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Executive Summary

1. Introduction

Amidst a global health and economic crisis and with an ongoing climate and biodiversity crisis, the call to transition to a green and inclusive economy rings ever louder. Unfortunately, Covid-19 recovery packages largely include business as usual projects that cannot be labelled as “green”¹. Nevertheless, economic recovery packages could still be instrumental to shift the paradigm towards a society and economic system that values nature and focusses investments on solutions that reduce the impacts of natural hazards, help mitigate and adapt to climate change and protect and enhance biodiversity. Nature-based Solutions in the realms of land use, forestry and river management are widely recognized (e.g. by IPBES, WEF, WBCSD, EC) as a promising avenue to these ends.

Pollution and human interventions in hydrology and land use have compromised the ecological state of rivers across the globe. In Europe most rivers are strongly modified by human interventions², resulting in a severe decline in populations and diversity of freshwater species: 60% of European water bodies has a moderate to bad quality status³. At the same time, climate change is resulting in changing rainfall patterns and more extreme weather events, leading to increased occurrence of floods and droughts⁴. In many cases, grey infrastructure is the first response to manage flood risk and adapt to climate change. In general, institutional set-up and incentives of public authorities responsible for water management are geared towards construction of grey, monofunctional infrastructure, instead of serving multiple objectives and evaluating a range of benefits.

The need to find a way to use our natural resources in a more sustainable manner is recognized in the European Green Deal, expected to mobilize at least € 1 trillion⁵, which aims to support green economic development in the EU and will include major investments in, among other things, protection and restoration of forests, soils, wetlands and rivers. Investments in these systems are typically identified and coordinated by public authorities in the course of river basin management. Economic evaluation often plays an important role in the selection of alternative solutions, demonstrating their economic rationale and identifying optimal solutions⁶. Embedding NbS in this process is not always easy: NbS have to compete with decades of institutional specialization and knowledge accumulation on technical, grey infrastructure solutions.

In this report, we examine whether NbS are valid investment to boost ecosystem services derived from European rivers and to enhance green economic development. We define the role NbS can play in a riverine context (section 2) and review the evidence base on the economic rationale of investing in NbS (section 3). Two cases are used to explore the potential of NbS investment to promote green recovery and economic development, in the Danube and Elbe.

2. NbS in freshwater ecosystems

Freshwater ecosystems are vital for the existence of human lives as they provide transport routes, hydropower, irrigation and drinking water and a wide range of other ecosystem services including recreation, landscape and biodiversity, contributing to human health and well-being. Unsustainable exploitation and modification of river functions and of ecosystem services by humans can lead to enormous impacts on river systems, often resulting in negative effects on biodiversity and nature and reducing the capacity to deliver the full spectrum of ecosystem services.

Balancing between different functions and users is the key to sustainable river management, and highly needed to tackle the full range of societal challenges facing river systems today. Where we often optimize or transform river systems for a single function in current practice, NbS can play an important role in making a shift towards a more natural, multi-functional river management approach. Nature-based solutions are the actions to conserve and restore ecosystems to make use of ecosystem services for societal purposes, such as climate adaptation or mitigation of floods and droughts.

Along the entire river system, from upstream headwaters to downstream estuaries, there are opportunities for small and large-scale NbS that support climate resilience (Figure 0.1). In upper river sections this includes sustainable land use management, restoration of natural forests, grasslands and peatlands and stream protection. In middle and lower river section, NbS include, amongst others, re-meandering, riparian shading, protecting marshy streams and floodplains, reviving or creating side channels, restoring and reconnecting floodplains, widening and lowering floodplains, restoring wetlands and constructing natural retention areas. In urban areas, disconnecting rainwater drainage, water storage in streets and public spaces replacing impermeable surfaces and sound zonation and building codes all contribute to reducing flooding.

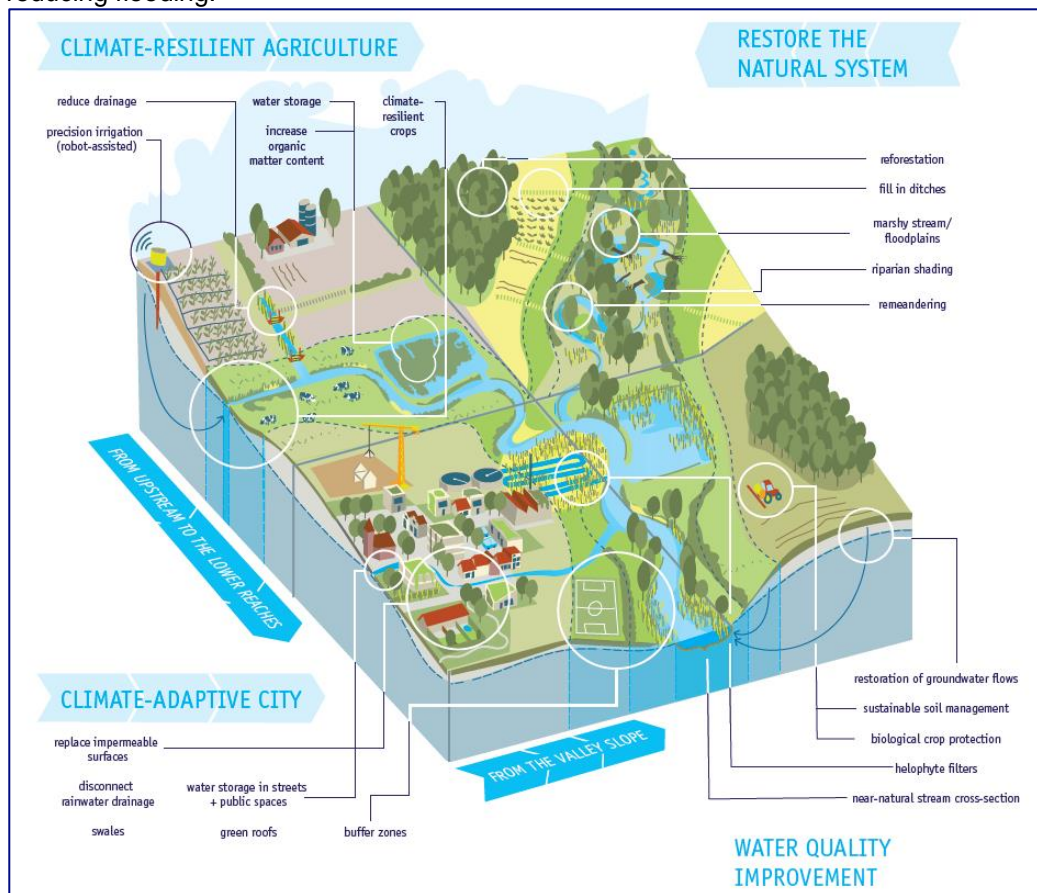


Figure 0.1 Action perspectives for climate resilient river valleys⁷.

Making combinations between NbS and hard infrastructure (hybrid solutions) and with non-structural interventions will most likely result in strategies that meet multiple management objectives in a cost-effective manner. To improve management of the entire river, localized NbS can be used in concert with large-scale approaches, such as integrated river management.

3. Economic rationale of investing in NbS

Public authorities employ a range of criteria and requirements to determine the merits and rationale of investment decisions in river management. Economic evaluation, e.g. in the form of cost-effectiveness or cost-benefit analysis, is often a key aspect in the decision-making process. To date, there is limited but increasing experience with quantifying the value of NbS in river systems: the growing number of initiatives in river restoration and application of NbS in freshwater ecosystems rapidly increases the evidence base on NbS effectiveness and cost-effectiveness.

1. Healthy rivers deliver valuable ecosystem services that are a prerequisite for human well-being and economic development

At its core, economic value is about the well-being of humans. Healthy rivers and their floodplains provide a wide range of vital ecosystem services that benefit humans, including water retention and regulation, biodiversity, drinking water provision, flood protection, carbon sequestration, erosion protection, spatial quality, recreational amenities (e.g. swimming, boating, fishing, birding, hiking), nitrate and phosphorus cycling^{8,9}. Optimizing one of these functions may negatively affect other functions: disturbed ecosystems have a disturbed potential for ecosystem service provision¹⁰. Against this backdrop, investment decisions in river systems should be analyzed under the wider framework of human wellbeing (Figure 0.2). This includes valuation of ecosystem services. The economic value of these ecosystem services consists of 'use' and 'non-use' values and can be calculated using market and non-market valuation approaches.

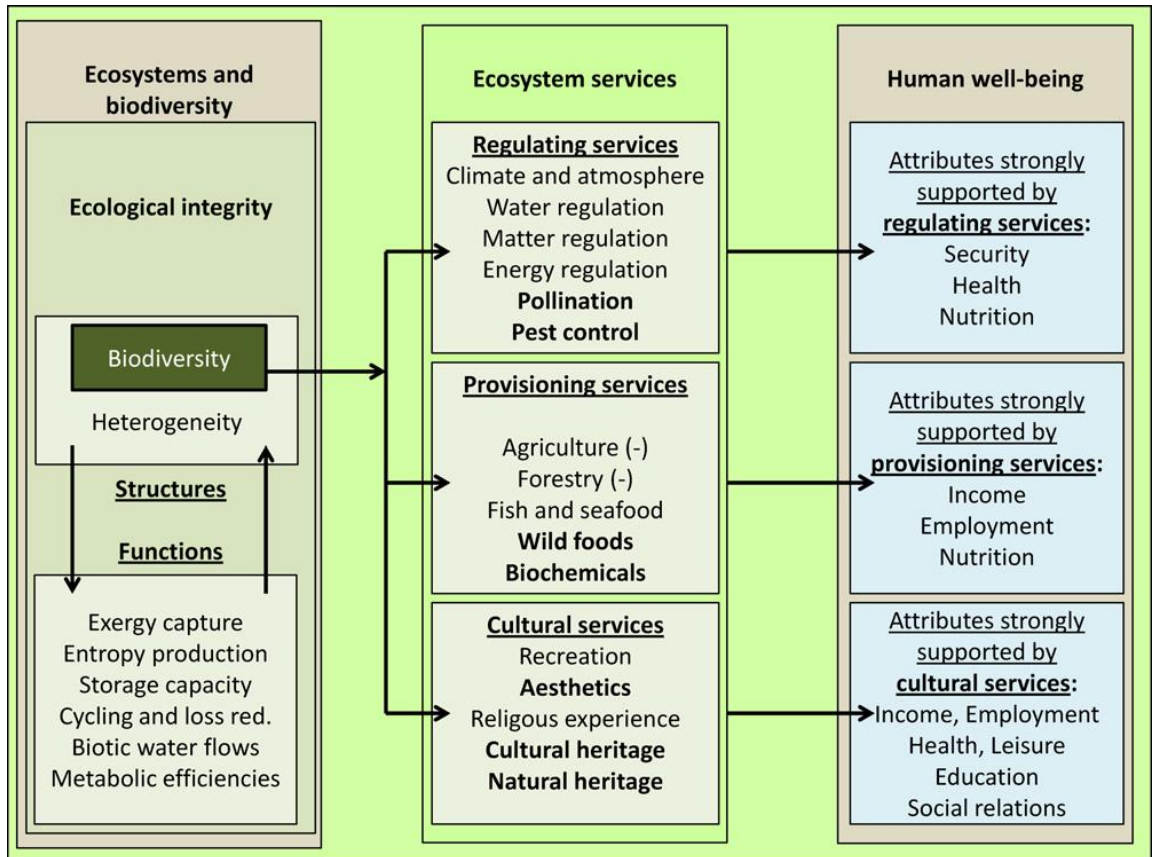


Figure 0.2 The relation between ecosystem services and human well-being¹⁰

2. NbS can play a crucial role in restoring Europe’s rivers, thereby enhancing multiple ecosystem services and optimizing economic potential, while at the same time preserving or enhancing biodiversity

The socio-economic case for large-scale investments in NbS to restore rivers to a more natural state and mitigate flood and drought risks is clear. Large-scale NbS implementation and uptake may reverse biodiversity decline and aid in climate change mitigation and adaptation. The myriad of ecosystem services delivered by rivers and their floodplains contribute directly or indirectly to human well-being and economic value. Cost benefit analyses of projects across Europe demonstrate that NbS or hybrid solutions are more attractive investments from a socio-economic point of view than their grey alternatives, when taking the full range of functions and ecosystem services into account^{11–13}.

Floodplain restoration in the Elbe

In the past, extensive embankments have been constructed along the Elbe to support economic development, converting natural floodplain forests to pasture-dominated grasslands. This has made the Elbe prone to flash floods in the upper sections, and high river discharges in the lower sections. Additionally, water quality in the Elbe is below the European WFD objectives. After severe flooding in 2002, by 2012 650 ha floodplain had been restored to reduce the flood risk and provide more 'room for the river'. Today, there is a potential to scale up floodplain restoration and to increase the project pipeline.

Grossman et al, (2010) evaluate the economic value of three alternative floodplain restoration strategies in the Elbe across the functions of flood protection, water quality, biodiversity protection and reducing GhG. The three alternatives include 1) large-scale (34.659 ha) floodplain restoration with dike reallocation (full restoration); 2) controlled retention polders (25.577 ha) which keep the current land use and dike location in place (no restoration), and 3) a combination of controlled retention polders and floodplain restoration (partial restoration; 7.545 ha).

The results of the economic comparison show that full floodplain restoration is the most attractive from socio-economic point of view, when additional benefits to water quality and biodiversity are considered and monetized: alternative 1 has a net present value (benefits – costs) of €2520 million, as opposed to €354 million in alternative 2, and €1418 m in alternative 3. If only flood control benefits are considered, the alternative with controlled retention polders would be most attractive: this illustrates the value and need for a broad economic evaluation including ecosystem services to arrive at a fair basis for decision making.

Even when not considering the full range of benefits but comparing NbS with grey alternatives from a mono-functional perspective, NbS or hybrid solutions may prove to be more cost-effective. This depends on the local characteristics, such as the state of the ecosystem and degree of modification, desired performance level and the time horizon of the economic analysis. Comparing strategies with respect to lifecycle costs is essential¹⁴.

An illustrative example lies in the field of dam and weir infrastructure. Over the past decades many rivers in Europe have been dammed – there are over a million barriers fragmenting Europe's river systems - and removal is often perceived extremely expensive. However, the technical lifespan of dams and weirs typically exceeds their functional lifespan: they often stay in place, sometimes for over 100 years, although water supply and water safety no longer depend on the dam. In this case, removal of the dam may be up to 10-30 times cheaper than continuous repair and maintenance over time^{8,15}.

With more inclusive economic methods and a longer-term outlook for management and intervention evaluation, the evidence base that NbS is often more cost-effective and economically attractive than conventional engineering alternatives is growing.

Economic rationale of floodplain restoration in the Danube

During the communist era the natural character of the Danube has been severely altered with extensive embankments, dams and drainage works to allow for intensive agriculture in the floodplains: to this day only a small percentage of floodplains remain in natural condition (75% in the lower Danube and 28% in the Danube Delta¹¹⁵). These developments came at the cost of severe ecological degradation, with many river species endangered, drastically changed soil regimes in the floodplains and changes in hydrological and geomorphological regime, leading to increased flood probability and a disturbed sediment balance. Today, many embankments in the lower Danube are in disrepair. Facing climate change, high embankment restoration costs and many river species severely endangered, now is the time to reconsider floodplain management in the lower Danube and Danube Delta.

A large-scale investment programme (estimated at € 7 billion) restoring of 4000 km² floodplains will have many economic benefits:

1. If no new policy is adopted, an estimated €572 million in investments are required to preserve the current flood protection level in the lower Danube by restoring and maintaining **degraded embankments**. Large-scale floodplain restoration **can reduce these costs by €230 million**.
2. If the current protection level is maintained, flood risk is expected to increase due to climate change, estimated in total around €3,3 billion 2100. Reinforcing the current protection system will lead to a technical and institutional lock-in – limiting the potential to shift to a different flood risk management strategy (e.g. floodplain restoration) in the future. **Floodplain restoration will reduce flood risk in the long term by €1,36 billion and bring more flexibility in flood management strategies in the long-term.**
3. Supporting economic recovery of the Covid-19 crisis through **providing an estimated 250.000 jobs in the short term** (to compare: New Zealand is currently using a \$1 billion budget to create 11.000 nature jobs to support economic recovery)
4. Under the current system, regional economies in the Danubes's floodplains will remain largely agricultural and little diversified, making them sensitive to economic and climatic shocks – already yields are declining due to salinization and aridification. Although floodplain restoration will see reduced agricultural yields in the floodplain, the resulting ecosystem services will **support diversification of the local economy** (-€766 million), bringing €1150 million in tourism and €140 million in fishery benefits.
5. Under current management, ecological degradation of the Danube will continue, with consequent loss in ecosystem services and possibly penalties for non-compliance with EU Habitat and Water Framework Directives - or high opportunity costs required to meet objectives. Floodplain restoration will contribute **improve ecological quality, restore hydrological and morphological processes, water quality and biodiversity**.

Although undoubtedly a costly affair, the benefits of floodplain restoration closely fit the objectives of the EU Green Deal and long-term recovery budget: supporting a greener, more resilient Europe with climate change and biodiversity protection at its core.

** Numbers based on stylized, quick-scan CBA using coarse assumptions*

3. NbS investments create employment opportunities in the short-medium term and stimulate economic sustainable development in the long-term

Investment in ecological restoration directly creates 6-33 jobs per invested million €¹⁶: tree planting and floodplain restoration are among the most labor-intensive activities, making NbS in river systems a very suitable investment for public employment programs in support of economic recovery. Created jobs include low-skill and fast-implementing mostly local jobs in small and medium-sized enterprises, as well as jobs in engineering companies and environmental science ¹⁷. In the long term the ecosystem services strengthened by large-scale NbS stimulate output and employment in a range of other industries through supplier and household spending effects. As such investments in NbS have the potential to contribute to more, and more diversified, local livelihoods in the long term, such as the fishing sector and recreation and tourism.

