DANUBE FLOODPLAIN OUTPUT 4.1:
FLOOD PREVENTION MEASURES TESTED IN PILOT AREAS

Interreg
EUROPEAN UNION
Danube Transnational Programme
Danube Floodplain

Project co-funded by European Union funds (ERDF, IPA)

Impressum

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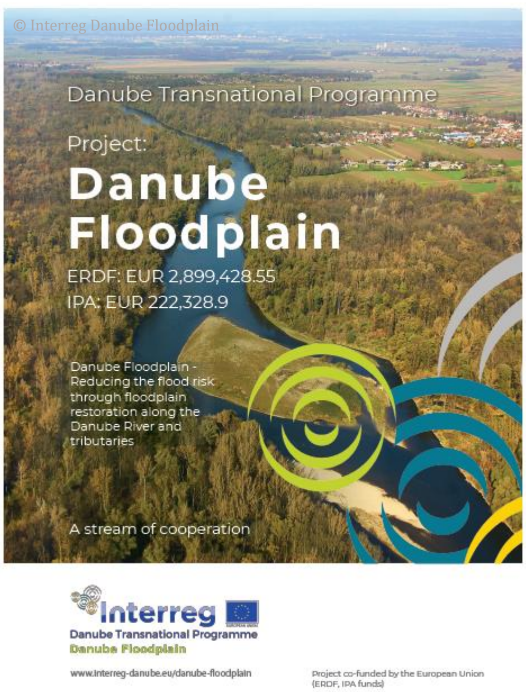
Abbreviations

DRSV	Slovenian Water Agency
TUM	Technical University of Munich
CUEI	Catholic University of Eichstätt-Ingolstadt
JCI	Jaroslav Cerni Institute for the Development of Water Resources
NARW	National Administration “Romanian Waters”
KOTIVIZIG	Middle Tisza District Water Directorate
VUVH	Water Research Institute
ARIES	Artificial Intelligence for Ecosystem Services
InVEST	Integrated Valuation of Ecosystem Services and Tradeoffs
CBA	Cost-benefit-analysis
BCR	Benefits-costs-ratio
GHGs	Greenhouse gases
IPCC	Intergovernmental Panel on Climate Change (IPCC, 2006; IPCC, 2014),
FAOSTAT	(FAO, 2019)
Eurostat	(European Commission, 2020)
EarthStat	(Monfreda et al., 2008)
HQ_{2-5}	Flood event that is reached or exceeded with a probability of 1/5 to 1/2 every year
HQ_{10-30}	Flood event that is reached or exceeded with a probability of 1/30 to 1/10 every year
HQ_{100}	Flood event that is reached or exceeded with a probability of 1/100 every year
ESS	Ecosystem service(s)
QGIS3	Quantum Geographic Information System, Free and Open Source Geographic Information System
CS	Current state
RS1	Restoration scenario 1
RS2	Restoration scenario 2
SDGs	Sustainable Development Goals
TESSA	Toolkit for Ecosystem Service Site-based Assessment
WP4	Work Package 4 of the Danube Floodplain Project
ΔQ	Reduction of maximum discharge between a restoration scenario and the current state scenario [%]
Δt	Translation of the flood peak between a restoration scenario and the current state scenario [hours]
2D	Two-dimensional

INTRODUCTION

MOTIVATION

The goal of the Danube Floodplain project is to improve transnational water management and flood risk prevention while maximizing benefits for biodiversity conservation.



The main project's outputs will be:

- The Danube floodplain restoration and preservation manual;
- A Sustainable Floodplain Management Strategic Guidance with the key findings;
- A Roadmap comprising agreed next steps towards realizing floodplain projects.

The project target groups are ministries, river basin authorities, practitioners, and stakeholders.

AIMS OF WORK PACKAGE 4

Work Package 4 (WP4) aimed at proving the efficiency and profitability of preservation and restoration projects for flood risk mitigation and improving the ecosystem services at the Danube and its major tributaries. This should be done in five pre-selected pilot areas, due to the complexity and necessary efforts of all required steps:

- Floodplain restoration scenarios were analysed with two-dimensional hydrodynamic models in Activity 4.1;
- In Activity 4.2, an analysis of favourable habitats for biodiversity was conducted through habitat modelling;
- Stakeholders were involved through workshops in the mapping of ecosystem services in Activity 4.2;
- In Activity 4.3, results from the first two activities were collected and embedded into an extended cost-benefit analysis, after modelling ecosystem services;
- Activity 4.4 applied feasibility studies and summarized the recommendations from the pilot areas.

This output was adapted from all relevant deliverables of WP4 of the Danube Floodplain Project (Danube Floodplain, 2019; Danube Floodplain, 2020a; Danube Floodplain, 2020b; Danube Floodplain, 2020c; Danube Floodplain, 2021a; Danube Floodplain, 2021b; Danube Floodplain, 2021c; Danube Floodplain, 2021d).

THE PILOT AREAS

- Begecka Jama
- Bistret
- Krka
- Middle Tisza
- Morava

THEORETICAL BACKGROUND

HYDRODYNAMIC MODELING

Two-dimensional (2D) models are broadly used to quantify and evaluate river hydrodynamics. Data requirements and processing is demanding, but clear advantages are the spatially detailed results that can be used for further planning (Stone et al. 2017). 2D hydrodynamic models reveal detailed patterns of flow conditions with a high spatial resolution during flood events and are therefore applicable for analyses of ecological functions (Gibson und Pasternack 2015). The models can reproduce the dynamic interactions between the river and its floodplain. These interactions are an important indicator for regulating hazard information (e.g. water depth or velocity maps) (Hattermann et al. 2018).

Consequently, the application of 2D hydrodynamic models in the five pilot areas of the Daube Floodplain Project is an ideal base for the further analysis of the flood prevention effect of floodplain restoration measures (Activity 4.1), the improvements for habitats and ecosystem services (ESS) (Activity 4.2), and the ESS extended CBA (Activity 4.3). It has to be mentioned that the 2D model results do not generate exact real conditions, but with several simulated scenarios an approximation can be yielded on how the floodplains would react in flood events (Stone et al. 2017).

HABITAT MODELING

The general aim of the habitat modeling work within the Danube Floodplain Project was to evaluate whether a certain floodplain restoration measure is capable of improving typical floodplain habitats. Such prediction was made based on environmental co-variables, like water depth, flood duration, flow velocity, etc. (Guisan and Zimmermann, 2000; Maddock et al., 2013). At the basis of the method, there is a conceptual understanding of how these environmental factors influence habitats and the species living in them. Therefore, quantitative formulations were made to link habitats and environmental variables.

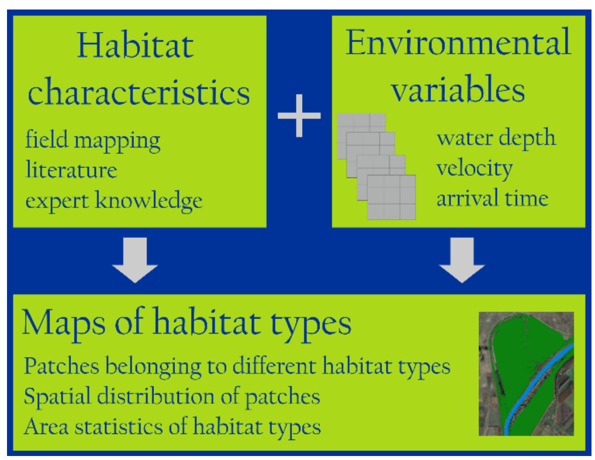


Figure 1. Habitat modeling at the meso-scale

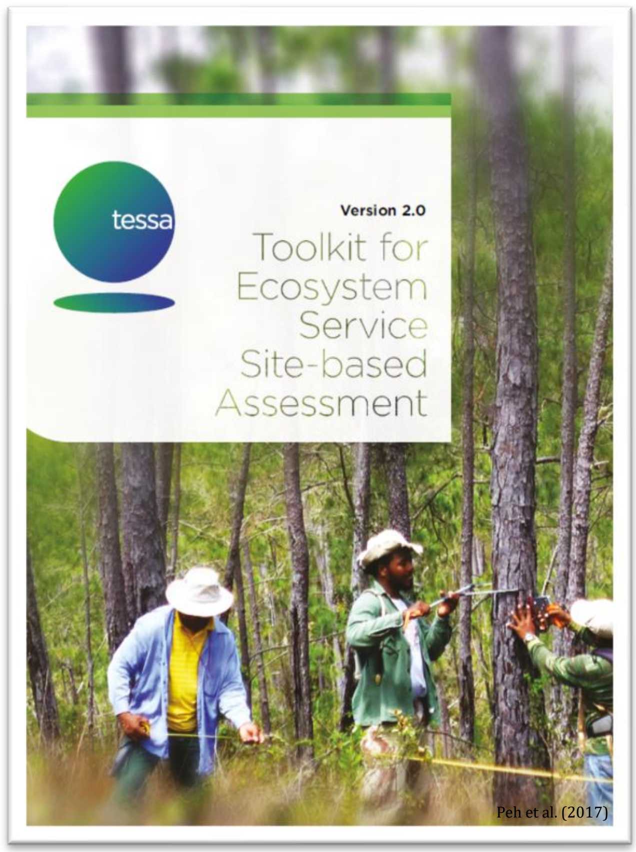
STAKEHOLDER ENGAGEMENT

An important aspect of the Danube Floodplain Project was to involve various stakeholders from the beginning of the project. It was not just to inform about the project, its outputs, and deliverables, but to increase the knowledge about floodplain restoration and to improve cooperation between different sectors (like water management, agriculture, and nature protection). This work was done within Work Package 2 (Danube Floodplain, 2018).

Figure 2. Stakeholder workshop for the Krka pilot area (Source: Gelhaus, 2019)

ECOSYSTEM SERVICES

Ecosystem services (ESS) are the benefits that humans get from nature. Many variables can affect ESS provision, which makes their estimation and their evaluation a complex process (Alcamo, 2003). The TESSA Toolkit (Peh et al. 2017) was used as theoretical background for the ESS estimation.



Without forgetting the stakeholders of the pilot areas, their contribution is included in the tool as input data, in the form of ESS maps, produced from the collaboration among stakeholders, local project partners (PPs), and the Catholic University of Eichstätt-Ingolstadt (CUEI).

EXTENDED COST-BENEFIT-ANALYSIS

The cost-benefit analysis (CBA) is a decisional method that estimates the economic efficiency of alternative options, by comparing the benefits derived from an option with the associated costs (ICPDR, 2015). An extended CBA requires specific methods to express environmental services in monetized benefits.

In flood risk management, the standard CBA considers as benefits the avoided flood risk. These benefits can be extended to integrate the results of the ecosystem services assessment of potential restoration strategies. A major challenge of the approach is to translate the ESS into quantitative values so that they can be considered in the decisional process.

FEASIBILITY STUDIES

The purpose of a feasibility study is to determine if a project is possible, practical, viable, as well as economically justifiable (Hoagland and Williamson, 2000).

A feasibility study will help decision makers take critical quick decisions to select the right opportunities. Feasibility studies that evaluate whether a restoration effort should be attempted can enhance restoration success by highlighting potential pitfalls and knowledge gaps before the design phase of a restoration. Feasibility studies can also bring stakeholders together before a restoration project is designed to discuss potential disagreements (Hopfensperger et al., 2007).

An extended feasibility study should analyze the current situation and describe the transformation process of reaching the desired state of floodplains, including proposals on land use conversion and water regulation systems within the landscape. These opportunities should be investigated before planning floodplain rehabilitation interventions.

PILOT AREAS OF WORK PACKAGE 4

The five pre-selected pilot areas show different properties in size, from 10 km² in the Begecka Jama area to 177 km² at the Romanian Danube in Bistret, but also in geographical characteristics and land use. Further, the purpose of restoration follows different motivations, e.g. flood risk management, reconnecting old oxbows and reactivating the floodplain, enhancing the ecological conditions to improve habitats for plant and fish species, or promoting sustainable development and ecotourism. The planned restoration measures also differ. Mainly dike relocation, land use change or excavation, and reactivation of old oxbows are implemented by topographical adjustments of the 2D model.

