Deliverable 4.2.3

Report on the assessment of biodiversity in the pilot areas

WP	WP 4: Flood prevention pilots
Activity	Activity 4.2
Activity-Leader	CUEI and TUM
Number and name of deliverable	D 4.2.3 Report on the assessment of biodiversity in the pilot areas including a database and maps of pilot areas' biodiversity and habitat modeling as input for D 4.4.1 and part of output 4.1.
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Participating partners	All partners from countries with pre-selected pilot areas
Connection with other deliverables/ outputs	D 4.4.1; output 4.1

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1. Introduction and Objectives

On a transnational level, the European Union demands to manage flood risk, nature conservation and integrative water resource management as required in the Floods Directive, the Water Framework Directive and the Habitats Directive. Floodplain management is affected by all these directives at the same time. Often, the requirements are contradictory making comprehensive floodplain management or restoration a challenging task. To satisfy these requirements, future flood protection measures and floodplain restoration projects are to be implemented in a way, where they increase risk reduction and nature conservation in optimal win-win solutions.

Against this background, the Danube Floodplain project aims to identify flood protection measures increasing the ecological conditions at the same time. The project is carried out on two spatial scales. On the one hand, a large scale assessment is done to identify floodplains in the different countries of the Danube basin and evaluate them regarding flood hazard reduction and ecological potential based on the floodplain evaluation matrix (Habersack et al., 2015). On a smaller scale, more detailed assessment of concrete measures in five so-called pilot areas is carried out (see Fig. 1 for an overview map). Aim is to create show cases to demonstrate that floodplain restoration can have positive effects on flood risk reduction and ecological condition at the same time. To achieve this, a detailed assessment of hydrological/hydraulic changes as well changes in the ecological conditions including an ecosystem service evaluation are carried out. For an in-depth evaluation, an extended cost-benefit-analysis (CBA) is carried out integrating ecosystem service into the traditional CBA approach. This deliverable on the assessment of biodiversity in the pilot areas is written within this context of the ecological evaluation. Following the application form, biodiversity is considered as the potential of floodplains to provide habitats for typical floodplain species. Thus, habitat diversity (as a major component of biodiversity) is used as an indicator of overall biodiversity. Floodplains are located at the interface of terrestrial and aquatic ecotones, a characteristic leading to a (potentially) complex structure with a wide range of different habitat types. This mosaic of habitats makes floodplains in a natural state to a hotspot of biodiversity (Ward et al., 2002; Naiman et al., 2005). This diversity is created and maintained by hydrological (and hydromorphological) dynamics driven by lateral, vertical and temporal connectivity between river channel and floodplain (Amoros & Bornette, 2002). Consequently, the focus of the assessment within this deliverable is on the impact of changes in lateral connectivity on changes in floodplain habitats.

The evaluation of habitat provision is carried out based on habitat modeling in order to carry out a quantitative evaluation of the effects of the floodplain restoration measures planned for the Danube Floodplain pilot areas. Traditionally, expert based judgements have been the basis for such evaluation. However, quantitative data and modeling approaches are able to provide more objective results as basis for management decisions (Funk et al., 2013). In the framework of the Danube Floodplain project, habitat modeling is carried out for each pilot area within

work package 4 using the results from the hydraulic modeling work in **activity 4.1** along with further spatial datasets like for instance digital elevation models or landcover data. This deliverable provides an overview over the specific characteristics of each pilot area and briefly introduces the restoration measures planned for each area. Then, the habitat modeling approach is introduced before giving the results along with a brief interpretation. Finally, a conclusions summarizes the major results and gives a final statement on the use of habitat models for the evaluation of floodplain restoration.

2. Overview over the pilot areas

2.1 Pilot area characteristics

All in all five pilot areas have been selected in Danube Floodplain for an in-depth evaluating the effect of floodplain restoration measures on flood protection, biodiversity (i.e. ecological conditions) and ecosystem services. Three out of five pilot areas are located at tributaries of the Danube River: At the Morava at the border between Czech Republic and Slovakia, at the Krka in Slovenia and at the Tisza in Hungary. The other two areas are located directly at the Danube: Begečka Jama in Serbia and Bistret in Romania. An overview over the location of the areas is given in Fig. 1.

Figure 1: Pilot areas of the Danube Floodplain project for which habitat modelling has been carried out (river network and catchment boundary of the Danube from https://danubis.icpdr.org, background map from OpenStreetMap)

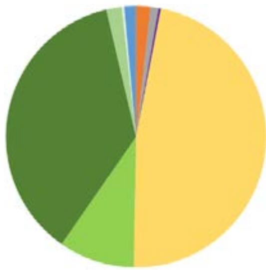
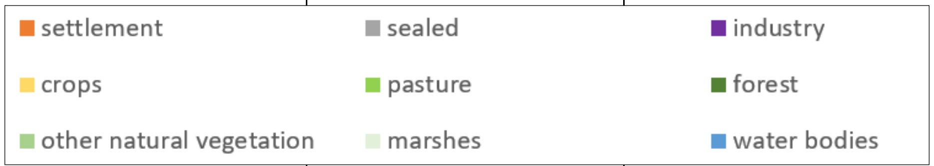
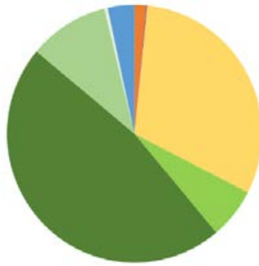
The pilot areas differ significantly in their characteristics. Most obvious is the size where they differ from approx. 10 km² in Begečka Jama to 177 km² in Bistret. But also the river and floodplain characteristics differ among the different pilot areas with a lowland meandering stream at the Morava, the Danube in Bistret or the relatively small tributary of the Krka in Slovenia. While all for all pilot areas the ultimate aim is to maximize flood risk reduction and ecological condition of floodplains in win-win practices of restoration, the detailed planning differs from site to site. While the ones focus on flood risk reduction, the others focus on enhancing the ecological situation in terms of biodiversity or want to improve particular ecosystem services such as ecotourism. A comprehensive overview over all pilot areas is given in table 1.

Table 1: Characteristics of the Danube Floodplain pilot areas (table compiled by Johanna Springer (TUM) together with partners from the 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/HARW	DRSV	KOTIVIZIG	VUVH/MRBA
Pilot area size [km²]	10.13	176.98	85.56	49.51	147.37
Geographical / morphological characteristics	Begečka Jama Nature Park (BJNatP) is located on the active floodplain on the left bank of the Danube River, upstream from the City of Novi Sad. The length of the area is approx. 7,8 km (rkm 1.276+200-1284), while the central point is 45° 13' 23“N, 19° 36' 23“E. Formerly, it was part of a larger floodplain, that was reduced to the current extent due to agricultural development and flood protection measures implemented as early as the 18th century. Several geomorphologic types of fluvial erosion of different	The **Bistret** pilot area is located on the left bank of the Danube river, just upstream of the confluence with Jiu river. It has an average length of approx. 24 km and an average width of about 7 km. The average altitude of the land in the Bistret enclosure is 27.50 mdMN, and the average slope is approx. 0.00833% The Bistret area also includes the Bistret lake in which the Desnatui tributary flows. The area is delimited in the south by the defense dikes from the Danube, in the west	The Kostanjevica na Krki pilot area is combined from the Kostanjevica na Krki town, Krakovski forest, and Šentjernej field. It is situated in the SE part of Slovenia, at (45°50'46'' N 15°25'29'' E, altitude 155m). The pilot area is influenced by moderate continental climates. The whole area has natural water retention function. The main watercourse is the Krka river (94 km, 2,315 km2). In the upper part, where the river is in a gorge, there are many karstic underground	The **Middle Tisza** region is a meandering river section. Flood risk and vulnerability are of particular importance in the area. After the river regulation in the 19th - 20th centuries both riverside are there dyke construction. These dyke sections protect the settlements, industrial zones and the arable lands from flood event. The Middle Tisza section is the lower section of the river, so in this area can accumulated more sediment on the floodplain area and lose	The **Morava River** is a lowland river, in the past strongly meandering, extensive river training works were done (channel straightening, cut-off meanders, uniform channel with bank protection, reduction of floodplain areas, interruption of longitudinal continuity by weirs and sills); confluence of Morava and Thaya on CZ side with large retention area to release flood discharges; several villages along the area but outside the floodplain area; modelling

Pilot Area	Begecka Jama	Bistret	Krka	Middle Tisza	Morava
	ages - islands, natural levees (ridges), oxbow lakes and backwaters, created mutually by fluvial erosion and reclamation, enabled the development of a mosaic of wetland habitats at different stages of succession of floodplain vegetation, which represent a refuge for many animal and plant species. BJNatP is an important reproduction area for many fish, amphibians and bird species. The status of the wetland habitats (oxbows, backwaters, wet meadows, marshes) and the hydrological regime have significantly deteriorated over the past 30 years due to siltation and aggradation caused by both natural processes and anthropogenic activities (forestry, pollution from the surrounding arable land, flood protection). Intensive land use caused habitat	by the compartmentalization dike between the Rast enclosure and the Bistret enclosure, in the north by the Bistret lake and the terrace, and in the east by the magistral irrigation channel Macesu-Nedeia. In the northern terrace area are the localities Bistret, Plosca, Dunareni, Sapata, Macesu de Jos. The average altitude of the terrace is about 31 mdMN. In the pilot area, drying and irrigation systems and pumping stations are executed. The main pumping stations that ensure the drying of the area are SP-Malaians in the upstream end which also ensures the gravitational discharge of Lake Bistret when flows on the Danube are less than aprox. 8000 m^3/s, SP-Stejaru, and SP-Nedeia located in the	springs. The surface tributaries appear in the lower part of the Krka river where the valley widens. Some of them (Radulja, Sajovec, Lokavec, Senuša) discharge into the Krka river near the pilot area. The lower part of the river is characterized by slow river flow and extensive flood plains – one of them is Krakovski forest, which represents the largest remnant of lowland floodplain forest (combined of Pseudostellario–Quercetum and Pseudostellario europaeae-Carpinetum (determining tree species are Quercus robur, Carpinus betulus, Alnus glutinosa)) in Slovenia. Beside the Krka river itself, it is the Krakovski forest which is important on the European level by its habitat and species	the conveyance capacity between the dykes. In the floodplain the main land use type is the forest, the second is crops and we can find some other less land use type (e.g. pasture).	area delineated by present flood dykes and the retention area on the confluence with Thaya river.

Pilot Area	Begecka Jama	Bistret	Krka	Middle Tisza	Morava
	degradation and fragmentation. River training and flood protection measures disrupted the dynamics of flood events. The planting and management of poplar plantations enabled the spreading of invasive plant species, whilst the backwaters, oxbows and wet meadows are being filled up due to forestry activities and needs. The area became less attractive for visitors due to the loss of aesthetic and recreational values.	downstream end of pilot area.	diversity (covered by the Habitat and Bird directives, and Natura2000 legislation). Šentjernej field is covered mostly by meadows, farmland, and scattered settlements. Kostanjevica na Krki is an important cultural and historical site. Geologically and geomorphologically we are talking about tectonic lowland depression on the carbonate geological basis, filled with clay-gravel sediments.		