4. The way forward

Around the globe, policy makers and investors are increasingly looking for solutions that stimulate development whilst slowing down or adapting to climate change and conserving and recovering biodiversity: the call for transition towards a green and inclusive economy rings ever louder. Healthy rivers and freshwater ecosystems are vital for economic development and water security: ecosystem services provided by rivers benefit multiple beneficiaries and contribute to an attractive, healthy living environment and provide a solid basis for diversified local livelihoods, making local communities more resilient. Yet, despite the high economic value of the wide array of ecosystems services, rivers across the globe have been modified for irrigation, hydropower, flood protection and navigation at the expense of other services, including a severe decline in populations and diversity of freshwater species. Current economic methods in investment decision making in river management largely neglect the value of nature: a fundamental change in decision making metrics is needed.

In this report, we compiled evidence on how a wider scope in reviewing the economic rationale of river management strategies supports the case for investment in (hybrid) NbS over traditional engineered management strategies of Europe's rivers. The socio-economic case for large-scale investment in NbS to restore Europe's rivers to a more natural state is clear:

1. Large-scale NbS implementation and uptake may reverse biodiversity decline and aid in climate change mitigation and adaptation.
2. NbS in river management contribute to restoring ecosystems of modified river systems and provide multiple co-benefits. Where grey infrastructure solutions may be cost-effective from a single-objective perspective in the short term, they are often inflexible and unsustainable under climate change and less attractive than NBS once a longer time horizon, wider spatial scope and multiple functions are considered.
3. Investments in NbS for river restoration are an attractive avenue for sustainable economic recovery as NbS: creating jobs in the short term, supporting economic development in the medium term, and supporting a shift towards nature-friendly, low-carbon, diversified local economies in the long term.

Although the integration of NbS in river management is ongoing across Europe, NbS are not yet mainstream and progress is slow. There are still many barriers hampering a speedy transition. Particularly large-scale NbS projects can be more complex to implement than grey alternatives due to their cross-disciplinary and cross-sectoral nature. Institutional compartmentalization and consequent limited scope in project development and appraisal act as disincentives for their uptake.

To address these barriers and support mainstream investment in NbS in river management, public authorities should:

1. Mandate standard inclusion of NbS in infrastructure project formulation processes.
2. Include a wide scope integrating all potential benefits in project appraisal, using a sufficiently large spatial and temporal scope and including upstream and downstream effects of all measures. This can be done by mandating a lifecycle cost approach and wider ecosystem service valuation in CBAs and taking long-term efficacy and depreciation of all proposed alternatives into account.
3. Adjust or strengthen the institutional framework throughout project planning cycles to support the decision to choose NbS,. For example, collaboration across jurisdictional and disciplinary boundaries is difficult, but exactly what is needed to identify and create multi-functional infrastructure like NbS. To support this, an institutional and legislative mandate for dealing with cross-sectoral issues at (sub) basin level is needed.
4. Prepare an enabling regulatory environment that incentivizes innovations such as NbS and discourage harmful activities that do not capture value of nature.

Throughout the EU, COVID-19 recovery, sustainable economic development and climate change adaptation funds offer an excellent opportunity to create incentives to accelerate and upscale NbS implementation. These funds can leverage existing funding to enable collaborations between departments and stakeholders at the basin level, to come up with a green, inclusive, multi-benefit investment portfolio in river systems, and help to reduce the financial risks of NbS project initiatives by providing budget guarantees upfront. At the policy level, the EU Green Deal, EU Adaptation Strategy and Biodiversity Strategy can be used to increase supporting incentives for NBS, such as legally binding ecological restoration targets.

The time to act is now

The clock is ticking on Europe's river systems. Climate change and biodiversity decline pose increasing challenges for societies. In response, the momentum is there for upscaling and mainstreaming NbS. Economic recovery packages and the EU Green Deal can catalyze this process: now is the time to make a change from old ways to new. To develop and invest in a diversified portfolio of NbS and conventional solutions to dealing with flood, drought and river management. To work with nature instead of against it. The examples are there: all we need to do is recognize the opportunities, be bold and rise to the challenge.

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1 Introduction

Presently, it is estimated that half of the world's population lives in areas that are water-stressed for part of the year ¹⁸. At the same time, annual economic damage and the number of people affected by flood events are rapidly rising ¹⁹. In Europe, flood risk is projected to increase under climate change from current expected annual damage (EAD) of €6,5 billion to €14-41,5 billion by 2100, in particular across Western Europe, northern Italy and the Upper Danube ⁴. Meanwhile, increasing water demands from agriculture put pressure on available water resources ²⁰. Damming and diking of European rivers have altered the natural flow of water and pollution from industries and agriculture has degraded water quality ²¹. There are well over 1.000.000 barriers (e.g. dams, weirs, ramps and culverts) fragmenting Europe's river systems, including more than 20.000 hydropower dams with an additional 8000 under consideration ². Populations of freshwater species are rapidly declining²² and 60% of European water bodies has a moderate to bad quality status³.

Amidst a global health crisis and with the prospects of a global climate and biodiversity crisis, people are looking for solutions that stimulate development without adverse impacts on climate and biodiversity. Natural systems can play an important role in reducing impacts of natural and man-made hazards and in mitigating and adapting to climate change, while also preserving biodiversity. So-called Nature-based Solutions (NbS) make use of these capacities of natural systems by managing, safeguarding or restoring them to address societal challenges.

A growing number of international organizations, multi-lateral agencies, financing institutions, and private businesses see the potential of NbS to address climate change and natural disasters in an efficient and sustainable manner. A total of 77% of nationally determined contributions (NDC) to the Paris Agreement on Climate Change include NbS to adapt and mitigate climate change. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) report endorsed NbS to conserve biodiversity²³. In the World Economic Forum's (WEF) New Nature Economy series nature-positive solutions are specifically recognized for their value in creating jobs and business opportunities, while simultaneously adding value to nature²⁴. The World Business Council for Sustainable Development's Natural Infrastructure for Business (NI4Biz) platform promotes investing in natural infrastructure. At the EU policy level, the EC recognizes in the €1 trillion Green Deal⁵, EU biodiversity strategy and EU adaptation strategy and corresponding research programmes (Horizon 2020; Horizon Europe) that NbS are instrumental in achieving a sustainable economy in Europe by turning climate and environmental challenges into opportunities that create synergies among nature, society and the economy²⁵.

The large-scale application of a variety of NbS in freshwater ecosystems can contribute to an improved quality of life for people (e.g. health, attractive environment), increased resilience to climate-related disasters, increased prosperity and wellbeing for all and contribute to a healthy planet by restoring and conserving biodiversity and natural habitats. In the recent decades, the widespread recognition of NbS and corresponding global frameworks and initiatives have resulted in the implementation of successful NbS projects across Europe in various landscapes and contexts. However, for river systems specifically, many of these projects have been mostly small-scale pilot projects, implemented along limited stretches of river systems. Also, in [prevailing economic valuation methods and investment decision making in river management across Europe, projects are mostly assessed on a mono-functional basis and the co-benefits of NbS remain largely unaccounted](#). Project benefits and impacts are often appraised solely within the project boundaries and on small spatial and temporal scales.

This means that essential benefits of NbS related to their adaptive, multi-purpose and sustainable character, are being disregarded. Also, NbS can typically have positive effects beyond the project site, for example by reducing flood risk not only locally, but also upstream and downstream of the project. Without accounting for these positive effects of NbS, the full potential of NbS remains underexploited. Existing disincentives for NbS – for example, as they are not standard practice, they are often regarded troublesome due to more complicated design and implementation - will inhibit their application at scale.

Safeguarding healthy rivers and developing sustainable management strategies for rivers and freshwater resources is urgently needed for both human well-being and sustainable development and nature. Conserving and restoring robust and resilient systems are more important than ever. There is a widespread call by scientists, politicians and civil society to scale up investment in this direction and aim for a 'green recovery' from the current economic crisis. [Integration of NbS in river management strategies will aid in shifting investments in freshwater ecosystems as a way of enhancing future sustainable economic development, resilience and wellbeing whilst conserving and restoring nature.](#) For NbS to be upscaled to their full potential, long-term and large-scale benefits must be recognized in a more structural manner, so they can become a regular part of investment portfolios. The strong economic rationale for NbS implementation and credible business cases should be elaborated on a structural basis to enable this transition. Although funding in NbS has increased over the last years, insight in the socio-economic merits is still largely lacking. [Building the evidence base of the socio-economic merits of NbS can contribute to convincing public investors to integrate NbS interventions in their infrastructure project portfolios.](#)

Overall, low-carbon and climate-resilient investments deliver far higher economic returns than investments in traditional infrastructure and fossil fuels. Restoring ecosystems is an investment in the basis of our economies as ecosystem services provide the main resources for farming, fishing, forestry and tourism. These services are valued at \$125 trillion annually ²⁶, and globally employ 1,2 billion people. The application of a variety of NbS in freshwater ecosystems at an appropriate scale (it should not be piecemeal) can contribute to improve the quality of life for people (e.g. health, attractive environment), increase resilience to climate-related disasters, increase prosperity and wellbeing for all and contribute to a healthy planet by restoring and conserving biodiversity and natural habitats.

In this report we build economic comparisons for river management strategies that work with NbS versus traditional engineered management strategies. We do this by first defining optimal NbS and river management strategies (Chapter 2) and by explaining how co-benefits can be quantified and illustrating this with supporting evidence from European rivers (Chapter 3). We show benefits and economic returns of both NbS and business as usual for different user groups and beneficiaries for two cases: the Danube (Chapter 4) and the Elbe (Chapter 5). Chapter 6 indicates how optimal strategies can be operationalized financially and politically. Chapter 7 present conclusions and the way forward.

2 Nature-based Solutions in freshwater ecosystems

2.1 Ecosystem services

Freshwater ecosystems are vital for the existence of human lives as they provide transport routes, hydropower, irrigation and drinking water and a wide range of other ecosystem services including recreation, landscape and biodiversity, contributing to human health and well-being. Rivers and their floodplains can provide a wide range of ecosystem services, defined as the benefits humans derive from the natural environment and healthy ecosystems. Including provisioning, regulating and cultural ecosystem services as well as underlying supporting ecosystem services such as pollination, habitat provision and nutrient cycling, these services contribute to human well-being in terms of security, health, and social and cultural relations (Figure 2.1). Clean and free-flowing rivers with high biodiversity as part of a high quality rural landscape are a key asset for recreation and tourism, bringing income to local populations and diversification of the economy⁸. The most common ecosystem services of rivers are provisioning of fish, water and air quality, drinking water security, flood protection, carbon sequestration, recreational amenities (swimming, boating, fishing, birding and hiking), nitrate and phosphorus cycling and water retention^{9,28}.

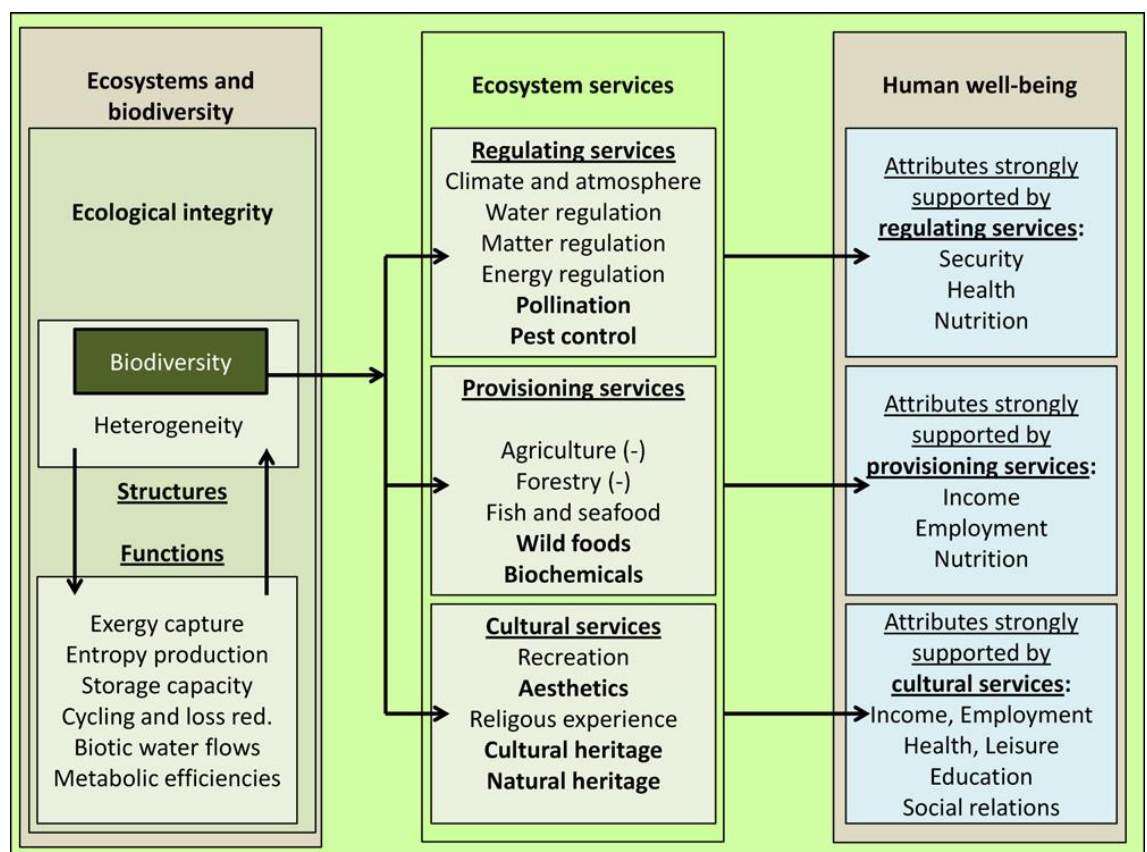


Figure 2.1 Ecosystems and their links to human well-being¹⁰

Prevalence of ecosystem services depends on the level of modification of the ecosystem (Figure 2.2). Modification typically leads to low ecological integrity, biodiversity and regulating services (e.g. the system is more prone to floods and droughts). In heavily modified systems, the ecosystem has a high productivity in specific ecosystem services, e.g provisioning ecosystem service (e.g. agriculture in floodplains, high fish production). More natural systems have a higher connectedness and are more heterogenous. In this state, regulating or cultural services can take the upper hand (e.g. recreation). The more natural an ecosystem becomes, the more complex it usually becomes, and limited accessibility may inhibit cultural services, and regulating services, such as biodiversity and ecological integrity, take the upper hand¹⁰.

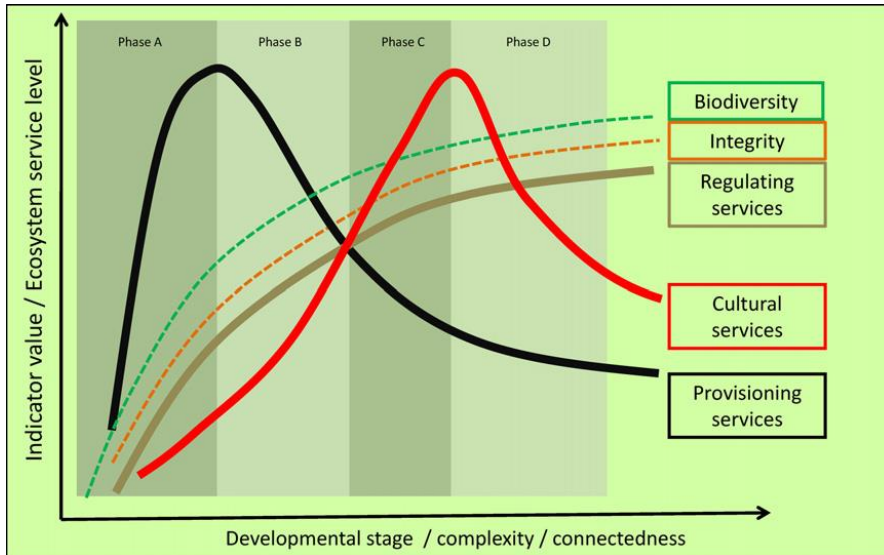


Figure 2.2 Development of biodiversity, integrity and ecosystem services under degree of modification of an ecosystem (phase A: highly modified, phase D; natural)¹⁰.

In Europe, many rivers have been modified to optimize them for specific functions, for example by building reservoirs to store water for hydropower or irrigation. Unsustainable exploitation and modification of river functions and of ecosystem services by humans can lead to enormous impacts on integrity of river systems, often resulting in negative effects on biodiversity and nature and reducing the capacity to deliver the full spectrum of ecosystem services. Interventions in river management should be developed with all services in mind and aim to conserve or enhance the natural values and biodiversity. Healthy and diverse ecosystems have a higher resilience to bounce back from disturbance events. Nature-based Solutions (NbS) can help to shape interventions in the most natural way. NbS are defined as actions to protect, sustainably manage, and restore natural or modified ecosystems to address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits²⁹. NbS are an important element in disaster risk management and climate change adaptation and mitigation. NbS typically support a wide range of ecosystem services and do not show adverse effects on other services, which conventional engineering tends to do. NbS in combination with conventional engineering, can constitute the basis for returning European rivers to a more natural state, striving to balance multiple services and ensuring water availability and safety.

2.2 Working with rivers

Working towards healthy European rivers requires action on two levels. Balancing between different functions and users on a basin scale is the key to sustainable and integrated river management. This is urgently needed to tackle the full range of societal challenges facing river systems and can draw from concepts developed to manage rivers in an integrated and multidisciplinary manner, such as Integrated Water Resource Management (IWRM), Integrated River Basin Management (IRBM) and Natural River Management (NRM). NRM aids in valuation of interventions in river basins with a focus on maintaining flows of water, sediment and nutrients. The most important elements of NRM are that projects should include multiple objectives, reduce avoidable interference and apply a risk-based approach for investment decisions and infrastructure construction. To structure and facilitate integrated management, planning cycles are generally used (Figure 2.3). These cycles help to develop an integrated master plan and translate this plan into a strategy that is compiled of multiple measures.