Table 1. Main characteristics of the Danube Floodplain Project's pilot areas

Pilot Area	Begecka Jama	Bistret	Krka	Middle Tisza	Morava
River	Danube	Danube	Krka	Tisza	Morava
Country	Serbia	Romania	Slovenia	Hungary	Slovakia, Czech Republic
Responsible PP	JCI	NIHWM/ NARW	DRSV	KOTIVIZIG	VUVH/ MRBA
Pilot area size [km²]	10.13	176.98	85.56	49.51	147.37

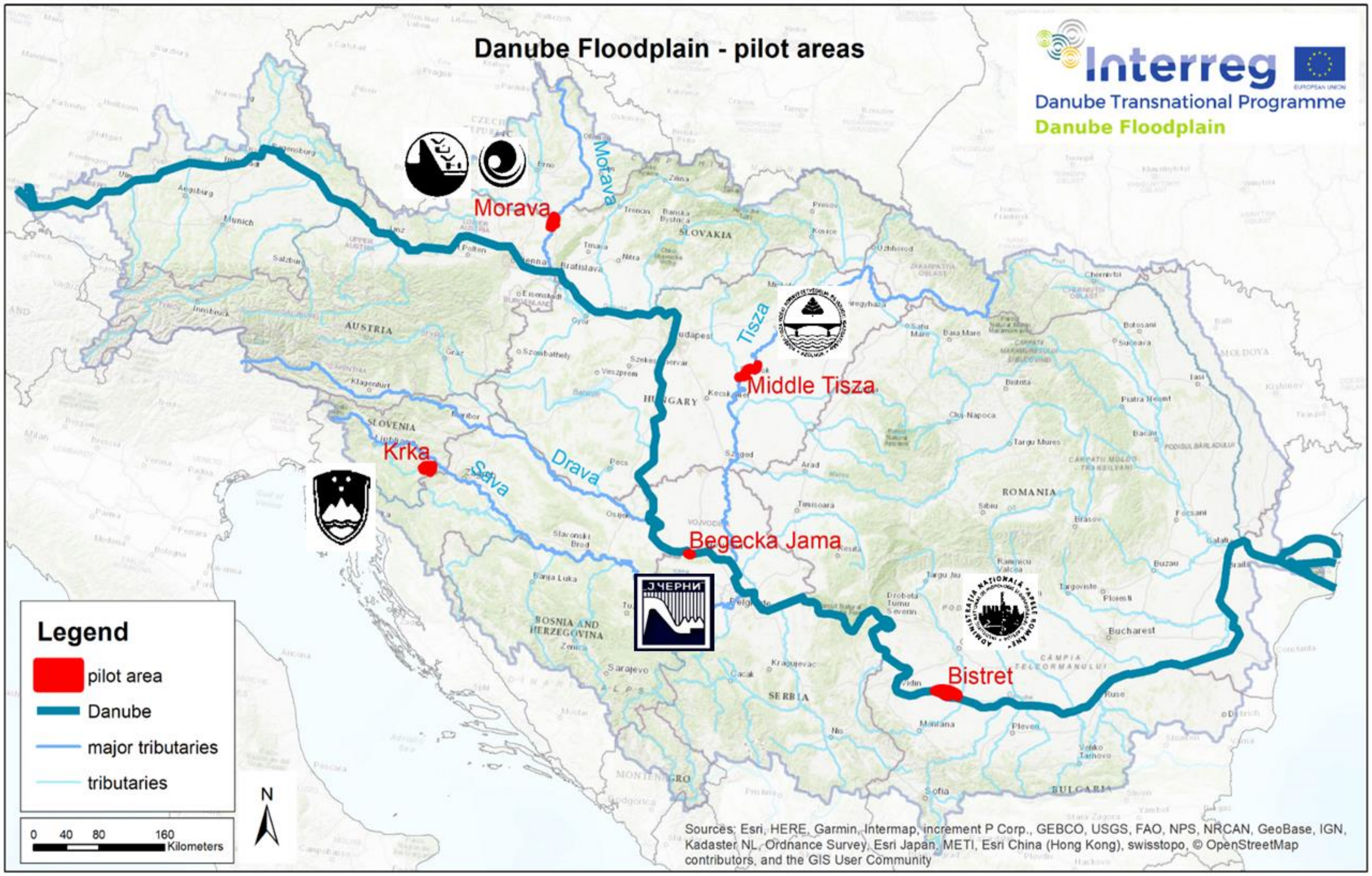


Figure 3. Location of the five pilot areas in the Danube Basin and responsible partners

1. HYDRODYNAMIC MODELING

1.1. METHODOLOGY

Each responsible national project partners (see Table 2) investigated their corresponding pilot area in the following steps:

- Request and collection of necessary data from other authorities (digital elevation model, ground survey data, land use data, hydrological data);
- Set up of the current state 2D hydrodynamic model (CS) including calibration and validation;
- Decision on measures for two restoration scenarios (RS1 and RS2) in cooperation with the identified stakeholders;
- Modification of the CS model geometry according to planned restoration measures to obtain two restoration scenario models (RS1 and RS2);
- Unsteady simulation runs for all set up models with three hydrological scenarios (HQ_{2-5}, HQ_{10-30}, HQ_{100});
- Results: spatial data and hydrographs.

A short overview of the properties of the set up 2D models in the five pilot areas is represented in the following table (Table 2).

Table 2. 2D hydrodynamic models' properties in all pilot areas

	Begecka Jama	Bistret	Krka	Middle Tisza	Morava
Developing PPs	JCI	NARW	IZVO-R ltd. (External partner of DRSV)	KOTIVIZIG	VUVH
2D model type and release	HEC-RAS 5.0.7	HEC-RAS 5.0.7	MIKE FLOOD v. 2012	HEC-RAS 5.0.7	HEC-RAS 5.0.7
DEM base	1x1m Lidar and Bathymetric surveys (2019)	5x5m (2007-2008)	1 x 1m Lidar (2015)	1x1m	2x2m (2010)
Major tributaries		Desnatui River	Radulja River	Zagyva River	Dyje River Myjava River
Temporal resolution	1 hour	1 hour	1 hour	1 hour	1 hour

1.2. 2D MODELING MAIN RESULTS

Table 3 shows the results of the 2D hydrodynamic modeling in the five pilot areas.

In Begecka Jama, no additional floodplain area or retention channels are implemented with the restoration measures, leading to almost no change in the reduction of maximum discharge ΔQ. However, many measures are simulated concerning the reconnection of lateral river branches or oxbows, thus a translation of the flood peak (Δt) is observable (flood peak approaches later) especially in the HQs with a smaller frequency in RS1. In RS2, this effect is minor, as an additional channel excavation was simulated, which lead to a shorter traveling distance for the flood wave.

In the Bistret pilot area; the restoration measures mainly focused on the reactivation of floodplains by dike removals and the creation of a new channel to supply lake Bistret with water. In both restoration scenarios; only a small effect on ΔQ can be achieved. The largest effect is simulated for an HQ_{100} in scenario RS1. However, when considering Δt, beneficial effects are simulated for the RS2 scenario. The creation of new floodplain areas by the complete dike removal, as implemented in Bistret for RS2, and the transformation of floodplains towards natural conditions allows longer retention of flood discharge in the floodplain areas, which contributes to a peak delay of 11 to 16 hours. Yet, the effect decreases with an increasing return period, as the capacity is limited.

Krka restoration scenarios do not differ between RS1 and RS2 in the type of measure, but in the magnitude in which it is implemented. This becomes also visible in the reduction of maximum discharge (ΔQ). Larger reductions are obtained in scenario RS2 than RS1, as a certain amount is stored in the additional retention areas (floodplain forest). Effects on Δt cannot be detected, i.e. no translation of the flood wave occurs.

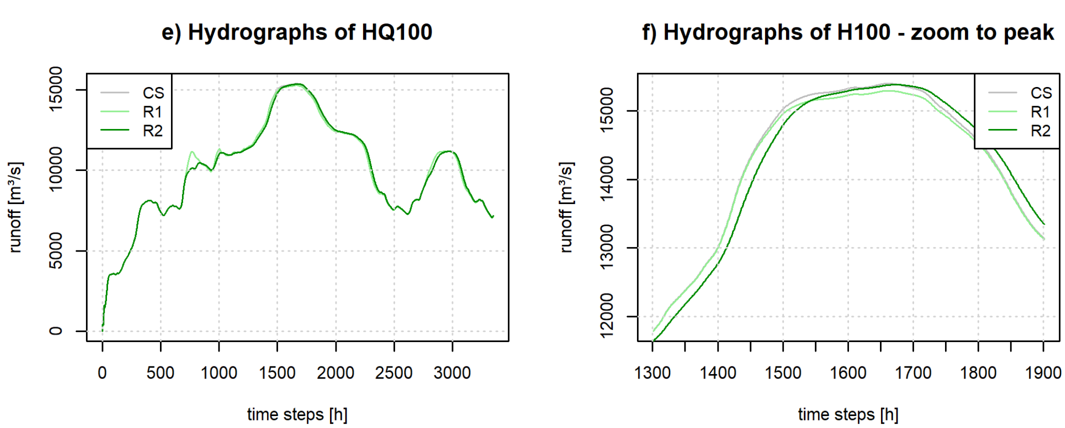


Figure 4. Example of hydrographs (HQ_{100} event) in the Bistret pilot area

Table 3. Results and analysis of the 2D hydrodynamic modeling in the five pilot areas

Relevant variable	Scenario	Begecka Jama			Bistret			Krka			Middle Tisza			Morava		
		HQ_{2-5}	HQ_{10}	HQ_{100}	HQ_2	HQ_{10}	HQ_{100}	HQ_2	HQ_{10}	HQ_{100}	HQ_2	HQ_{10}	HQ_{100}	HQ_2	HQ_{10}	HQ_{100}
Q_{max} [m^3/s]	out CS	5767	6476	8372	10569	13098	15398	319	370	431	1929	2172	2727	667	728	833
	out RS1	5764	6476	8370	10568	13086	15295	318	364	422	1927	2173	2728	657	685	776
	out RS2	5767	6476	8370	10545	13083	15383	319	361	416	1937	2163	2728	673	670	751
Change in flooded area [%]	RS1-CS	0.0	0.0	0.0	0.4	43.2	66.8	6.3	4.1	-0.2	6.2	5.0	6.2	-24.0	-30.0	-24.2
	RS2-CS	1.2	0.0	0.0	300.7	329.3	347.0	6.1	4.2	-0.3	6.1	4.4	6.1	-7.1	-16.8	-8.6
ΔQ_{max} [m^3/s]	RS1-CS	-2.8	0.2	-2.1	-0.8	-12.1	-103.2	-1.6	-6.6	-9.1	-1.8	1.3	1.2	-9.6	-43.4	-57.6
	RS2-CS	0.5	-0.2	-1.6	-23.9	-14.5	-15.2	-0.2	-9.6	-15.9	8.4	-9.5	1.2	6.3	-57.8	-81.9
ΔQ_{max} [%]	RS1-CS	-0.1	0.0	0.0	0.0	-0.1	-0.7	-0.5	-1.8	-2.1	-0.1	0.1	0.0	-1.4	-6.0	-6.9
	RS2-CS	0.0	0.0	0.0	-0.2	-0.1	-0.1	-0.1	-2.6	-3.7	0.4	-0.4	0.0	0.9	-7.9	-9.8
Δt [hours]	RS1-CS	3	-1	0	0	0	0	-1	0	-1	8	4	15	-20	5	-11
	RS2-CS	0	-1	0	16	11	11	-1	0	0	7	0	6	-20	7	-15

The restoration scenarios of Middle Tisza are focusing on the increase and transformation of floodplain areas to natural conditions. In RS2, afforestation is additionally implemented in the floodplain and a retention channel is created. Nevertheless, no distinct effects on ΔQ are achieved with these measures. Yet, retention of the flood discharge and thus a translation of the flood wave (Δt) is achieved, but with inconsistent magnitudes among the hydrological events. The marginal effect on ΔQ and the more pronounced effect on Δt suggest that the flood discharge is retained by the floodplain for a certain amount of time and is then released, resulting in a later but equally large flood peak after the floodplain.

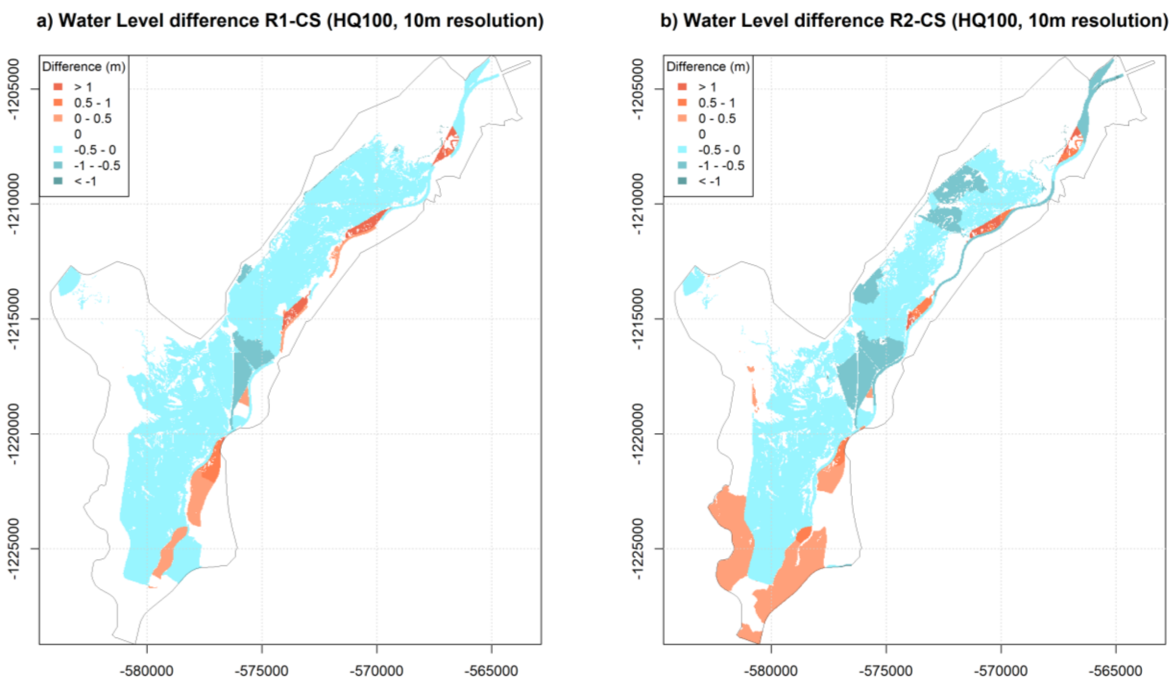


Figure 5. Example of water level differences maps (HQ_{100} event) in the Morava pilot area

Restoration measures in the Morava river differ from each other. RS2 includes several measures concerning the river channel itself and the extent of the floodplains, whereas in RS1 only floodplain expansions are implemented. Morava is the only pilot area that investigated a modification of the river course (meandering). Thus, the effects of ΔQ and Δt are variable. Additionally, special tributary conditions have to be considered in the Morava model area. It is important to also investigate the lateral inflows from the tributaries, as the discharge conditions of the tributaries and the Morava can differ and shift the results. For example, the restoration measures do not seem effective by the means of the flood wave translation for HQ_5 and HQ_{100}, but effective for an HQ_{10}. However, when analyzing the results subjected to the discharge of the Morava main channel and the discharge of the Dyje tributary, it is noted that for the HQ_5 and HQ_{100} the share of discharge of the Dyje is rather high and the effect of the upstream restoration measures is attenuated at the confluence.