Pilot Area	Begecka Jama	Bistret	Krka	Middle Tisza	Morava
land cover (CORINE 2020) of 2D model area			  		
Current ecological status and deficits	The pilot area belongs to the Danube River Water Body RSD8: Danube between Novi Sad and HR-RS State border. The status assessment below is taken from the Danube RBMP update 2015, ICPDR (DanubeGIS): - The water body is provisionally HMWB, - The chemical status is poor (assessed with low confidence),	3 Surface Water Bodies has been identitified for the active floodplain - RORW14-1-27_B172 Desnatui -Ac. Fantanele - Ac. Bistret in moderate ecological status status (river continuity and morphological conditions in moderate status). Moderate status for fishfauna (caused by upstream river dam Fantanele) - RORW14-1-27-	General data of the Water body Krka (Otočec – Brežice) (according to RBMP for Danube basin district) - Overall ecological status evaluation: GOOD - Significant diffuse pressures: Agriculture - Significant point pressures: Communal waste waters, Industrial waste waters - Significant hydromorphological	The Middle Tisza River is a natural category with heavily modified sections. This section of the river, based on physico-chemical data supporting biology, has excellent potential and the concentrations of the hazardous substances we studied did not exceed the environmental quality limit. The narrow strip of floodplains between the dams of the Tisza active floodplain, plays an	Heavily modified water body (HMWB) - Ecological status: 3 - moderate; Hydromophological quality: 4 - poor

Pilot Area	Begecka Jama	Bistret	Krka	Middle Tisza	Morava
	- The ecological potential is moderate (assessed with medium confidence).	8_B176 Buzat - izvor - cf. Desnatu;RORW14-1-27-7_B175 Baldal (Jivan) - izvor - cf. Desnatui in good ecological status - Good chemical status with a small increasing for CCOCr for all WB	pressures: Land use in the riparian area - Other significant anthropogenic pressures: No - In almost 200 years the watercourse topology has not changed at all nor were any dykes constructed along the river. - The river's floodplains are connected to the river by regular flooding. - The river itself is under Natura2000 protection. - All five floodplains are partly (the smallest with 14 %, up to the biggest with 96 %) within the Natura2000 areas. - The entire area is characterized by high biodiversity. More than 50 species from the Natura2000 protected species list can be found in the river and on its floodplains. Some of them are on the International Union for the	important role in the migration and spreading of aquatic and aquatic habitats as ecological or green corridors. The floodplain of the Middle Tisza, due to its function as a core area and as an ecological corridor, is of great natural value and is of great ecological importance. Unfortunately, nowadays floodplains are the most important routes and channels for the invasion of invasive plant species. This process could significantly reduce biodiversity in the future. In addition, floodplain management is in many cases not consistent with the requirements of natural floodplain habitats. The area is also part of the Middle Tisza (HUHN10004) Special Protection Area and the Middle Tisza	

Pilot Area	Begecka Jama	Bistret	Krka	Middle Tisza	Morava
			Conservation of Nature and Natural Resources red list.	(HUHN20015) Special Area of Conservation.	
Major restoration purposes	• Adequate water supply throughout the year in the Begečka Jama lake, oxbows and channel system and improving habitats for aquatic species • Increase in the water surface area and depth of the oxbows and existing channels • Increase in biodiversity and spawning areas as a result of habitat restoration • Increasing the types of ecosystem services, as well as improvement of the quality and quantity of existing ecosystem services of the area	• Flood protection for population (major damages during 2006 flood) • Sustainable development and ecotourism	Improvements for: • Flood risk management • Nature protection • Forestry	• Increasing conveyance capacity/ floodplain area • Decreasing flood hazard	• Improvement of flow conditions in the river floodplains with respect to flood protection and nature protection goals • Optimization of water regime in the floodplains • Enhancement of conditions for diverse biotopes, which can be found in the area of interest • Improvement of conditions for fish migration

Pilot Area	Begecka Jama	Bistret	Krka	Middle Tisza	Morava
Restoration measures Scenario 1 - realistic	• Cleaning and widening of the existing connecting channel between Danube River and Begečka Jama lake and weir reconstruction which allow fish migration • Floodplain DEM modification via the deepening of existing oxbows and channels and the excavation of new channels between the deepened oxbows, which would allow for the controlled inflow/outflow from the system • Increase the diversity of the river morphology as a result of the excavation, deepening and cleaning of oxbows, and existing and new channels. • Creation of new fish spawning areas which contribute to the maintenance and increase of biodiversity.	• Construction of a recreational and fishfarming lake (200 ha) in the area of Rast • Relocation of the dikes in the confluent area of Desnaţui River with Bistret Lake • Creation of a large water drainage channel to supply Lake Bistret and to facilitate the natural flow of Desnatui River back in the Danube	SC1 - Scenario 1 is a combination of a corridor enabling floodplain activation, and measures to increase water conductivity in the river bed through Kostanjevica, thus lowering water levels within the settlement. It comprises 2 measures: K1- river bed deepening of the northern stream of the Krka river through Kostanjevica, and an inundation at the bifurcation, and K3- a corridor to the floodplain, length 650 m, width 45 m.	• Increase floodplain area: Dike relocation • Land use change: Arable land to pasture • Create fish spawning area	• removal of weirs • Removal or adjustment of selected barriers (weirs, sills) • removal of levees • relocation of flood dykes (to include the cut off sidearms in the floodplain area)

Pilot Area	**Begecka Jama**	**Bistret**	**Krka**	**Middle Tisza**	**Morava**
Restoration measures Scenario 2 - optimistic	• Cleaning and widening of the existing connecting channel between Danube River and Begečka Jama lake and weir reconstruction which allow fish migration • Floodplain DEM modification via the deepening of existing oxbows and channels and the excavation of new channels between the deepened oxbows, which would allow for the controlled inflow/outflow from the system • Increase the diversity of the river morphology and diversity of cross profiles of the river as a result of the excavation, deepening and cleaning of oxbows, and existing and new channels as well as the widening of the existing river channel. • Creation of new fish spawning areas which contribute to the	• Additional dike relocation from the Danube close to the villages along the alluvial terraces	SC2 - Scenario 2 is a combination of 4 measures, being three corridors enabling floodplain activation, and additional measures within the river bed in Kostanjevica: K1– river bed deepening of the northern stream of the Krka river through Kostanjevica, and an inundation at the bifurcation; K2– a corridor to the floodplain, length 950 m, width 30 m; K3– a corridor to the floodplain, length 650 m, width 45 m; K4– a corridor to the floodplain, length 280 m, width 60 m.	• Increase floodplain area: Dike relocation and Controlled dike overtopping • Land use change: Plough (cultivated) land to pasture • Vegetation regulation: Controlled afforestation • Create wetland habitats (eg. lake)	• R1 + relocation of flood dykes (further than in R1) • Renewal of river pattern Reconnection of oxbows with the main Morava channel (at present state they are behind the dyke) Deepening of existing oxbows

Pilot Area	Begecka Jama	Bistret	Krka	Middle Tisza	Morava
	maintenance and increase of biodiversity.				
Major recent floods	2006: HQ100	2006: >HQ100 (ICPDR 2008)	2010: HQ100	2000: ~HQ100	2010: >HQ100 (ICPDR 2012)
	2010: HQ10-20 (HIDMET 2014)	2010: >HQ20 (ICPDR 2012)			
HQs investigated	HQ2-5	HQ5	HQ2-5	HQ2, HQ5	HQ5
	HQ10-20	HQ30	HQ10	HQ10, HQ30	HQ30
	HQ100	HQ100	HQ100	HQ100	HQ100

2.2 Restoration scenarios

The restoration scenarios are developed by the responsible project partners of each pilot area in close cooperation with the responsible authorities and relevant stakeholders identified prior to the planning process. Two stakeholder workshops have been dedicated to the development of the scenarios, their results are summarized in Danube Floodplain **deliverable D 4.2.1.**

Two particular scenarios have been developed: A realistic scenario (RS1) where all intended measures are likely to be implemented and an optimistic scenario (RS2) where the maximum of restoration potential in terms of flood protection and ecological enhancement should be implemented without the consideration of practical limitations e.g. by landownership. An overview of the intended restoration measures of the different pilot areas is given in table 2.

Table 2: Restoration measures to be implemented by the pilot areas (table compiled by Johanna Springer (TUM) together with partners from the pilot areas)

restoration scenario	RS1	RS2	RS1	RS2	RS1	RS2	RS1	RS2	RS1	RS2
Which measures are implemented in the pilot areas?	**Begecka Jama**		**Bistret**		**Krka**		**Middle Tisza**		**Morava**	
1. constructions										
1.1 dike relocation			X	X			X	X	X	X
1.2 dike removal				X			X	X		
1.3 controlled dike overtopping / gaps in dike			X				X	X		
1.4 removal of weirs									X	X
1.5 change operation mode of weirs	X	X								X
1.6 migration permeability at weirs	X	X								
1.7 removal of culverts										
2. land cover and lateral branches										
2.1 convert land cover towards natural conditions				X			X	X		
2.2 modify floodplain DEM	X	X			X	X	X	X	X	X
2.3 increasing the roughness of floodplain (afforestation)								X		
2.4 create and connect new lateral branches or pools / new water regime	X	X	X	X	X	X				
2.5 create retention areas / flood channels			X		X	X		X		
2.6 connection of lateral branches/owbows	X	X	X							X
2.7 deepening lateral branches/oxbows	X	X								X
2.8 reconnect old oxbow										X
2.9 increase floodplain area				X	X	X	X	X	X	X
3. river channel geometry alteration										
3.1 increasing the roughness in the river channel (according to natural bedrock)										
3.2 widening of river channel		X			X	X				
3.3 increase of the river bed (decrease of water depth)										
3.4 increase the diversity of the river morphology (riffles, pools, potholes, sand or gravel banks, cut banks and slip-off-slope, broader and narrower passages of the river,...); diversity of cross profiles of the river	X	X								
3.5 removing bank stabilizations / embankments							X	X		
3.6 riperian vegetation (increase roughness, stabilizes the riverbank, decreases nutrient inflow)										
3.7 implementing groynes, boulders or dead wood to initiate meandering										
3.8 change course of river (meandering)										X
3.9 removing ground sills, plunges									X	X
3.10 create fish spawning areas	X	X						X		
3.11 Removing sand bars							X	X		

RS1 = realistic implementation scenario
RS2 = optimistic implementation scenario

Despite the obvious differences between the different restoration scenarios, they all have in common that it is about the increase of lateral connectivity between channel and floodplain. Additionally, the scenarios at the Tisza and in Bistret envisage an active modification of the landcover. The clear focus, however, is on increasing lateral connectivity. Thus, the focus of the biodiversity assessment carried out by means of meso-scale habitat modeling to evaluate the change of typical floodplain habitats affected by hydrological connectivity.

3. Overview over habitat modeling strategies

The general aim of the habitat modeling work within this deliverable is to evaluate whether a certain floodplain restoration measure is capable to improve typical floodplain habitats. Such prediction is made based on environmental co-variables like water depth, flood duration, flow velocity etc. (Guisan & Zimmermann, 2000; Maddock et al., 2013). Basis is the conceptual understanding how these environmental factors influence habitats and the species living there. Basing upon this conceptual understanding, quantitative formulations are made to link habitats and environmental variables. Different options are available to establish this linkage.