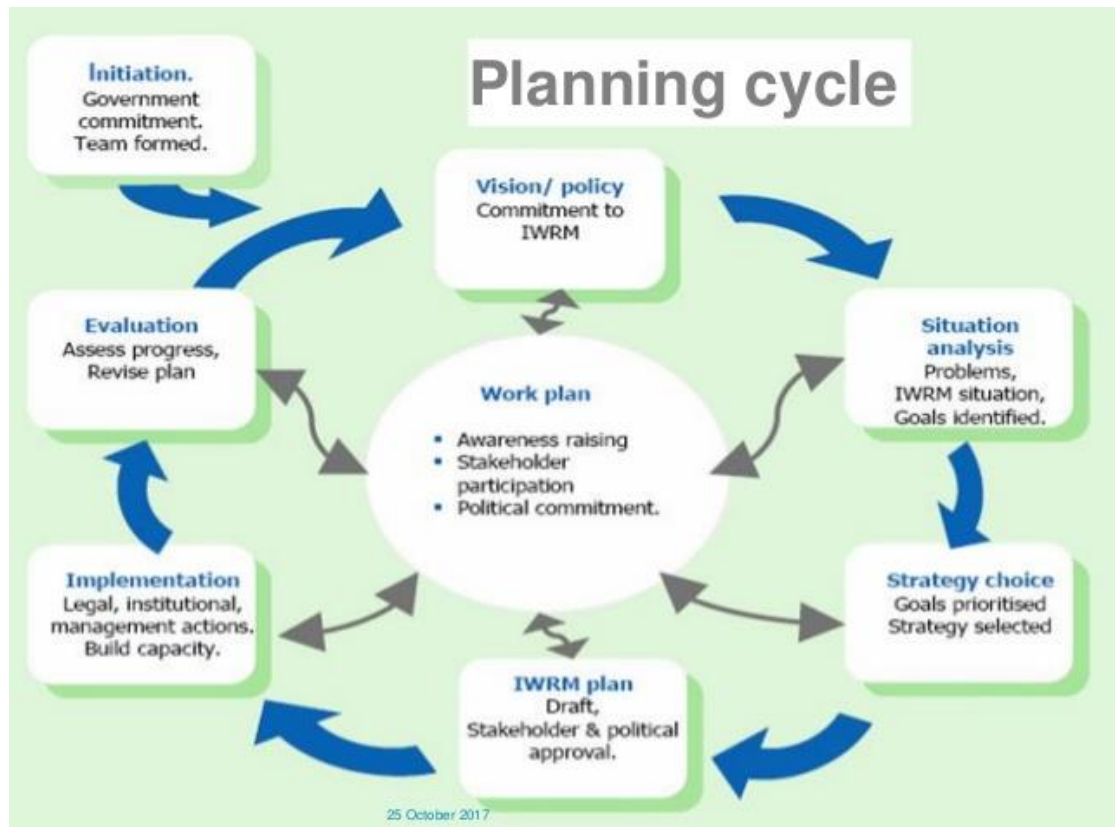


Figure 2.3 Example of a planning cycle sketching the different stages of integrated water resource management. Similar cycles are available for Flood Risk Management and for implementation of Nature-based Solutions (Copyright: Deltares 2017, DSD-INT 2017 Establishing Integrated Water Resources Management for River Basins Planning guidelines - Ter Maat)

River management is still heavily dominated by hard or grey infrastructure. However, grey interventions can result in unprecedented and irreversible changes. For example, it is often thought that straightening, narrowing, embanking, and shortening a river ('regulation') will improve navigation and mitigate flood risk. For example, in the nineteenth century the Upper Rhine River in Germany was regulated. This straightening of the Rhine was effective at first, but over the years flow velocity and erosion in the channel increased and led to 10 meter incision of the riverbed, and navigation became nearly impossible. To make the Upper Rhine navigable again, a 50 km by-pass canal was constructed in the middle of the 20th century (Grand Canal D'Alsace).

In turn, this diversion of the main discharge caused a dramatic drop in groundwater level in the area, resulting in the desiccation of natural and agricultural areas upstream, while increasing flood hazard downstream. Hence, nowadays floodplain restoration projects are still being implemented along this stretch of the Rhine to delay discharge and retain water upstream to mitigate for upstream drought effects and downstream floods. This illustrates that interventions in river basins should include multiple objectives (e.g. not only navigation, but also agriculture, flooding and nature) and should take effects in the entire river system into account (upstream and downstream of the intervention).

2.3 Working with NbS in rivers

NbS can play an important role in making a shift towards a more natural, multi-functional river management approach. NbS can be implemented along the entire river system, from upstream headwaters to downstream estuaries. In rivers, attenuating peak flows and optimizing water availability are often important objectives to mitigate against floods and droughts. These objectives are translated in strategies (Figure 2.4), and these strategies are realized through combinations of diverse interventions (Table 2.1). Strategies for mitigation of floods and droughts often focus on retaining water in upstream areas, storing and delaying water in the midsection and discharging in the downstream part. Making combinations between NbS and hard infrastructure (hybrid solutions) and with non-structural interventions will most likely result in a portfolio of measures that can meet multiple management objectives in a cost-effective manner. The portfolio that meets the demands best depends on the exact objectives.

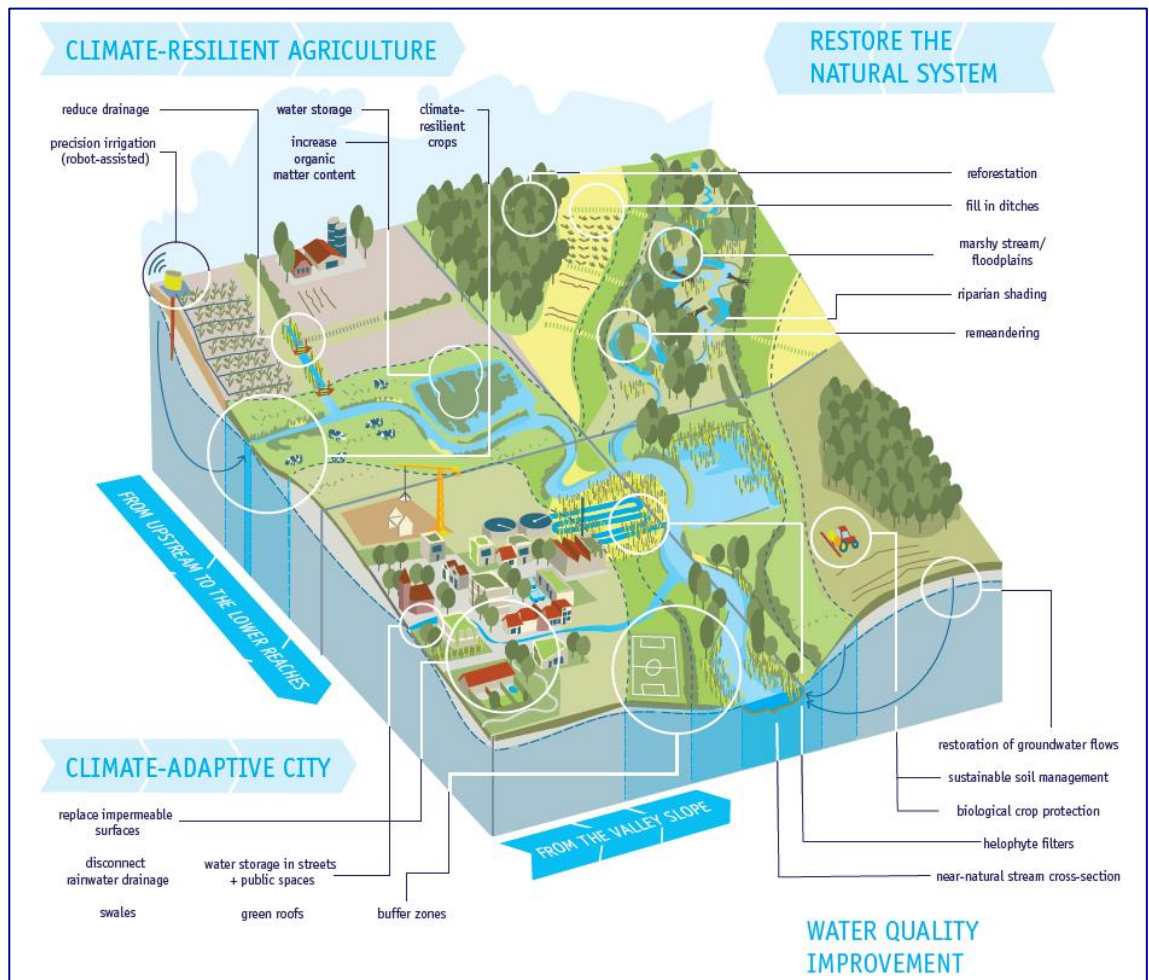


Figure 2.4 Action perspectives for climate resilient river valleys. From (Stowa, 2020)

Table 2.1 Overview of interventions in rivers. Colors indicate NBS (green), hybrid (light green) and grey (grey) solutions.

	Interventions	Effects on floods and droughts	Other benefits	Possible costs
U P S T R E A M	Restoration of natural forests, grasslands and peatlands	<ul style="list-style-type: none"> • Reduces peak flow • Reduces risk on flash flooding and land slides • Increases infiltration capacity 	<ul style="list-style-type: none"> • Increases natural value if native ecosystems are restored • Increases recreation potential • Strongly reduces erosion and improves soil composition 	Loss of land for agriculture
	Sustainable land use management and improve agricultural practices	<ul style="list-style-type: none"> • Reduces risk on flash flooding and land slides 	<ul style="list-style-type: none"> • Strongly reduces erosion 	Alternative crops and cropping methods need to be adopted, reducing capacity for certain popular crops
	Construction of retention areas (green or grey)	<ul style="list-style-type: none"> • Reduces peak flow • Increases retention capacity • Increases infiltration capacity 	<ul style="list-style-type: none"> • Possible natural values • Possible recreational values • Water storage • Decrease urban heat effect 	Only effective at certain locations in the river basin and effectiveness strongly depends on duration of discharge peaks and on retention capacity
	Building codes/zonation	<ul style="list-style-type: none"> • Increase discharge capacity • Increase infiltration capacity 	Potential for development of nature and recreation areas	Enforcement of zoning proves troublesome
M I D S T R E A M	Lift-up/ Relocate Communities	<ul style="list-style-type: none"> • Increase discharge capacity • Increase infiltration capacity 	<ul style="list-style-type: none"> • Potential for development of nature and recreation areas • Potential for agricultural use 	Often difficult with respect to social safeguards. Needs a good community involvement and consultation process.
	Meander restoration	<ul style="list-style-type: none"> • Reduces peak flow • Increases infiltration capacity 	<ul style="list-style-type: none"> • Decreases bed degradation • Improved water quality • Natural value • Aesthetics 	Loss of land
	Creating/ reviving side channels	<ul style="list-style-type: none"> • Reduces peak flow • Increases infiltration capacity 	<ul style="list-style-type: none"> • Decreases bed degradation • Natural value • Aesthetics 	Loss of land
	Floodplain widening/ restoration	<ul style="list-style-type: none"> • Reduces peak flow • Increases retention space • Increases infiltration capacity 	<ul style="list-style-type: none"> • Natural value • Aesthetics • Decrease bed degradation 	Loss of protected land
	Floodplain lowering	<ul style="list-style-type: none"> • Reduces peak flow • Increases infiltration capacity 	<ul style="list-style-type: none"> • Decreases bed degradation • Sets back succession 	Loss of seedbank and present vegetation

D O W N S T R E A M	Embankment	<ul style="list-style-type: none"> • Blocks flooding locally • Increases flow velocity • Reduces infiltration time 	<ul style="list-style-type: none"> • Constant fairway 	May cause higher flood peaks and flow velocity downstream
	Partial/full embankment removal	<ul style="list-style-type: none"> • Reduces peak flow • Increases area for water retention • Increases infiltration capacity 	<ul style="list-style-type: none"> • Decreases erosion • Space for wetland restoration 	Loss of protected land
	Summer and winter dikes	<ul style="list-style-type: none"> • Two levels of protection against floods 	<ul style="list-style-type: none"> • Fertile sediment deposition still allowed on agricultural land behind summer levee 	Land that floods periodically can only be used for certain functions
	Wetland restoration (connected to the river)	<ul style="list-style-type: none"> • Reduces peak flow • Increases retention area • Increases infiltration capacity 	<ul style="list-style-type: none"> • Increases recreational value • Increases natural value • Improves water quality 	Effects on flooding strongly depend on location of wetland in the basin and flow path
U R B A N	Wadi's/bioswales	<ul style="list-style-type: none"> • Reduces peak flow • Increased retention capacity 	<ul style="list-style-type: none"> • Decrease urban heat effect • Improves water quality • Aesthetics 	Semi-natural and more maintenance than concrete storm water run-off
	Construction of retention areas (green or grey)	<ul style="list-style-type: none"> • Reduces peak flow • Increases retention capacity • Increases infiltration capacity 	<ul style="list-style-type: none"> • Possible natural values • Possible recreational values • Water storage • Decrease urban heat effect 	Only effective at certain locations in the river basin and effectiveness strongly depends on duration of discharge peaks and on retention capacity
	Building codes/zonation	<ul style="list-style-type: none"> • Increase discharge capacity • Increase infiltration capacity 	<ul style="list-style-type: none"> • Potential for development of nature and recreation areas 	Enforcement of zoning proves troublesome
	Lift-up/ Relocate Communities	<ul style="list-style-type: none"> • Increase discharge capacity • Increase infiltration capacity 	<ul style="list-style-type: none"> • Potential for development of nature and recreation areas Potential for agricultural use 	Often difficult with respect to social safeguards. Needs a good community involvement and consultation process.

2.4 NbS Effectiveness for mitigation of floods and droughts

With a growing number of initiatives in river restoration and application of NbS concepts in freshwater ecosystems, the evidence base on their effectiveness and cost-effectiveness is increasing rapidly. Despite the lack of proper monitoring in many projects, overall river restoration has proven to be effective for mitigation of downstream flooding.

Nature-based Solutions can be implemented along the full river system, from upstream headwaters to downstream estuaries. However, for each river section and for each desired function specific interventions are most effective (Figure 2.4). Additionally, for certain interventions impacts may reach upstream and downstream. Hence, for solving floods and droughts causes and possible interventions, upstream, downstream and locally can be explored. In upstream and midstream areas where usually slopes are steeper, several NbS can help with retaining water (Figure 2.5). Land-use management and restoration of vegetation and ecosystems can increase infiltration capacity and reduce run off. Vegetation improves infiltration capacity and fixation of the soil, thereby reducing risk on landslides and flashfloods. In addition, these so-called Natural Water Retention Measures (NWRM) are effective to increase low flows during dry periods. They are defined as having a primary function of enhancing and/or restoring the retention capacity of aquifer, soil and aquatic ecosystems and many examples of this type of NBS can be defined, ranging from upland restoration of the natural forest cover to the technical installation of green roofs.

Midstream, storing water in wetlands and floodplains and increasing the length of the flow path are important to reduce effects of floods and droughts. Downstream, connection of the river to the floodplains is essential to bring fresh water and clay to floodplains³⁰.



Figure 2.5 NBS for restoring flood risk in upper, middle and lower river sections. From Life IP Rich Waters

Good examples of combinations of green and grey measures for reducing flood risk in downstream river sections are constituted by the Dutch Room for the River Program (Figure 2.6)³¹.

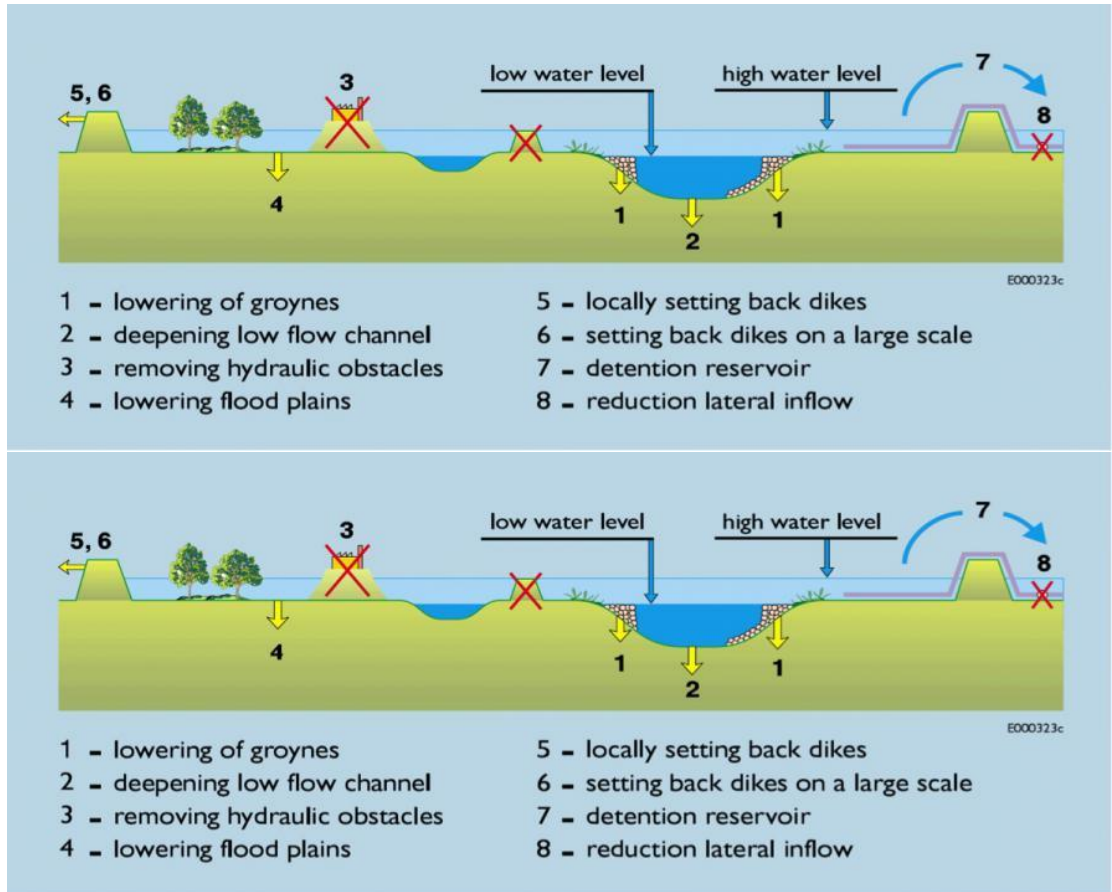


Figure 2.6 Measures for floodplain restoration as applied in the Room for the River program (source: Stowa³²)

In the UK, Dadson et al. (2017) review evidence on the effectiveness of natural flood management projects: natural flood management approaches have demonstrated to significantly reduce hazards associated with small floods in small catchments but are not expected to have a major effect on extreme events³³. The authors' main conclusions are that:

- i. Interventions that increase the stability of soils to absorb and retain water (e.g. land management) are most effective at the small scale and for smaller floods;
- ii. Storage (e.g. ponds, natural floodplains, retention basins) can be effective depending on extent of storage, location within the watershed and mode and timing of employment;
- iii. Reconnecting floodplains by setting back defenses can reduce peak flows and water levels.