Once more, the importance to consider local conditions during the evaluation of the effectiveness of restoration measures is confirmed.

Figure 6 and Figure 7 show the effects of the implemented restoration measures of RS1 and RS2 on the flood peak reduction (ΔQ) in percentage and the flood wave translation (Δt) in hours during hydrological events with return periods of 2-5 years, 10-30 years, and 100 years in each of the five pilot areas.

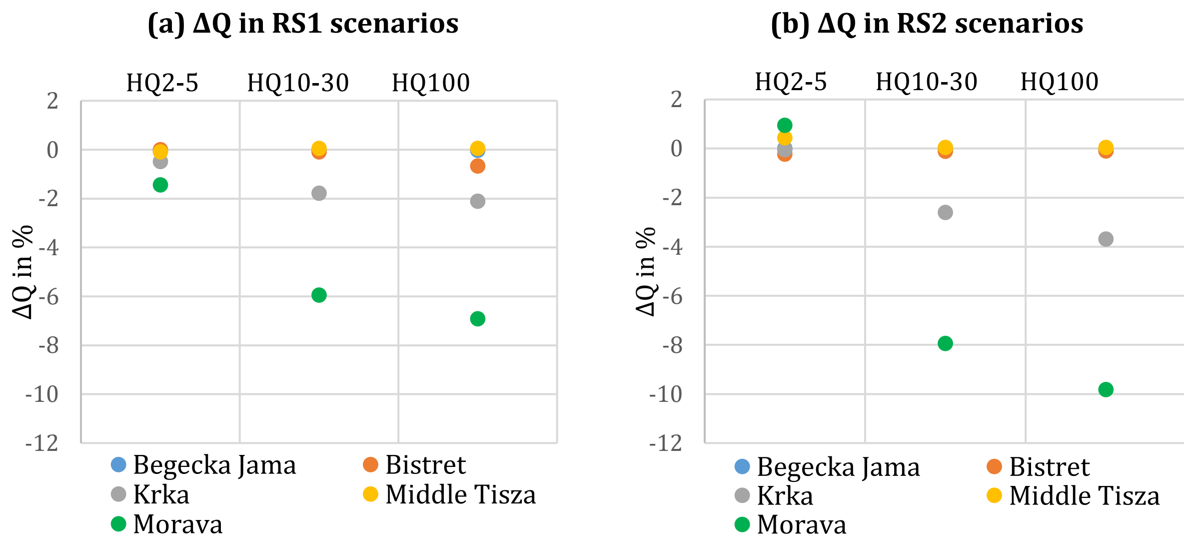


Figure 6. Flood peak reduction (ΔQ) in % compared to the CS in all pilot areas in (a) the R1 and (b) the R2 scenario

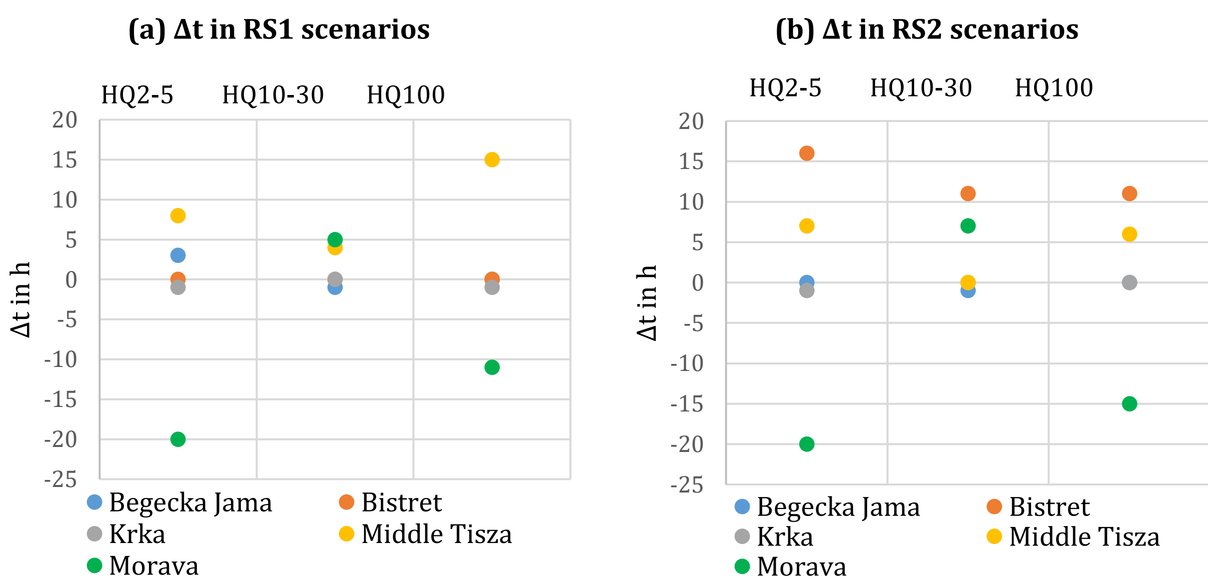


Figure 7. Flood wave translation (Δt) in hours compared to the CS in all pilot areas in (a) the RS1 and (b) the RS2 scenario

1.3. CONCLUSIONS FROM 2D HYDRODYNAMIC MODELING

- The **2D hydrodynamic models** well reproduce the current state (CS) and demonstrate the effects of floodplain restoration in the pilot areas.

- The effects of the restoration scenarios to the flood peak are **variable** and depend on the type of measure and scale of restoration, the investigated flood events, and the shape of the hydrograph.

- Overall, the largest **reduction of the peak discharge (ΔQ)** is obtained for the Morava pilot area in the RS2 scenario (10%). Some scenarios do not show a notable impact on the peak value (e.g., Begecka Jama and Bistret), attributed to the kind of restoration measures.

- The **delay of the time to flood peak compared to CS (Δt)** is in many cases negligible, with values below +/- 1h, explained by the 1h temporal resolution. An increase in the flooded area through restoration measures mostly generates a proportional delay of the flood peak.

- To affect the peak discharge, we consider it crucial not only to consider a single restoration measure but a **combination of multiple measures**, on the river channel, the floodplain extent, and the character of the floodplain (natural conditions).

- It is recommended to investigate the lateral inflows from the **tributaries**, as the discharge conditions of the tributaries and the main river (e.g., Morava) can differ and shift the results.

- The **spatial results** allow us to conclude habitat suitability, potential ecosystem services, and flood risk in the restoration scenarios. Due to their ability to create detailed spatial information of restoration effects on the whole floodplain area, 2D hydrodynamic models can be recommended for planning floodplain restoration measures.

2. HABITAT ASSESSMENT

2.1. METHODOLOGY

Table 4 gives an overview of typical floodplain habitats at the meso-scale. A semi-automated approach was chosen for deriving these habitat types from the hydraulic parameters. First, k-means clustering was carried out for all hydraulic variables available for the respective pilot area to obtain initial spatial patterns. The results of the clustering were used along with expert knowledge to derive a set of (fuzzy) rules to describe the different habitats. For instance, the description of the class "channel" is *"IF the arrival time is short AND the flow velocity is high AND the water depth is high, THEN the pixel belongs to class channel".* These rules were elaborated separately for each pilot area as the characteristics, as well as the datasets, were heterogeneous among the pilot areas. An evaluation was carried out only based on a plausibility check, as no independent validation data was available.

Table 4. Meso-habitats of floodplains; Please note that this is not an exhaustive list.

Floodplain meso-habitat	Habitat characteristic
Channel	Patch with permanent inundation and high depth and flow velocity even during minor flood events.
Laterally connected oxbows and oxbows	Patches formed by former meanders and laterally connected to the recent main channel from at least one side
Ponds and only vertically connected backwaters	Patches formed by depressions filled with water without direct surface connection to the river channel
Laterally connected floodplain	Patches of the floodplain flooded by surface water during minor flood events (HQ_{2-5})
Aquatic-terrestrial transition zones[1]	Patches at the interface of channel and floodplain with low slope and high flood duration during minor flood events (HQ_{2-5})

[1] Not applicable in Danube Floodplain project

2.2. MAIN RESULTS

Figure 8 shows the main results from the meso-scale habitat modeling in the pilot areas.

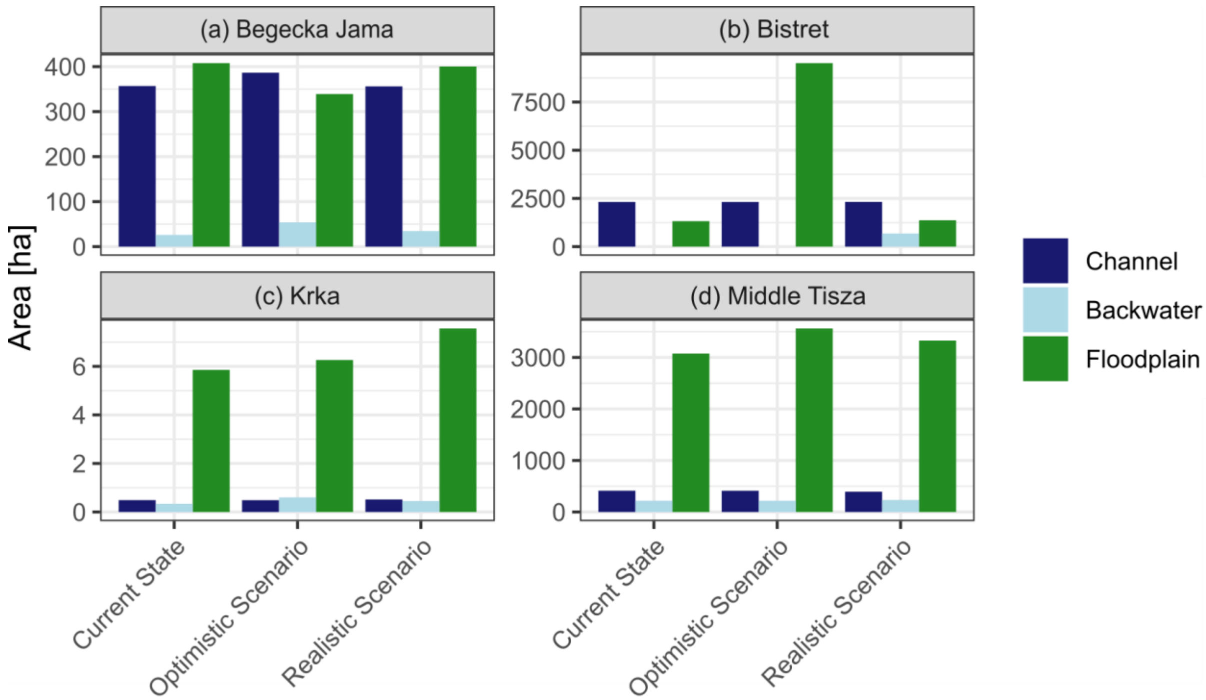


Figure 8. Changes in meso-habitat areas of the pilot areas Begecka Jama (a), Bistret (b), Krka (c), and Middle Tisza (d).

In Begecka Jama (Figure 8 (a)), the state of lateral connectivity of the floodplain is already good in the current state. 205 ha or 52 % of the total area are laterally connected to the Danube during a 2-5-year flood event. In RS1, the connection between the backwaters is improved by creating/widening didges between the different backwater systems. In addition, the connection to the Danube is improved by opening a didge from the lake in the northeast of the pilot area to the Danube. RS2 plans to construct a new side channel in addition to the increase in backwater connectivity. This increases the total channel area and decreases the backwater area. Overall, both restoration scenarios would increase the typical floodplain habitats in form of backwaters. The specific ecological scope is slightly different for the scenarios: while RS1 would increase and improve backwater habitats, RS2 would mainly increase the in-channel habitat. Thus, it depends on the specific ecological targets of restoration which option to prefer.