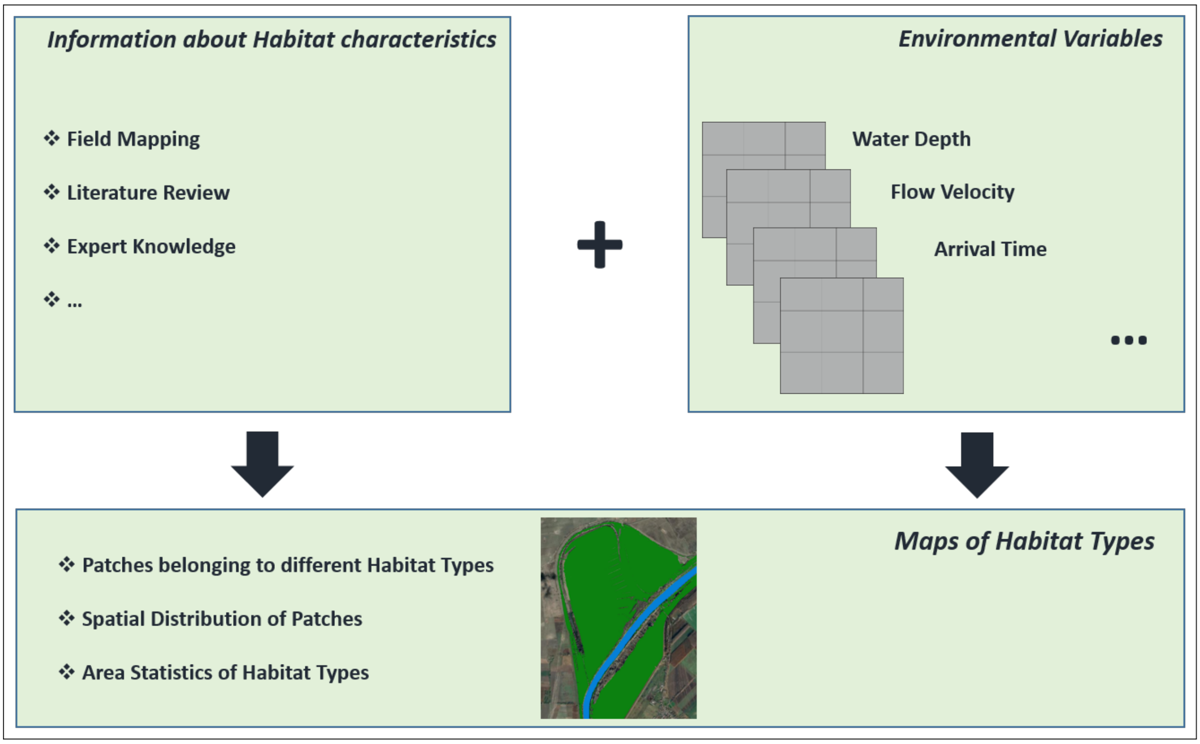


Figure 2: Principle of habitat modeling on the meso-scale

As riparian ecosystems depend on the hydrological connectivity between channel and floodplain, the habitat modeling work depends on external hydraulic modeling results which have been provided by the project partners of the pilot areas. Due to the complexity of floodplain terrain, 2D hydraulic models are required. For each pilot area three scenarios (current state, realistic restoration scenario, optimistic restoration scenario) have been computed with three hydrological scenarios (HQ2-5, HQ30, HQ100). For the habitat modeling, more frequent flood events are the most relevant, thus the HQ2-5 scenario has been chosen for this purpose. The available data differs from pilot area to pilot area but as a minimum flow velocity and water depth have been available. In addition, arrival time also was provided by 4 out of 5 pilot areas. In initial tests, this parameters has proven to be a suitable indicator of connectivity to the main river channel. Unfortunately, flood duration was only partly available as this is a crucial parameter for riparian vegetation development.

In the context of ecohydraulics, there are different spatial scales relevant for habitat modeling following conceptual developments from hydromorphology (Zavadil & Stewardson, 2013). These conceptual frameworks emphasize the role of multiscale analysis ranging from the entire catchment over river segments and reaches to single geomorphological or hydraulic units. However, as the pilot areas with a rather small spatial extent are the focus of this deliverable, the focus is on smaller spatial scales on the level of hydraulic or geomorphological units. Within ecohydraulics, these spatial scales are often referred to as the meso-scale and microscale (Newson & Newson, 2000; Zavadil & Stewardson, 2013). In the following sections, habitat modeling at these specific scales is described in further detail. This deliverable focuses on the assessment of habitat structures on the mesoscale due to the high number of pilot areas and potential indicator species. Nevertheless, habitat modeling an overview of habitat modeling on the microscale is given along with a suggestion of indicator species. Detailed habitat suitability maps for these species will require field work to elaborate the specific habitat preferences. Thus, this deliverable stays on the level of habitats and does not dive into detailed species assessment. In case of particular interest, detailed habitat suitability maps on the species level can be elaborated at a later stage of the project.

3.1 Floodplain habitat modeling on the meso-scale

On the meso-scale, the focus is on the identification of patches of typical floodplain habitats as defined in table 1. Floodplain ecology is driven by the connectivity between the channel and the floodplain. Specifically, four types of connectivity can be discriminated: longitudinal, i.e. in the upstream-downstream direction, lateral, i.e. via surface flow between the channel and the floodplain, vertical via groundwater as well as temporal considering the flow regime of a river (Amoros & Bornette, 2002; Naiman et al., 2005). Within the habitat modeling work in Danube Floodplain, only lateral floodplain connectivity is considered due to the nature of the hydraulic models and the hydrological scenarios used in this project. This gives only a part of the picture, as the vertical connectivity via the groundwater is not considered (Amoros & Bornette, 2002). However, the consideration of flow regime and groundwater is beyond the scope of the Danube Floodplain project as these parameters are not included in the hydraulic modeling framework. Table 3 gives an overview of typical floodplain habitats on this particular spatial scale.

Table 3: 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 (HQ2-5).
Aquatic-terrestrial transition zones*	Patches at the interface of channel and floodplain with low slope and high flood duration during minor flood events (HQ2-5)

*not applicable in this deliverable

A semi-automated approach has been chosen for deriving these habitat types from the hydraulic parameters. First, k-means clustering has been carried out for all hydraulic variables available for the respective pilot area to obtain initial spatial pattern. The results of the clustering have then been 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 have been elaborated separately for each pilot area as the characteristics as well as the datasets are quite heterogeneous. An evaluation has been carried out only based on a plausibility check as no independent validation data is available.

3.2 Floodplain habitat modeling on the microscale

On the microscale, the suitability of each location to be habitat for a specific species is predicted (Zavadil & Stewardson, 2013). Detailed modeling of individual species for a range of different habitat types, all pilot areas and all scenarios is beyond the scope of this deliverable. Nevertheless, a brief overview over suitable indicator species for the different floodplain habitats tailored to the pilot areas is given here in order to stimulate ongoing analysis of floodplain habitats. The databases of the Natura 2000 and the Emerald network are a good source of information for restoration planning as they offer quite consistent data. Previous studies have already proved their suitability for analyzing site conditions and perform restoration planning (Cortina & Boggia, 2014). Funk et al. (2019) suggest all in all 10 species relevant as indicator species relevant for assessing the ecological status of floodplains along the Danube. Comparing their species list with the species abundant in the Natura 2000 or Emerald sites in the vicinity of the pilot areas allows to derive a set of species tailored to the assessment of the mesoscale habitats (section 3.1) and the specific requirements of the different pilot areas.

Table 4: Natura 2000 and Emerald sites relevant for selection of indicator species; the corresponding data can be downloaded from the following URLS: https://www.eea.europa.eu/data-and-maps/data/natura-10#tab-gis-data; http://emerald.eea.europa.eu/.

Pilot Area	Site Code and Name
Begecka Jama	RS0000021 (Emerald) Koviljsko-Petrovaradinski Rit
Bistret	ROSCI0045 (Natura 2000) Coridoruk Jiului
Kostanjevica na Krki	SI3000051 (Natura 2000) Krakovski gozd
Middle Tisza	HUHN20015 (Natura 2000) Közép-Tisza
Morava	CZ0624119 (Natura 2000) Soutok – Podluží SKCHVU016 (Natura 2000) Zahorske Pomoravie

Table 5 gives an overview over indicators species suitable for assessing the habitat conditions of the pilot areas in more detail. However, for such in-depth assessment, detailed data on species as well as on natural condition is required to make accurate predictions. Most relevant is accurate information on the species, either precise abundance locations in a statistically meaningful number or in-depth knowledge on the local habitat preferences of the species under consideration. Both sources of information are quite limited within Danube Floodplain, thus the preference is given to the meso-scale approach.

Table 5: Indicator species for habitat modelling on the microscale (based on Funk et al., 2019)

Species	Indicator Value	Pilot areas where applicable
Indicators for lateral connectivity of oxbows and backwaters		
Gymnocephalus baloni (fish)	Reophilic species migrating between main channel and side arms	Begecka Jama, Bistret, Morava, Tisza
Indicators for vertically connected backwaters and ponds		
Bombina Bombina Bombina variegata (amphibian)	Indicator for pond like (i.e. only vertically connected) waterbodies	Begecka Jama, Bistret, Morava, Tisza, Krka
Misgurnus fossilis (fish)	Stagnophilic species preferring low velocity ponds with aquatic vegetation	Begecka Jama, Bistret, Morava, Tisza, Krka

Indicators for the aquatic-terrestrial transition zone		
Chenopodion rubri (plant) *Bidention spp.*	Herbaceous plant species growing in the aquatic-terrestrial transition zone; Indicator for water level dynamics	Begecka Jama, Bistret, Morava, Tisza
Indicators for general lateral floodplain connectivity		
Alnus glutinosa (plant)	Woody plant species being part of the softwood riparian forest	Begecka Jama, Bistret, Morava, Tisza, Krka
Quercus robur (plant)	Woody plant species belonging to the hardwood riparian forest	Begecka Jama, Bistret, Morava, Tisza, Krka
Indicator of general naturalness		
Lutra lutra (mammal)	Indicator for general ecological integrity on the floodplain as this mammal depends on natural conditions without anthropogenic disturbance	Begecka Jama, Bistret, Morava, Tisza

Of course, also further species groups suitable as indicator for floodplain habitat condition exist like for instance mollusks (*Mollusca*) or ground beetles (*Carabidae*). They can be used for complementary assessment of the habitat conditions. However, their assessment in terms of habitat modeling is challenging as their specific habitat requirements as related to hydrological dynamics are still not fully understood. The species listen in table 5 are clearly linked to the different meso-habitat types and should be able to give further insights in the structure and quality of each meso-habitat patch in the pilot areas during later project stages. This assessment might be done by machine learning approaches in case sufficient georeferenced abundance data of the species is available. Otherwise, a fuzzy logic based approach might be chosen similar to the meso-habitat assessment carried out within this deliverable.