Generally, there has been limited monitoring of restoration projects and their effects to date. The EU REFORM project evaluated failure and success of 671 European case studies, showing that most projects provided no information regarding the results ⁶ (Figure 2.7).

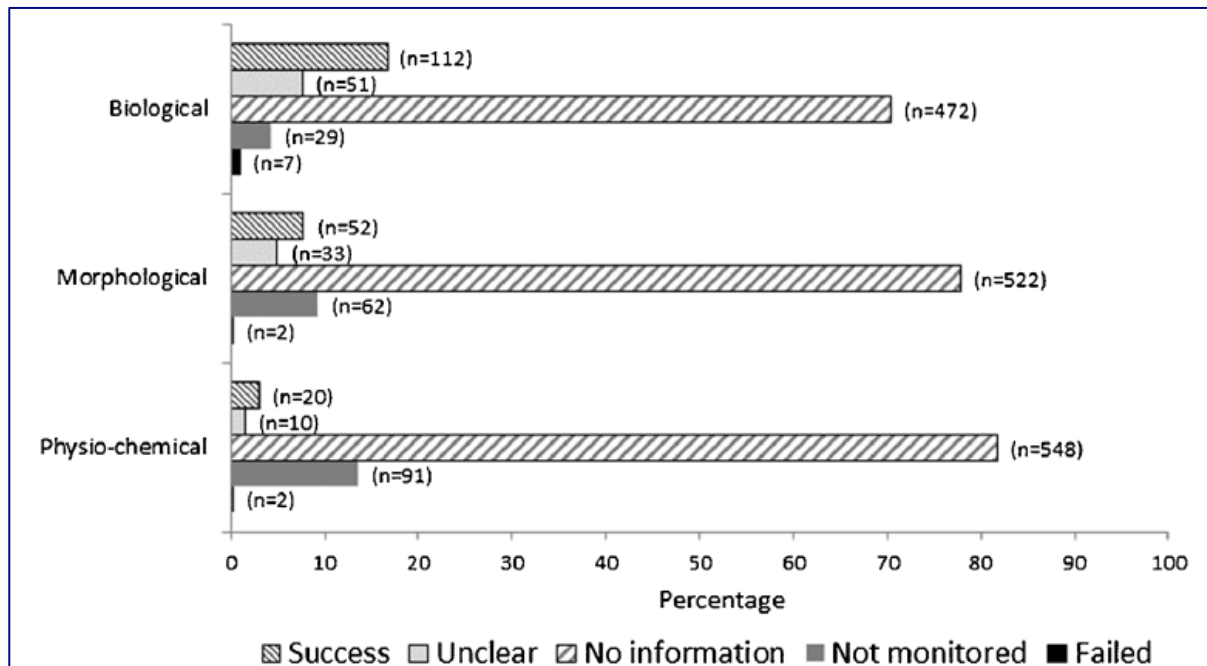


Figure 2.7 Evaluation of failures and successes in European river restoration projects (Source: REFORM, reference 6)

On the other hand, river restoration projects in the EU that were evaluated, have been rather successful in reducing flood risk³⁴. The UK Environment Agency has a particularly extensive database synthesizing evidence from literature and 65 UK cases on among other things the effectiveness of NbS in reducing flood risk ³⁵. The impact of NbS in flood risk reduction depends on the scale of the solution and watershed. Although in some cases this effect can be hard to predict, evidence suggests that all NbS has a significant contribution to flood risk management.

Watershed restoration in Scotland

The Scottish Environment Protection Agency (SEPA) is very active in restoring rivers, streams and watersheds for flood risk reduction, environmental quality, biodiversity and community benefits. A good example is constituted by the Eddleston project ¹¹⁶. The project involves river re-meandering, the planting of over 200,000 trees in the most upstream areas and the creation of new wetlands and retention ponds. This should slow the speed and impact of floodwaters as well as creating new wildlife habitat, such as improved spawning for salmon.

For a more general overview on literature and cases on global use of Nature-based Solutions, the NbS Evidence Platform³⁶ is a valuable source;

Table 2.2 gives an overview of sources particularly relevant to NbS in European rivers.

Table 2.2 Overview of information sources on nature-based solutions for reduction of flood risk and mitigation of droughts in European rivers.

Program	Aim	Measures	Number of projects	Source
Natural Water retention measures	Reduce drought	Natural water retention measures	139	http://nwrn.eu/
Room for the River	Reduce flood risk	River widening, side-channels, retention areas, obstacle removal	30	https://www.rijkswaterstaat.nl/english/about-us/gems-of-rijkswaterstaat/room-for-the-river/index.aspx
RESTORE	Reduce flood risk	River restoration	1333	https://restorerivers.eu/wiki/index.php?title=Main_Page
WWNP	Working with nature Processes to reduce flood risk	River restoration	65	https://www.gov.uk/government/publications/working-with-natural-processes-to-reduce-flood-risk
Dam removal	River restoration	Removing of old unused dams	34	https://damremoval.eu/

3 Economic rationale of investing in NbS

NbS constitutes an attractive public investment opportunity, as part of regular river management investment programs as well as in the light of green economic recovery and development: NbS can save costs, contribute to multiple goals at once, they often have an attractive socio-economic rationale and can support economic recovery and development by creating jobs.

3.1 The economic rationale of public investments

Economic evaluation is an essential part in the decision-making processes of public and private investments. New concepts in valuing economic development such as inclusive and green economic development adopt an increasingly wide perspective, for example by including natural and social capital.

Public authorities in river management employ a range of criteria and requirements to determine the merits and rationale of investment decisions. Some kind of economic assessment, such as cost-effectiveness or cost-benefit analysis, is usually included. The most common method to determine the economic rationale of project alternatives is a cost-benefit analysis (CBA), which compares investment costs against a wide range of socio-economic effects. The purpose of a CBA is to provide a sound basis for decision making, taking human welfare at the heart. Where possible all effects are quantified in monetary units as a basis for comparison. Alternatively, cost-effectiveness analysis weighs investment costs against effectiveness in relation to a direct single project goal (e.g. water safety). This analysis usually does not address potential environmental or socio-economic effects of distinct strategies.

New insights in valuing economic development, such as inclusive and green economic development concepts, adopt an increasingly wide perspective, for example by including natural and social capital. In this context, it makes sense to assess public investments on their merits for natural capital, ecosystem services or biodiversity, and additional economic outcomes such as impact on local livelihoods and job provision. Particularly if those investments have the purpose or potential of stimulating green economic development or sustainable economic recovery. NbS also provide opportunities for attracting private investment and blended finance solutions (Box 3.1)^{37,38}. However, this is outside the scope of this report.

In this chapter, we highlight results from studies and NbS projects in freshwater systems in Europe regarding:

- Cost-effectiveness of NbS compared to grey alternatives
- Economic value of river ecosystem services
- Impact of NbS on livelihoods.

ECONOMIC RATIONALE FOR INVESTMENT VERSUS BANKABILITY OF A PROJECT

Public investments should have a socio-economic rationale, implying that the expected benefits for society are higher than the invested (public) funds. But with considerable funding gaps in infrastructure and natural capital, there are many more projects with an economic rationale than there is public money available. Therefore, there is a keen interest in involving the private sector to bridge this funding gap. This can materialize if there are opportunities to generate positive *financial* returns for communities and investors within the project, beyond wider economic benefits: with their multi-functional character, NbS provide more opportunities for this than more mono-functional grey infrastructure projects. The financial returns can be capitalized, for example by setting up profitable enterprises under the wing of the NbS project, and thus help make these projects *bankable*: investable by private financiers, rather than just governments and philanthropy (WWF: Bankable Nature Solutions, 2020).

3.2 Cost-effectiveness

There is growing evidence that under certain conditions NbS can be more cost-effective than conventional engineering alternatives.

Cost-effectiveness analysis is used to identify the least-cost alternative for a predefined outcome or outcomes, e.g. a certain flood risk reduction level. Although public investors should ideally take a wider economic perspective to evaluate project alternatives, in some cases (e.g. when benefits cannot be valued) cost-effectiveness analysis is used to select the alternative with the lowest cost effectiveness ratio (e.g. most 'flood risk reduction' per unit invested €)¹.

Navigation, flood protection and water quality

Boerema et al. (2018) analyzed cost-effectiveness of sediment management and flood protection solutions across four functions: navigability and flood protection, water quality regulation (nitrogen) and climate regulation (carbon). Three scenarios are evaluated:

- S1: Nature-based alternatives for dredging (i.e. fluid mud concepts, sediment traps, re-using dredged materials) + traditional dike heightening
- S2: Conventional dredging + nature-based alternatives for dikes (i.e. flood control areas)
- S3: Nature-based alternatives for dredging + nature-based alternatives for dikes

Results show that regarding navigability and flood protection, scenarios S1 and S3 are the most cost-effective. For water quality regulation and climate regulation the alternative dike strategies (in S2 and S3) are most cost-effective; only nature-based alternatives for dikes have an effect on these ecosystem services. When all four functions are considered simultaneously, S3 is the most optimal.

In a study on the merits of levee setbacks to achieve flood protection benefits and ecosystem restoration by the US Army Corps of Engineers, Smith et al. (2017) concluded that levee setbacks are often an economic, environmentally beneficial and cost-effective non-structural alternative for achieving reduction in flood damages. This is particularly the case for levee systems in flood-prone settings.

¹ If benefits cannot be valued, e.g. due to time or data limitations, additional effects can be addressed in a complementary multi-criteria analysis.

Netherlands: Room for the River

In preparation of the Dutch 'Room for the River' program which in the end included 34 projects, a cost-effectiveness analysis of a large set of flood risk reduction measures in the Netherlands demonstrated that in most cases [floodplain restoration is more cost-effective than increasing elevation of existing dikes](#) ⁴¹.

To protect the Netherlands from increasing peak discharge levels due to climate change, two alternative strategies were analyzed by de Bel (2014): 1) increasing the elevation of existing dikes or 2) investing in a range of measures that increase the 'room for the river' – e.g. floodplain reconnection, bypasses and levee setback (Figure 2.6). The cost-effectiveness of suggested measures is calculated based on water level reduction, with distinct requirements per river. Additional benefits for spatial quality, nature and recreation were included in the cost-effectiveness analysis as well.

On the whole, 63% of projects were equally or more cost-effective than a dike strategy (Table 3.1). The result is influenced by local characteristics, e.g. in relation to the prevailing failure mechanisms of existing dike stretches. In most river sections 70-80% of NbS measures was deemed more cost-effective than the alternative dike strategy.

Table 3.1 Results from Cost-effectiveness analysis RVDR. Adapted from: De Bel (2014). The lower the CEA score the better.

River	CEA score dike strategy in river section	# of projects with CEA score < or > than dike strategy	% of NbS projects more cost-effective than dikes
IJssel en Pannerdensch kanaal	41139-62500	4 projects > 60.000 12 projects < 60.000	75%
Waal	56188	4 projects > 60.000 10 projects < 60.000	71%
Merwerdes	75000	2 projects > 75.000 8 projects < 75.000	80%
Maas	35000	3 Projects > 35.000 13 projects < 35.000	81%
Limburgse Maasvallei	20.000-35000	22 projects > 35.000 18 projects < 35.000	45%

Increasing the evidence base

At present, most evidence regarding effectiveness and cost-effectiveness of NbS in river systems has been built around flood mitigation. Further research is needed to assess effectiveness of NbS on other ecosystem services and to expand the current evidence base to represent a wider basis of environmental, social and economic settings.

A good starting point to further research in this regard is the guideline for cost-effectiveness analysis in river restoration developed under the EU REFORM project ¹⁴. When reviewing cost-effectiveness of solutions it is important to consider the scale (both spatially and temporal) of the analysis.

The impacts of large-scale pressures which are not addressed by individual measures can override the (e.g. hydromorphological) improvements made locally by individual measures, and NbS typically have benefits upstream and downstream of the project site. Ideally, solutions for specific objectives (e.g. implementation of WFD, flood prevention) should be optimized at a river basin scale consisting of a variety of (hybrid) NbS, rather than at the scale of individual measures ²⁸.

3.3 Economic value of NbS in river management

Restoring rivers and their floodplains to a more natural state by applying nature-based solutions can help to achieve a future in which healthy river systems contribute to diversified regional economies and human well-being.

3.3.1 Economic value of healthy fresh-water ecosystems

Total economic value

The economic value of ecosystem services consists of 'use' and 'non-use' values. Use values include provisioning, regulating and cultural goods or services with a reflection in actual economic markets. Direct use values include e.g. raw products like fish and building materials. Indirect use values include e.g. the ecological functions that maintain and protect natural and human systems such as flood mitigation and water quality improvement. These values can be derived from actual markets, e.g. by using the price of fish, drinking water purification costs, or by deducing the value of landscape quality based on the travel time of visitors or values of nearby properties (revealed preference).

Non-use values relate to the value placed by humans on the existence of natural resources (supporting services) regardless of the current or future possibilities to use them, such as value attached to the preservation of biodiversity for future generations. These values can be derived with stated preference methods, often including questionnaires ⁴².

Ecosystem service values of fresh water ecosystems

Building on the TEEB database, the Ecosystem Service Valuation Database (ESDV) is a global database of monetary values of ecosystem services across all biomes, compiling results from 393 studies and 4042 value records, of which 2917 could be standardized to \$/ha/year at price level 2020. Although data records are from across the globe, the data is skewed towards the UK, which has provided 36% of value records ⁴³.

Overall, with €91.738 per ha/year, rivers and lakes are among the most valuable ecosystems and biomes on earth (Table 3.2), comparable to tropical forests (€100.809) and coral reefs (€134.235). The most valuable services include waste treatment, provision of water, maintaining genetic diversity and opportunities for recreation and tourism. Particularly valuable services of inland wetlands (overall €41184/ha/year) include their role in regulating water flows and moderating extreme events (acting as natural water retention to limit floods and droughts), food provision, maintaining genetic diversity and non-use values, e.g. related to preservation of biodiversity.

Willingness to pay for river ecosystem services in Europe

A specific study for Europe by Ayres et al (2014), used on such revealed and stated preference methods to analyze the willingness to pay – an indicator for economic value – for ecosystem services resulting from 30 river restoration projects across Europe²⁸. Results indicated that households are willing to pay (WTP) between €25-40 for the ecosystem services resulting from river restoration. In studies focusing specifically on better water quality and improved aesthetic landscape quality the willingness to pay lay between respectively €25-30 and €16-25 for these services per household. The studies also show a relation between the scale of the restoration project and the WTP for these services: the larger the scale, the higher the WTP.

In an analysis of 38 restoration projects across the US and Europe, the median WTP of households for ecosystem services resulting from river restoration projects was €45 per project (ranging from €2,5-186, due to large variety in project size). This translates to €0,3-4,2 per kilometer, with a median of €0,8. Results from the US indicate an added WTP of €0,70 per additional km of river restored ²¹.

Table 3.2 Ecosystem service values for River and Lakes and Inland Wetlands. From ⁴³

Mean standardised values per ecosystem service and biome (Int\$/hectare/year; 2020 price levels)		
	Inland wetlands	Rivers and lakes
Food	6.030	2.288
Water	1.934	9.198
Raw materials	1.682	92
Genetic resources	60	
Medicinal resources		
Ornamental resources		
Air quality regulation	34	
Climate regulation	150	251
Moderation of extreme events	13.320	18
Regulation of water flows	3.638	4.221
Waste treatment	2.043	50.760
Erosion prevention		
Maintenance of soil fertility		6.189
Pollination		
Biological control		142
Maintenance of life cycles of migratory species	1.886	803
Maintenance of genetic diversity	3.427	17.987
Aesthetic information	49	2.276
Opportunities for recreation and tourism	2.660	13.633
Inspiration for culture, art and design	114	310
Spiritual experience	1	76
Information for cognitive development	120	116
Existence and bequest values	11.498	
Sum	48.647	108.361

Embedding ecosystem service valuation in infrastructure project appraisal

There is a wide range of guidelines, methodologies and databases with cost and benefit data that is used to quantify costs and benefits of investments in (water) infrastructure, focusing mostly on flood risk reduction investments (see Appendix A). Quantifying the benefits particular to NbS - such as the wide array of supported ecosystem services - is relatively novel in the context of economic analysis and project appraisal in river management. Quantifying costs and benefits of NBS can be challenging, as: 1) there is much less experience with optimizing and estimating life cycle costs for green-grey infrastructure than for conventional infrastructure, and 2) the broader benefit base of NbS means quantification can be time – and data- intensive ⁴⁷. Still, there have been significant advances in the past decade in developing methodologies for quantifying and monetizing costs and benefits (ecosystem services) of NbS that provide valuable tools for embedding them in cost-benefit analyses, such as ^{43,47-49}.

