NATURE-BASED INFRASTRUCTURE
GLOBAL RESOURCE CENTRE

Sustainable Asset Valuation (SAVi) of River Restoration in Greece

NBI REPORT

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Sustainable Asset Valuation (SAVi) of River Restoration in Greece

May 2023

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Author Contributions

All authors are listed in alphabetical order. Ronja Bechauf contributed to defining the scope of analysis and writing the report. Emma Cutler developed the system dynamics model and integrated cost-benefit analysis and led the writing of the report. Marco Guzzetti conducted the spatial analysis.

Executive Summary

Thessaly is an agricultural region in Greece that faces frequent floods, water scarcity, declining water quality, soil degradation, and loss of natural habitats. The region is expected to get hotter and drier as climate changes, which will exacerbate water management challenges. Thessaly is also a flood-prone area, and flooding is projected to continue in the future.

Policy-makers, investors, and civil society organizations are looking for solutions to these challenges in Thessaly. While current plans focus on conventional grey infrastructure, such as dams and dikes, stakeholders are also exploring how nature-based infrastructure (NBI) can reduce flood risks, improve water quality and quantity, and deliver additional benefits.

We partnered with the Global Infrastructure Basel Foundation (GIB) and World Wide Fund For Nature to develop an integrated cost-benefit analysis of restoring 1,520 hectares of floodplains and riparian forest and building small sediment retention dams in the Pineios River Basin. Implementing the measures could directly benefit the 54,732 people (approximately 27,366 men and 27,366 women) living in the municipalities of Karditsa, Kampou, and Palama.

We used the Sustainable Asset Valuation (SAVi) methodology to holistically assess the social and environmental outcomes of the NBI compared to grey infrastructure (dikes) that provides similar flood risk reduction benefits. The assessment combines a spatially explicit analysis with a system dynamics model to quantify the social, environmental, and economic outcomes of three scenarios:

1. **NBI:** Riparian forests and floodplain restoration are implemented.
2. **Hybrid infrastructure:** Riparian forests and floodplain restoration are implemented, and small dams are built upstream to reduce sedimentation.
3. **Grey infrastructure:** New dikes are built along the river channel.

For each scenario, we monetize the following indicators in an integrated cost-benefit analysis:

- Costs
    - NBI costs: Land expropriations and forest planting costs
    - Small dam construction costs
    - Dike construction and maintenance costs
- Added benefits
    - Increased agricultural production due to reduced erosion
    - Discretionary spending from job creation
    - Income taxes from job creation

- Avoided costs
    - Water pollution due to nutrient uptake
    - Carbon emissions due to enhanced carbon sequestration
    - Sediment removal from the river channel due to decreased erosion[1]

The full integrated cost-benefit analysis is in Table ES1. Key results include:

- The NBI intervention has the highest benefit-to-cost ratio over the next 25 years. The benefit-to-cost ratio of the NBI is 2.9, compared to 2.4 for the hybrid and 1.5 for the grey infrastructure.
- Even without considering the avoided flood damages, the additional benefits, such as increased agriculture production and avoided costs of emissions are sufficient to justify the investment in the NBI. The net benefits would be even larger when considering avoided flood losses, particularly from extreme events.
- The carbon storage value of NBI, which is equal to EUR 12.8 million, is, on its own, larger than the costs of the NBI (EUR 6.8 million) and of the hybrid infrastructure (9.3 million).
- The NBI decreases sediment export, which provides significant value for the local community. Specifically, the increase in agricultural production due to reduced erosion is equal to EUR 4.5 million over 26 years. If NBI avoids one sediment removal event, then the avoided costs of cleaning the channel are EUR 2.6 million. If building small dams avoids an additional cleaning event, then they increase the net benefits of the NBI.
- River restoration would improve the local environment, which also benefits people. For example, considering the social cost of carbon, the carbon stored by the NBI has a value of EUR 12.8 million. The NBI would also improve habitat quality and support biodiversity, which could provide recreational opportunities and/or improve agricultural productivity.
- Building dikes may be less expensive than NBI but does not increase agricultural productivity, sequester carbon, or reduce water pollution. Therefore, the net benefits of dikes are much lower than the NBI (EUR 900,000 compared to EUR 12.8 million).

These results can be used to make the business case for NBI for flood risk reduction in the Pineios River Basin and to inform financing strategies. Specifically, IISD will complete a financing analysis of this project based on the results in this report. Other uses of these results are presented in Table ES2.

---

[1] Sediment and debris naturally accumulate in the river channel. Thus, it is necessary to periodically clean the channel, which costs money. We estimate cost savings from infrastructure that reduces sedimentation.

Table ES1. Integrated cost-benefit analysis. Values are cumulative over 2025 through 2050 and are undiscounted.

	NBI: Riparian buffers and retention ponds		Hybrid: NBI with small dams		Grey: Dikes	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Costs (thousand EUR)						
Construction	6,820	6,820	9,320	9,320	1,310	1,310
Maintenance	0	0	0	0	330	330
Total costs	6,820	6,820	9,320	9,320	1,640	1,640
Added benefits (thousand EUR)						
Agricultural production	4,480	4,350	4,480	4,350	0	0
Income tax	-120	-120	-120	-120	-3	-3
Discretionary spending	-210	-210	-220	-220	-6	-6
Total added benefits	4,150	4,020	4,140	4,010	-9	-9
Avoided costs (thousand EUR)						
Avoided sediment cleaning cost	2,550	2,550	5,100	5,100	2,550	2,550
Avoided cost of carbon emissions	12,810	12,810	12,810	12,810	0	0
Avoided water pollution cost	80	80	83	83	0	0
Total avoided costs	15,440	15,440	17,990	17,990	2,550	2,550
Net benefits (thousand EUR)	12,770	12,640	12,810	12,680	900	900
Benefit-to-cost ratio	2.9	2.9	2.4	2.4	1.5	1.5

Table ES2. How stakeholders can use the results of this analysis

Stakeholder	Role in the project	How can the stakeholder use the results of the assessment?
Civil society organizations	Civil society organizations, such as WWF Greece and GIB, aim to implement pilot projects in Thessaly, develop a regional implementation program, and inform wider efforts of scaling up NBI.	WWF Greece and GIB can use these results to generate interest in NBI for flood risk reduction in Thessaly and to demonstrate the holistic value of these investments. Ultimately, this can help to generate stakeholder buy-in and inform funding and financing decisions.
Financial institutions	The European Investment Bank (EIB) has been involved in funding project preparation activities and could provide financing for implementation.	The EIB can use these results to understand the value of NBI compared to grey infrastructure, particularly regarding environmental impacts, such as reduced erosion, carbon storage, and improved habitat quality/biodiversity. This can help to inform investment decisions.
Local governments	Local governments can provide input to project preparation and oversee implementation.	Local governments can use these results to generate buy-in from farmers and other residents. This can help increase the viability of implementation.
National government	National government is involved in flood risk management and water resources policy throughout the country.	National government can use these results to understand the value of NBI for water resources management and risk reduction. This can help to motivate investments to implement NBI on larger scales throughout Greece.