4. Results

4.1 Begecka Jama

The pilot area of Begecka Jama is located directly at the Danube River. Main restoration goal is to increase the connectivity between the Danube and backwaters and the floodplain itself with the intention to improve fish spawning habitat. However, the state of lateral connectivity of the floodplain is already not too bad also in the current state. 205 ha or 52 % of the total

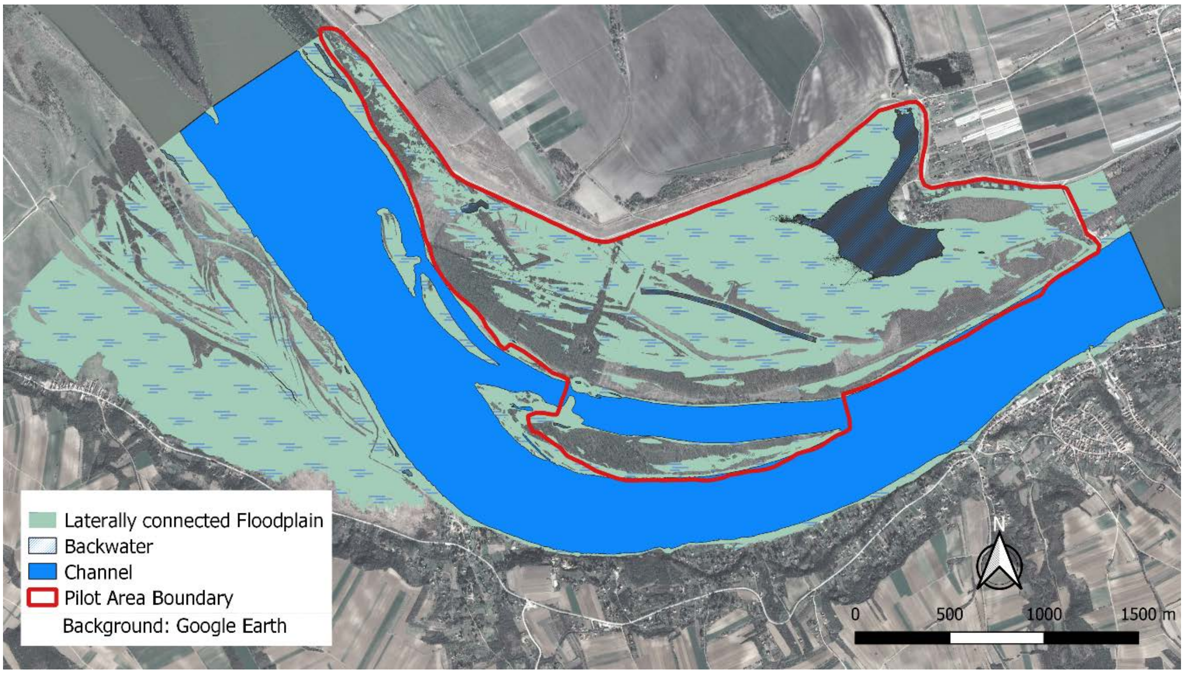


Figure 3: Mesohabitats of the current state scenario for Begecka Jama; the area evaluation in the text refers to the red polygon defining the boundary of the pilot area

area of the pilot area are laterally connected to the Danube during a 2-5 year flood event. Natural vegetation development on the floodplain will depend mainly on flood duration, a parameter not available for this pilot area. In general for an area of this connectivity status, the expectation would be mixed riparian forest, in areas with higher flood duration also softwood riparian forest. In the vicinity of the backwaters, also reed belts for instance with *Phragmites australis* are likely to occur. Also backwaters are existing in the current state. Three isolated ponds or lakes result in a total backwater area of 27.5 ha or 7 % of the total pilot area where the majority of the area is contributed by a lake in the northeastern part of the floodplain. Their low connectivity and low flow velocities of 0.04 m/s makes them a suitable habitat for amphibians such as *Bombina bombina* or potentially also stagnophilic fish like *Misgurnus fossilis*. The in-channel habitats are not the focus of this deliverable, thus it is not regarded in further detail here. It has an entire area of 30 ha contributing. During regular flow or low flow events, the channel area between the floodplain and island might be suitable as spawning habitat for reophilic species like *Gymnocephalus baloni*. However, this assumption is not supported by the hydraulic data for the HQ2-5 considered for this study.

In the realistic restoration scenario, 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. The area of the hydrologically connected floodplain slightly decreased to 200 ha as the backwater area increased to 47.7 ha. The connectivity of the remaining area does not change significantly. Thus, no hydrologically driven change of vegetation can be expected. However, in total the area hydrologically connected to the Danube increased from 232.5 ha to 247.7 ha. Also the connectivity within the backwater system has significantly improved due to a system of didges in the central part of the floodplain (see Fig. 4). In addition, the connection to the Danube has improved as well.

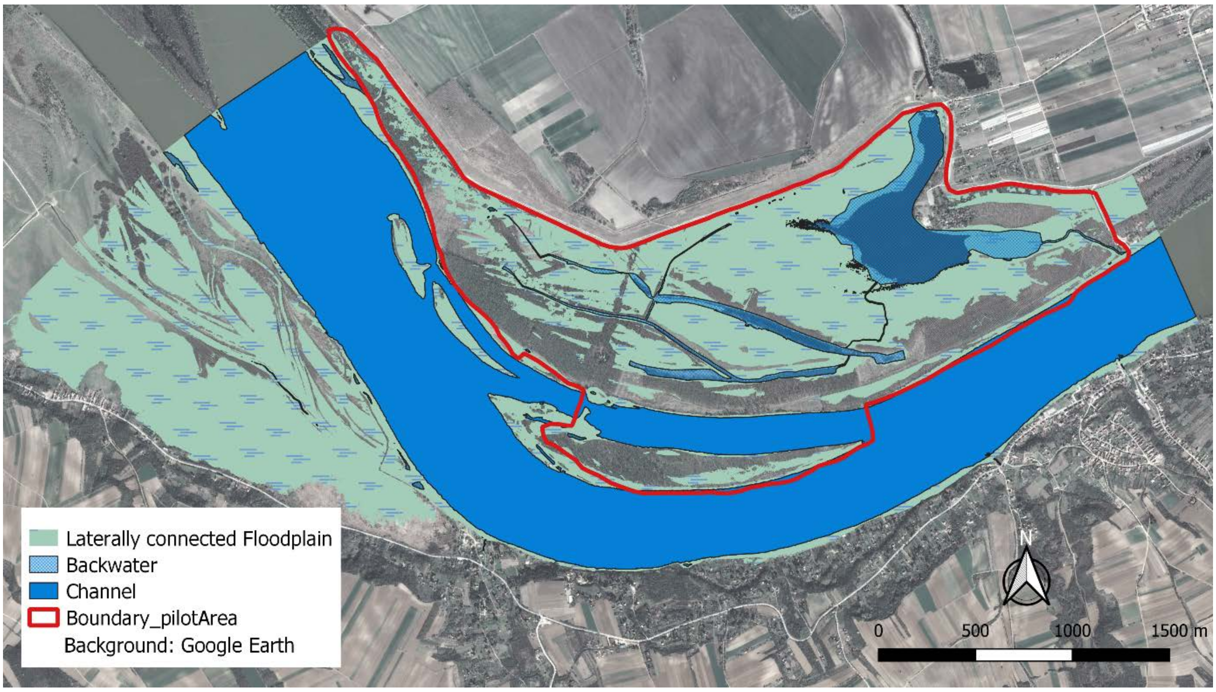


Figure 4: Mesohabitats of the realistic restoration scenario for Begecka Jama; the area evaluation in the text refers to the red polygon defining the boundary of the pilot area

This increases the suitability of the backwaters to be spawning habitat for fish species migrating between the main channel and the backwaters like for instance *Gymnocephalus baloni.* As flow velocity remains low with, the backwater system remains a suitable habitat for stagnophilic fish species as well. However, the habitat suitability for amphibian species like *Bombina bombina* is likely to decrease due to the pressure from fish. The area and characteristics of the channel area does not change in the realistic restoration scenario.

The optimistic restoration scenario plans to construct a new side channel in addition to the increase in backwater connectivity (Fig. 5). This increases the total channel area in the pilot area from 30 ha to 71.5 ha. The backwater area in this scenario is 34.5 ha, thus smaller compared to the realistic scenario. In addition, the flow velocity in the backwater system slightly increased what might lead to a slight decrease in habitat suitability for stagnophilic fish species like *Misgurnus fossilis* or also amphibians*.* On the contrary habitat conditions will improve for other fish species like *Gymnocephalus baloni* or similar species migrating between main channel and backwater. The area of the hydrologically connected floodplain slightly decreases to 183.6 ha due to the conversion to channel.

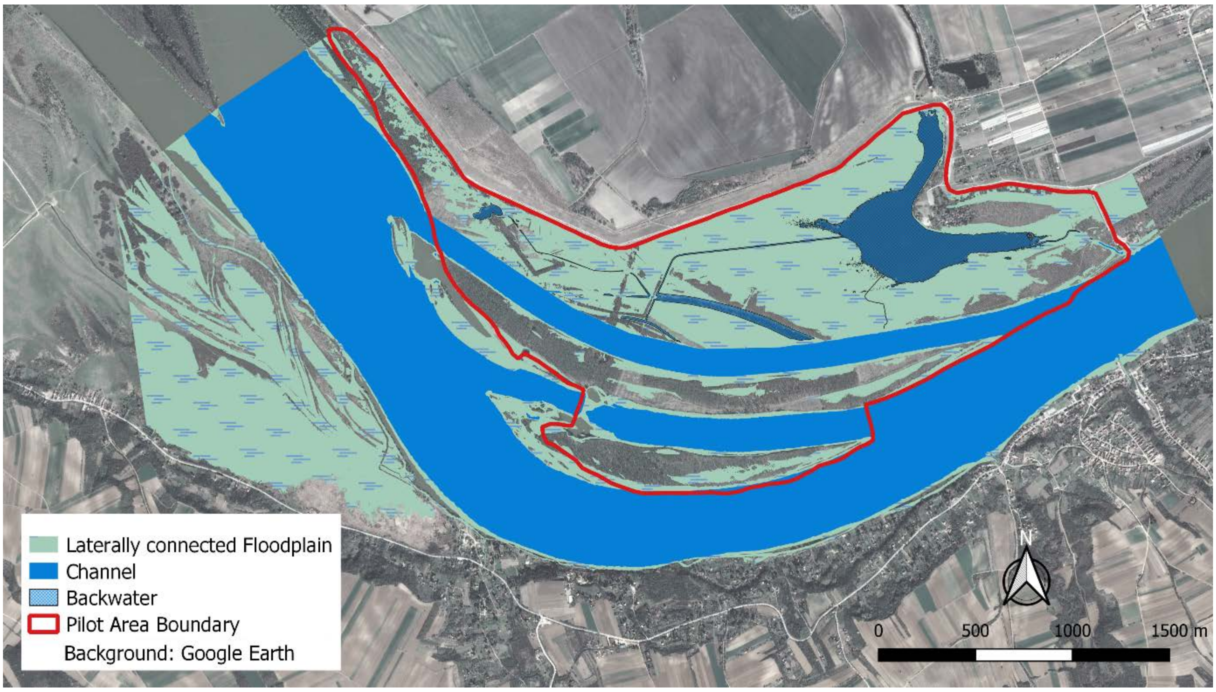


Figure 5: Mesohabitats of the optimistic restoration scenario for Begecka Jama; the area evaluation in the text refers to the red polygon defining the boundary of the pilot area

In an overall evaluation, both restoration will gain typical floodplain habitats in form of backwaters (Fig. 6). While the aim of both scenarios is to increase lateral connectivity between the channel and the floodplain, the specific ecological scope is slightly different for the scenarios. While the realistic scenario will increase and improve backwater habitats, the optimistic scenario mainly increases in-channel habitat. Thus, it depends on the specific ecological targets of restoration which option to prefer.