Ecosystem services Eddleston watershed restoration, Scotland

As part of a natural flood management project in Eddleston, Scotland, 225 ha woodland, 28 ponds and 116 log dams were created by 2019. Key benefits of the project include flood risk reduction, habitat improvement, CO₂ sequestration and timber production. Observations thus far indicate an increased lag time before flood peaks; increased infiltration in the woodland area. Restoration of in-stream features and morphology contributes to better and more diverse habitats for aquatic organisms. Key ecosystem services (beyond flood mitigation) were valued, expressed in net present value over 30 years: carbon sequestration (€0,9 million), biodiversity (€0,3m), timber production (€0,5m) and education (€0,2m). Foregone agricultural benefits were valued at €0,3-0,6m. Potential benefits on recreational use and associated health benefits were not included in the assessment, although these could be very significant – estimated in order of magnitude of €0,9 million, particularly if additional infrastructure is installed to increase accessibility of the area ¹¹⁷.

The study concludes that based on flood-risk reduction and ecological restoration benefits alone the economic case for the project is not that strong; in particular carbon sequestration, timber production and recreation benefits significantly strengthen the economic case. As such a wider ecosystem service assessment is not standard procedure in flood scheme options appraisal procedures in the UK, these economic arguments run the risk of not being weighed in investment decisions, at the risk of arriving at a sub-optimal outcome for society.

3.3.2 The economic rationale of NbS

In most cases, prevailing challenges in river management in Europe – e.g. flood mitigation, drought, biodiversity restoration, improving water quality and restoring sediment balances – are tackled by single objective conventional solutions. At present, there are still not many economic analysis studies that compare NbS with conventional alternatives in a river management context. Studies that are available, demonstrate that NbS are mostly economically attractive particularly when multiple benefits are compared at the same time (see also sections **Error! Reference source not found.** and 5.4). In the previous section we discussed the economic value of river ecosystems in general: NbS typically strengthen a wider spectrum of these values. In this section we highlight a few key promising areas where NbS can have a clear economic rationale for investment; removing obsolete dams, regulating water flows and contributing to improved water quality.

Removing obsolete dams

There are well over 1.000.000 barriers including dams, weirs, ramps and culverts fragmenting Europe's river systems, of which many were developed in the past century. This fragmentation contributed to the significant decrease of 81% in species in rivers, wetlands and deltas between 1970-2012. Many of these dams are now obsolete: they no longer serve the function for which they were designed e.g. water supply and water safety. Removing these dams can lead to significant – and very necessary - recovery of river habitats and return of fish, provide benefits for local communities and economies, and strengthen socio-cultural values⁸.

Dams and weirs typically have a technical lifespan of 50-100 years, but often remain in place for over 100 years. Removal is often perceived prohibitively expensive ¹⁵. This is not necessarily justified: [removal of obsolete dams, though expensive, can be up to 10-30 times cheaper over time than continuous repair and maintenance of the dams](#) ^{8,15}.

Sanz and Rubial (2016) reviewed costs and benefits of six dam removal projects in Spain. In general, benefits include reduced flood risk, increased habitat quality and availability, increased recreational opportunities, benefits for local populations and economies and improved the aesthetic quality⁵⁰. The authors did not monetize the benefits but scored them using a weighted multi-criteria analysis (Figure 3.1). Results indicate that there is a positive trend between costs and environmental and social benefits obtained. However, the graph also shows that the slope of this trend is less than one, implying that for more costly projects the benefits may not outweigh the costs².

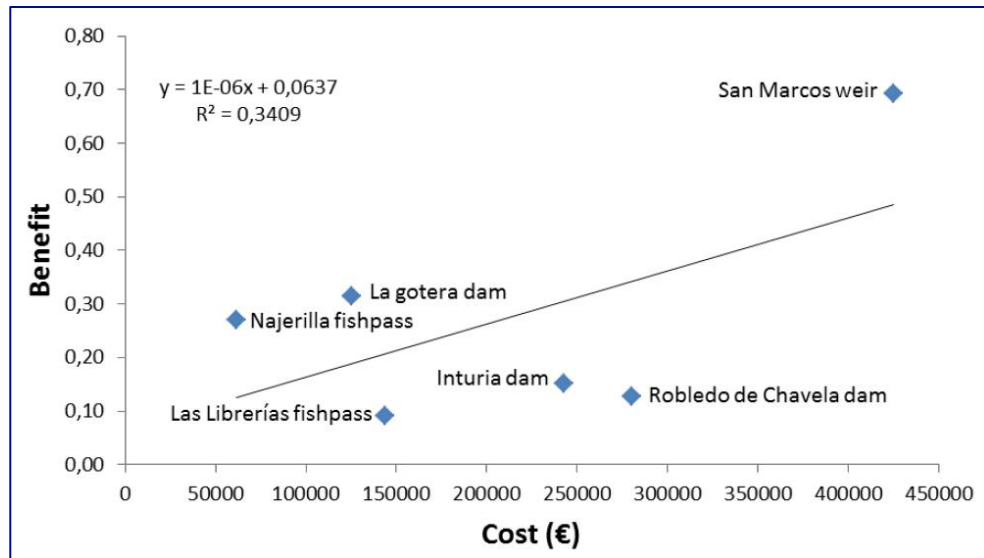


Figure 3.1 Comparison between costs of dam removal/ fishpass project and benefit score. Source⁵⁰

To achieve restoration on a large (river basin) scale, the removal of a single barrier has limited effects beyond benefits on a local scale. Ideally, a strategy prioritizing removal or adjustment of barriers along the whole basin should be developed, with priority to removal of obsolete barriers, barriers where removal is cheaper than repair, and barriers located at critical junctions or fish migration⁸.

The role of NbS in improving water quality

Good water quality is the basis for healthy ecosystems and is essential for drinking water quality: a low water quality leads to higher treatment costs and/or increased health risks. In Europe, 88,2 % of all freshwater use comes from river and groundwater sources⁵¹. Most water bodies in Europe presently do not have a good ecological status³. Mack et al., (2019) assessed the expected development of Europe's water quality under future climate change and land use scenarios. In two out of three scenarios, water quality of particularly rivers is expected to decrease further due to increased nutrient inputs, land use change, climate change and inadequately managed water abstraction.

² This study has only limited data points and is therefore unsuitable for drawing any solid conclusions.

Cost-benefit analysis of river restoration in the Werra River Basin

In the Werra river basin in Germany, agriculture, potash mining and wastewater from private households negatively impact water quality. Dams used for drinking water supply, hydropower, flood prevention and irrigation obstruct ecological continuity in the river. Aiming to achieve a 'good' ecological status by 2015 in accordance with the EU Water Framework Directive, ecological and hydrological stakeholders identified potential measures in the early 2000's. This included a mix of regular and nature-based solutions aiming to 1) improve river morphology and continuity and 2) reduce diffuse emissions and point source emissions.

To assess the optimal strategy, Hirschfeld et al. (2005) analyzed the benefits and beneficiaries of these measures (Table 3.3).

Effect of measures in Werra river basin	Beneficiaries
Increased fish stocks	Professional fishing companies
Improved drinking water quality	Increased health; citizens Drinking water company
Improved recreational opportunities in catchment: angling, boating, biking, hiking	Tourism/ recreation sector (hotel & catering industry/ recreational services)
Improved habitat provision, biodiversity; nutrient retention, improved water quality	Authorities responsible for good ecological status
Conservation of biodiversity in the river ecosystem	Local population; those who value preservation of biodiversity

Table 3.3 Economic benefits from ecological restoration of the Werra Catchment and potential beneficiaries

Tourism and recreational use of water and fishing derive benefits from good water quality and rich morphological structures. Conservation and improvement of current biodiversity in the Werra catchment has economic benefits of 11-15,6 million €/ year. Recreational benefits linked to water quality and morphology are valued at 4,2-4,6 €million /year. **This amounts to a present value (with discount rate 3%) of €150-197 million over 20 years, or €294-388 million over 50 years. These benefits outweigh the investment costs of measures up to 5 times.**

Although treatment or prevention at the source is the most effective way to reduce pollution - nitrate pollution from livestock manure and artificial fertilizers is a key pressure across Europe. NbS can play an additional role in reducing the pollution load in our river systems. Wild (2020) reviewed the evidence base of NbS in contributing to water quality and water body status in Europe⁵³. Although there is still a significant knowledge gap on the benefits of NbS on water quality, case studies throughout Europe indicate that NbS interventions particularly in urban environments can lead to cost savings in water treatment by reducing stormwater flows and combined sewer overflows and reduce health risks. In rural communities, NbS for water purification and flood mitigation can outperform grey infrastructure alternatives at a similar cost based on integrated valuation.

Regulating water flows

Integrating NbS into flood control systems can complement engineered infrastructure and relieve pressure on the system. NbS are especially effective at mitigating impact of short-duration, low-impact floods⁵⁴. Floodplains and bypasses can store and slowly convey water and sediment that overtops riverbanks during flood events. Inland wetlands can store up to 9400-1400 m³ floodwater per hectare, to be released during dry periods. Natural stream beds and banks can help slow the river flow, e.g. meandering path of vegetated riparian areas. Upland forests with deep soils help to slow and retain runoff, resulting in lower peak flows: particularly effective to mitigate and slow moderate floods of short duration.

3.4 Jobs and livelihoods

Investment in NbS directly creates jobs in the implementation and maintenance & operation phase of projects. In the long term the provided ecosystem services have the potential to contribute to more, and more diversified, local livelihoods.

Employment in ecological restoration

Investments in ecological restoration typically create low-skill and fast-implementing mostly local jobs: in the US estimates were found between 7-40 jobs per invested million \$, outperforming investment in e.g. oil and energy industry¹⁶. The 'restoration economy' is a \$25 billion industry in the US alone, providing 221000 jobs, with \$ 9 billion flowing into restoration and management of aquatic, riparian and wetland environments⁵⁵.

South Africa: Working for Water

In South Africa, invasive species such as eucalyptus use more water than native species, putting additional pressure on an already water-stressed region. Water use by invasive species is currently estimated at 4 % of the nations' water supply, with a risk of increasing up to 16% if left unchecked. In the Working for Water programme, 20.000 people were employed in short-term contracts – benefiting particularly disadvantaged groups such as youth, women and people with disabilities - to reduce the impacts of invasive species on water use and to restore native vegetation in aquatic ecosystems (Lieuw-Kie-Song and Pérez-Cicera (2020).

Tree planting and floodplain restoration are particularly labor-intensive, making these NbS very suitable investments for public employment programs focusing on informal economy workers in rural areas. Aside from low-skill jobs, small and medium-sized enterprises active in forest and land restoration also benefit from investments in NbS, as well as engineering companies and environmental science jobs: in WWF and ILO's 'Nature Hires report'¹⁷, the employment opportunities from NbS investments are further detailed (Table 3.4).

Elbe Dyke Lenzen, Germany – a tourist attraction on the international Elbe Bike Trail

In Lenzen, Germany, the river dyke was relocated in order to create more room for the river to reduce flood risk and create a more natural environment to increase biodiversity in riparian areas. The floodplains were previously used for pasturing. In the new situation, part of the floodplain has been reforested. After the project was finished, it was established as regional attraction on the international Elbe Bike trail: a center for environmental education and a visitor center were constructed. The area has since seen an endured increase in visitors to the area bringing economic benefits to the region⁸⁶.

Long term livelihood provision

Aside from short-term employment, large-scale restoration investments in particular stimulate output and employment in a range of other industries through supplier and household spending effects¹⁶. Additionally, such investments lead to supplementary income for rural workers and provide jobs in economic use of invasive species (timber, fodder, bio-energy). In the long term, the ecosystem services resulting from NbS in river systems can create or improve opportunities for livelihoods of local communities, e.g. in the fishing sector or recreation and tourism and conservation¹⁷.

Table 3.4. Job intensity and returns of NbS and related activities and investments. Adapted from Lieuw-Kie-Song and Pérez-Cicera (2020)

NBS river management/restoration	Type of work activities	Type of job	FTE/inv ested million \$	FTE/ha
Management and conservation of protected areas and buffer zones	Management and education, monitoring & reporting, stakeholder involvement and inclusivity, indigenous & technical knowledge transfer, ecotourism	Rangers, Managers and educators, community liaison officers, environmental science, tourist guides	N.A.	0.004-0.0002
Construction of wetland systems for treatment of sewage	Ecosystem monitoring & reporting, landscape planning, diverse forms of construction, stakeholder involvement and inclusivity	Construction workers, engineers, maintenance workers, Environmental science jobs	As per similar construction work in the area	N.A.
Removal and management of invasive alien species	Removing invasive weeds, shrubs and trees. ecosystems monitoring & reporting, indigenous & technical knowledge transfer	Managers, semi-skilled workers, administrative jobs, Environmental science jobs	N.A.	0.002-0.014 for lightly infested areas 0.05-0.14 For heavily infested areas
Watershed improvement	Structures/measures to reduce soil erosion, allow for groundwater recharge, rehabilitating native vegetation, stakeholder engagement & inclusion	Urban planners, Environmental science jobs (hydrologists), construction workers	166 to 500	1 to 3

4 Case study: The Lower Danube

In the past decades, the natural character of the Danube and its floodplains has been significantly modified with extensive embankments, dams and drainage works to allow for intensive agriculture in the floodplains. This came at the cost of severe ecological degradation. Along the lower Danube, many embankments are presently in disrepair and in need of costly reparation and upgrading in order to adapt to the changing climate: this is a good time to reconsider floodplain management in the lower Danube. Large-scale investment in NbS like floodplain reconnection can turn the tide on ecological degradation, save costs in dike re-enforcement, help reduce flood risk in the long term, offer significant employment opportunities during and after implementation and strengthen local economies with livelihoods depending on ecosystem services.

4.1 The Danube: current status

The Danube has a high ecological value, but this has been corroded since the 1960's by significant human interventions along the entire river to support agricultural development in the floodplains.

Originating in southern Germany, the Danube and its tributaries flow through 15 countries, including Austria, Slovakia, Croatia, Hungary, Serbia and Romania with a length of approximately 2800 kilometers (Figure 4.1)⁵⁶. This 'Amazon of Europe' has a high ecological value, with valuable natural habitats such as floodplain forests, river islands and gravel – and sand banks⁵⁷.



Figure 4.1 Main course of the Danube river. From: google maps.

Sadly, the natural character of the river was severely reduced when the river and its floodplains were significantly altered since the 1960's to support agricultural development in the floodplains, following the paradigm of conquering nature to support economic development. In the decades after 1960, extensive embankments (3250 km), 78 dams (affecting 39% of the river) and drainage works were constructed in and along the main course of the Danube and its floodplains⁵⁸. The majority of floodplain areas was affected and to this day, only about ~15,5 % remain in natural condition. The modifications resulted in significant changes in the hydrological and geomorphological regime, in turn leading to an increased flood hazard (higher discharge levels). Although there are no large-scale flood risk studies for the Danube, an estimated 1:150 year event in 2006 in Romania illustrates the potential severity of the consequences: 72700 ha was flooded⁵⁹. Increased streamflow and lower sediment loads have further led to lateral erosion and river bed incision, narrowing the river bed.

The ecological degradation following the developments after 1960 was severe and many river species are currently endangered⁵⁶. In the river itself, the discharge regime changed, fish populations were isolated and their spawning habitats reduced. The floodplain's capacity to capture nutrients was reduced and connectivity to natural water systems lost. Soil regimes in the now mostly embanked floodplains were drastically changed, with increasing soil salinity and droughts, aggravated by fertilizer-aided intensive agriculture. Although many floodplain forests were destroyed, the Danube and its tributaries still host most of Europe's remaining floodplain forests (Figure 4.2), although remaining riparian vegetation changed in structure and composition⁵⁹. With the embankment of floodplains, the sediment balance in the Danube was severely altered. This has negative implications for ecology (habitat loss related to morphodynamics, lower groundwater levels), hydropower, navigation, flood risk management and coastal management: sediment input to the black sea was reduced with 60%, leading to coastal erosion⁶⁰.

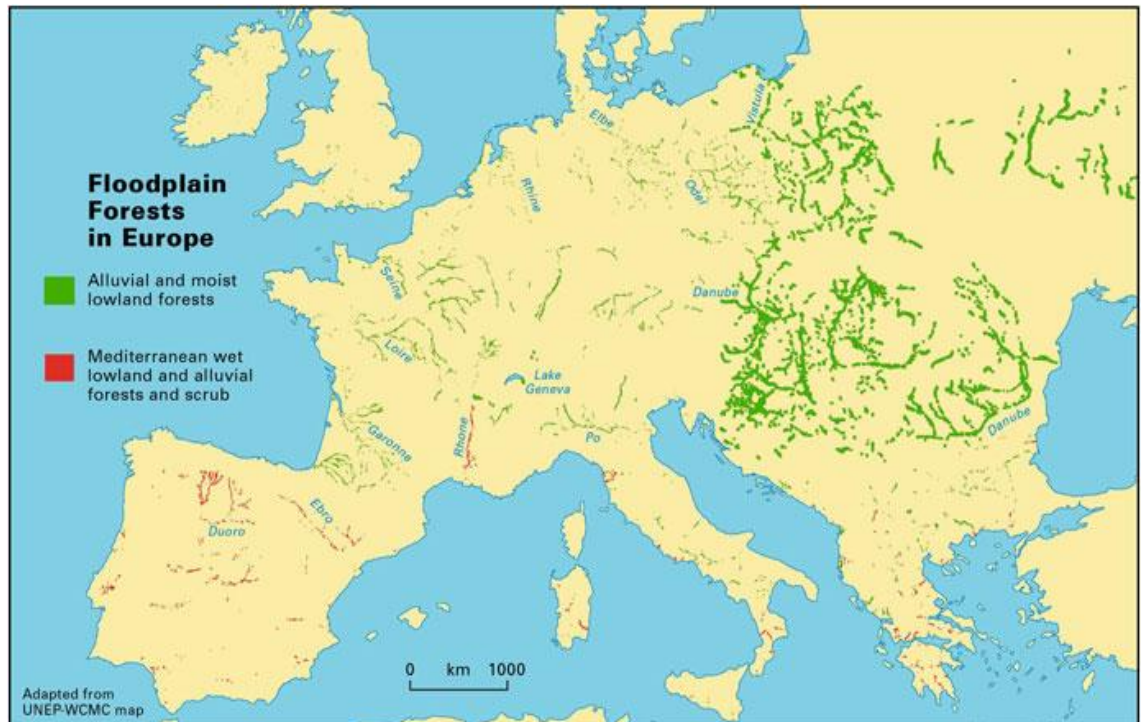


Figure 4.2 Remaining European floodplain forests around AD 2000⁶¹.