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Glossary

Indicator: Parameters of interest to one or several stakeholders that provide information about the development of key variables in the system over time and trends that unfold under specific conditions (United Nations Environment Programme [UNEP], 2014).

Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST): "A suite of models used to map and value the goods and services from nature that sustain and fulfill human life. It helps explore how changes in ecosystems can lead to changes in the flows of many different benefits to people" (Natural Capital Project, 2019).

Methodology: The theoretical approach(es) used for the development of different types of analysis tools and simulation models. This body of knowledge describes both the underlying assumptions used as well as qualitative and quantitative instruments for data collection and parameter estimation (UNEP, 2014).

Net benefits: The cumulative amount of monetary benefits accrued across all sectors and actors over the lifetime of investments compared to the baseline, reported by the intervention scenario.

Scenarios: Expectations about possible future events used to analyze potential responses to these new and upcoming developments. Consequently, scenario analysis is a speculative exercise in which several future development alternatives are identified, explained, and analyzed for discussion on what may cause them and the consequences these future paths may have on our system (e.g., a country or a business).

Simulation model: Models can be regarded as systemic maps in that they are simplifications of reality that help to reduce complexity and describe, at their core, how the system works. Simulation models are quantitative by nature and can be built using one or several methodologies (UNEP, 2014).

1.0 Introduction

Thessaly is an agricultural region in Greece that faces frequent floods, water scarcity, declining water quality, soil degradation, and loss of natural habitats (Jurík et al., 2022; Kairis et al., 2022). The region is expected to get hotter and drier as climate changes, which will exacerbate water management challenges (Georgoulias et al., 2022; Nastos et al., 2015; Politi, Vlachogiannis, Sfetsos, & Nastos, 2022; Politi, Vlachogiannis, Sfetsos, Nastos, et al., 2022; Vlachogiannis et al., 2022). Thessaly is also a flood-prone area, and flooding is projected to continue in the future (Jurík et al., 2022; Kourgialas, 2021).

For example, in September 2020, a devastating cyclone known as Ianos Medicane hit Greece, bringing more rainfall in 48 hours than some affected areas usually receive in a year. Damage was particularly severe in the Thessaly region, where floods inundated cities like Karditsa, destroyed harvests, washed away bridges, and killed several people ("Cyclone Ianos,"2020; Zekkos et al., 2020). The economic losses from the event amounted to over EUR 700 million (T. Giannakakis, personal communication, April 12, 2023).

In addition to floods, water scarcity and water pollution are challenging for the farmers, residents, and ecosystems in Thessaly. The region is the most productive agricultural area in Greece, consisting of a plain area with intensive agriculture, surrounded by mostly forested mountains. Irrigation accounts for up to 95% of the water use in the region (Psomas et al., 2016). Most of this water is abstracted from the groundwater through boreholes, which has lowered the groundwater depth to more than 100 metres in some areas (Jurík et al., 2022). Pollution is increasingly making the groundwater unsuitable as drinking water, and many surface water bodies are in poor or bad ecological status (Jurík et al., 2022; Kourgialas, 2021; Stamatis et al., 2011).

Policy-makers, investors, and civil society organizations are looking for solutions to these challenges in Thessaly. While current plans focus on conventional grey infrastructure such as dams and dikes, stakeholders are also exploring how nature-based solutions (NbS)/nature-based infrastructure (NBI) can reduce flood risks, improve water quality and quantity, and deliver additional benefits.

Figure 1. Grey infrastructure situation with dams and gabions along the Kalentzis river

Source: Photo by Thanos Giannakakis.

The Global Infrastructure Basel Foundation (GIB) and World Wide Fund For Nature Greece (WWF Greece) developed a pre-feasibility study, funded by the MAVA Foundation, the European Investment Bank (EIB), and WWF Netherlands, for NBI in the Pineios River Basin in Thessaly (Jurík et al., 2022). The pre-feasibility study confirms the general viability of NBI, including riparian buffers, retention ponds, and floodplain and wetland restoration and management, and lays the foundation for additional technical studies and stakeholder dialogues.

Figure 2. NBI situation with riparian forest and natural floodplain

Source: Photo by Thanos Giannakakis.

The NBI Global Resource Centre partnered with GIB and WWF Greece to develop an integrated cost-benefit analysis of the proposed NBI in one sub-catchment (the Kalentzis sub-basin) within the Pineios River Basin. The proposed actions in the Kalentzis sub-basin include restoring 1,520 hectares of floodplains and riparian forest. Implementing the measures could directly benefit the 54,732 people (approximately 27,366 men and 27,366 women) living in the municipalities of Karditsa, Kampou, and Palama (A. Kardamaki, personal communication, November 6, 2022). Considering all sub-catchments in the Pineios River Basin District, the number of inhabitants and potential beneficiaries rises to 750,445.

The pre-feasibility study by GIB and WWF included consultations with key stakeholders from all 10 municipalities in western Thessaly, and additional engagement with local stakeholders is planned for the upcoming feasibility assessment (Jurík et al., 2022). Ultimately, GIB and WWF Greece aim to implement nature-based pilot projects in Thessaly, develop a regional NbS implementation program, and inform wider efforts of scaling up NBI.

The proposed NBI in western Thessaly would support multiple policies regarding water management. For example, Greek legislation, based on the EU Water Framework Directive, focuses on maintaining ecological functioning and economic valuation while taking a river basin management approach. Furthermore, the proposed NBI projects align with Greece's National Adaptation Strategy and the country's biodiversity strategy (Jurík et al., 2022).

Box 1. Nature-based solutions or nature-based infrastructure?

The International Union for the Conservation of Nature (IUCN) defines NbS as "actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously benefiting people and nature" (Cohen-Shacham et al., 2016).

NBI is a subset of NbS with a focus on the infrastructure services provided by nature. The NBI Global Resource Centre considers NBI to include:

- Natural ecosystems or working landscapes that can be conserved, rehabilitated, and maintained to enhance capabilities and reduce the necessity for grey infrastructure.
- Hybrid infrastructure that combines engineered and nature-based solutions.

We assess the proposed interventions in Thessaly as NBI, that is, we consider the restoration to be an infrastructure investment designed to address flooding as an alternative to river dikes. However, many organizations, including WWF, GIB, and EIB, refer to these projects as NbS.

We used the Sustainable Asset Valuation (SAVi) methodology to holistically assess the social and environmental outcomes of the NBI compared to grey infrastructure (dikes) that provides similar flood risk reduction benefits. We used a spatial analysis to quantify carbon storage, sediment and nutrient export, flood risk mitigation, and habitat quality associated with the NBI. We combined these results into a system dynamics model to generate an integrated cost-benefit analysis, focusing on the co-benefits of river restoration. The results of this analysis will feed into a separate study that explores financing options for NBI in Thessaly.