In Bistret, the current state shows the majority of the floodplain being disconnected from the Danube. In addition, there is no backwater habitat on this floodplain, as shown in Figure 8(b). Lake Bistret is supplied by water from the Desnatui River but the connection between Desnatui, Lake Bistret, and the Danube is disturbed by the dykes along the Danube. Thus, in the current state, there are hardly any typical floodplain habitats. In RS1, the main restoration measure is the creation of a connection channel between Lake Bistret and the Danube. This measure shall on the one hand add water supply to Lake Bistret, on the other hand, the drainage of the Desnatui River shall be enhanced. This, however, does not establish an extended area of laterally connected floodplain and the majority of the floodplain remains disconnected. From the prediction, a patch of the Lake Bistret and the connection channel might be a suitable backwater habitat with high connectivity and low flow velocities. In RS2, the dyke would be removed from the northern shore of the Danube. This would increase the total laterally connected floodplain area. As no flood duration data were available, no predictions were made on the potential vegetation cover. Here, more intensive studies would be necessary, having a closer look at the local flow regime.

The floodplains of the Krka River in the pilot area are in a good condition from a hydrological connectivity point of view. However, from an ecological perspective, the focus of restoration is the Krakovski gozd, a patch of mixed riparian forest dominated by *Quercus robur*. In RS1, a channel is constructed to bring water from the Krka to the Krakovski gozd. Since no data were available about flood duration for the Krka pilot area, no assumption can be made if the additional water might cause a change from the hardwood riparian forest dominated by *Quercus robur* to a forest with an increasing number of softwood riparian species like *Alnus spp*. Within this area, also backwaters evolve and are expected to form ponds with a low flow velocity, making them a habitat suitable for amphibian species. In RS2, a second channel will be constructed to establish an additional connection between the river and floodplain forest. This would increase the connectivity and backwater habitats would benefit from the additional connection.

The Middle Tisza has experienced a high degree of modification by humans by the construction of dykes and the disconnection of oxbows and other backwaters. In the current state scenario, most of the floodplain area is covered by maintained floodplain forest. “Anthropogenic” backwaters are present in the form of didges filled up by flood water, even during more regular flood events (HQ_2). These backwaters have a low flow velocity and are potential habitats for amphibians and stagnophilic fish. In RS1, a dyke relocation would increase the laterally connected floodplain area. The backwater and channel area would not change significantly. In terms of lateral connectivity, RS2 does not differ from RS1. In RS2, floodplain forest would be planted in the floodplain, and fish spawning areas would be created. “Forest with undergrowth” would create a more natural riparian forest, being characterized by multiple vegetation layers.

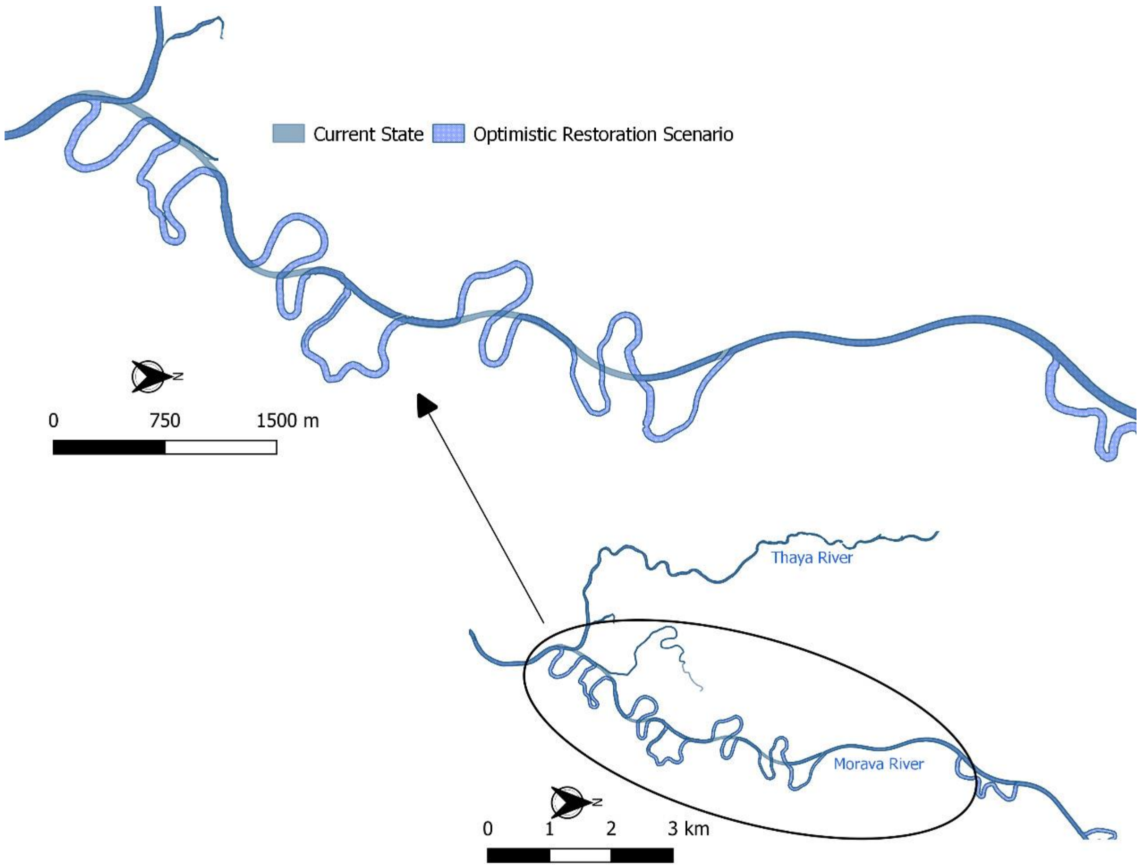


Figure 9. Meandering restoration in Morava corresponding to the optimistic scenario (RS2)

The Morava pilot area is located at the confluence of the Thaya and Morava River. Naturally, the Morava has been an actively meandering river with extensive oxbows and backwaters. In the current state, the majority of the hydrologically connected area is covered by a mixed riparian forest. The backwaters provide habitat for amphibians and fish species, whose habitats are reduced by limitations of connectivity. In RS1, dyke relocation is intended to re-connect oxbows and parts of the floodplain to the main channel that would create valuable habitat for fish species migrating between channel and backwater. However, for some oxbows, the connectivity is not fully restored by dyke relocation alone and further measures such as oxbow deepening might be necessary. In RS2, it is intended to re-establish meanders in the channelized river. The planned meanders increase the area belonging to the channel habitat and reduce the flow velocity during an HQ_{2-5} flood event, increasing the habitat suitability for lowland river fish species. Moreover, the area of backwater habitats is significantly increased by RS2. The pond-like backwaters are highly relevant habitats for amphibians. Due to the complexity of the floodplain topography of the Morava area and the complex hydrological reaction of this terrain further, a more detailed investigation is recommended for a final evaluation

2.3. CONCLUSIONS FROM HABITAT MODELING

- In the Danube Floodplain Project, **biodiversity** is understood as the ability of a floodplain to provide typical floodplain habitats for species and species communities. The biodiversity of floodplain habitats is extremely complex and driven by a variety of biotic and abiotic factors.

- Reducing the **connectivity between channel and floodplain** is the major threat of floodplain ecosystems in the Danube Basin. The approaches to achieve lateral connectivity in pilot areas are different. The most common measure is the relocation of dykes, others are the creation of connection channels or the modification of channel planform.

- The restoration measures focused on **aquatic habitats** like oxbows or connected backwaters, being these relevant (spawning) habitats for fish. However, floodplains can also provide typical habitats for **amphibians** (pond-like backwaters ideally) or **floodplain vegetation**.

- The **results of meso-scale biodiversity assessment** in the pilot areas show that floodplain habitats, and thus biodiversity, can benefit from increasing the lateral connectivity, as intended by the majority of restoration scenarios.

- While the assessment on the meso-scale shows the general tendency for the development of habitats, a **microscale analysis** gives insights on the level of species or specific communities. However, this requires in-depth knowledge of the setting and cannot be obtained without extensive fieldwork.

3.STAKEHOLDER ANALYSIS

3.1. METHODOLOGY

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The planned floodplain restoration measures affect a wide range of stakeholders, including landowners and residents. Therefore, their interest in the Danube Floodplain Project was particularly high. The knowledge of the stakeholders was used to record and evaluate the ecological, economic, and cultural values of the pilot areas with the aid of the ecosystem services approach.

Stakeholder workshops were held in the pilot areas. The assessment of ecosystem services with the help of stakeholders needs a detailed analysis regarding which interest groups are suitable for the stakeholder workshops. Among stakeholders, we could find residents, water authorities, nature conservation authorities and associations, and representatives of agriculture, fishery, and tourism. Residents often have a good knowledge of the area and its traditions, and could thus give an overview of the economic, environmental, and cultural situation. To identify other stakeholders, a list of 25 relevant ecosystem services for German rivers and floodplains from the “River Ecosystem Service Index (RESI)” Project was used (Podschun et al., 2018). This list was used to identify further stakeholders. The aim was to invite stakeholders for the workshops who are familiar with the individual ecosystem services in order to be able to evaluate them. The identified stakeholders were finally assigned to different target groups (local, regional, and national public authorities, sectoral agencies, interest groups including NGOs, higher education and research, international organizations, and general public).

3.2. MAIN RESULTS

Various target groups from different interest fields took part in the workshops. Depending on the pilot area. The number of participants varied between the pilot areas. The workshop in Hungary was the most visited (71 participants), the lowest number of participants (17) was in Slovenia. The background of the participants of the five workshops was very different. (Figure 10). A total of 204 people took part in the workshops. Of these, 75% came from water management, from nature conservation, or were representatives of affected communities. The remaining 26% were distributed among the remaining sectors, of which 8% were scientists. The highest interest in the Danube Floodplain project as well as in the assessment of ecosystem services in the pilot areas came from the water management sector, followed by participants from different nature conservation or protection groups. During the workshop, the stakeholders had time to discuss the project, the planned measures in the pilot areas as well as the expected outputs of the project. This was particularly the case in the Bistret pilot area, where the flood protection measures had not yet been conclusively identified. Since flood protection is not the only major issue in this region, but also the spatial development is of great interest to the residents, the project partners and municipalities also discussed which possibilities for improving the economic situation through restoration approaches.

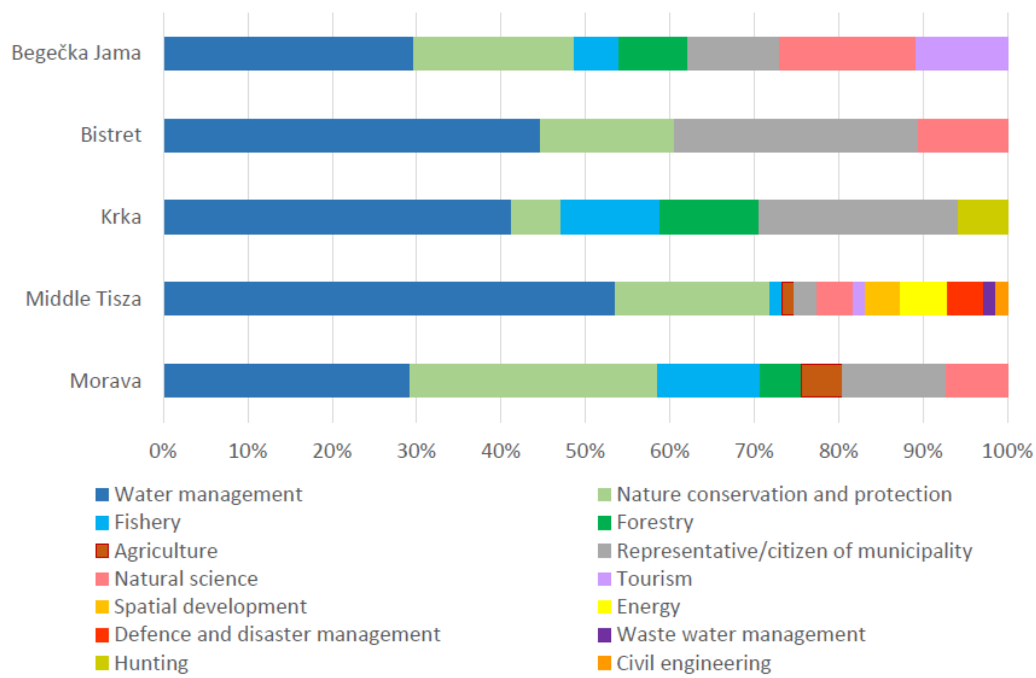


Figure 10. Number of participants from different interest field

3.3. CONCLUSIONS FROM STAKEHOLDER ENGAGEMENT

- The workshops enabled everyone to expand their knowledge of the pilot area and their understanding of its different uses. The acquired knowledge and understanding of other sectors can help in the later **planning and implementation** of flood protection and restoration measures.

- The **workshops' participants** benefitted in several ways, i.e. by receiving knowledge from other areas, by expressing their interests, by having the opportunity to expand their network, and by getting in contact with the authorities implementing the measures.