Re-envisioning the management of the Danube basin would enable a shift from unsustainable floodplain use (e.g. intensive agriculture) to more diversified and sustainable economic functions of the river and its floodplains. The timing for a new, more sustainable direction in river management is right. With a risk of permanent loss of biodiversity and many artificial levees along the lower Danube severely damaged and in need of (costly) reparation works, choosing a new direction for the Danube seems opportune and can avoid a technological and institutional lock-in that may result from levee upgrading, for the following decades.

4.2 NBS projects in Danube & their effectiveness

At present, historic and ongoing efforts in floodplain restoration in the Danube illustrate that such projects can be successful in ecological restoration and flood risk reduction.

Figure 4.3 shows historic, ongoing and planned investments in floodplain restoration in the lower Danube and its' tributaries, supported by programs such as the 'Lower Danube Green Corridor'⁶² and 'Ecological and Economic Resizing of Lower Danube Floodplain' (REELD). Studies on specific projects in the area demonstrate that these projects can be effective in reducing flood risk and improving ecological quality.

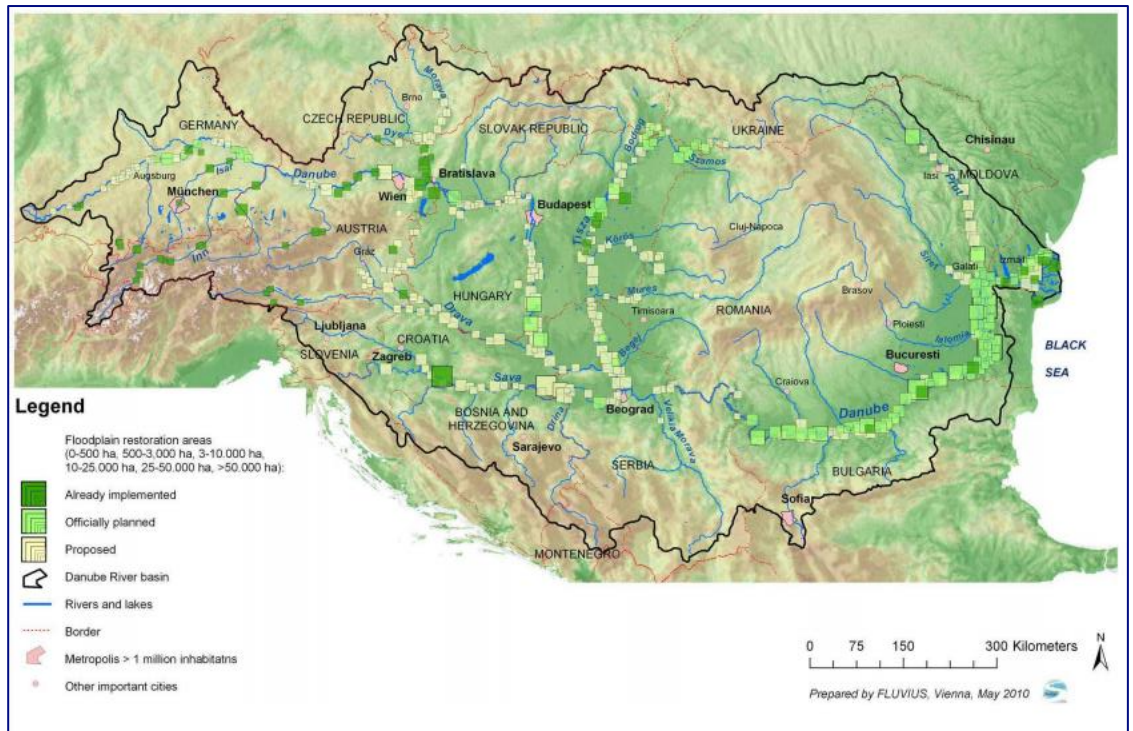


Figure 4.3 Restoration efforts in the Danube. From ⁶³.

4.2.1 Flood risk reduction

Hein et al. (2016) analyze implemented floodplain restoration projects in the Danube Delta (2) and between Vienna and Bratislava (6) on their success in achieving functional and structural objectives⁵⁶. Results indicate that the restoration of river floodplains can significantly reduce flood risk, as the capacity of sections with reconnected floodplains to reduce the flood peak is significant. In general, the hydrological connectivity of restored floodplains increased from receiving river water less than 30 days per year to more than 180 days per year. The efficiency of floodplain restoration in reducing water levels depends on several factors, such as geomorphology and roughness of the floodplain, flood wave form, flood magnitude, and the relation between the time of floodplain inundation and flood peak. In all projects, floodplain restoration shows significant positive effects in reducing downstream flood risk as opposed to classical engineering through dikes which only protect the hinterland at the nearby location but often amplify downstream flood risk by increasing the height of the flood peak.

4.2.2 Biodiversity restoration

The remaining wetlands and floodplain habitats in the lower Danube and the Danube Delta still belong to the most biodiverse regions in the world, sheltering rare and endangered habitats and species. Restoring the river to a more natural state, allows for protection and enhancement of this biodiversity. Long-term monitoring programmes to analyze effectiveness of project and interventions are largely lacking. An exception is constituted by the Babina Island project ⁶⁴. Ten years after reconnecting the floodplains on Babina Island, site-specific biodiversity has returned, eutrophication is reduced and macro- and microhabitats in aquatic, semi-aquatic and terrestrial areas have developed.

Floodplain restoration on Babina Island

The restoration of 2100 ha polders in Babina Island in 1994 in the region of Tulcea, Romania is one of the first projects that showcases that ecological restoration of former floodplains can be effective in reaching ecological goals. Previously this location was dyked and floodplains were converted to agricultural polders, drained by a system of channels. Over time, these polders were increasingly unprofitable and became partly abandoned. In the project, part of the International 'Green Danube' program, dykes and channels were opened in key hydrological and ecological locations, resulting in a return of site-specific biodiversity, re-establishment of habitats and spawning grounds for fish and a reduction in nutrients. Ecological restoration induced a return of livelihood provision in the form of fishing, reed harvesting, grazing and ecotourism ⁶⁶.

4.3 Livelihoods in the lower Danube region

The lower Danube and the Danube Delta are characterized by a relatively low welfare level. Nature conservation and restoration and sustainable use of natural resources could support long-term socio-economic stability for communities along the lower Danube.

The population in the lower Danube region has a relatively low health, a low life expectancy, low income, low access to education, lack of professional representatives, lack of mobility and transport infrastructure and limited access to public services, such as water supply and ill-management of waste. Natural habitats and biodiversity are the basis for natural, renewable resources and sustainable use of these resources could be the basis for long-term socio-economic stability for communities along the lower Danube ⁶⁴. However, current efforts to conserve nature in the region are threatened by economic activities such as overfishing, intensive agriculture and aquaculture and industrial activities leading to heavy metal water pollution ⁶⁵.

Approximately 14000 people, spread over 23 settlements, live within the borders of the Danube Delta Biosphere Reserve (DDBR). As in most rural areas, villagers mostly depend on multiple income generating activities. An assessment in 2005 (Apostol et al.) shows the distribution of livelihoods across the employed population (81%) in the DDBP area:

- Agriculture (29%): both for commercial as well as subsistence farming. Although there are no estimates on average annual income from agriculture, it is deemed a much less lucrative source of income than fishing. High costs of transportation are the main obstacle for commercial production.
- Fishing (15,3%): there are 1375 professional fishing permits in the DDBP, and almost all households have a family fishing permit for private consumption. Generated income from professional fishing is estimated at € 1900/year (price level 2019; average annual household income level in Romania is 5240 \$/years)
- Public and social services (19,7%)
- Other (36%): including e.g. tourism industry.

Since 2010, tourism in the area has grown steadily. The Danube Delta is one of the most significant tourist regions in Romania and is declared UNESO's natural heritage. There is potential for further development of ecotourism inside the reserve ⁶⁷.

4.4 Current trends in Danube river management

There are various transboundary and international institutional arrangements in place that support cross-boundary cooperation for sustainable management of the Danube river basin. However, despite these programs and initiatives, the general line of managing the Danube's floodplains remains focused on preservation of the status quo of the mostly embanked and regulated floodplains to enable intensive agriculture. Key barriers include conflicting interests regarding land-use, unclear responsibilities of actors in river basin management and lack of a supporting regulatory framework, funds and political willingness.

Policy and management

The Danube River Protection Convention (SRPC) signed in 1994 is the overall legal instrument for cooperation and transboundary water management, aiming to ensure sustainable and equitable management of ground water and surface water in the Danube River Basin. In 2009 the Danube River Basin District Management plan identified the main pressures for water quality. One of the key aims of this plan is to implement restoration measures to reconnect old and protect existing floodplains. In 2010, the EU Strategy for the Danube Region was installed. The primary aim of this strategy was to coordinate existing plans and policies across the Danube, focusing particularly on supporting environmentally sound policies and actions which account for climate change impacts⁵⁹. A transboundary management program was installed in 2012 for the UNESCO Biosphere Reserve of the Mura-Drava-Danube, aiming to harmonize river management practices and install a joint management programme⁵⁷. Overarching EU policies such as the Water Framework Directive, Floods Directive and Birds and Habitats Directive foster efforts to protect remaining floodplains and restore former hydrodynamics by reconnecting old floodplains to the river. However, despite these programs and initiatives, the general line of managing the Danube's floodplains remains to preserve the status quo of mostly embanked and regulated floodplains to enable intensive agriculture. So far ongoing restoration efforts have been unable to reverse trends in ecosystem service decline⁶⁸.

Challenges in sustainable river basin management

Conflicting socio-economic demands on use of land and water resources are a key challenge for the implementation of floodplain restoration in the lower Danube and Danube Delta^{56,65}. These demands include settlements, agriculture, forestry, hydropower generation, navigation (the Danube is a priority axis in EUs Trans-European Network of Transportation), economic development and nature protection. Furthermore, there is unclarity in responsibilities of different actors in relation to basin management, and no supporting legal framework in place. The EC's Water Framework, Floods and Habitats Directives provide a sound basis, but lack funds and political willingness for efficient implementation. This is further aggravated by a lack of cooperation across boundaries and between different institutes and public actors. There is no sound, long-term strategy in connection to land use in the floodplains. Land ownership presents a particular challenge as after 1990 most floodplain lands returned from state ownership to private ownership and these lands are mostly exploited for agricultural profits⁵⁸. These floodplains are now a major source of income for local communities, hence there is a lack of societal support for investments and changes in the use of floodplains. Awareness raising on ecological issues and stakeholder engagement with local communities will be needed to help find compromises between ecological and economic demands. Other conflicts of interests between stakeholder groups with respect to revitalization of floodplains include:

- Hunting/ sport fishing associations, fishing companies and ecologists
- Local people and private concessionaires
- Fishermen and fish-eating birds
- Advocates of biodiversity conservation versus advocates for economic development

Aside from social and institutional challenges in implementation of restoration activities, there are several ecological challenges as well. For example, invasive species and climate change threaten the ecological integrity of the Danube River basin and may influence the effectiveness of restoration efforts.

4.5 Investment opportunities in Danube river management

Of the Danube floodplains, 8102 km² has potential for restoration. In the lower Danube, approximately 3944 km² has a medium to high potential.

Hein et al. (2016) assess the potential for restoration in the Danube floodplains, based on land use and hydro-morphological characteristics. Results indicate that 8102 km² floodplains has a high potential for restoration. Of these floodplains, 1797 km² is still an active floodplain at present; 6305 km² exists of former floodplain areas. Restoration potential is determined by drivers of degradation. These differ between Upper and Lower Danube (Table 4.1). In the Delta, around 75% of potential restoration areas are currently used as agricultural polders. These areas can be reconnected at relatively low costs. In the lower Danube and in the Delta, preservation of intact floodplain habitats is essential. Biodiversity is still high here, but is rapidly declining.

Tetelea (2017) analyses the restoration potential specially for the Lower Danube⁶⁹, using a multi-criteria analysis on physical restorability, habitat provision potential and current land cover. The resulting floodplain restoration potential in the lower Danube would be 4587 km², slightly less than the 5038 km² estimated by Hein et al. (2016).

Table 4.1 Overview of restoration potential along the Danube⁵⁶

	Main pressures	Potential for restoration	Examples of significant floodplains
Upper Danube	Impoundments, altered hydrological regime; construction of dikes between 1870-1950	532 km ²	Confluence Danube/Isar, Donau-Auen National Park
Middle Danube	Many free-flowing sections, but channel incision; disconnected floodplains for drainage, agriculture and flood protection between 1890 and 1970	1562 km ²	Gemenc National Park, Kopacki Rit
Lower Danube	Systematic disconnection after 1960, no large-scale elevation yet; relatively good status	5038 km ²	Lower Danube Islands (Belene), Islands of Braila
Danube Delta	River modification for navigation and agriculture after 1970; relatively good status	970 km ²	Sfantu Gheorge branch, Kilya Channel

4.6 The costs and benefits of large-scale floodplain restoration in the lower Danube

With many embankments in the lower Danube are in disrepair and in need of costly restoration and possibly upgrading in order to adapt to the changing climate, governments in Romania and Bulgaria are now at a crossroads: invest in upgrading embankments and polder systems, or set back levees and reconnect former floodplains to the river. In this section we illustrate the economic rationale for large-scale floodplain restoration in the lower Danube. Due to lack of data and limited scope of this study, this is a stylized, 'quick scan' exercise.

4.6.1 Reference situation

In the case that no new policy is adopted, existing embankments will be restored in order to maintain current flood protection levels (the reference situation). Flood risk will potentially increase further in the future, estimated at (present value) € ~3,3 billion until 2100. Significant investments in preserving the current flood protection level by restoring degraded embankments (estimated at €332 million) will lead to a technical and institutional lock-in that reduces the potential to shift to a floodplain restoration strategy if circumstances change in the future. Agriculture in the floodplains will continue to be the main land use, although yields from agriculture may continue to decrease, as destruction of irrigation systems and forest shelter belts and climate change leads to salinization and aridification, particularly in the south and east of Romania⁷⁰. Ecological degradation will continue, with consequent loss in ecosystem services and possibly penalties for non-compliance with EU Habitat and Water Framework Directives. Furthermore, regional economies remain largely agricultural and little diversified, making them sensitive to economic or climatic shocks.

4.6.2 Large-scale floodplain restoration

In a large-scale floodplain restoration programme, 4000 km² of floodplains could be restored in the lower Danube and the Danube Delta. After reconnecting the floodplains to the river, agricultural use will still be possible to some extent, but there will also be more room for nature as old river arms are re-activated and dikes are set back to allow for inundation of the floodplains. We assume agricultural land use in the floodplains will drop from the current 70% to 50%, and intensive farming models will make place for extensive farming models. The percentage of land use for nature will increase from 10% to 30%. Figure 4.4 provides an illustration of land use change after floodplain reconnection.

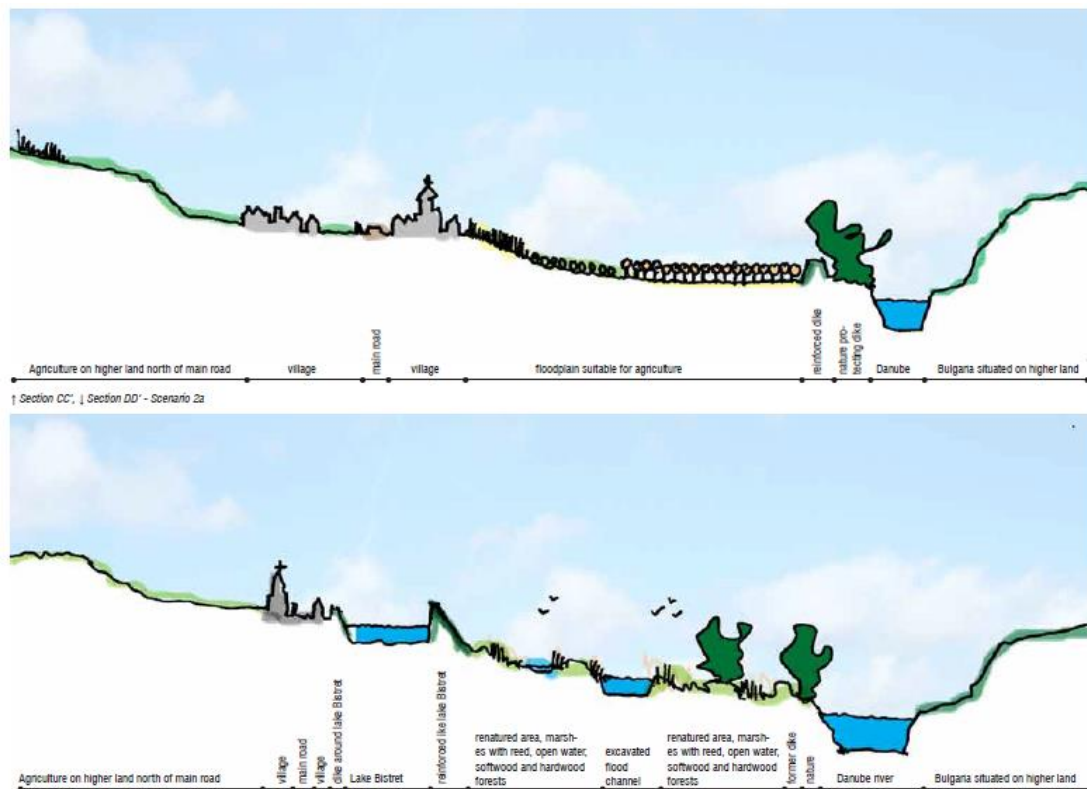


Figure 4.4 Land use change after floodplain reconnection/ room for the river project in the section between km 690 and 748 in Dolj Country, Romania. From scenario study by Witteveen + Bos, 2011)⁷¹.