2.0 Methodology

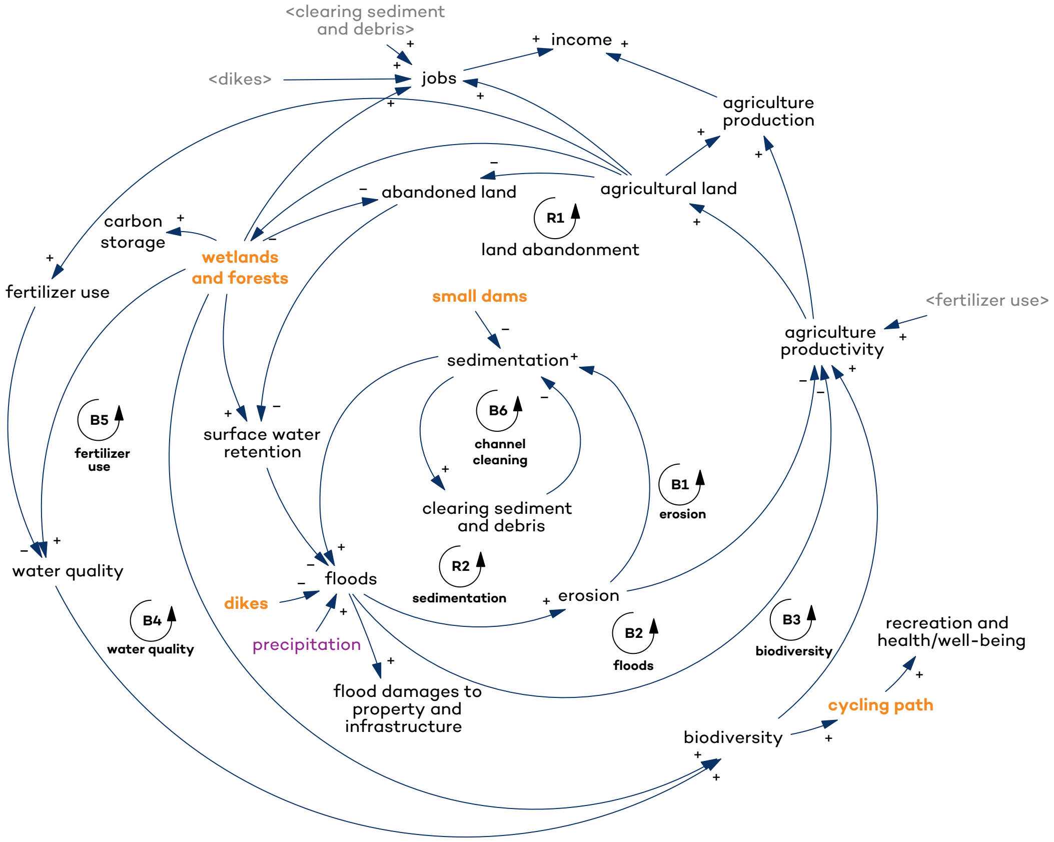
The assessment process starts with developing a system map, called a causal loop diagram. This diagram visually displays how important parts of the system interact with each other. Based on the diagram, we identify key ecosystem services that we quantify using a spatially explicit analysis. The causal loop diagram also informs a quantitative system dynamics model and reveals indicators to be included in an integrated cost-benefit analysis.

2.1 Causal Loop Diagram

A causal loop diagram shows relations among components of a system. Arrows indicate causality, and plus and minus signs are used to show the direction of causality. A plus sign means that two variables change in the same direction (a positive correlation), while a negative sign means that they change in opposite directions (a negative correlation). Feedback loops are labelled as either reinforcing (R) or balancing (B). A reinforcing loop indicates that a change in one variable will lead to further change in the same direction, thus amplifying change. Conversely, balancing loops dampen change.

We created a causal loop diagram to explain observed changes in the Kalentzis sub-basin and to understand the possible system-wide outcomes of NBI and grey infrastructure interventions (Figure 3). This diagram was validated by WWF Greece and EIB.

Figure 3. Causal loop diagram



Source: Authors' diagram.

As demonstrated in the causal loop diagram, agricultural expansion encroaches on wetlands and forests. This has reduced surface water retention, making floods and erosion worse, and has damaged biodiversity. Furthermore, fertilizer inputs combined with the decrease in wetlands and forests have made water quality worse, which also harms biodiversity. Flooding, erosion, and loss of biodiversity lower agricultural productivity, and so agricultural expansion in the region has slowed (B1, B2, B3, B4, B5). With declining productivity, land is also abandoned, as farming becomes less profitable. Abandoned land further reduces surface water retention, exacerbating flooding and erosion, so productivity declines more (R1).

Erosion also worsens sedimentation in the river channel. This makes flooding worse, which causes more erosion, creating another reinforcing feedback loop (R2). These floods cause damage to infrastructure and property. Thus, as sedimentation progresses, it becomes necessary to clear sediment and debris from the channel (B6).

To address flooding in the catchment, dikes could be raised and/or reinforced or wetland and forest restoration could be used to enhance water retention. Both options would create jobs. The nature-based approach would also improve water quality and enhance biodiversity. It is possible that with a higher-quality environment, a cycling path could be built along the river. This would create more opportunities for recreation and physical activity, which has health benefits. As a result of these added benefits, the NBI will have a larger benefit for agricultural productivity and the overall quality of the area and human well-being.

2.2 Spatially Explicit Analysis

We use the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) suite of models to quantify ecosystem services based on a landcover map (Natural Capital Project, 2019). Specifically, we calculate the following services:

- Carbon storage
- Nitrogen and phosphorus retention
- Sediment retention
- Water retention
- Habitat quality

We run the models once using a landcover map from 2018 and once using a landcover map that reflects the proposed NBI interventions. See the technical appendix (part A) for full details on the spatial analysis.

2.3 System Dynamics Model

The system dynamics model simulates water flow and erosion in the Kalentzis sub-catchment, subdivided into an upper, middle, and lower basin. The amount of runoff to the river depends on precipitation depth and the percentage of water retained by the landcover. When there is more water in the river, flow speed increases. The model also simulates agricultural production and water quality. See the technical appendix (part B) for full details on the system dynamics model.

WWF-Greece provided local biophysical and economic data. Data gaps were filled using peer-reviewed scientific literature from international locations.