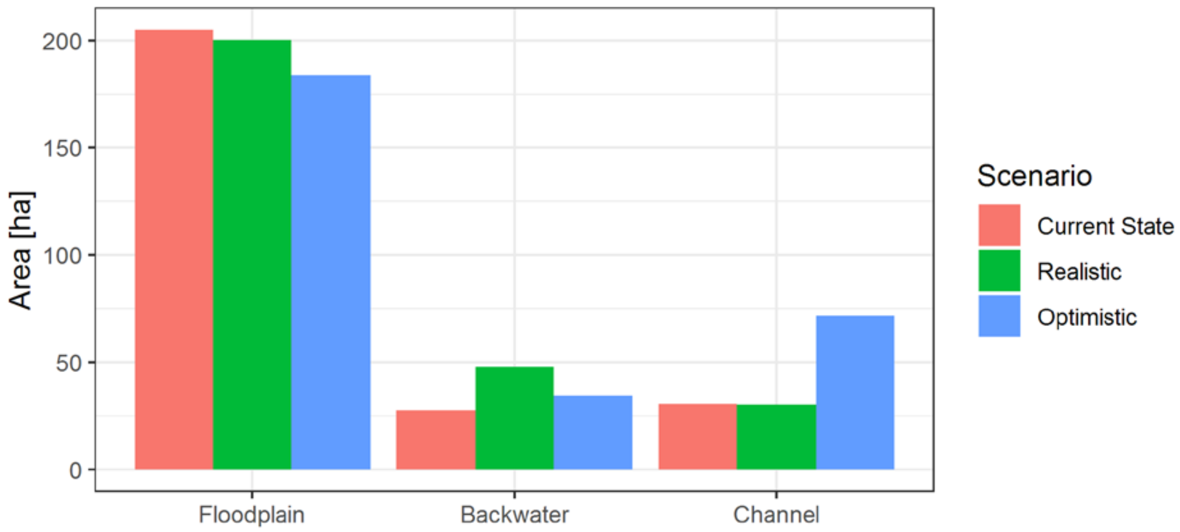


Figure 6: Changes in meso-habitat areas of the Begecka Jama pilot area

4.2 Bistret

In the current state, the majority of the floodplain in Bistret is disconnected from the Danube. Only few areas in the foreland of the dyke at the northern shore and some area on the southern shore are flooded during the HQ2-5 flood event. In addition, there is no backwater habitat on this floodplain. A remarkable feature in the landscape is the Lake Bistret which is supplied by water from the Denatui River. However, the direction connection between Denatui, Lake Bistret and Danube is disturbed by the dykes along the Danube. Thus, in the current state, there are hardly any typical floodplain like backwaters or ponds at all.

In the realistic restoration scenario, the dykes along the Danube remain. Main restoration measure is the creation of a connection channel between the Lake Bistret and the Danube. This measure shall on the one hand add an additional water supply to Lake Bistret, on the other hand, the drainage of the Denatui River shall be enhanced. The creation of this connection channel does not establish extended area of laterally connected floodplain, the majority of the Bistret floodplain remains disconnected. However, some patches along the connection channel will become hydrologically connected. From the prediction, an approximately 680 ha big patch of the Lake Bistret along with the connection channel might be a suitable backwater habitat with high connectivity and low flow velocities.

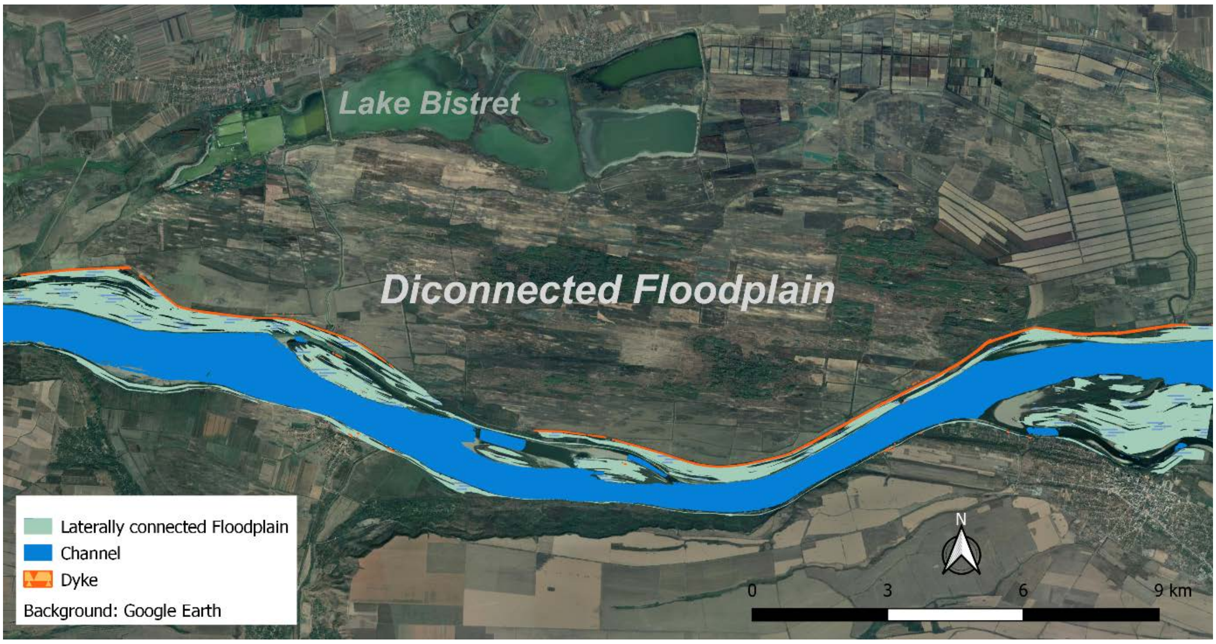


Figure 7: Current state scenario for the Bistret pilot area; the disconnection by the dykes allow hardly any typical floodplain habitats to exist at all.

This would make it a potential habitat for species like *Gymnocephalus spp.* migrating from the main channel to backwaters. However, the stagnant lake character of the Lake Bistret is from an expert point of view not considered as a backwater habitat while the connection channel itself might be.

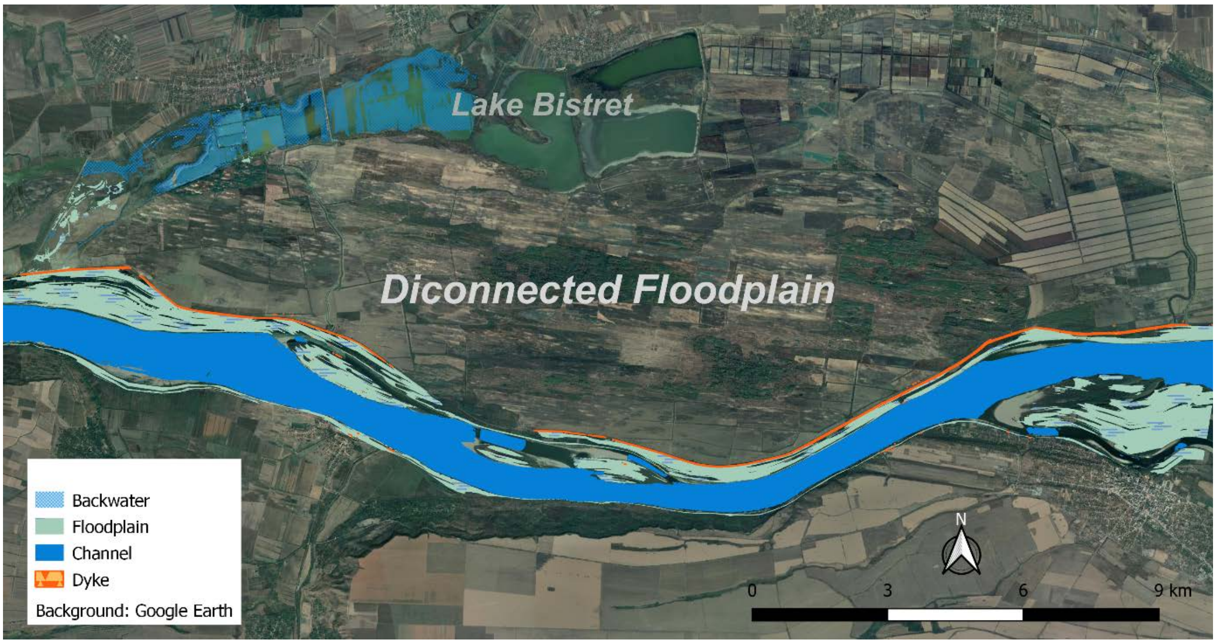


Figure 8: Habitats of the Bistret pilot area for the realistic restoration scenario; the backwaters being predicted by the model are assumed to be artefacts of the model

In the optimistic restoration scenario, the dyke is removed from the northern shore of the Danube. This increases the total laterally connected floodplain area from 1321 to 9520 ha (Fig. 10).

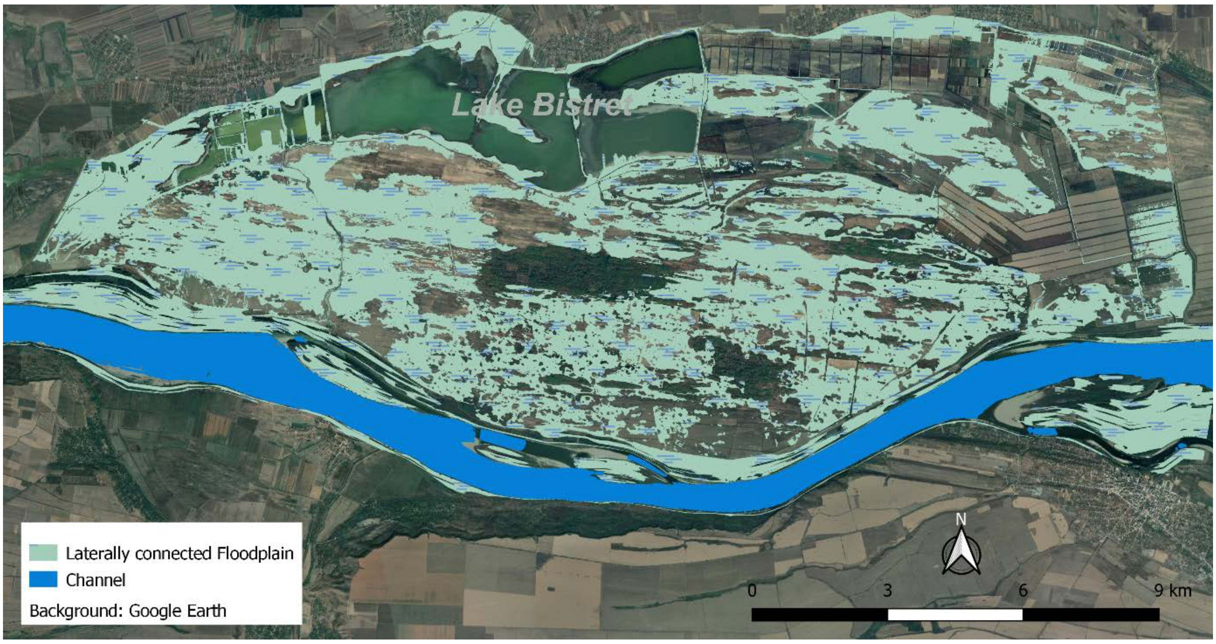


Figure 9: Increase of lateral connectivity in due to dyke removal in the optimistic restoration scenario in the Bistret pilot area

As no flood duration data is available, it is hard to predict what the potential vegetation cover is likely to be. Here, more intensive studies would be necessary having a closer look at the local flow regime.