4.6.3 Costs and effects of large-scale floodplain restoration

A large-scale floodplain restoration programme would have many benefits, including reduced costs for dike reinforcement (€229 million), reduced flood risk (€1360 million), more flexibility in flood risk strategies in the long-term, and diversification of economy (e.g. tourism: €1152 million and fishery: €140 million) in the long term and job provision in the short term (supporting ~200.000 jobs³).

Then there are various additional (not monetized) ecosystem services provided by floodplain restoration: improved water availability and quality, improved supporting services such as restoration of hydrological and morphological processes and, a return to ecological integrity: supporting biodiversity and restoration of the sediment balance. These services are not quantified but would result in significant both monetary and non-monetary benefits in terms of coastline stability, food and water security, health and wellbeing.

The costs of executing a 4000 km² large-scale floodplain restoration program along the lower Danube and Danube Delta are estimated at approximately €7 billion, based on an extrapolation of the costs of a similar in the Netherlands. Table 4.2 gives an overview of investments costs and effects of large-scale floodplain restoration as compared to the reference alternative. Of course floodplain restoration also means that the value of the floodplains for agriculture is reduced (losing €775 million in value).

³ Assuming 30 jobs/ invested million €, following BenDor (2015)¹⁶.

Table 4.2 Results illustrative cost-benefit analysis of large-scale floodplain restoration in the lower Danube.. Based on EUR (price level 2020) present value, discount rate 5,5% over the 2020-2050 (w/ exception for flood risk, which is calculated over 2020-2100).

Reference alternative	In EUR million	Large-scale floodplain restoration	
		Investment costs	in EUR million
Reinforcement of embankments & O&M	572	Flood plain reconnection	7115
Value of agricultural land use flood plains	1513	Effects	
Flood Risk	3348	Reduced yield/ agricultural value of flood plains	-766
Ecological quality	--	Reduced costs dike reinforcement	229
Diversification regional economy	-	Reduced flood risk	1360
Flexibility flood risk management strategy	--	Income from tourism/ recreation	1152
		Income from fisheries	140
		Water quality	++
		Biodiversity/ habitats	++
		Employment opportunities during implementation	200.000 jobs
		Flexibility in flood risk management strategy	++
		Prevented investments/ sanctions on compliance EU Water Framework and Habitat Directives	++
		Benefits	2116
		Benefit-cost ratio	0,297464
		NPV	-4999

4.6.4 In conclusion

Large-scale floodplain restoration is costly and challenging. Based on a quick scan assessment of potential costs and benefits of floodplain restoration along the lower Danube and – Delta, results indicate that benefits such as flood risk reduction, reduced dike restoration costs and new income streams from fishing and tourism are significant, but **costs still outweigh the quantified benefits by € 5 billion. However, benefits that could not be monetized at this stage would likely result in significant monetary and non-monetary benefits.** Preservation and restoration of the severely degraded ecosystem and water quality in the Danube will likely contribute to health and wellbeing and support achieving objectives from EU Water Framework and Habitats Directives. A more stable water availability and higher groundwater tables will support a basis for water and food security. Restoring the river's sediment balance will likely have benefits for navigation, flood risk and coastal management. The large-scale investment in floodplain restoration will support 200.000 jobs in the short term in support of economic recovery, and support livelihoods and diversification of local economies in the long term.

If these non-monetized benefits are worth € 5 billion or more, there is a rationale for investment. A very valid follow-up question is therefore: What will it cost society if these flood plains are not restored? What are these non-quantified benefits worth to current and future generations? Although floodplain restoration is undoubtedly a costly affair, the benefits of floodplain restoration closely fit the objectives of the EU Green Deal and long-term recovery budget: supporting a greener, more resilient Europe with climate change and biodiversity protection at its core.

5 Case study: Elbe

Land use changes in the past have made the Elbe prone to flash-floods in upper sections, and high discharges in lower sections. Water quality is below the desired level. To address these issues, an integrated flood protection approach combining grey infrastructure and NbS is used in the region. There is still potential to scale up the amount of NbS projects: economic analysis has shown large-scale floodplain restoration is attractive from socio-economic point of view despite trade-offs with agricultural use and navigability.

5.1 Status and existing policy

To support economic development, extensive embankments have disconnected floodplains from the river, enabling pasture-dominated grasslands over natural floodplain forests. After severe floods in 2002 and 2013, a new Flood Protection Action Plan is in place, aiming to develop more room for the river, i.e. floodplain restoration.

The Elbe River is one of the largest rivers in Central Europe, with about 1100 km and a catchment area of almost 150,000km² (Figure 5.1). About 365 km lies within Czech territory, and 727 km in Germany. Even through many river segments are in a near-natural state, nearly 80% of the original active floodplain areas are disconnected from the river by dikes developed in the 19th and 20th centuries ⁷².



Figure 5.1 Geographical outline of the Elbe river. From ¹¹⁸

The 240 km section in the Czech Republic contains many weirs and barrages, the mayor weir in Germany lies near Hamburg (Geesthacht).

Economic development of the floodplains has led to a shift from natural floodplain forests to pasture dominated grasslands, protected by embankments. This has made Elbe prone to flash-flooding in the mountainous regions and led to large inundation volumes in the lowlands. Additionally, there is concern the Elbe's water quality do not meet objectives defined at the European level. There are local/sub-basin drought occurrences, but these are not considered to be significant^{72,73}.

Flood risk

Extreme flood events in 2002 (1:150-200 year event) and 2012 (1:50-100 year event) highlighted the flood protection shortcomings of the present dyke and water management system^{74,75}. In response, German and Czech authorities developed the Elbe Flood Protection – Action Plan⁷⁶. Since then, the flood protection approach has become more integrated, including a combination of NbS and structural measures to reactivate and manage floodplains. The concept of “room for the river” is central in the flood protection strategy, including the relocation of dykes (Figure 5.2). As of 2011, 650 ha of floodplain had been reactivated at 4 sites⁷⁷.

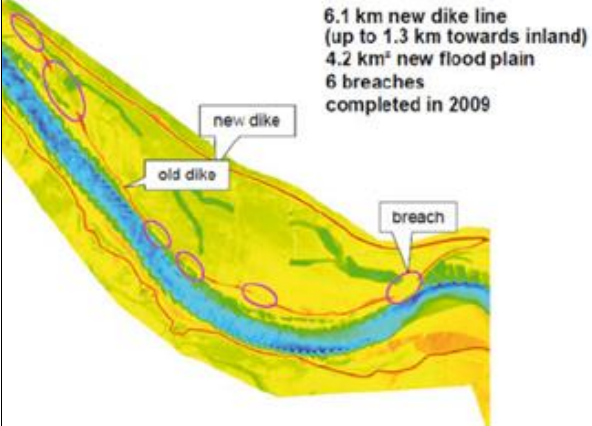
<p>Example project; dyke relocation of the middle Elbe River</p>	<p>Key elements of the Flood Protection Action Plan Elbe</p>
<p>Investigation strategies / „room for the river“: Dyke re-location Lenzen</p> 	<ul style="list-style-type: none"> • Improving natural retention of floodwaters in the flood plains as well as in tributaries and natural wetlands; • Identification and realization of basic principles in land use planning, reactivating former flood plains where this is feasible such as through the relocation of dykes; • Improve flood prevention in flood hazard areas, including measures related to risk preparedness and management and early warning systems; • Review design flood criteria and implementation of structural measures aiming at flood protection.

Figure 5.2 Concept for making room for the river in the Elbe^{75,76}.

Water quality

Water quality is a concern in the Elbe river system: in 2015, 91% of rivers and 77% of lakes did not achieve good ecological status and potential⁷⁸. Agricultural and industrial development in the previous century led to a nutrient and chemical pollution in the Elbe river, and this remains a key pressure for surface and groundwater quality to this day. Particulate matter and fine sediments are often loaded with heavy metals and arsenic⁷⁹. The sediment balance in the river is also disturbed: sedimentation rates in the port of Hamburg are quite high, requiring dredging works of up to 2.5 million tons per year⁸⁰. Of particular concern is the water quality in the port of Hamburg, where oxygen concentration levels sometimes reach critical levels during summer⁸¹.

In 2018 a Strategy for Nutrient Reduction in Waters in the International Elbe River Basin District was approved, with supraregional objectives and solutions⁸². Other topics covered in the River Basin management plan include improving the surface water structure and continuity – e.g. re-establishing habitats for aquatic organisms by increasing lateral connectivity between rivers and their floodplains, and improved sediment balance to reduce fine sediment transport and improve river continuity for fish migration⁷⁸.

International policy

The International Commission for the protection of the Elbe River (IKSE; Czech-German cooperation) periodically publishes the international management plan for the Elbe river basin district. Priorities include providing flood protection, reducing significant nutrient and pollutant loads and improving the surface water structure and navigability. The Elbe is navigable for 1,000-ton barges as far as through the Vltava, and waterborne transport across the Elbe is considered a key element of the European Union connectivity policy. For example, the Elbe River has traditionally secured access to the sea to the Check Republic⁸³.

5.2 NbS projects in the Elbe

About 20.000 ha of the Elbe's floodplain can potentially be restored. Projects executed in the past decade show positive impacts on flood risk and environmental quality.

Grossmann (2012) estimates 20,749 ha of floodplains have the potential to be restored, spread over 60 sites (**Error! Reference source not found.**)⁸⁴. The study illustrates how effective increased retention can be in reducing flooding, particularly in upstream reaches of the river basin.

Floodplain restoration in Lenzener Elbtalau

Various projects have demonstrated the effectiveness of floodplain restoration and dike reallocation. The most emblematic restoration project is the 'Lenzener Elbtalau', which includes the first large scale dike reallocation in Germany (420 ha) executed from 2002 to 2011⁸⁵. The project successfully combined flood protection and nature conservation objectives⁸⁶. The strongest impact on flood risk reduction is at the project site itself: the positive impact downstream and upstream – the site is a bottleneck - diminishes with distance.

Ecological impact floodplain restoration

Rumm, Foekler, Deichner, Scholz, and Gerisch (2016) evaluate the impact of restoration measures in the Elbe on species diversity and composition, using mollusks as bio-indicator for ecological quality⁸⁷⁻⁸⁸. The study area is a 140-hectare alluvial area in the Middle Elbe within the UNESCO biosphere reserve "Middle Elbe/Elbe River Landscape". Results indicate that that species diversity and composition of the mollusk fauna responded quickly and considerably to re-flooding after restoration efforts (Figure 5.4).

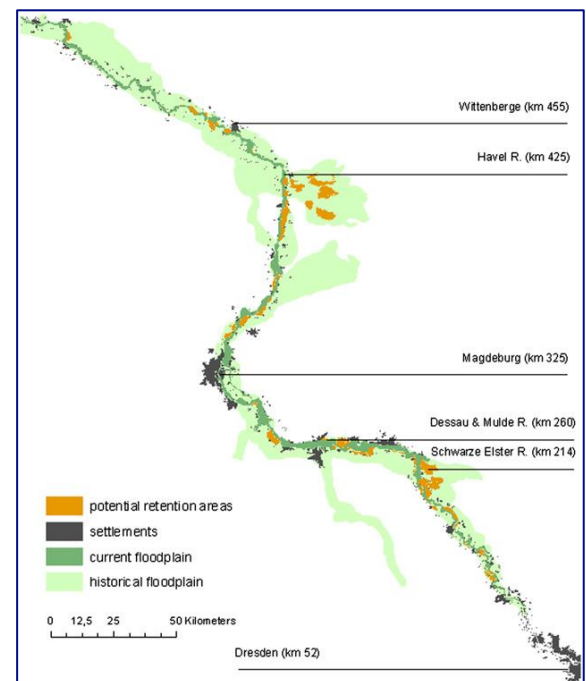


Figure 5.3 Potential floodplain restoration sites along the Elbe. From Grossmann (2012)

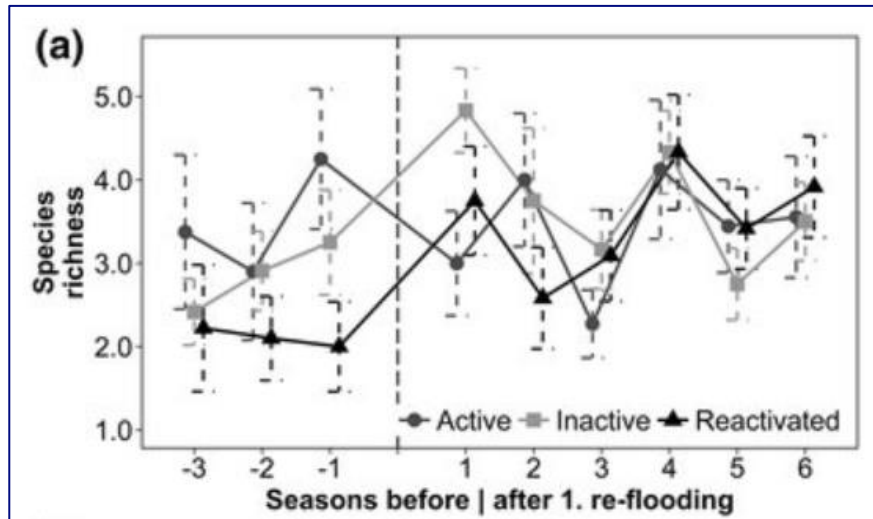


Figure 5.4 Changes in species diversity before (left of vertical dashed line) and after reconnection⁸⁷

5.3 Economic value of NbS in the Elbe

Various studies have addressed the economic value of floodplain restoration in the Elbe across key ecosystem services including flood protection, water quality, biodiversity protection and reduction of greenhouse gas emissions.

Floodplains operate as nutrient retention sinks; reconnecting them leads to an increase in water quality. The economic value of this ecosystem service can be determined based on opportunity costs: how much would it cost to reach a similar level of water quality using a technical substitute. The value of the Elbe floodplains as a nutrient sink is conservatively estimated at 7 million euros annually for a floodplain area of 15.000 ha; [this corresponds to approximately 530 euros per hectare and year](#)⁸⁹. Across time and space, the actual economic value of this service will strongly depend on local context, such as the availability of substitute abatement options (e.g. waste water treatment) and abatement targets⁸⁴.

The value of biodiversity is a typical non-use value, for which the economic value can be derived by deriving the willingness to pay based on revealed or stated preference (see section 3.3). Based on interviews with 864 residents living in the Elbe, Weser and Rhine catchments, Meyerhoff and Dehnhardt (2007) conclude that households are willing to pay on average €5,3 per year for protecting endangered species⁹⁰. Extrapolating this result to the number of households in the area (29,1 million) leads to a total [WTP for protection of endangered species in those three catchments between €153 million - €252 million](#). Households living in the vicinity of the river may be willing to pay even more: Fuchs, Bauer, Heuner, Schmidt-Wygasch, & Schröder (2013) find that if flood safety is not compromised, households are willing to pay €27 per year for restoring bank habitats⁹¹.

Grossmann and Dietrich (2012) calculate the relative price of reducing greenhouse gas (GHG) emissions through fen wetland restoration for 35 wetland sites along the Elbe River (3840 km²)⁹². The researchers estimate that degraded wetlands emit between 17.5–25.5 tCO₂e ha⁻¹ per year. Decreasing water availability in the river basin is expected to lead to a 2-5% increase in these emissions over the next 50 years. Presently, there are two wetland conservation programs in Germany: 1) stabilization of fen peat through adapted agricultural management practices, and 2) complete restoration of fen peat sites by rewetting, involving permanent conversion of agricultural land use and water management infrastructure. Fen stabilization costs between €10–20 tCO₂e⁻¹. Full restoration of fen peatlands by rewetting costs between €7–14 tCO₂e⁻¹.

These costs are lower than the projected market price of traded carbon of €18–37 tCO₂e-1; wetland restoration can therefore be a relatively low-cost option for GHG abatement ⁹².

Damages from flooding in the Elbe River basin can be very significant: the damage from the 2002 floods in Germany alone amounted to € 7,607 million. With inundated area of approximately 300 km², this corresponds to an average damage of 0.25 million € per ha ⁸⁴. Grossmann, Hartje and Meyerhof (2010) find that nature-based flood protection measures are not more cost-effective than conventional dike strengthening strategy in reducing flood risk, but when taking all benefits – e.g. quality, nutrient retention and GHG reduction - into account, they do have the highest benefit-cost ratio and the most attractive from environmental and socio- economic perspective (see also section 5.4)⁹³.

5.4 The economic case for large-scale floodplain restoration

In light of prevailing flood risk and ecological challenges in the Elbe river basin, there is a potential to further scale up floodplain restoration activities. When the economic value of various floodplain restoration strategies is assessed across the functions of flood protection, water quality, biodiversity protection and reducing GhG, results show that full floodplain restoration is the most attractive strategy from socio-economic point of view: there is a clear economic case for scaling up floodplain restoration efforts in the Elbe.

5.4.1 Floodplain restoration alternatives

Grossmann, Hartje and Meyerhof (2010) compare the costs and benefits of three alternative flood management programs, consisting of different constellations of dike reallocation and retention polders⁸⁴. 1) large scale dike reallocation, fully restoring the floodplains; 2) Controlled retention polders which keep the current land use and dike location in place, but allow for temporal flooding of floodplain polders and 3) a combination of polders and dike relocation⁹³.