3.0 Scenarios and Assumptions

3.1 Scenarios

We simulate three scenarios:

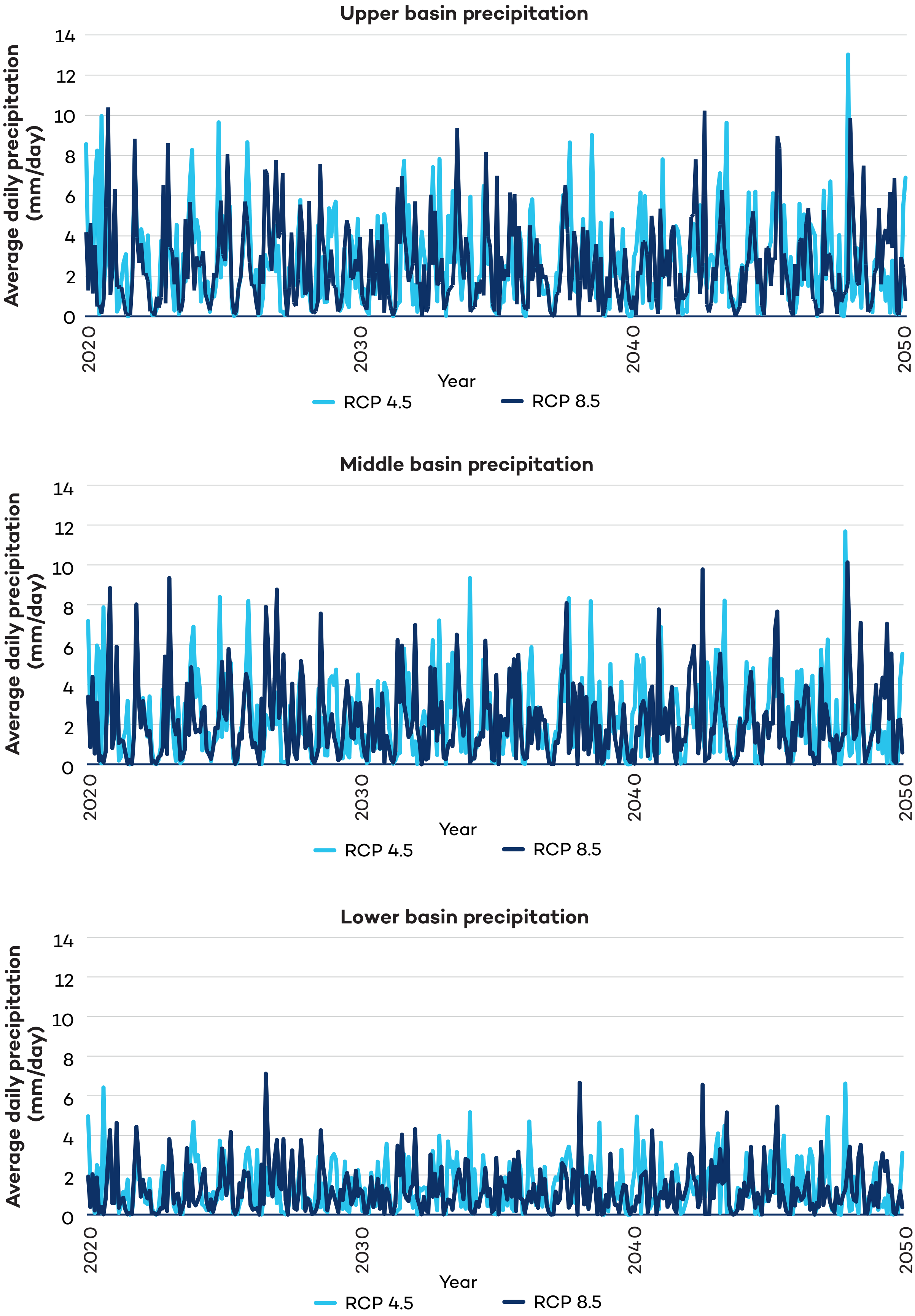
1. **NBI:** Riparian forests and floodplain restoration are implemented, restoring 1,520 hectares of land. These are the nature-based interventions that are planned in the Kalentzis sub-catchment (Jurík et al., 2022). For this scenario, we do not include the complementary grey infrastructure that is also planned for the area.
2. **Hybrid infrastructure:** Riparian forests and floodplain restoration are implemented on 1,520 hectares, and small retention dams are built upstream to reduce sediment input to the river channel by 20%. These are all the interventions (nature-based and grey) that are planned in the Kalentzis sub-catchment (Jurík et al., 2022).
3. **Grey infrastructure:** New dikes are built along 50 km of the river channel to reduce flooding.

All scenarios are reported relative to business-as-usual, in which no interventions are made. Interventions are assumed to begin in 2025, and the simulation is run through 2050.

3.2 Climate Scenarios

Precipitation across Thessaly is projected to decrease as a result of climate change (Nastos et al., 2015; Politi, Vlachogiannis, Sfetsos, & Nastos, 2022; Vlachogiannis et al., 2022). We include these climate impacts by simulating results using precipitation projections from two climate scenarios (Figure 4). The first, Representative Concentration Pathway 4.5 (RCP 4.5) assumes that greenhouse emissions peak mid-century and then begin to decline. The second, RCP 8.5, assumes emissions continue to increase through the 21st century. For each scenario, we use a precipitation time series from a single regional climate model. Thus, the time series used are neither central estimates nor most likely outcomes for the given emissions pathway. Rather, they are possible precipitation trajectories given low or high future greenhouse gas emissions. This allows us to assess the impact of two plausible precipitation scenarios. Data were downloaded from the Data Extraction Application for Regional Climate tool (Data Extraction Application for Regional Climate-Clima, n.d.). In all parts of the sub-basin, precipitation is expected to be lower under RCP 8.5.

Figure 4. Precipitation projections



Source: Authors' diagram using data from Data Extraction Application for Regional Climate-Clima, n.d.

3.3 Costs and Benefits

Based on the biophysical outputs of the system dynamics model, we calculate the following indicators as part of our integrated cost-benefit analysis:

- Costs
    - NBI costs: land expropriations and forest planting costs
    - Small dam construction costs[2]
    - Dike construction and maintenance costs
- Added benefits
    - Increased agricultural production due to reduced erosion
    - Discretionary spending from job creation
    - Income taxes from job creation
- Avoided costs
    - Water pollution due to nutrient uptake.
    - Carbon emissions due to enhanced carbon sequestration. To monetize the value of carbon emissions, we use a recently revised estimate for the social cost of carbon, equal to USD 185 (EUR 164) per ton (Rennert et al., 2022).
    - Sediment removal from the river channel due to decreased erosion.[3]

The assumptions and data used to calculate the costs and benefits are detailed in the technical appendix (part B). All monetary values are converted to constant 2021 EUR using consumer price index data from the World Bank (World Bank, 2022).

Historically, flooding has been a large concern for this area. The NBI project has been designed to address flood impacts. However, at this time, we do not have quantitative information regarding the impact of NBI on flood losses. A hydraulic/hydrologic modelling study that will estimate the flood-reduction benefits of the NBI is underway. We, therefore, focus this analysis on quantifying the co-benefits of the NBI (listed above) compared to those of a grey infrastructure alternative. Because we do not include flood impacts, the value of the NBI, hybrid, and grey interventions is higher than what we estimate.

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[2] As reported by WWF Greece, the only ongoing costs for the NBI and hybrid scenarios are the costs to remove sediment from the channel, which we include as an avoided cost. Thus, in this analysis, we assume that the maintenance costs in the NBI and hybrid scenarios are 0.