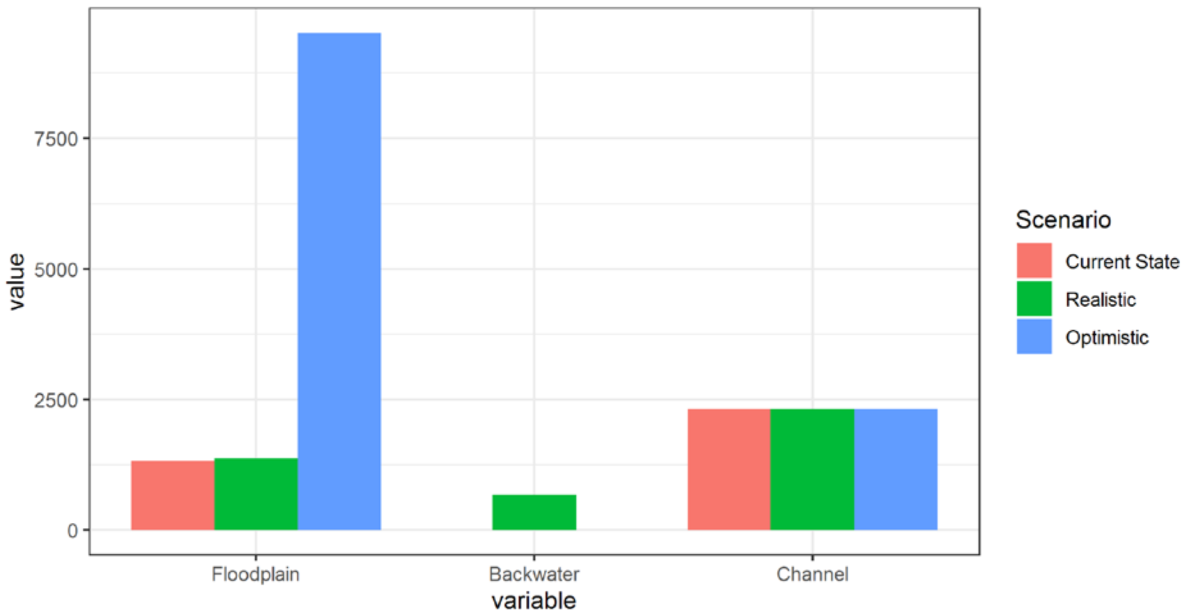


Figure 10: Changes in the area of floodplain meso-habitats in Bistret

4.3 Krka

The floodplains of the Krka River in the pilot area are in general in a good condition from a hydrological connectivity point of view. All in all, approximately 1400 ha are hydrologically connected to the Krka. However, from an ecological perspective, the focus of restoration is the Krakovski gozd, a patch of mixed riparian forest dominated by *Quercus robur.* Even if this

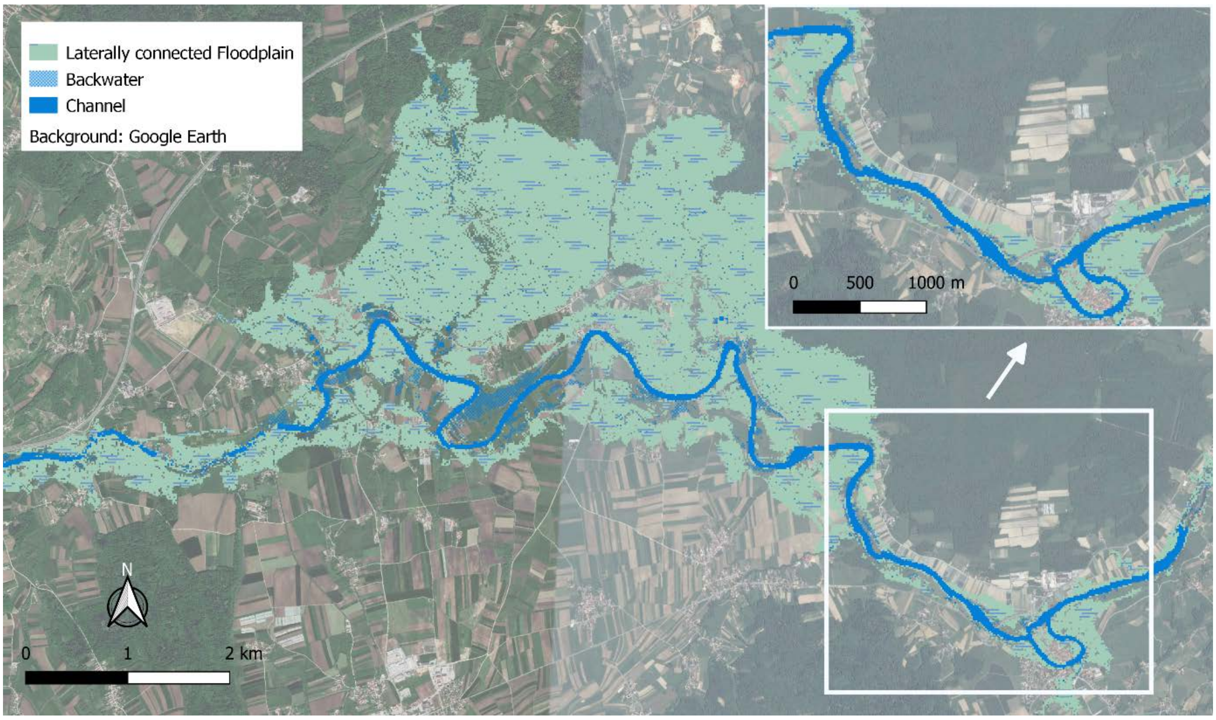


Figure 11: Meso-habitats of the Krka floodplain; the inlet shows the area of Kostanjevica na Krki with the Krakovski gozd, a riparian mixed forest belonging to the Natura 2000 network

forest type belongs to the hardwood riparian forest, it depends on regular flooding with an average annual duration of 5-20 days depending on the local site condition. Thus, this floodplain vegetation type is dependent on the hydrological connectivity to the river channel. The area of the Krakovski gozd is shown in the inlet map in Fig. 11-13. In the current state of the Krka River, the Krakovski gozd is laterally disconnected from the Krka River. This lack of connectivity is a potential threat for this forest. This mixed riparian forest is the dominating habitat type in the focus of this pilot area. Extensive backwaters, neither laterally connected nor disconnected do not exist along the Krka River. A total area of 76 ha is classified as backwater in the current state. Another approximately 110 ha belong to the river channel.

In the realistic restoration scenario, a channel is constructed to bring water from the Krka to the Krakovski gozd (Fig. 12). This is carried out by means of a channel established between the Krka and the forest patch. Within the forest, water is diverted within existing depressions, even though the area has no pronounced floodplain topography with former channels, oxbows or similar. The water diversion leads to an entire area of 183 ha being now connected to the hydrological regime of the Krka via surface water. Data about flood duration is not available for the Krka pilot area.

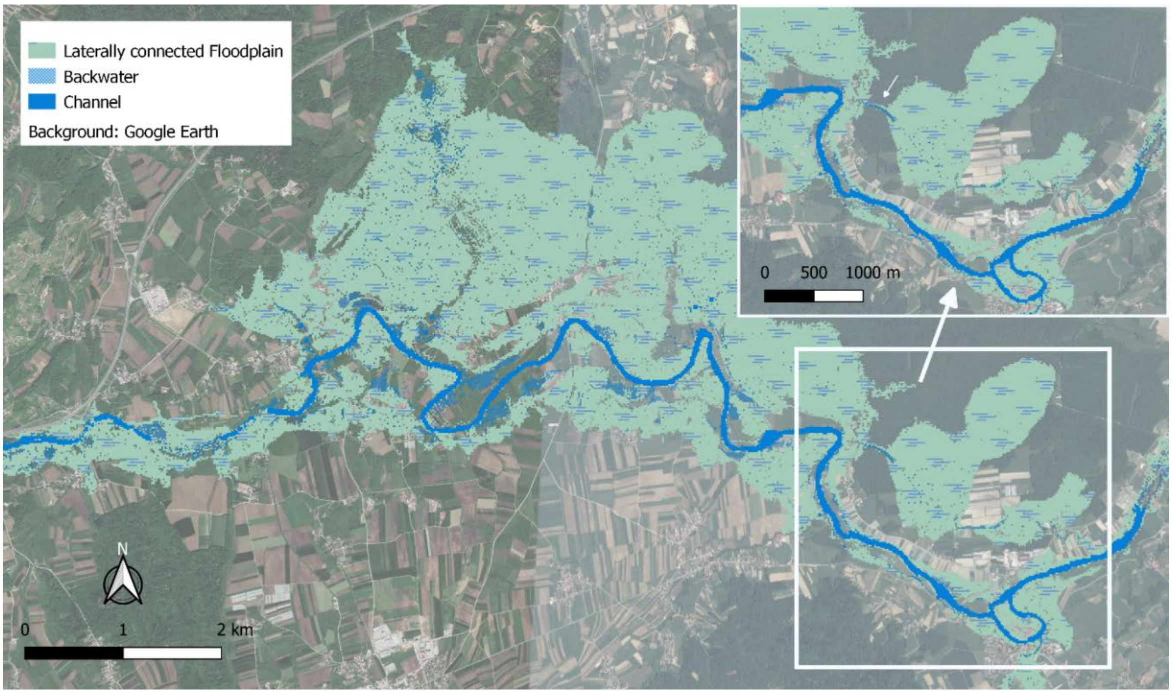


Figure 12: Meso-habitats of the Krka floodplain in the realistic restoration scenario; the inlet shows the area of Kostanjevica na Krki with the Krakovski gozd, a riparian mixed forest belonging to the Natura 2000 network