1) Full floodplain restoration

A large-scale dike relocation programme would allow full floodplain restoration of all 60 potential (total 34659 ha) sites along the river stretch 117-536 km: dikes are set back to allow a natural flood regime in the floodplains. The costs of a full restoration and dike reallocation strategy include land acquisition costs (5500 €/ha), landscaping (300 €/ha), operation and management (10 €/ha) and construction of new dykes (525 €/ha).

2) Retention polders

Thirty-one floodplain sites are suitable to be converted to controlled retention polders, along the river stretch Elbe km 117 – 427. In controlled retention polders, the land can still be partly used for agricultural and forestry activities. The water management regime in the polders can be either a flood or an ecological regime: in a flood regime, polders are opened to accommodate all flood levels (low-high). In an ecological regime, the polders are opened to low and intermediate flood levels but closed for major flood events to prevent damage to natural habitats and functions. Required investments include installation of weirs to regulate the inflow of water, estimated at a capital investment of 650 000 € per weir, and operation and maintenance costs of €4500 per year.

3) Combination of controlled retention polders and floodplain restoration

In this alternative, in 6 sites controlled retention polders with an ecological flood regime are combined with 11 sites with full floodplain restoration.

5.4.2 Costs and benefits

The results of Grossmann et al (2010) indicate a positive socio-economic case for all three alternatives: the benefits are higher than investment costs (Table 5.1). Full scale floodplain restoration, alternative 1, brings an additional storage capacity of 738 million m³, which corresponds to an avoided annual flood damage of on average 165 €/ha. Additional benefits include water quality (nutrient retention), habitat provision and biodiversity protection and reduced maintenance costs of dike infrastructure. The net present value (NPV⁴) of this alternative is 2,520€Million. Alternative 2, in which 25,576 ha are converted to controlled retention polders, provides a total storage capacity of 494 million m³, which translates into avoided average annual damage up to 1015 €/ha. These controlled polders do not significantly contribute to other ecosystem services. The NPV of this strategy is 354€Million. In hybrid alternative 3 has a NPV of 1,481€Million.

Alternative 1, full restoration of 34658 ha of floodplains has the most attractive economic rationale for investment⁹³. The authors also investigate the outcome if benefits for water quality (nutrient retention) and biodiversity would not be considered, and only flood risk reduction benefits are included. In this case, the outcome would be different: large-scale floodplain restoration (alternative 1) would have a negative economic rationale with costs outweighing benefits by 128 € million. This negative result is largely due to the high opportunity costs in floodplain land use: agriculture and forestry are lucrative land uses, leading to high land purchasing costs. In this situation, controlled retention polders (alternative 2) yields the highest value (354 € Million).

Table 5.1 Results cost-benefit analysis for the Elbe river. Scenario 1: co-benefits are not included, Scenario 2: co-benefits are included⁹³.

Alternative	Area (ha)	NPV scenario 1 (Mio. €)	NPV scenario 2 (Mio. €)
Alternative 1: Dike relocation (large scale)	34,659	-128	2,520
Alternative 2: Controlled retention polders (large scale)	25,577	354	354
Alternative 3: Combination of polders with ecological flooding and dike relocation	7,545	326	1,481

There is a clear economic rationale for large-scale floodplain restoration in the Elbe river considering the benefits for water quality (nutrient retention), biodiversity and flood risk reduction. If only flood risk reduction benefits were to be considered, a more 'hybrid' NbS with no significant benefits for ecology would be deemed the most attractive. This illustrates how important assessment of the full range of benefits is for establishing the economic rationale of different river management strategies.

⁴ NPV: net present value. This is the balance (benefits – costs) of discounted costs and benefits over time. A positive net present value means that benefits are higher than the costs, and there is an economic rationale for investment.

6 Steps forward and conclusions

Current economic methods largely neglect the value of nature, hence a fundamental change in economics is required to better include and value natural capital

Amidst a global health and economic crisis, and with an ongoing climate and biodiversity crisis, the prosperity and wellbeing of humans around the globe is under threat. The recently published Dasgupta Review (2021) on The Economics of Biodiversity – the first comprehensive economic framework of its kind – stipulates that the road towards truly sustainable development lies in recognizing that long-term prosperity relies on nature, and in consequence rebalancing our demands on nature's goods and services. This requires a fundamental change in how we think about and approach economics: nature should be valued as our most precious asset. This means adopting new metrics for economic success, accounting for the benefits from investing in natural assets, transforming our institutions and systems – particularly regarding financial flows and education – and moving towards conservation and sustainable exploitation of natural capital and increasing our investment in nature-based solutions.

Around the globe, policy makers and investors are increasingly looking for solutions that stimulate development whilst slowing down or adapting to climate change and conserving and recovering biodiversity: the call to transition to a green and inclusive economy rings ever louder. This is also underlying the €1 trillion European Green Deal⁶, which aims to support green economic development in the EU and will include major investments in protection and restoration of forests, soils, wetlands and rivers. Most rivers in Europe have been strongly modified by human interventions, resulting in a severe decline in populations and diversity of freshwater species. In this report, we compiled evidence on how changing metrics for economic success of river management strategies supports the case for investment in (hybrid) NbS rather than traditional engineered management strategies of Europe's rivers.

Healthy rivers and freshwater ecosystems are vital for economic development and water security

Healthy river and freshwater ecosystems provide a wide range of ecosystem services. Among other things, healthy rivers provide fish and building materials, opportunities for recreation, an attractive landscape and biodiversity, nitrate and phosphorus cycling and water. Ecosystem services of rivers and lakes have an economic value averaging €91.738 per ha/year. This means rivers and lakes are among the most valuable ecosystems and biomes on earth, in league with tropical forests (€100.809) and coral reefs (€134.235). The most valuable ecosystem services of rivers and lakes include treatment of pollutants, drinking and irrigation water provision, maintaining genetic diversity and opportunities for recreation and tourism. Inland wetlands are also very valuable (€41184/ha/year), particularly in regulating water flows and moderating extreme events food provision, maintaining genetic diversity and preserving biodiversity. The wide range of ecosystem services provided by rivers creates an attractive living environment and provides a solid basis for diversified local livelihoods: multiple beneficiaries profit from these services, making local communities more resilient in the long-term. Yet, despite the high economic value of the wide array of ecosystems services, rivers across the globe have been modified for irrigation, hydropower, flood protection and navigation at the expense of other services.

Nature-based solutions in river management contribute to restoring ecosystems of modified river systems and provide multiple co-benefits that can support jobs in diverse branches.

The socio-economic case for large-scale investments in NbS to restore rivers to a more natural state and mitigate flood and drought risks is clear. Large-scale NbS implementation and uptake may reverse biodiversity decline and aid in climate change mitigation and adaptation. Over the previous decade a transition in river management towards inclusion of alternative nature-based measures is emerging globally. For example, many of the 34 projects in the Dutch “Room for the River” focus on reconnecting floodplains and creating retention areas to restore river functions and lower water tables. Several programs of the Environment Agency and the SEPA in the UK and Scotland focus on re-meandering and creating bypasses, and finally, WWF is executing large-scale removal of dams in Europe. These approaches work with and restore - entirely or in part - natural characteristics and dynamics of the river system. By doing so flood and drought resilience increases in a more sustainable and environmentally friendly way than by applying conventional engineering solutions.

Public investments supporting sustainable economic recovery from a crisis offer opportunities to: 1) create jobs in the short term; 2) support economic development in the medium term, and 3) shift the economy towards nature-friendly, low-carbon approaches on the long term^{94,95}. In the context of economic recovery, investments in NbS for river restoration are an attractive avenue, as NbS can help to meet both short-term, mid-term and long-term objectives. NbS contribute to multiple functions simultaneously and provide a range of additional ecosystem services. Reforestation, ecosystem and watershed rehabilitation and management of invasive species, are some of the most job-intensive activities. To illustrate, after the 2008 crisis South Korea invested \$10 billion in river restoration⁹⁶ and the US invested \$ 167 million in coastal restoration habitats under the American Recovery and Investment Act of 2007, creating 17 jobs per invested million \$. During the Great Depression, about 3 million people were employed in, among other things, planting 3 billion trees⁹⁴. Presently, New Zealand is using a budget of \$1 billion to create 11.000 nature jobs¹.

In the example of the lower Danube, we showed that investing in a 4000 km² floodplain restoration program is likely to deliver many economic benefits. The resulting lower water levels will reduce flood risk and save costs in renovating the current flood risk infrastructure. The wide array of ecosystem services, including increasing fish stocks and more attractive, natural environments will strengthen the fishery and tourism industry and thus, contribute to diversifying local economies. The restoration program will potentially create over 200.000 jobs in the short to medium term, and improve ecological quality, water quality, biodiversity and restore the natural functioning of the river and its floodplains. Although such restoration would undoubtedly be a costly affair (estimated at €7 billion), expected benefits closely fit the objectives of the EU Green Deal and long-term recovery budget: supporting a greener, more climate resilient and biodiverse Europe.

In the example of the Elbe river, existing studies on the benefits of floodplain restoration show how important an assessment of the full range of benefits is to establish the economic rationale between different river management strategies. If only flood risk benefits are considered, conventional or ‘hybrid’ interventions with little benefits for nature are economically most attractive. However, there is a clear economic case for large-scale floodplain restoration as an intervention if benefits for water quality (nutrient retention), biodiversity and flood risk reduction are all included.

Integrating human and natural capital in cost-benefit assessments will facilitate large scale uptake of Nature-based Solutions and capitalization of their full potential.

Although large-scale NbS projects may be attractive in the long-term and deliver several co-benefits, they are not yet mainstream in river management. Investment costs of NbS can be high, especially in systems that are heavily modified. Additionally, their implementation can be more complex than conventional approaches due to their cross-disciplinary and cross-sectoral nature. Consequently, in many cases water management institutions are inadvertently geared towards grey infrastructure. The success of scaling up NbS strongly depends on the local enabling institutional framework and budget rules³⁸. In practice, budgets are often splintered, like the institutions themselves, and financial and economic power lies mostly with engineering and civil works departments rather than disaster management and environment institutions. Public authorities should therefore prepare an enabling regulatory environment that incentivizes innovations, such as NbS, and discourage harmful activities that do not capture value of nature^{38,97}. Decisions on large-scale investment programs that affect common resources, such as water availability and biodiversity, would largely benefit from a broad perspective encompassing all benefits on a large spatial and temporal scale. When reviewing the merits of NbS solely on a case by case basis instead of taking a larger river stretch or entire (sub-)basin perspective, many benefits will stay off the radar. To substantiate the potential and rationale for investing in NbS, future projects should include i) a wide scope integrating all potential benefits, ii) sufficiently large river stretches and iii) including upstream and downstream effects of all measures and their interdependencies.

Standard inclusion of NbS in infrastructure project formulation processes can help NbS to become as one of the preferred options within the range of interventions considered for a project. To enable this, decision making procedures on infrastructure investment planning need to be aligned to reflect the particularities of NbS, to allow for a fair comparison of the benefits of NbS. This can be done by mandating a lifecycle cost approach and wider ecosystem service valuation in CBAs and taking long-term efficacy and depreciation into account. However, still NbS may turn out to be more complex to realise than conventional infrastructure in project development and delivery. For example, stakeholder engagement, land ownership and project delivery with respect to NbS tendering and permitting procedures and partnership models, may all be more complicated⁹⁸. Taking these hurdles can be done through awareness raising, capacity building in executing agencies and setting policy goals on NbS and natural capital inclusion in public projects⁹⁹. Early stakeholder engagement at all spatial levels to gain support is also a key enabler for NbS.

Throughout project planning cycles, there are various phases where adjustment or strengthening of the institutional framework can support the decision to choose NbS. For example, collaboration across jurisdictional and disciplinary boundaries is difficult, but exactly what is needed to identify and create multi-functional infrastructure like NbS. To support this, an institutional and legislative mandate for dealing with cross-sectoral issues at (sub) basin level is needed. This can be done by appointing a coordinating institution. Such an institution can set up expert committees composed of public sector stakeholders, local environmental experts, conservation NGO's, investment communities and project developers in key watersheds. These committees can develop a country-wide or basin-scale strategy on hotspots for disaster risk reduction and climate change adaptation and help to direct (public) investments and develop a (hybrid) NbS project pipeline. These committees should make sure objectives in the Water Framework Directives are achieved, ensure alignment of DRR/CCA strategies with local development and land-use plans, and identify activities and plans that may harm water and biodiversity objectives.

In response to the biodiversity and climate crisis, the momentum is there for upscaling and mainstreaming NbS. Economic recovery packages and the EU Green Deal can catalyze this process.

The clock is ticking on Europe's river systems. Climate change and biodiversity decline pose increasing challenges for societies. The economic crisis resulting from the Covid-19 pandemic has brought unprecedented unemployment levels around the globe and the deepest recession in EU history. The recovery strategy could have implications for the climate and biodiversity crisis, as efforts to address these may temporarily be deprioritized and communities may lean more heavily on natural resources. However, economic recovery packages and the EU Green Deal also offer opportunities to stimulate the transition towards inclusive green economic development^{100,101}. The EU Green Deal, EU Adaptation Strategy and Biodiversity Strategy present a concrete opportunity to stimulate uptake of NbS in river management: legally binding restoration targets present a strong supporting incentive. The synergy with the forthcoming European Forest Strategy and its commitment to plant 3 billion trees across the EU provides another incentive for NbS for the restoration of floodplains and upper catchments. As the relatively short experience with NbS application competes with decades of knowledge development on grey infrastructure, there is a clear need to accelerate and share knowledge on all aspects of NbS project development and delivery. The EU can support adoption and upscaling of NbS by organizing data collection and monitoring of NbS projects. This would provide the necessary knowledge base for evaluating performance, costs and benefits, design characteristics and feasibility of NbS in project appraisal processes throughout Europe.

COVID-19 recovery, sustainable economic development and climate change adaptation funds offer an excellent opportunity to create incentives to accelerate and upscale NbS implementation. These funds can leverage existing funding to enable collaborations between departments and stakeholders at the basin level, to come up with a green, inclusive, multi-benefit investment portfolio in river systems, and help to reduce the financial risks of NbS project initiatives by providing budget guarantees upfront⁹⁹.

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Appendix A: overview of guidelines for monetary valuation of flood risk infrastructure

	Source	Method	Title (hyperlink)	Content
Cost	NOAA (2013)	Cost estimation	Adaptation report	Chapter 2 discusses how to analyse the adaptation strategies' impact on flood risk, including a number of case studies; chapter 3 on monetizing this impact.
	TU Delft (2010)	Cost estimation	Coastal defence cost estimates – Case study of the Netherlands, New Orleans and Vietnam	Cost estimates at project and system level for low-lying deltaic coastal areas: unit cost estimates for both conventional and BwN approaches.
	NAIAD2020	Life cycle Cost approach NBS	Costs of Infrastructures: Elements of method for their estimation	Outlines how the LCC methodology can be tailored to NBS, including an overview and references to available cost figures and empirical data.
FR Impact	NOAA	Flood-risk + ecosystem services	A guide to assessing green infrastructure costs and benefits for flood reduction	Guide for assessing flood risk and co-benefits of green infrastructures (stormwater drainage) to prevent riverine/ rainfall flooding
	Greeninfrastuctureenw.co.uk (2010)	Flood risk + ecosystem services	Building natural value for sustainable economic development. The green infrastructure valuation toolkit user guide	Calculation toolkit for estimating the benefits of green infrastructure, including impact on flood risk: relevant for riverine/ estuary flood risk.
CEA	NAIAD	Water-related damage estimation		Economic water-related risk damage estimation
	Paper; PLOSone (2016)	Costs-effectiveness (quick-scan)	The effectiveness, costs and coastal protection benefits of natural and nature-based defences.	Evidence-based analysis of cost-effectiveness of coastal building with nature projects
	World Bank	Cost-effectiveness; cost-benefit	Implementing nature-based flood protection – principles and implementation guidance	Principle 3 on performance evaluation (needed for CEA); Step 5 on estimation of effectiveness, costs and benefits.
	COASTADAPT (2016)	Cost-benefit analysis	Information manual – Assessing costs and benefits of adaptation	Clear description, explanation and links to other sources on cost-benefit analysis and other approaches in coastal adaptation context.
	Renaud et al (2017)	Cost-benefit analysis	Ecosystem-based disaster risk reduction and adaptation in practice. Part I: Economic approaches and Tools for Eco-DRR/CCA	Number of book chapters discussing valuation of BwN strategies – best practices, existing studies and various case studies.
CBA	WUR (2014)	CBA: valuing ecosystem services	Economic viewpoints on ecosystem services	General introduction into ecosystem services valuation and tools – not specific for coastal infrastructure/ ecosystems.

	GIZ (2017)	Cost, benefits & FR impacts	Valuing the benefits, costs and impacts of ecosystem-based adaptation measures – a sourcebook of methods for decision-making	Elaborate guideline on valuing BwN benefits, including case studies, and an overview of tools.
	Ecoshape (Origin: Netherlands environmental agency Sijtsma et al., 2009)	Nature index	This tool outlines a methodology to include nature qualities in planning processes by defining a quantitative nature index	Tool description, guideline, practical applications.
	TEEB	Database for ecosystem service valuation	Ecosystem Service Valuation Database	Database of monetary values of ecosystem services based on 300 case studies, including in coastal/ wetland/ watershed biome types.
	CoastAdapt	Real options analysis	Real options for coastal adaptation	Guideline on applying real options analysis to coastal adaptation.
Dealing with uncertainty	Coastadapt	Sensitivity analysis + scenario analysis	Information manual – assessing costs and benefits of adaptation	Chapter 5 discusses uses of sensitivity analysis and further links to guidelines on how to do so.
	Coastadapt	Adaptation pathways	Costs and benefits manual	Chapter 8 introduces adaptation pathways and links to various guidelines/ approaches and examples.

Table 0.1 (not conclusive) overview of methods and back ground documents of cost-estimation, flood risk (FR) impact, cost-effectiveness assessment (CEA), cost-benefit analysis (CBA) and dealing with uncertainty in the context of NBS in fluvial and coastal system. From: (Groenendijk et al., 2020)

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