[3] Sediment and debris naturally accumulate in the river channel. Thus, it is necessary to periodically clean the channel, which costs money. We estimate cost savings from infrastructure that reduces sedimentation.

3.3.1 Grey Infrastructure Comparison

Currently, the rivers of the Kalentzis sub-catchment are highly channelized, with dikes lining the banks. As our grey infrastructure comparison, therefore, we assume that these dikes are rebuilt to widen the channel. Although the required width the channel must achieve to have similar flood benefits as the NBI is unknown, for purposes of this analysis, we assume that it is possible to construct dikes that would have the same flood-reduction benefit.

The cost of building the dikes depends on their height and length. For our analysis, we use the cost of a 1-metre-high dike. It is possible that to have similar flood benefits as the NBI, higher dikes would be required. However, without knowing how high they would need to be, we use the costs of a 1-metre-high dike to estimate the lower bound of the grey infrastructure costs (i.e., the best-case scenario for the cost of the dikes).

4.0 Results

Key results from the spatial analysis and integrated cost-benefit analysis include:

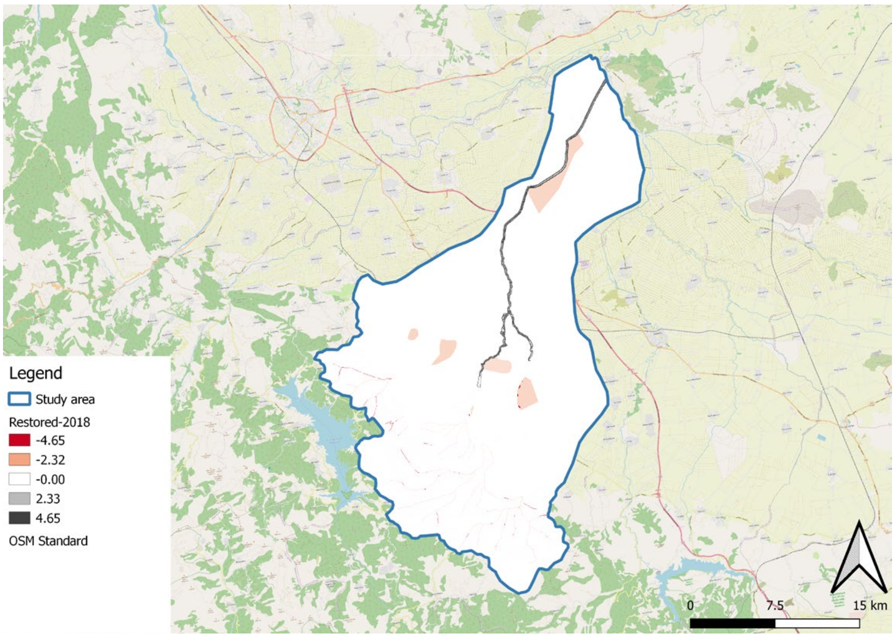
- The NBI intervention has the highest benefit-to-cost ratio over the next 25 years. The benefit-to-cost ratio of the NBI is 2.9, compared to 2.4 for the hybrid and 1.5 for the grey infrastructure.
- Even without considering the avoided flood damages, the additional benefits, such as increased agriculture production and avoided costs of emissions are sufficient to justify the investment in the NBI. The net benefits would be even larger when considering avoided flood losses, particularly from extreme events.
- The carbon storage value of NBI, which is equal to EUR 12.8 million, is, on its own, larger than the costs of the NBI (EUR 6.8 million) and of the hybrid infrastructure (EUR 9.3 million).
- The NBI decreases sediment export, which provides significant value for the local community. Specifically, the increase in agricultural production due to reduced erosion is equal to EUR 4.5 million over 26 years. If NBI avoids one sediment removal event, then the avoided costs of cleaning the channel are EUR 2.6 million. If building small dams avoids an additional cleaning event, then they increase the net benefits of the NBI.
- River restoration would improve the local environment, which also benefits people. For example, considering the social cost of carbon, the carbon stored by the NBI has a value of EUR 12.8 million. The NBI would also improve habitat quality and support biodiversity, which could provide recreational opportunities and/or improve agricultural productivity.
- Building dikes may be less expensive than NBI but does not increase agricultural productivity, sequester carbon, or reduce water pollution. Therefore, the net benefits of dikes are much lower than the NBI (EUR 900,000 compared to EUR 12.8 million).

4.1 Spatial Analysis

The spatial analysis quantifies expected changes in carbon storage, water retention, sediment and nutrient export, and habitat quality. Details of the spatial analysis are in the technical appendix (part A).

The proposed NBI projects in the Kalentzis sub-basin would increase carbon storage by an estimated 21,277 tons, which would be a 1% increase in carbon storage in the Kalentzis sub-basin (an area of 64,600 hectares).

Figure 5. Change in carbon storage.



Red areas show a decrease in carbon storage, and black areas show an increase in carbon storage. There is a net increase in carbon storage.

Source: Authors' diagram.

Likewise, the NBI intervention would decrease nitrogen export by 3,142 kg per year, phosphorus export by 296 kg per year, and sediment export by 58,712 tons per year. However, in the case of sediment export, this is likely an underestimate, particularly from the mountainous area, as the analysis does not consider topography.