- Not all stakeholders are familiar with the **concept of ecosystem services** and enough time should be planned to present the concept in detail.

- Reaching stakeholders is not always an easy task, and **stakeholder engagement strategies** should be applied. Helpful strategies are communication in the mother tongue, field visits, informal conversations on a one-to-one basis, and organizing at least two workshops, to enable clarification of questions and create a forum.

- The pilot area responsible project partners raised considerable interest in the project and the proposed restoration measures amongst stakeholders; the project partners appreciated the **multi-layered approach** to managing floodplains and encourage using a similar methodology to deal with floodplain restoration projects in the future.

4. LAND-USE LAND-COVER ANALYSIS FOR ECOSYSTEM SERVICES

4.1. METHODOLOGY

To assess and map potential ESS provided in the pilot areas and to estimate the change in these after the implementation of planned restoration measures, the method of Burkhard et al. (2009) was modified. Burkhard et al. (2009) used CORINE land cover data to estimate the capacity to provide ESS (Copernicus Programme, 2018). In the DFP, provisioning and regulating ESS were based on land cover/land use data from Copernicus (Copernicus Programme, 2012) and additional CORINE land cover. The most detailed MAES ecosystem classification (level 4) was used, which can be seen in Table 5. With this, maps of the intensity of each provided ESS were created for the three scenarios for each pilot area.

The cultural ESS were not determined using the adapted method of Burkhard et al. (2009), because at the time of the assessment there was no data on changed paths or accessibility within the pilot areas for the restoration scenarios. Therefore, cultural ESS were identified and assessed with the help of stakeholders during the stakeholder workshops for current state and restoration scenario 1. Thus, no maps could be produced for the cultural ESS.

Table 5. Values of the potential provided ecosystem services for each land cover/land use type of all pilot areas. Columns in red = provisioning ESS; Columns in green = regulating ESS.

LCLU type of pilot areas	MAES level 4	Animal product	Wood	Animal product	Game meat	Honey	Water	Fish	Air purification	Local climate	Low water regulation	Flood retention	Noise regulation	Nutrient retention	Provision of habitats
Continuous urban fabric (in-situ based or IM.D. >80-100%)	1111	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dense urban fabric (IM.D. >30-80%)	1112	0	0	0	0	1	0	0	0	1	0	0	1	0	0
Industrial or commercial units	1113	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Low density urban fabric (IM.D. 0-30%)	1121	0	0	0	1	3	0	0	1	2	0	0	1	0	1
Road network and associated land	1211	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Railways and associated land	1212	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mineral extraction, dump and construction sites	1311	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Green urban areas T.C.D. >= 30%	1411	0	1	0	0	0	0	0	4	3	2	3	4	0	2
Sport and leisure facilities T.C.D >= 30%	1421	0	1	0	0	0	0	0	4	3	0	2	0	2	2

LCLU type of pilot areas	MAES level 4	Animal product	Wood	Animal product	Game meat	Honey	Water	Fish	Air purification	Local climate	Low water regulation	Flood retention	Noise regulation	Nutrient retention	Provision of habitats
Sport and leisure facilities T.C.D < 30%	1422	0	0	0	0	0	0	0	2	3	3	1	1	0	1
Non-irrigated arable land	2111	5	0	0	1	0	0	0	0	1	5	1	0	1	0
Greenhouses	2121	5	0	0	0	0	0	0	0	0	0	0	0	0	0
Irrigated arable land and rice fields	2131	3	0	0	0	3	0	0	0	1	5	1	0	1	0
Vineyards	2211	3	1	0	0	0	0	0	1	1	5	2	0	1	1
High stem fruit trees	2221	3	1	2	2	5	0	0	2	2	5	2	1	1	2
Low stem fruit trees and berry plantations	2222	5	0	0	0	5	0	0	1	1	5	1	1	1	1
Complex cultivation patterns	2321	4	1	3	2	4	0	0	1	3	4	1	1	2	1
Land principally occupied by agriculture with significant areas of natural vegetation	2331	3	1	3	3	4	0	0	2	4	3	3	2	3	3
Riparian and fluvial broadleaved forest	3111	0	5	1	5	4	0	0	5	5	1	4	5	5	5
Other natural & semi-natural broadleaved forest	3131	0	5	1	5	1	0	0	5	5	1	4	5	4	3
Highly artificial broadleaved plantations	3151	0	5	1	5	1	0	0	4	4	1	3	3	3	1
Riparian and fluvial coniferous forest	3211	0	5	1	5	3	0	0	5	4	1	3	4	3	2
Riparian and fluvial mixed forest	3311	0	5	1	5	4	0	0	5	5	1	4	5	4	4
Transitional woodland and shrubs	3411	0	4	2	5	2	0	0	2	4	2	1	3	3	3
Lines of trees and scrub	3412	0	2	1	3	2	0	0	2	4	2	4	2	4	3
Managed grasslands with trees and scrubs	4111	0	1	5	3	3	0	0	2	4	2	3	2	3	2
Managed grassland without trees and shrubs	4112	0	2	5	3	3	0	0	1	3	3	1	1	3	2
Mesic grasslands with trees	4212	0	2	5	5	5	0	0	2	4	2	3	2	5	3
Dry grasslands without trees	4221	0	1	5	0	3	0	0	1	3	3	1	1	2	3
Mesic grasslands without trees	4222	0	1	5	5	5	0	0	1	3	3	1	1	4	3
Sparsely vegetated areas	6111	0	0	0	0	0	0	0	0	0	5	1	0	2	3
River banks	6213	0	0	0	0	0	3	0	0	4	5	3	0	3	5
Inland freshwater marshes	7111	0	0	0	4	0	3	5	1	5	1	4	0	5	5
Permanent interconnected running water courses	9111	0	0	0	4	0	2	5	0	5	4	5	0	5	5
Highly modified natural water courses and canals	9113	0	0	0	3	0	5	3	0	4	1	4	0	3	1
Separated water bodies belonging to the river system	9121	0	0	0	5	0	5	5	0	5	2	5	0	5	5
Natural water bodies	9211	0	0	0	4	0	5	5	0	5	5	5	0	5	4
Intensively managed fish ponds	9214	0	0	0	5	0	3	5	0	5	5	5	0	5	1

4.2. MAIN RESULTS

Measures that are primarily intended to benefit flood protection also have a positive effect on other regulating ecosystem services. These so-called synergies between individual ecosystem services could be observed in the evaluation of the regulating services between the individual ESS flood retention, nutrient retention, local climate regulation and provision of habitats. In contrast, provisioning services, such as agricultural products, decrease with the promotion of the ESS flood retention.

The assessment of the potential ESS provided produced a large number of maps. Therefore, the provision of the ESS provision of habitats for the current situation and the restoration scenarios RS1 and RS2 of the pilot area Middle Tisza is given here as an example (Figure 11). According to CICES (Haines-Young and Potschin, 2017), the ESS provision of habitats was considered as a regulating ESS in the Danube Floodplain Project. As this ESS is difficult to monetize, it was not evaluated with TESSA. Nevertheless, the ESS provision of habitats is indispensable for the assessment of measures that are intended to benefit both flood protection and nature.

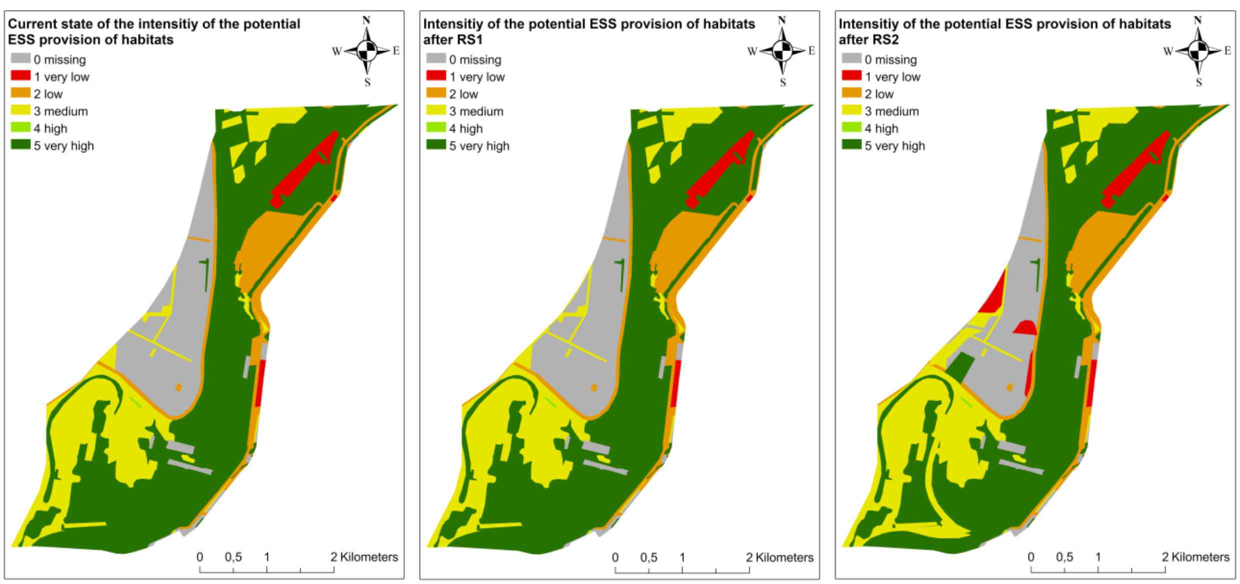


Figure 11. Results of the assessment of the potential supply of the regulating ESS provision of habitats for the current situation (left), the restoration scenario RS1 (middle) and the restoration scenario RS2 (right) for the pilot area Middle Tisza

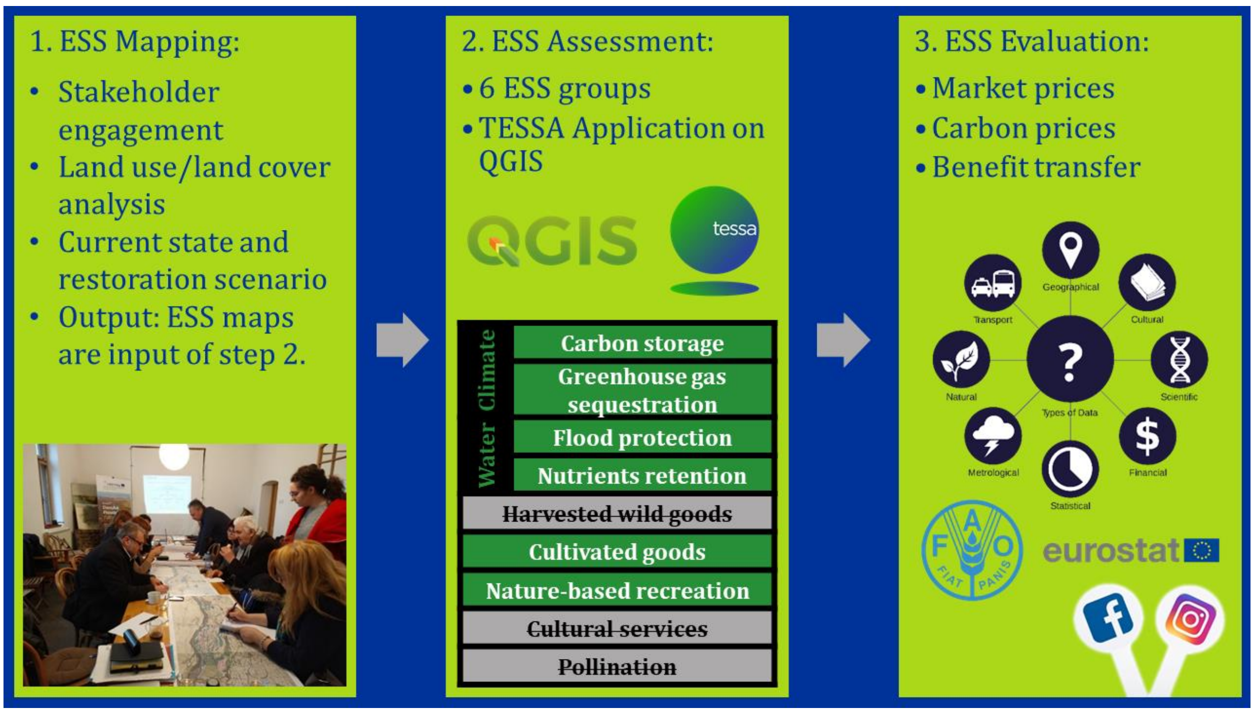
4.3. CONCLUSIONS FROM LAND-USE LAND-COVER ANALYSIS FOR ECOSYSTEM SERVICES

- The engagement of **stakeholders** can help to identify and assess the used **cultural** ecosystem services.
- The assessment of the potentially provided **provisioning** and **regulating** ecosystem services based on **land cover/land use data** can give a first impression of the intensity of the potential ESS provision of a planning area.
- **Small-scale measures** such as the connection or deepening of oxbow lakes are difficult to represent with this method and are therefore **underestimated**.
- For a more accurate assessment, however, **further data** should be available, such as on soil properties and groundwater depth, as well as more precise data on the actual land cover/land use.
- This method can be used to record the **potential ESS** provided, but not the ESS actually used. This should be considered when analyzing the results and should be clearly communicated to the public.