Thus, 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.*

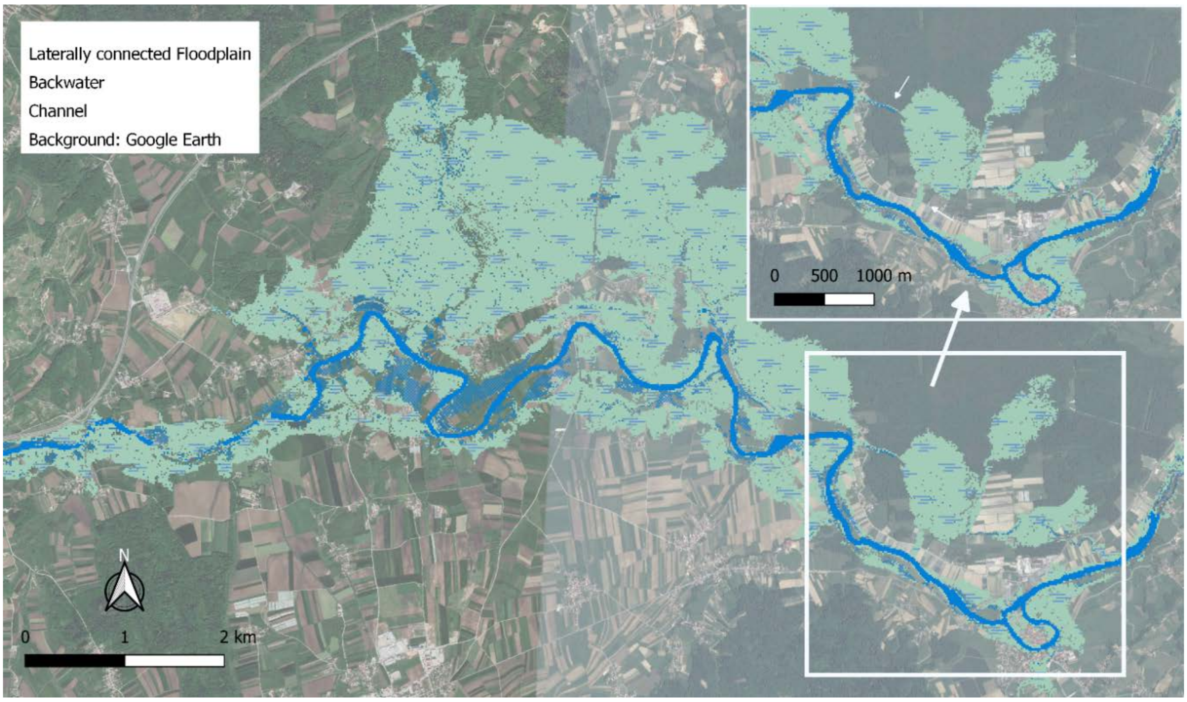


Figure 13: Meso-habitats of the Krka floodplain in the optimistic restoration scenario; the inlet shows the area of Kostanjevica na Krki with the Krakovski gozd, a riparian mixed forest belonging to the Natura 2000 network

Within this area, also backwaters evolve. In the realistic scenario, 102 ha of backwaters can be expected contrary to 76 ha in the current state. Due to the terrain, the backwaters are expected to form mostly as ponds with a low flow velocity making them a habitat suitable for amphibian species like *Bombina variegata*, a species already abundant in the Krakovski gozd.

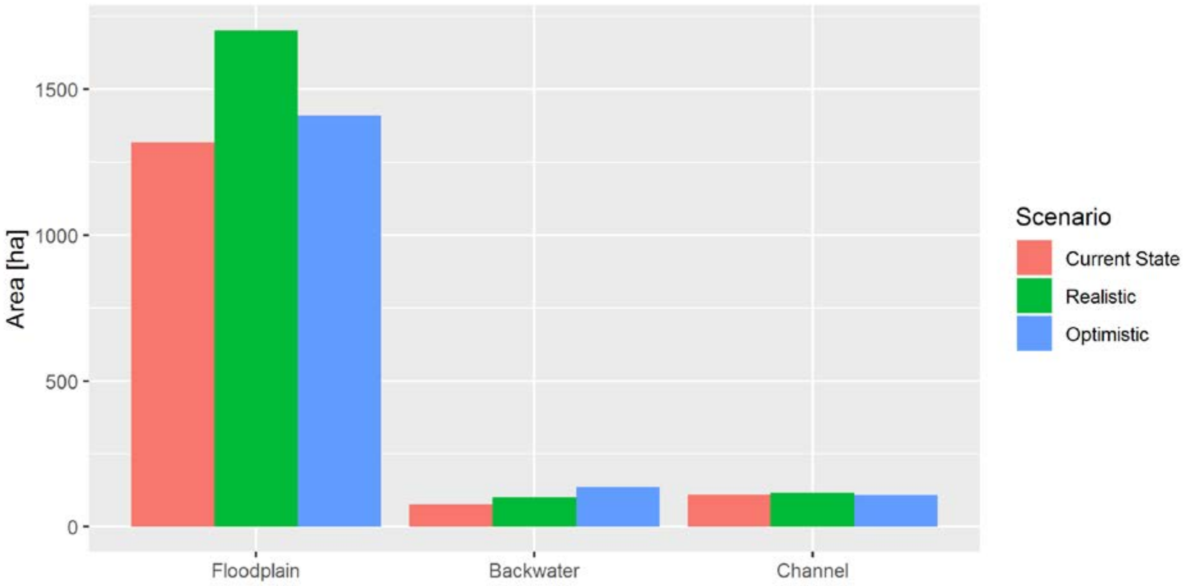


Figure 14: Changes in meso-habitat areas of the Krka pilot area

The optimistic restoration scenario differs not too much from the realistic one. In addition to the connection channel to the Krka in the west of the Krakovski gozd, a second channel will be constructed to establish an additional connection between river and floodplain forest (Fig. 13). However, despite the obvious increase in connectivity, the area of Krakovski gozd actually having a connection to the Krka via overland flow decreases from 183 ha to 127. The reasons are unclear, an assumption might be a faster drainage of the forest at the falling limb of a flood event due to the southern connection channel. On the contrary, backwater habitats benefit from the additional connection. Their area shows a slight increase (see Fig. 15).

4.4 Middle Tisza

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 for this pilot area, the entire area of connected floodplain is 3075 ha. The land cover of this floodplain area is managed, most of it is covered by maintained floodplain forest. A number of backwaters exist in the Tisza in form of oxbows but also in the form of didges which are obviously of anthropogenic origin. The oxbows are potential habitats for fish species migrating from the channel to backwaters like for instance *Gymnocephalus spp.* The “anthropogenic” backwaters are didges in the floodplain filled up by flood water even during more regular flood events as considered for the modeling scenario (HQ2). These backwaters have a low flow velocity and are potential habitats for amphibians like *Bombina bombina* or stagnophilic fish like *Misgurnus fossilis*.

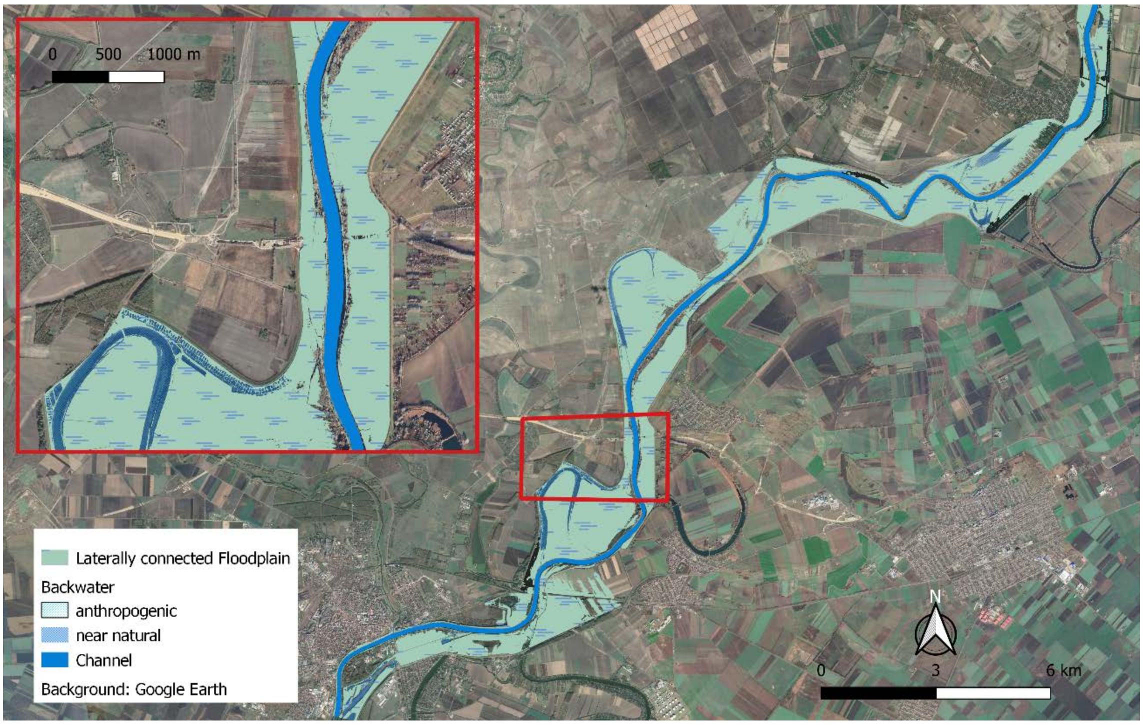


Figure 15: Middle Tisza pilot area in the current state; the inlet of the map shows the location where dyke relocation is planned.

In the realistic restoration scenario, a dyke relocation in the southern part of the pilot area is intended (inlet maps in Figs. 15 and 17). This leads to an increase of the laterally connected floodplain area from 3075 to 3327 ha. Backwater and channel area do no change significantly.

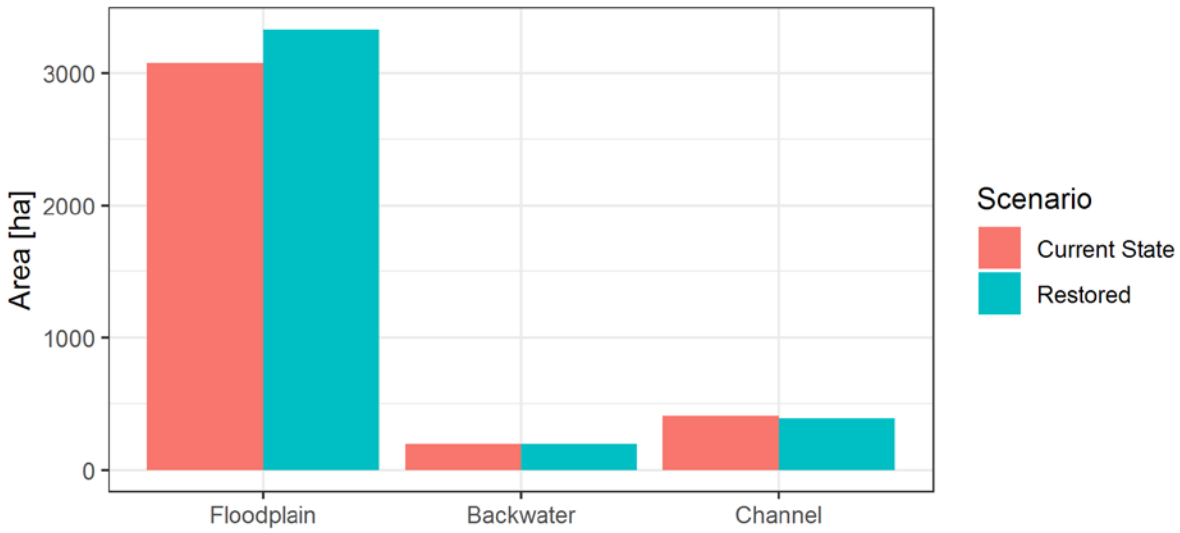


Figure 16: Area of meso-habitats of the Middle Tisza

In terms of lateral connectivity, the optimistic scenario does not differ from the realistic one as the same dyke relocation is intended to be carried out. Thus, the area of connected floodplain, channel etc. do not differ between the two scenarios. In the optimistic scenario, the intention is to modify the land cover of the floodplain by actively planting floodplain forest and establishing spawning areas for fish.