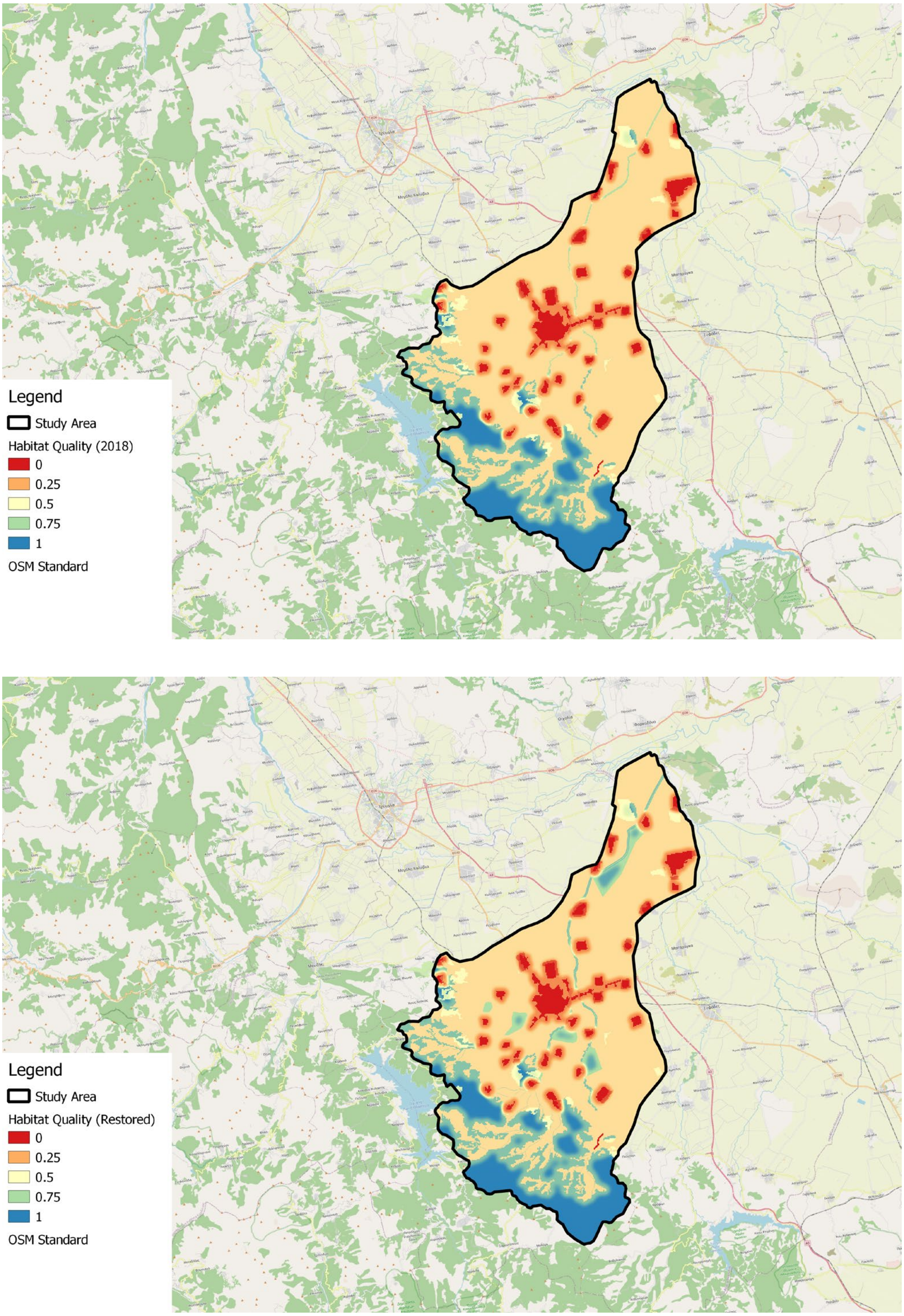
Looking at the full sub-basin, the changes in landcover would increase water retention by over 5% after 154.6 mm of rainfall and almost 9% after 254.2 mm of rainfall. Considering only the area immediately around the city of Karditsa, water retention increases by 20% after 154.6 mm of rainfall and by almost 33% after 254.2 mm. This increase in water retention after extreme precipitation suggests that the NBI could significantly reduce flood damage in the city and throughout the sub-basin.

4.1.1 Biodiversity Benefits

Habitat quality will increase in the areas where NBI is implemented (Figure 6). This is most visible along the river channel, where riparian buffers will be planted, and at the retention ponds. It is expected that this increase in habitat quality will have a positive impact on biodiversity. Specifically, the long riparian forest will improve ecosystem connectivity.

We do not have sufficient data to monetize the value of this biodiversity increase. However, it is possible that agricultural production would increase if the improved habitat supported pollinators. Furthermore, there may be more opportunities for recreation. For example, if a cycling path were built, people may be motivated to go out and enjoy the restored area. Although it is unlikely that this would attract visitors from elsewhere, increased physical activity and the improved quality of the area would benefit the health and well-being of the local population (Box 2).

Figure 6. Change in habitat quality



Source: Authors' diagram.

Box 2. Building on benefits: The case for a cycling path

The spatial analysis shows that implementing the NBI would improve habitat quality in the Kalentzis sub-catchment along the river channel and in places where retention ponds will be created. This enhanced habitat can provide biodiversity benefits and improve the overall quality of the area. There are a number of complementary interventions that could create additional value from the forest restoration. For instance, if a cycling path is built along the river, people would be expected to use it from the nearby municipalities of Karditsa, Kampos, and Palama as a means of enjoying the natural environment. Additional cycling will have population health benefits.

Assuming that a cycling path could be built along 25.5 km of the river (representing the channel length of the lower basin) with construction costs of EUR 1.8 million per km (GTP editing team, 2022) and operations and maintenance costs of EUR 937 per km per year (American Trails, 2007), the total costs of construction and 25 years of maintenance would be EUR 46.5 million.

Using the World Health Organization Health Economic Assessment Tool, we estimate that each kilometre cycled has an avoided cost of EUR 136, based on the value of a statistical life. Therefore, if, on average, there is an increase of 13,675 person kilometres ridden each year, the cumulative health benefits of the cycling path will offset the construction and maintenance costs. This is equivalent to 456 people choosing to go for a 30-km ride that they would not have done if the cycling path and NBI were not built. Combined, the municipalities of Karditsa, Kampos, and Palama have an adult population of just over 44,000. Thus, if approximately 1% of the population goes for 1 additional ride each year, the health benefits of the cycling path along the improved lower basin channel can justify the investment.

4.2 Integrated Cost-Benefit Analysis

The results of the integrated cost-benefit analysis are shown in Table 1, while Table 2 shows the net benefits and benefit-to-cost ratio of different combinations of benefits. Considering the costs, added benefits, and avoided costs included in this analysis, the NBI and hybrid infrastructure create more value for money than the grey infrastructure alternative, even though the dikes are less expensive. This is primarily due to the carbon storage value of NBI, which is equal to EUR 12.8 million because of the high social cost of carbon. On its own, this is larger than the costs of the NBI (equal to EUR 6.8 million) and of the hybrid infrastructure (equal to 9.3 million).

Considering only the added benefits (agricultural income, income tax, and discretionary spending), the value created is not sufficient to cover the costs. One reason for this is that, in all scenarios, the avoided sediment cleaning means that the total number of jobs and wages earned over the 25-year simulation is less than in business-as-usual, which results in a negative benefit. This demonstrates that the avoided costs are critical in the value creation of the NBI. Specifically, the avoided costs of sediment cleaning and the avoided cost of carbon emissions are important, as the avoided cost of water pollution is small.

Other significant benefits of NBI include the increase in agricultural income and the avoided costs of sediment cleaning. Together, these two indicators are large enough to justify the investment in NBI, creating net benefits of EUR 210,000 under RCP 4.5 and EUR 80,000 under RCP 8.5. This demonstrates the importance of reducing erosion, which both increases agricultural productivity and reduces sedimentation in the river channel. These benefits of erosion control would be more pronounced when considering extreme events.

Table 1. Integrated cost-benefit analysis. Values are cumulative over 2025 through 2050 and are undiscounted.