5. ECOSYSTEM SERVICES ASSESSMENT

5.1. METHODOLOGY

The Toolkit for Ecosystem Service Site-based Assessment (TESSA) (Peh et al., 2013) was used as theoretical background for the ESS estimation and evaluation. A detailed description of the methodology is presented in Deliverable D 4.3.2. To facilitate reproducibility, the steps were reproduced in a python code for QGIS3. The workflow followed can be seen below.



The ESS maps, a result of the stakeholder meetings and ecosystem services analysis described in the previous chapter, give a set of important input data. A consistent quantity of additional input data was necessary. The statistics deal with the parameters that affect ESS, such as agricultural production, population density, or emission factors of different greenhouse gases. When lack of data characterized the area of study, publicly available data were used for each country from different institutions and databases: such as IPCC reports (IPCC, 2006; IPCC, 2014), FAOSTAT (FAO, 2019), Eurostat (European Commission, 2020), EarthStat (Monfreda et al., 2008), etc.

The expected output of ESS evaluation with TESSA consists of singular ESS monetary values and ESS maps for each scenario (CS, RS1, RS2) and each ESS group (flood mitigation, global climate regulation, cultivated goods, nutrients retention, nature-based recreation). Then, the total ESS values were calculated by summing the singular ESS groups for each scenario.

5.2. MAIN RESULTS

Taking into account five ESS (Figure 12), floodplain restoration is bringing added annual monetary value for all pilot areas that we considered, for at least one floodplain restoration scenario. The total annual added value of the ESS benefits of the "realistic" restoration measures (RS1), was estimated at approximately 1.2 million USD^{2019}/yr in Begecka Jama, 601,000 USD^{2019}/yr in Bistret, 1.0 million USD^{2019}/yr in Krka, and 0.7 million USD^{2019}/yr in Morava. For "optimistic" restoration measures (RS2), the total annual added value of the ESS benefits was estimated at approximately 1.5 million USD^{2019}/yr in Begecka Jama, -255,000 USD^{2019}/yr in Bistret, 237,000 USD^{2019}/yr in Krka, and 3.1 million USD^{2019}/yr in Morava.

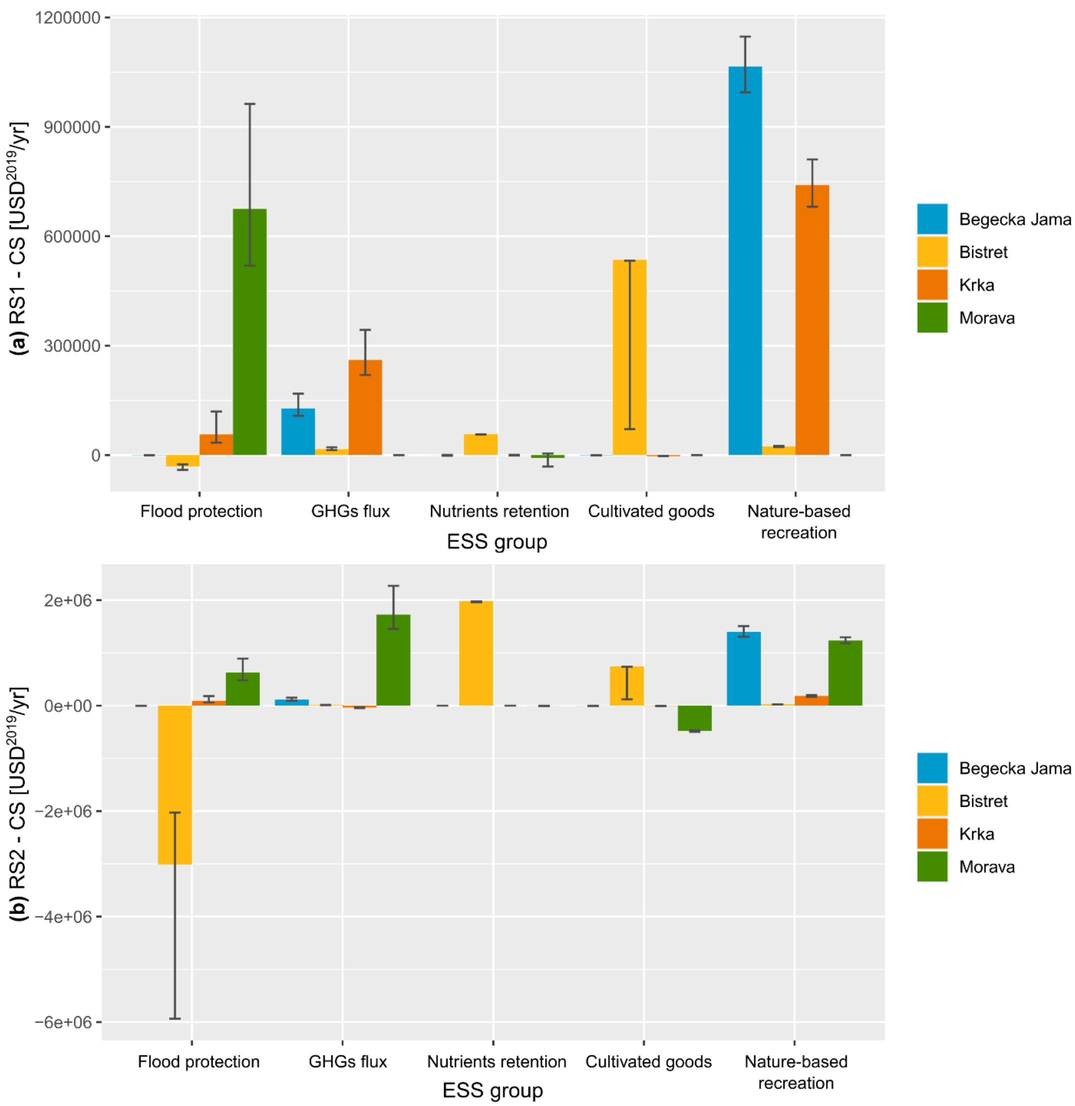


Figure 12. Added ESS value of the floodplain restoration scenarios RS1 (a) and RS2 (b) in comparison to the current state (CS) homogenized to USD^{2019}/yr in all four pilot areas

The restoration projects have a different impact on different types of services. The provisioning ESS (here represented by the cultivated goods) are decreasing in three out of four pilot areas, while the regulating and cultural services are increasing in a much more complex spectrum of services. These results are in line with previous results from floodplain restoration analyses in Nepal by Merriman et al. (2018) and the U.K. by Peh et al. (2014). The results can be the basis for further analysis of the interaction among ESS, such as the nexus analysis approach suggested by Fürst et al. (2017) and Babí Almenar et al. (2021). This could help us better understand the cause-effect relationship of benefitting from one ESS group (e.g. provisioning) to the availability of other ESS groups (e.g. regulating or cultural).

The bar plots in Figure 13 also display the NBS added value per unit area. Krka and Morava show comparable trends, in which the added ESS values are of the same order of magnitude for flood mitigation (1) and nature-based recreation (2). The latter has instead the highest value per area unit for Begecka Jama, which is also mainly profiting from the RS in terms of GHGs sequestration and nutrients retention. Different from the other three pilot areas, Bistret shows ESS losses in terms of flood mitigation.

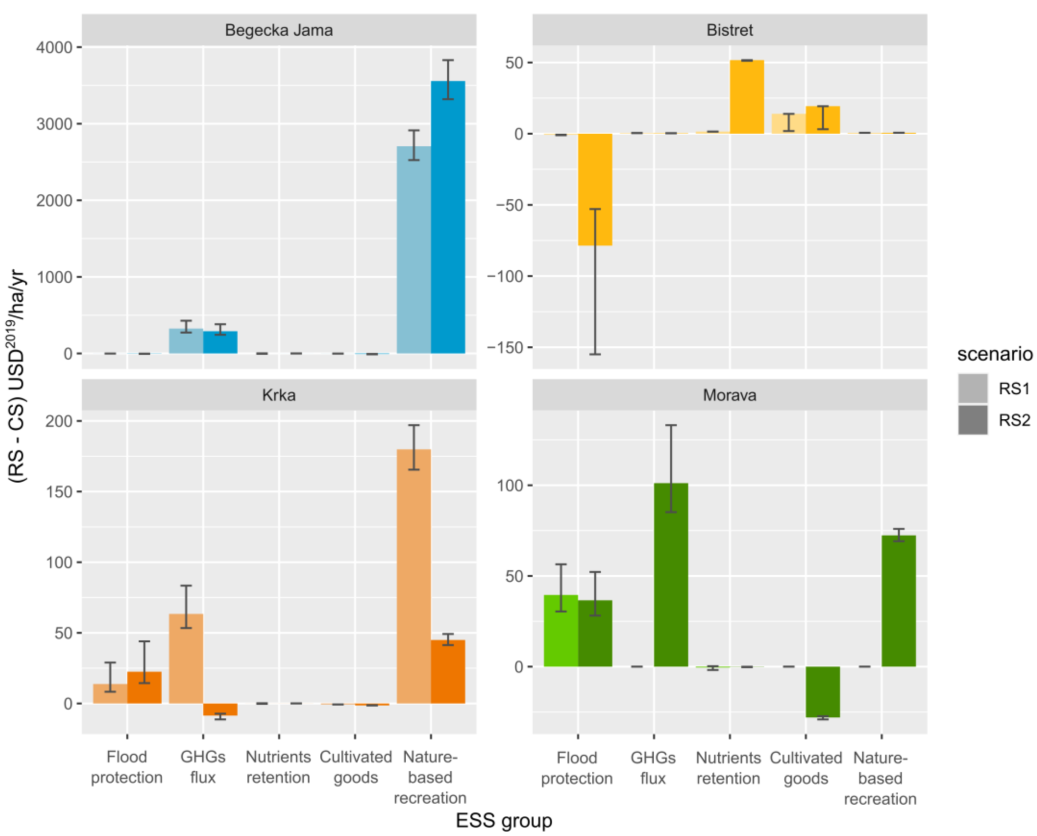


Figure 13. Added ESS value by unit area of the floodplain restoration scenarios RS1 and RS2 in comparison to the current state (CS) homogenized to USD[2019]/ha/yr in all four pilot areas: (a) Begecka Jama, (b) Bistret, (c) Krka, and (d) Morava. Adapted from Perosa et al. (2021).

5.3. CONCLUSIONS FROM ECOSYSTEM SERVICES

- We estimated the **ecosystem services (ESS)** of floodplain restoration, to understand the added value of these nature-based-solutions (NBS).

- We provided an application example to four pilot sites, with a **mixed application of TESSA and alternative methods**, for a broader knowledge on the consequences of floodplain restoration

- In the **pilot areas**, we estimated a **maximum total gain of ESS** of approximately 1.5 million USD^{2019}/yr in Begecka Jama (RS2), 600,000 USD^{2019}/yr in Bistret (RS1), 1.1 million USD^{2019}/yr in Krka (RS1), and 3.1 million USD^{2019}/yr in Morava (RS2). The results are mainly affected by greenhouse gas fluxes, nature-based recreation, and cultivated goods services.

- For these specific pilot areas, **floodplain restoration** NBS cannot be justified for **flood mitigation** only; NBS remain a flexible and resilient way to address natural hazards (Acharya et al., 2020; Faivre et al., 2017).

- The **stakeholder workshops** were of great help to collect information about the areas and to map the ESS. Nevertheless, a broader consultation may have described and judged the ESS differently (Merriman et al., 2018).

- A better interpretation of the results might be given by analyzing the ESS **uncertainties**; Further, **more modeling** could be implemented to get a more detailed estimation of certain ESS (e.g. water quality)

- ESS assessment help **decision-makers** locating areas of ecosystems' restoration (Krol et al., 2016); **researchers** should develop new methodologies to evaluate the missing ESS types, which are not included in commonly used ESS assessment guidelines (TESSA) or software (InVEST, ARIES, etc.), such as groundwater recharge or noise regulation.

6. EXTENDED COST-BENEFIT ANALYSIS

6.1. METHODOLOGY

The approach of cost-benefit-analysis (CBA) is rare in river restoration projects (Logar et al., 2019). In the Danube Floodplain Project, a consistent extended CBA was applied to four pilot areas, allowing a comparison among four spatially and distant analyses. The extended CBA process is graphically conceptualized in Figure 14.

