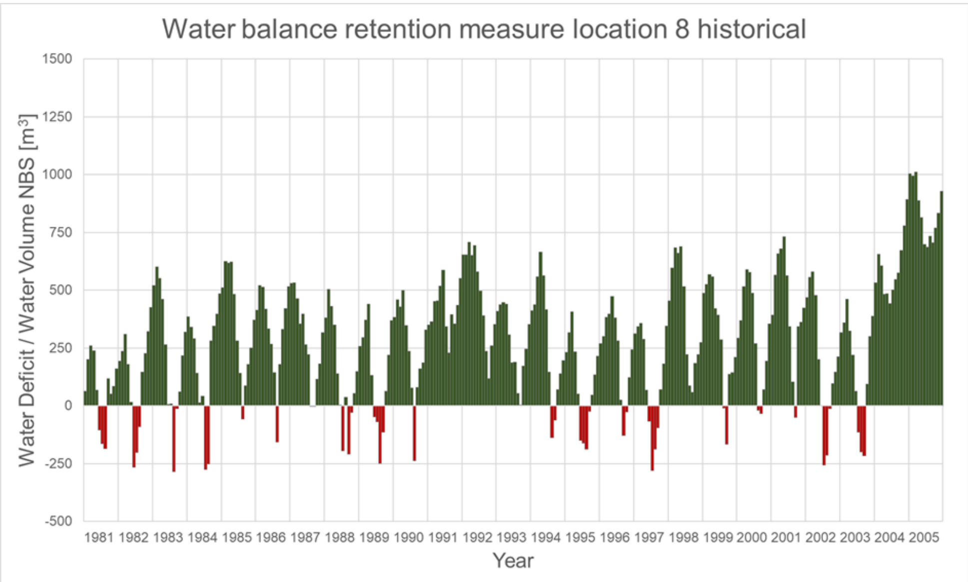



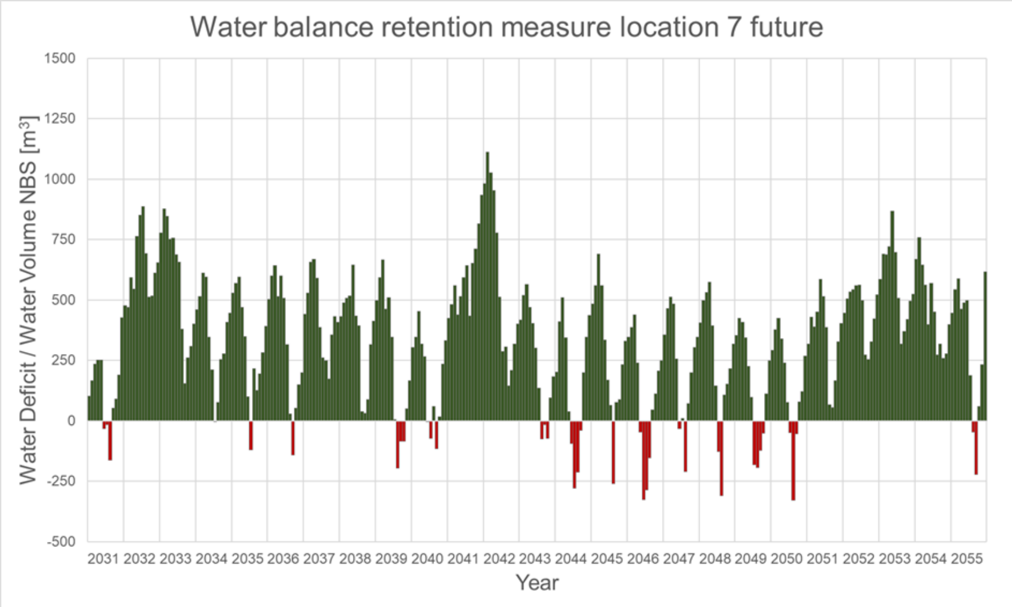





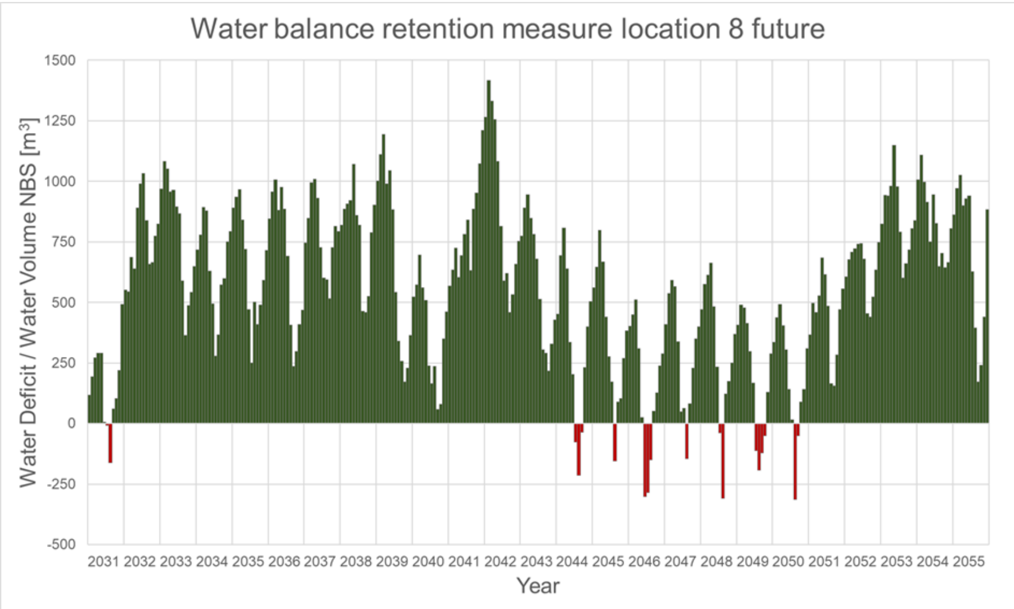

Water Balance in Field 3:





Water balance retention measure location 7 future
Water Deficit / Water Volume NBS [m³]
1500
1250
1000
750
500
250
0
-250
-500
2031 2032 2033 2034 2035 2036 2037 2038 2039 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049 2050 2051 2052 2053 2054 2055
Year

Water balance retention measure location 8 future
Water Deficit / Water Volume NBS [m³]
1500
1250
1000
750
500
250
0
-250
-500
2031 2032 2033 2034 2035 2036 2037 2038 2039 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049 2050 2051 2052 2053 2054 2055
Year

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