	NBI: Riparian buffers and retention ponds		**Hybrid: NBI with small dams**		**Grey: Dikes**	
	RCP 4.5	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**
Costs (thousand EUR)						
Construction	6,820	6,820	9,320	9,320	1,310	1,310
Maintenance	0	0	0	0	330	330
Total costs	6,820	6,820	9,320	9,320	1,640	1,640
Added benefits (thousand EUR)						
Agricultural production	4,480	4,350	4,480	4,350	0	0
Income tax	-120	-120	-120	-120	-3	-3
Discretionary spending	-210	-210	-220	-220	-6	-6
Total added benefits	4,150	4,020	4,140	4,010	-9	-9
Avoided costs (thousand EUR)						
Avoided sediment cleaning cost	2,550	2,550	5,100	5,100	2,550	2,550
Avoided cost of carbon emissions	12,810	12,810	12,810	12,810	0	0
Avoided water pollution cost	80	80	83	83	0	0
Total avoided costs	15,440	15,440	17,990	17,990	2,550	2,550
Net benefits (thousand EUR)	12,770	12,640	12,810	12,680	900	900
Benefit-to-cost ratio	2.9	2.9	2.4	2.4	1.5	1.5

Table 2. Net benefits and benefit-to-cost ratio for all scenarios. Values are cumulative over 2025 through 2050 and are undiscounted.

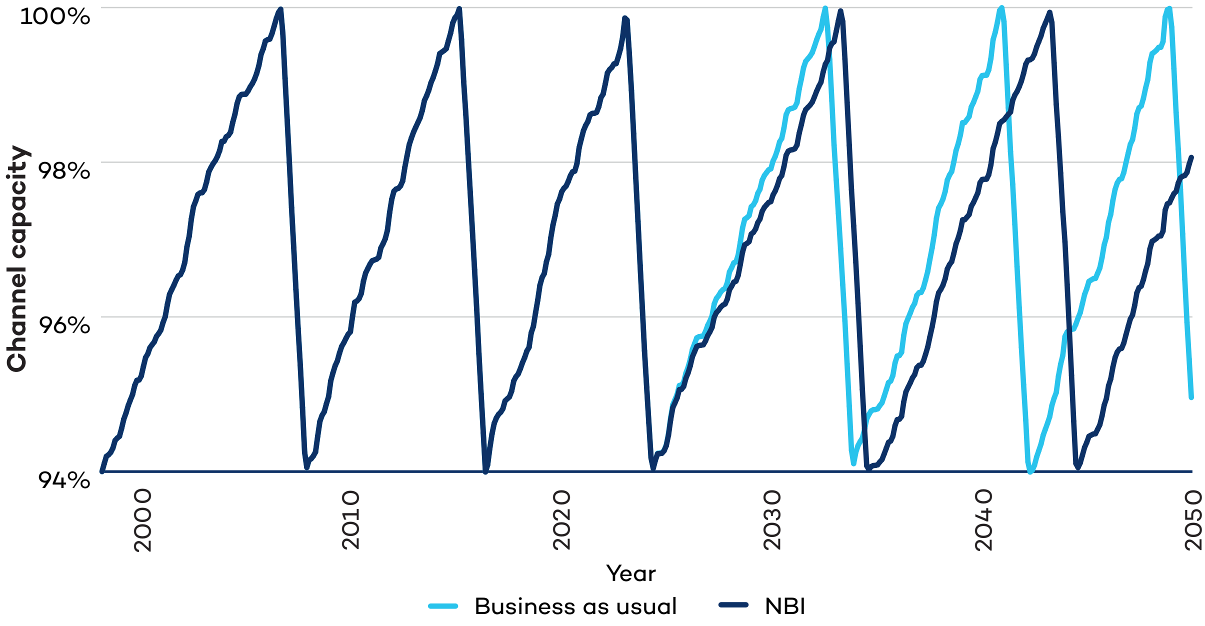
			NBI: Riparian buffers and retention ponds	Hybrid: NBI with small dams	Grey: Dikes
All benefits and avoided costs	Net benefits (thousands EUR)	RCP 4.5	12,770	12,810	900
		RCP 8.5	12,640	12,690	900
	Benefit-to-cost ratio	RCP 4.5	2.9	2.4	1.5
		RCP 8.5	2.9	2.4	1.5
Only carbon storage	Net benefits (thousands EUR)	RCP 4.5	5,990	3,490	-1,640
		RCP 8.5	5,990	3,490	-1,640
	Benefit-to-cost ratio	RCP 4.5	1.9	1.4	0
		RCP 8.5	1.9	1.4	0
Only added benefits	Net benefits (thousands EUR)	RCP 4.5	-2,670	-5,180	-1,650
		RCP 8.5	-2,800	-5,310	-1,650
	Benefit-to-cost ratio	RCP 4.5	0.6	0.4	0
		RCP 8.5	0.6	0.4	0
Only agricultural income and avoided sediment cleaning costs	Net benefits (thousands EUR)	RCP 4.5	210	260	-1,650
		RCP 8.5	80	130	-1,650
	Benefit-to-cost ratio	RCP 4.5	1.0	1.0	0
		RCP 8.5	1.0	1.0	0
Excluding sediment cleaning costs	Net benefits (thousands EUR)	RCP 4.5	10,220	7,720	-630
		RCP 8.5	10,090	7,580	-630
	Benefit-to-cost ratio	RCP 4.5	2.5	1.8	-191.1
		RCP 8.5	2.5	1.8	-191.1

4.2.1 Avoided Sedimentation

Sediment export and erosion throughout the sub-basin result in sediment accumulation in the channel. This sedimentation is worse after floods, which can also result in larger debris being deposited in the river channel. This sedimentation and accumulation of debris also make flooding worse. Thus, it is necessary to periodically clean the channel, which is costly.

The system dynamics model simulates sediment export to the river channel. However, we do not have sufficient data to adequately model sediment dynamics within the channel. Thus, we cannot simulate the amount of sediment that accumulates. However, we can demonstrate that NBI and small dams reduce sedimentation and decrease the frequency with which sediment must be removed from the channel. Figure 7 shows a schematic representation of sediment accumulation. When the sediment in the channel reaches 100% of a specified maximum, sediment is removed from the channel. The figure shows the relative accumulation rates under the NBI scenario and a business-as-usual scenario. This evidence supports our assumption that the NBI could eliminate the need for one channel cleaning over the timeframe of analysis.

Figure 7. Channel sediment accumulation schematic. When the sediment capacity is reached, the channel is cleaned. Sediment accumulates more slowly after the NBI is implemented.



Source: Authors' diagram.

Historically, small mountainous dams have been very effective at reducing sedimentation and flooding downstream. Previous modelling studies have estimated that small dams in the mountainous region of the Kalentzis sub-basin would reduce sediment export to the river by 20%, although further research is needed to confirm this number (T. Giannakaki, personal communication, April 23, 2023). To fully understand the impact of this decrease on sedimentation in the channel would require an accurate estimate of the quantity of sediment exported from the upper basin. However, our spatial analysis does not consider topography and, therefore, likely underestimates sediment export in the mountainous upper catchment area. Thus, we make the simplified assumption that the hybrid infrastructure (NBI with small dams) would reduce the number of channel cleanings by two, compared to business as usual. Because the NBI and hybrid infrastructure have positive net benefits even when excluding the avoided costs of sediment cleaning, results are not sensitive to the assumptions that NBI avoids one cleaning and hybrid infrastructure avoids two cleanings.