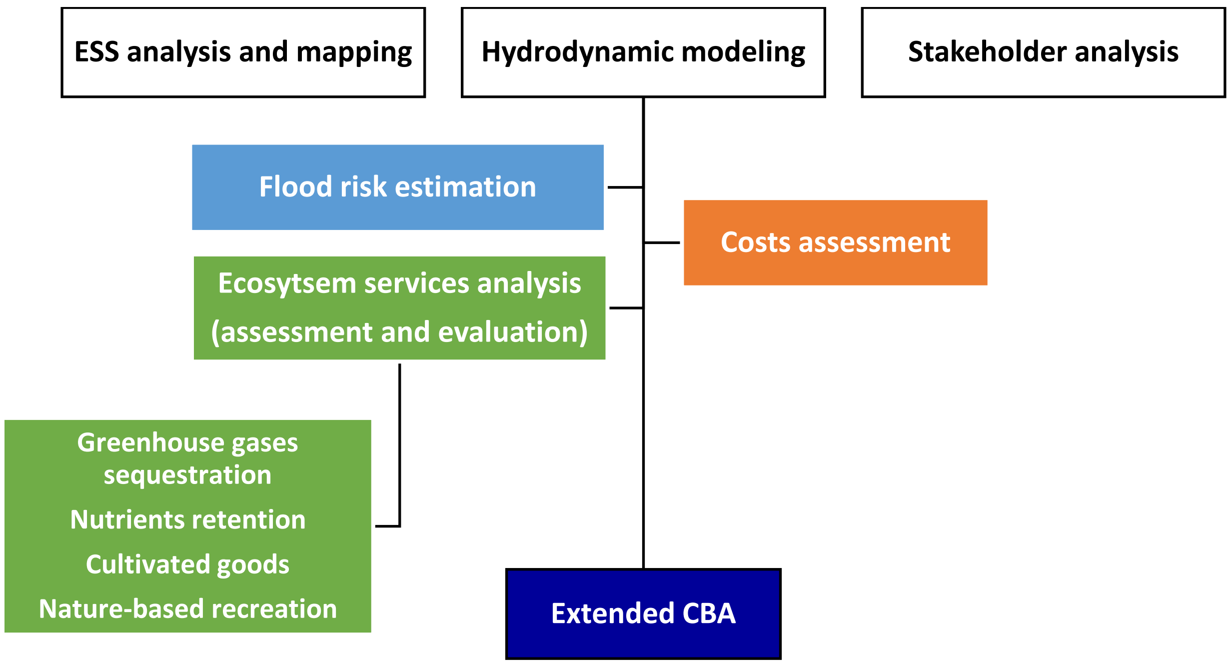


Figure 14. Workflow of the extended cost-benefit analysis for floodplain restoration measures

Benefits and costs of the restoration measures were discounted to be made comparable with each other, where we chose a discount rate (r) of 4% based on the literature (Monge et al., 2018; Dittrich et al., 2019; Jeuland and Pattanayak, 2012; Sartori, 2015; Terrado et al., 2016 and a project life (n) of 50 years. The discounted values were then used in this project to estimate the benefits-costs-ratio. The benefits-costs-ratio (BCR) is a common parameter used in CBA analysis to evaluate its results. It consists of the following equation (1). A BCR higher than one corresponds to a profitable project.

$$BCR = \frac{PV\ of\ Benefit\ Expected\ from\ the\ Project}{PV\ of\ the\ Cost\ of\ the\ Project} \tag{1}$$

6.2. MAIN RESULTS

Considering the costs of the measures and the discounting of the ESS benefits, the extended CBA results are promising. Figure 15 shows that the results of the benefit-cost ratios (BCR) of the extended CBA (i.e. considering all ESS) of the restoration measures are always higher than the BCR of the standard CBA (i.e. considering flood mitigation as only ESS).

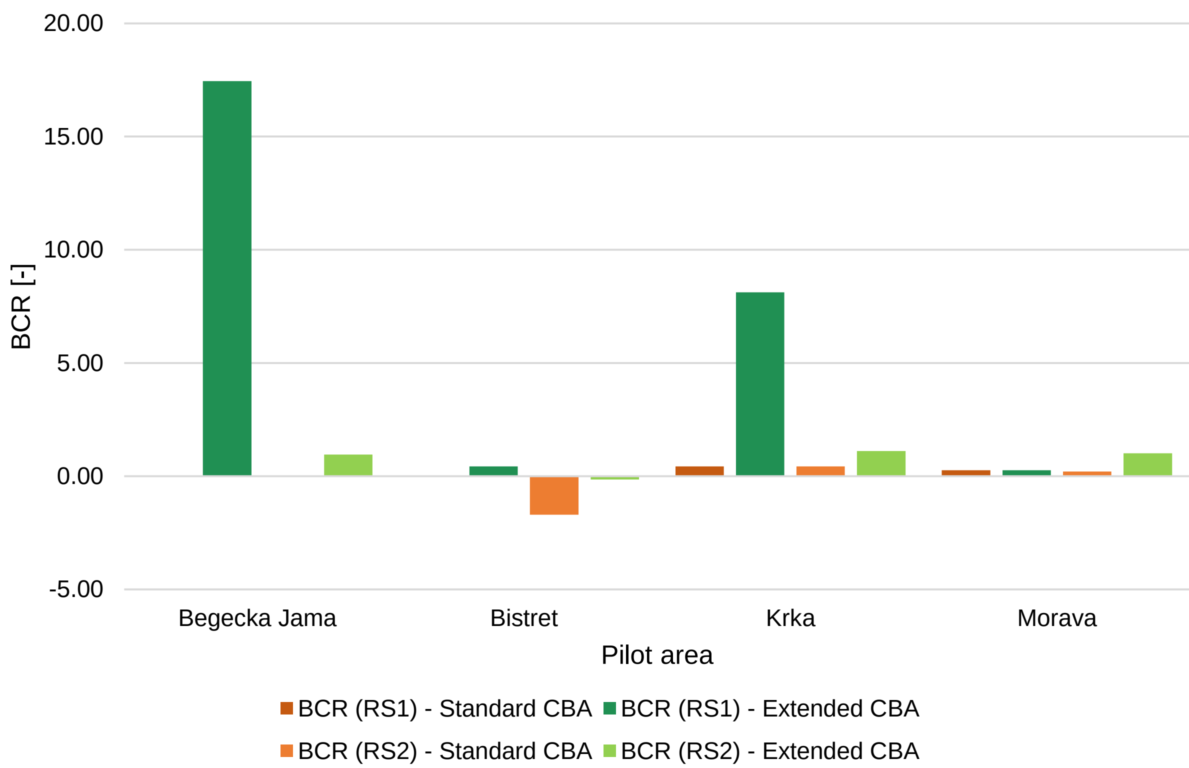


Figure 15. Benefit-cost ratio (BCR) between discounted benefits and discounted costs in all four pilot areas.

In Begecka Jama, both restoration measures lead to a BCR approximately equal (RS2) or higher (RS1) than 1, when using an extended CBA. The standard BCR shows instead results close to zero for both restoration scenarios. In this case, the standard CBA misses recognizing the profitability of the restoration measures, which is instead identified by the extended CBA. These parameters predict better overall restoration effects for the RS1 scenario, due to a positive benefits-costs-difference and a BCR of around 17. If the standard CBA results were to be used, RS1 would still be the preferable scenario between the two restoration measures, but it would not be shown as profitable (BCR<1).

In Krka, both restoration measures show extended BCR higher than 1, being the BCR of RS1 much higher than the BCR of RS2, also due to the higher costs of the RS2. The standard BCR is instead 0.4 for both restoration scenarios, meaning that the discounted benefits in terms of flood risk reduction are equal to 40% of the discounted costs. Similar to Begecka Jama, the Krka pilot area clearly shows different results when using the standard or the extended CBA method. Here, the highest profitability would be provided by the RS1 scenario, when including the ESS in the estimation, with a BCR of 8. When omitting ESS from the equation, the difference between the two restoration scenarios is not as marked anymore and the floodplain restoration loses its profitability advantage (BCR<1).

In Morava, the only BCR higher than 1 corresponds to the scenario RS2 calculated with the extended CBA method. All other configurations show a BCR between 0.2 and 0.3. Therefore, when considering the extended CBA, the preferable scenario tends to be RS2, according to its BCR (>1), while if we only considered the benefits derived from avoided risk, RS1 would the preferable restoration measure, although it would not be profitable (BCR<1).

A divergent result than all other pilot areas is shown in Bistret, where the extended BCR does not reach 1. In any way (standard or extended), since the total benefits are negative, the restoration measures do not seem to be profitable, although the BCR for RS1 is promising (0.43). By looking at Bistret results, we can tell that the CBA is not always the right way to evaluate floodplain restoration projects, or more generally nature-based solutions. However, the more suitable restoration measure would be the realistic one (RS1), although our results cannot prove its profitability when comparing that scenario with the current state.

When examining these results, we should remember that some factors could substantially modify the results. First, the costs and benefits values are influenced by the parameters used for discounting. Moreover, we point out that the costs for the restoration measures were roughly estimated and that they might change, as usual, during the implementation process.

In decision-making for flood risk purposes, the goal might be to obtain a BCR slightly higher than 1, which would mean that there is a balance between investment costs and returning benefits. In the case of an extended CBA including ecosystem services evaluation, we should ask ourselves whether our goal should be to maximize a BCR, or whether we should focus on other CBA parameters, such as the benefit-costs differences or a benefits-vs.-costs-graph.

Another important question to answer is whether in the future we should avoid showing the different results between a standard and an extended CBA. On one hand, by keeping both CBA methods, decision-makers might still perceive the standard CBA as the reference method to trust, and might not take seriously the results of an extended CBA. On the other hand, comparing the standard CBA with the extended CBA might be a way to show the limitations of a commonly accepted methodology and put traditional methods into question.

6.3. CONCLUSIONS FROM EXTENDED CBA

- We included the estimation of ecosystem services (ESS) in a standard cost-benefit analysis (CBA), resulting in an "**extended cost-benefit analysis**". The ESS estimations were used to include (in monetary values and discounted) the co-benefits of floodplain restoration measures into CBA analyses.

- As a consequence of the ESS estimations, the **extended CBA justifies the implementation of both floodplain restoration measures** (RS1 and RS2) in Begecka Jama and Krka, and one in Morava (RS2). All these scenarios would not be categorized as profitable if evaluated with a standard CBA. Besides, the extended CBA might support the "realistic" restoration measure (RS1) in Bistret, although additional funding should be considered to cover the not fully profitable investment.

- With an extended CBA, we brought **further evidence** in favor of floodplain restoration measures to be implemented for the general benefit of the communities.

- Some authors, such as Baveye et al. (2013), **criticize the use of monetary valuation of ESS**. Nevertheless, ESS monetization is a way to include the benefits that nature brings to humans that would otherwise be neglected in decision-making (Schägner et al., 2013). Also, economics and ecology are very influential aspects when dealing with ESS (Chaudhary et al., 2015).

- We finally call for better inclusion of ESS assessment in the Danube River Basin **Management Plans**, because ESS improvement intersects with the achievement and monitoring of the **Sustainable Development Goals (SDGs)**. ESS assessment can act to encourage a sustained, inclusive and sustainable economic growth (Goal 8) and to facilitate sustainable management of water (Goal 6) and terrestrial ecosystems (Goal 15) (United Nations General Assembly, 2015).

- The documents "ESS-CBA Decision Support Model and Methodology" (Kis and Ungvári, 2019) and "Hungary: Tisza Pilot CBA" (Kis and Ungvári, 2020) show the **alternative methodology and results** of the extended cost-benefit analysis in the Middle Tisza pilot area.

7. FEASIBILITY STUDIES

7.1. METHODOLOGY

Pre-feasibility and feasibility studies summarize methods, results, and lessons learnt from the pilot areas. A feasibility study attempts to describe and summarize the current situation and problems that initiated the necessary development. It also attempts to describe the methodologies, different aspects of the feasibility, and the constraints and challenges that a project may face during and after the implementation.

Before setting up scenarios (Point 5. in Figure 16), technical, economic, legal, and operational circumstances should be stated. First of all, a good definition of a problem is needed. As a second step, good practices should be collected that already dealt with solutions for similar problems. Then, those methodologies should be chosen that can be used to examine and solve the situation. For successful implementation, those indicators should be selected that can best describe the expected changes. This is followed by setting the scenarios, for which feedbacks from various stakeholders should be collected. The feedback can be incorporated into the scenarios. Then, the scenarios are tested and the feasible option can be selected.

Setting up proper scenarios is important: the alternatives should be clearly separable solutions (boundary conditions are different) and need to be produced from an iterative process. Selection of proper interventions is also a crucial factor. This was supported in the project by the regulating ecosystem services-based indicator, which already indicates if a planned intervention-combination improves water balance of the area or not. This could be a first filter in designing such scenarios. In cases where the scenarios brought none or small effect on flood mitigation, other possibilities should be evaluated like restoration of more floodplain areas or including bigger floodplain areas, if possible.