Furthermore, because the small dams reduce sediment in the channel, it is likely that the hybrid infrastructure would avoid at least one more cleaning than the NBI on its own. If this is true, then the hybrid infrastructure will have larger net benefits than the NBI.

4.2.2 Extreme Weather and Climate Adaptation

The avoided costs and added benefits are slightly larger under RCP 4.5 compared to RCP 8.5 because there is more precipitation under the lower climate scenario (Figure 4). With more precipitation, there are more potential losses from erosion, so the value of avoiding those costs is greater. However, the differences between the two climate scenarios are small because, although there is less precipitation under RCP 8.5, the differences are not pronounced enough to have a large impact on the outputs of the integrated CBA.

In this analysis, we have considered the impact of precipitation on erosion. We do not consider water scarcity and the potential impacts of drought on agricultural production. We have excluded this impact because water scarcity is not a concern in the Kalentzis sub-basin. Specifically, groundwater, which is used to meet most of the water demand, is plentiful (information provided by the Local Land Reclamation Organisation of Tavropos [A. Kardamaki, personal communication, March 14, 2023]). However, if water quantity becomes a concern in the future as precipitation decreases, then NBI could avoid some of the costs of decreased water availability by increasing water retention. Similarly, water scarcity is a problem in other parts of Thessaly (Jurík et al., 2022; Kourgialas, 2021). In these areas, the avoided costs of NBI may be higher than in the Kalentzis sub-basin due to the possibility that increased water supply could improve agricultural productivity.

This analysis also does not include the impact of extreme precipitation, primarily because this will be assessed in a forthcoming hydraulic/hydrologic analysis. However, including the impacts of flooding in an integrated cost-benefit analysis would increase the net benefits (Box 3).

Box 3. Extreme precipitation and avoided flood losses

Thessaly regularly experiences flooding, causing damage to infrastructure and agriculture (Kourgialas, 2021). On average, damages are approximately EUR 2.6 million per year, and extreme events have resulted in significantly larger losses (data retrieved from the Special Secretariat for Water of the Ministry of Energy and Environment [A. Kardamaki, personal communication, March 21, 2023]). For example, flooding from Medicane Ianos in September 2020 caused economic losses of over EUR 700 million (T. Giannakakis, personal communication, April 12, 2023).

Given the magnitude of these flood losses, mitigating even a small percentage of the damage to infrastructure or reduction in agricultural productivity would result in large avoided costs and improve the economic and financial attractiveness of the NBI. For example, losses from the Ianos Medicane were at least EUR 700 million. Considering an event of similar magnitude, if NBI reduced the losses by 1%, the avoided costs would be EUR 7 million, which is larger than the total costs of the NBI. Thus, with the possibility of extreme events, the NBI could "pay for itself" very quickly when considering avoided flood losses.

4.2.3 Grey Infrastructure Comparison

The net benefits and benefit-to-cost ratio of the grey infrastructure (i.e., dike construction) are lower than those of the NBI (i.e., river restoration). Specifically, the net benefits of the NBI (EUR 12.8 million under RCP 4.5) are more than 14 times larger than those of the grey infrastructure (EUR 900,000). This is because the grey infrastructure does not improve agricultural productivity or sequester carbon. For the NBI, these two outcomes combined provide value of over EUR 17 million. Thus, although the dikes may be a less expensive way to reduce flooding (assuming it is possible for a dike to mitigate flood impacts to the same extent as the NBI), their total value, when considering numerous co-benefits, is much less than that of the NBI.

For the purpose of this analysis, we assumed the lowest possible cost for the dikes based on 1-metre-high dikes with construction costs of EUR 26.20 per metre. However, these costs would vary widely depending on the necessary height of the dikes from EUR 54.70 per metre for a 1.5-metre-high dike to as much as EUR 88.80 per metre for a 2.5-metre-high dike (A. Pistrika, personal communication, February 1, 2023). Assuming that annual maintenance costs are 1% of the construction costs (A. Pistrika, personal communication, February 27, 2023) and that the dikes will be 50 km long, the cumulative costs could be as high as EUR 11,100 (Table 3). Thus, it is very possible that the net benefits and benefit-to-cost ratio of a 50 km dike would be lower than what is shown in Table 1.

Table 3. Construction, maintenance, and total costs for a dike 50 km long as a function of height. Costs are undiscounted and cumulative over 2025–2050.

Dike height (m)	Construction costs (EUR)	Operations and maintenance costs (EUR/year)	Cumulative undiscounted costs, 2025–2050 (EUR)
1	2,620	26.2	3,275
1.5	5,470	54.7	6,838
2	6,440	64.4	8,050
2.5	8,880	88.8	11,100

We also did a sensitivity analysis on the length of the dike required to achieve the assumed benefits (Table 4). For this sensitivity analysis, we vary only the length, and therefore the costs, of the dike. We assume the benefits and avoided costs are the same regardless of the length. From this, we see that the longer the dike required, the lower the net benefits and benefit-to-cost ratio. This is as expected because a longer dike is more expensive to build and maintain. Table 4 also shows that even a dike that is only 25 km long has lower net benefits and benefit-to-cost ratio than the NBI. Thus, although we do not know how long or how high a dike must be to achieve similar flood reduction benefits as the NBI, this analysis shows that it is very likely that the integrated net benefits of a dike would be less than those of the NBI.

Table 4. Net benefits and benefit-to-cost ratio of a 1-metre-high dike as a function of length. Values are undiscounted and cumulative over 2025–2050

Dike length	25 km	50 km	100 km
Net benefits (thousands EUR)	1,408.6	896.9	-126.5
Benefit-to-cost ratio	2.7	1.5	1.0

5.0 Conclusions

This report presents the results of an integrated cost-benefit analysis for river restoration in Thessaly, Greece, focusing on the Kalentzis sub-catchment of the Pineios River Basin. We used spatial models to quantify the ecosystem services provided by the NBI and monetized environmental, economic, and social co-benefits of the flood risk reduction project. We did not quantify the avoided flood losses because a separate study is examining the hydrologic and hydraulic changes resulting from the proposed NBI interventions.

This analysis has shown that NBI and hybrid infrastructure are more cost-effective than upgraded dikes to address flood risk in the Kalentzis sub-basin. This is because, unlike the grey infrastructure, the NBI sequesters carbon and improves agricultural productivity. Furthermore, the NBI improves habitat and biodiversity. The analysis has also shown that the erosion-control services of the NBI and hybrid infrastructure provide substantial value.

Given the extent of these co-benefits, quantifying the flood risk reduction is not necessary to justify the investments in river restoration. However, flooding is a problem in the area. Understanding the flood reduction benefits of the NBI is important, and including this avoided cost in our analysis would raise the net benefits. The forthcoming study on hydraulic and hydrologic changes will indicate the extent to which river restoration can mitigate flooding and can, therefore, complement the SAVi assessment.

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