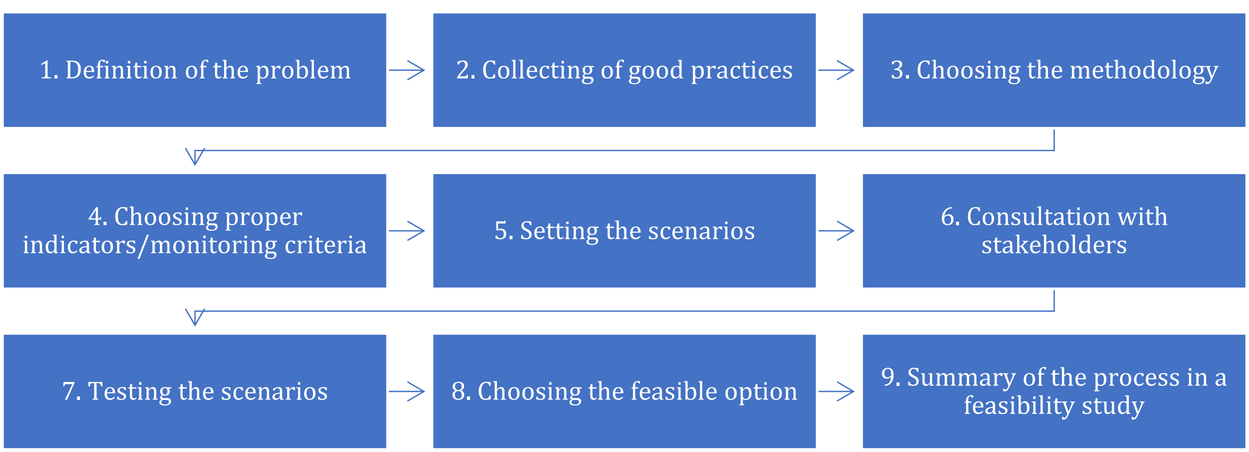


Figure 16. Steps to perform a feasibility study

7.2. MAIN RESULTS

For all five pilot areas, feasibility studies were implemented according to the scenarios applied in the Danube Floodplain Project. On the Middle Tisza pilot area, additional analyses were conducted on land use activities, which are adapted to the regular water presence, have economic relevance, and are acceptable for water management. To support ecological aspects, potential vegetation of new regularly inundated conditions was evaluated. This helped see not only what biological communities are most sustainable under new conditions, but also made visible what effect the planned interventions have on the water balance of the area. A practical and transparent tool to compare the scenarios is to compile a table with various benefits and to give scores for each scenario, so that the scores can be summed.

In case of Begecka Jama pilot area, the improvement of the ecosystem services is the main benefit. The realistic scenario is more profitable, also reflecting the stakeholders' preferences and the compatibility with the measures of the Begecka Jama Nature Park Protection Study. For this scenario, institutional analyses were elaborated and a potential way to proceed forward was suggested, i.e. the realization of the restoration through the protected area manager's annual program of works, also based upon the Law on planning and construction.

In case of the Bistret pilot area, the scenario that meets the maximum score as a result of analyzing the impact of the project from a technical, socio-economic, environmental/sustainability and remaining risks, is an "A" scenario which creates the premises for the sustainable development of the area and ecological tourism.

In case of the Kostanjevica na Krki pilot area, measures in the riverbed and for the activation of floodplains do not bring significant improvements to the hydraulic/hydrological parameters. Thus, appropriateness of selected measures might be revised. Still, the increase of the inflow to floodplains in very frequent floods (HQ2-HQ5) is useful for other aspects (e.g. improved ecological circumstances). The economic net asset value is only positive in the optimistic scenario, which considers, among others, also protective measures within Kostanjevica itself (where the greatest effects occur, especially in terms flood risk reduction).

In case of the Middle Tisza pilot area, flood protection purposes of restoration were partly met: conveyance capacity and floodplain area were increased and show a significant effect in flood volume storage. However, a decrease of the flood hazard with the two restoration scenarios can only be considered as a local effect. It can be concluded that the more floodplains are restored on catchment level, the higher impact can be achieved in gaining all possible advantages. Also, improvement of ecological conditions and ecosystem services as from the restorations were proven. For the measures' realization, the realistic scenario was chosen, since it already has integrative benefits, which can be further developed with optimistic scenario in the future.

7.3. CONCLUSIONS FROM FEASIBILITY STUDIES

- Feasibility studies serve as **decision-support tools**. They describe and summarize the **current situation** and problems that initiated the necessary development, **methodologies**, and the **constraints and challenges** that the project may face during and after the implementation.

- Selected **restoration scenarios** were properly evaluated and compared. Total project goal was achieved on pilot areas **Middle Tisza and Bistret**, where in at least one scenario, not only **flood risk** was reduced, but also **economic** and **ecological** benefits could be achieved. In case of **Begecka Jama and Kostanjevica na Krki**, the modelled measures could be revised for the **improvement** of flood risk reduction.

- **Time and budget** represent a difficulty, giving a strict limit of the restoration scenarios, because it can happen that the scenarios present no considerable effect on the highlighted problem.

- The content of the feasibility studies based on **legal obligations** do not necessarily meet the feasibility studies' content developed in the Danube Floodplain Project. This might raise some difficulties for the project partners.

- There are usually preliminary surveys on the project sites with potential for restoration. These **preliminary surveys** can be vague or detailed. If these exist and are in proper quality, the pilot area responsible entities can consider compiling a feasibility study unnecessary.

- We suggest to provide **financial resources** for compiling **feasibility studies**. If no financial resources and incentives are available, this would cause vague and not proper quality feasibility studies. The cost-benefit analysis (CBA) and consideration of its results during the decision-making are key factors. Without CBA, the scenario analysis will lose its role and importance.

CONCLUSIONS

SUMMARY AND DISCUSSION

With the 2D hydrodynamic models, we investigated the reduction of the peak discharge (ΔQ) and the delay of the time to flood peak compared to CS (Δt). The effects of the restoration scenarios are variable. The largest ΔQ was by 10% (Morava pilot area) but in some cases, ΔQ was negligible. Also Δt was in many cases negligible (below +/- 1h) but increased with in the flooded area generated by restoration measures.

Due to their ability to create detailed spatial information of restoration effects on the floodplain areas, 2D hydrodynamic models can be recommended for planning floodplain restoration measures. After analyzing the results, we conclude that, to affect the peak discharge, it is crucial not only to consider a single restoration measure but a combination of multiple measures (on river channel, floodplain extent, etc.). We also recommend to investigate the lateral inflows from the tributaries, as the discharge conditions of the tributaries and the main river can differ and shift the results.

The results of meso-scale biodiversity assessment in the pilot areas show that floodplain habitats, and thus biodiversity, can benefit from increasing the lateral connectivity, as intended by the majority of restoration scenarios.

In each pilot areas, we estimated a maximum total gain of ecosystem services between 600,000 USD^{2019}/yr (Bistret) and 3.1 million USD^{2019}/yr (Morava). The results are mainly affected by greenhouse gas fluxes, changes in nature-based recreation, and cultivated goods services, but flood mitigation is often negligible.

In Begecka Jama, Krka, and Morava at least one restoration measure lead to an extended benefits-costs-ratio (BCR) equal or higher than 1. In Bistret instead, the extended BCR does not reach 1. The standard BCR shows always results smaller than one and closer to zero than the extended BCR.

In the pilot areas, floodplain restoration NBS cannot be justified for flood mitigation only; however, this output is only valid for these specific pilot areas and NBS remain a flexible and resilient way to address natural hazards (Acharya et al., 2020; Faivre et al., 2017).

The stakeholder workshops were of great help to collect information about the areas and to map the ESS. Their assessment can be useful for decision-makers to locate areas of ecosystems' restoration (Krol et al., 2016), and their evaluation can be useful to maximize profitability and provide proof of the manifold advantages of floodplain restoration and preservation.

Feasibility studies, as a frame for complex measures such as floodplain restoration, serve as a proper tool to see a holistic approach and objective methodologies.

OUTLOOK

Using two-dimensional (2D) hydrodynamic models is an appropriate way to analyze the impacts of possible restoration scenarios on the flood hazard and the corresponding risk. Yet, it is crucial to consider that restoration measures and their impacts can differ remarkably. Conclusions on the effects of floodplain restoration should thus not be made a priori, but considering potential effects of each measure to hydraulic parameters.

In hydrodynamic modeling, the calibration of roughness coefficients can increase uncertainty and create equifinality problems (Beven, 2012; Pappenberger et al., 2005). One limitation of the Danube Floodplain Project is that uncertainties of 2D models were not evaluated. For further assessments, it is recommended to include an uncertainty analysis for the models, following e.g. Beven and Freer, 2001 or Blasone et al., 2008.

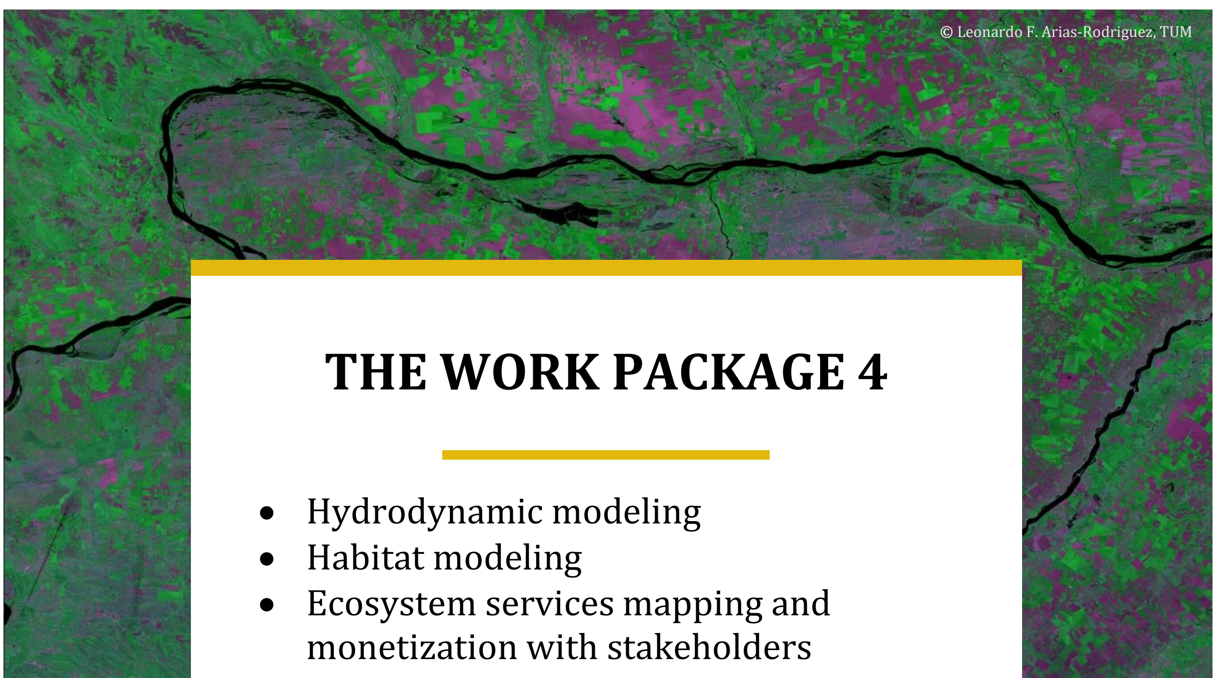
Regarding the modeling of habitats, an assessment on the meso-scale was applied in the Danube Floodplain Project. However, a microscale analysis would have given insights on the level of species or specific communities. This requires in-depth knowledge of the setting and cannot be obtained without extensive fieldwork. Therefore, if future projects should put the focus on the habitat improvement of floodplain restorations, resources should be planned for dedicated fieldwork, personnel, and equipment. Additionally, time and resources should be considered for further hydrodynamic modeling activities, which focus on frequent flood events.

According to the experience of Danube Floodplain project partners, reaching stakeholders is not always an easy task. In the future, stakeholder engagement strategies should be improved, e.g. by creating stakeholder forums, encouraging the communication in the mother tongue, planning field visits, and organizing at least two workshops, which should be planned for a later stage of the project. Anyway, policymakers and researchers should give stakeholders a greater role in the design of floodplain restoration measures and in their evaluation, including ecosystem services assessment and monetarization.

Concerning ecosystem services modeling, researchers should develop new methodologies to evaluate the missing ESS types, which are not included in commonly used ESS assessment guidelines (TESSA) or software (InVEST, ARIES, etc.), such as groundwater recharge or noise regulation, and more modeling could be implemented to get a more detailed estimation of certain ESS (e.g. water quality). Furthermore, a better interpretation of the results might be given by analyzing the ESS uncertainties. Therefore, we suggest to monitor implemented restoration measures, to confirm or discard the ESS assessment's results. In fact, a high number of factors influence the floodplain ecosystem and the phenomena taking place in it. For this, we should make sure that the assumptions used do not invalidate the assessments.

On a broader scale, scientists should study the effects (e.g. on nature-based recreation) of upscaling local-scale methods to the national (or river basin) extent, especially in case more floodplain restoration measures are implemented at the same time. Accordingly, we call for a better inclusion of ESS assessment in the Danube River Basin Management Plans. This could not only be done by including ESS in an extended cost-benefit analysis when planning new measures, as done in this project, but also by developing payments for ecosystem services (PES). With PES schemes, stakeholders that are negatively affected by the restoration measures (e.g. agricultural landowners) could be compensated by those who are benefitting (e.g. tourism agencies).

Compiling feasibility studies before starting a restoration project is obligatory in some Danube countries. The obligation can be a requirement of the funding source or a legal expectation. However, the compilation of feasibility studies with a full and detailed content might be costly and, if financial resources are not provided, the project partners might probably skip this exercise. If there are no incentives to compile feasibility studies, the project partners will not share this exercise among each other, but probably subcontract it. This would cause vague and not proper quality feasibility studies.



THE WORK PACKAGE 4

- Hydrodynamic modeling
- Habitat modeling
- Ecosystem services mapping and monetization with stakeholders
- Extended cost-benefit-analysis
- Feasibility studies and recommendations

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