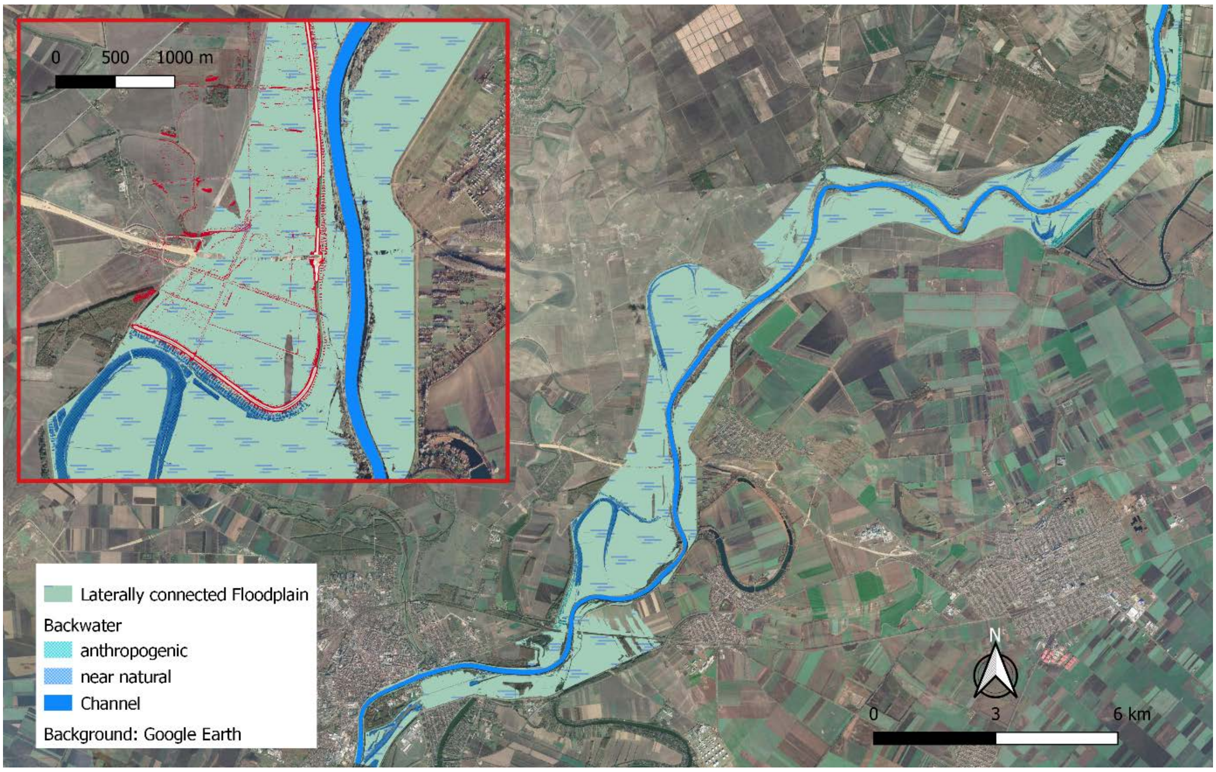


Figure 17: Middle Tisza pilot area in the restoration scenario. The red line in the inlet map is the relocated dyke.

Figure 18 shows the intended landcover change from the current state to the optimistic restoration state. It is intended to develop all in all 39 ha of forest in the pilot area. Out of this, 26 ha are dedicated to "forest with undergrowth" in the planning material. This comes closer to a natural riparian forest also being characterized by multiple vegetation layers. In terms of habitat conditions, the re-connected floodplain patch with a flood duration of approximately 15-20 days should be well suited for the development of hardwood riparian forest like with a mixture of *Quercus* and *Ulmus (Querco-Ulmetum).* In areas with higher flood duration, the habitat is also suitable for softwood riparian species like *Populus or Salix*. However, the vegetation development is intensively managed by afforestation, thus the hydrological conditions will have only a minor effect at least on the short term.

In addition, the plans for the optimistic restoration scenario intend to establish a fish spawning area in of approximately 10 ha. However, so far this spawning area is not reflected in the hydraulic scenario yet. Thus, no specific evaluation is possible at this stage. In general, the explicit establishment of such spawning area is highly valuable as the pilot area has only a limited area of backwaters suitable as spawning habitat and also the channel itself has rather limited options due to the channelization by dykes.

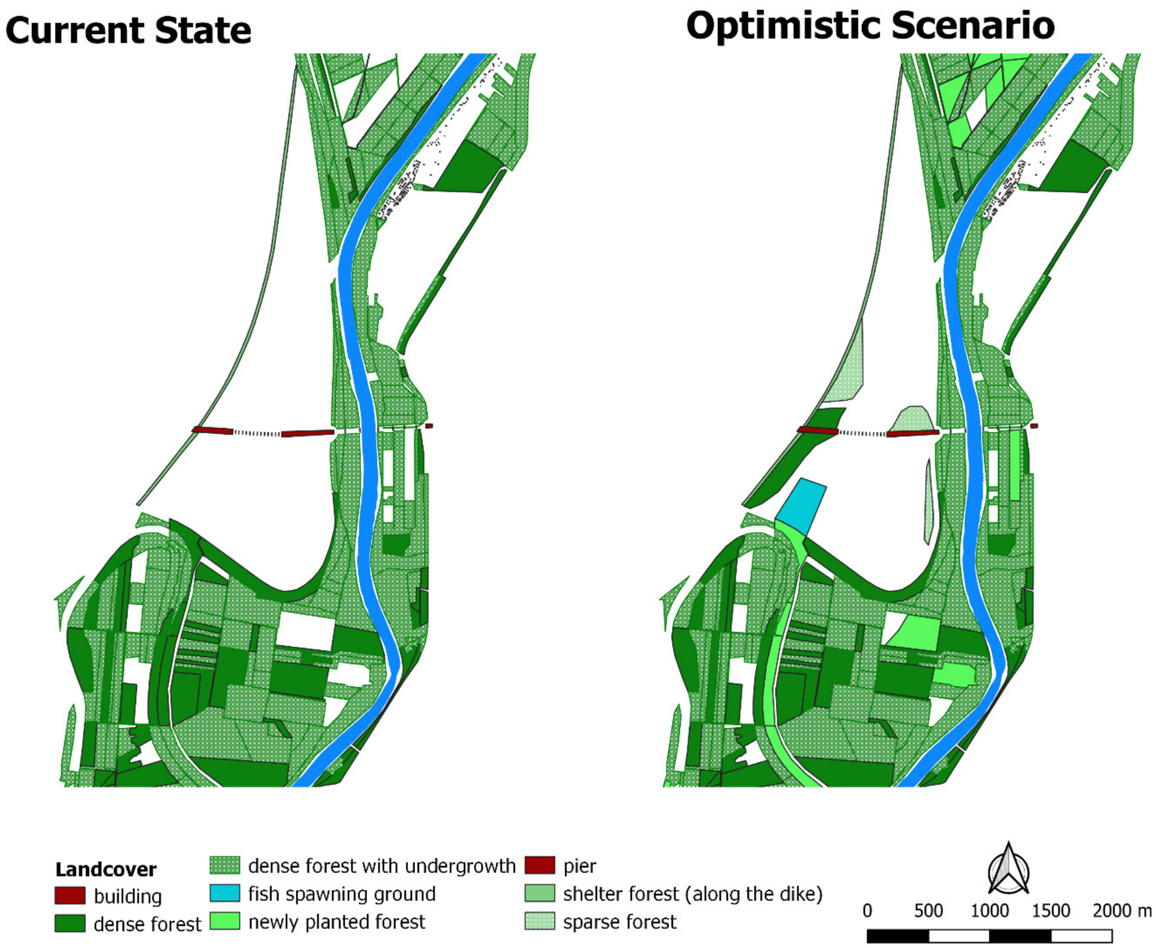


Figure 18: Intended landcover change on the restoration site in the Middle Tisza pilot area

4.5 Morava

The Morava pilot area is located at the confluence of the Thaya and Morava River at the border between Slovakia and Czech Republic. Naturally, the Morava has been an actively meandering river with extensive oxbows and backwaters created by the morphodynamics of this river. This geomorphological origin has created an extremely complex floodplain terrain which is still visible in today’s topography. Figure 19 shows a hillshade of a digital elevation model highlighting the complex terrain. This topography still influences the pattern of floodplain habitats today even if a channelization and the construction of dykes have disconnected the river from the floodplain.

In the current state, the total area hydrologically connected during the HQ2-5 flood event is already more than 4000 ha. It is obvious that the activation of the floodplain is driven by the old channel structures still abundant in the terrain. The majority of this area is covered by mixed riparian forest, the habitat type we can expect from flood duration and water depth.

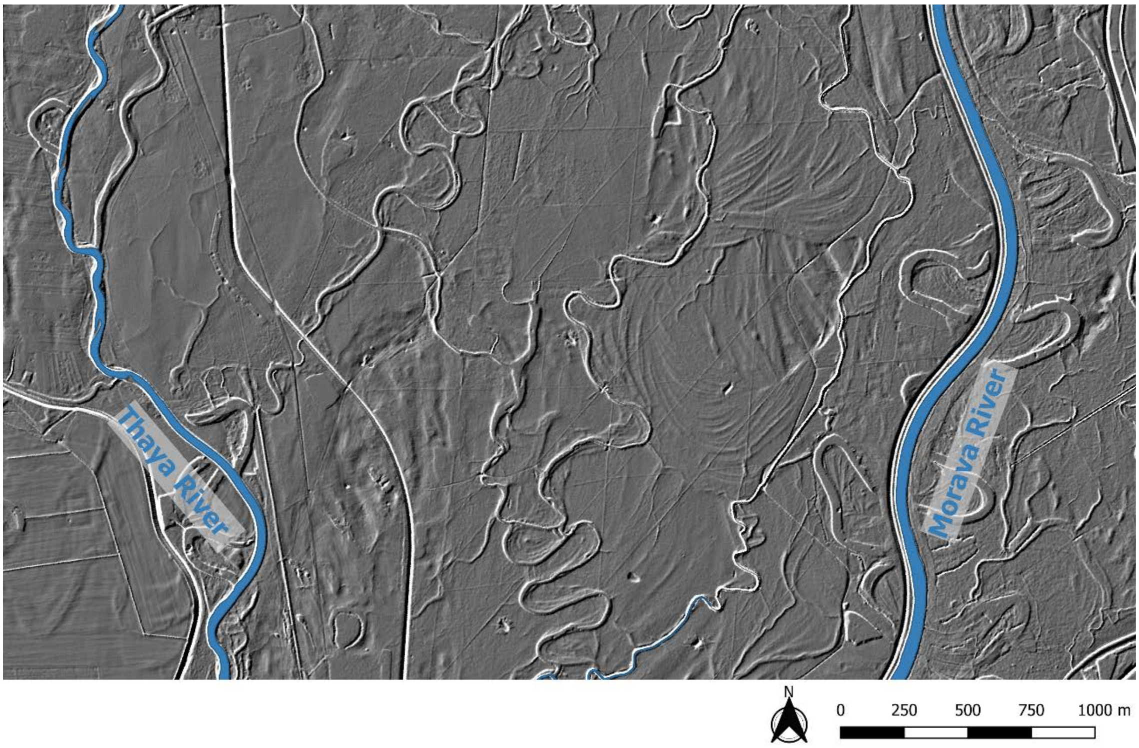


Figure 19: Hillshade of the floodplain topography of the Morava pilot area

Also backwaters exist in the current state. They concentrate in the area at the confluence of the Thaya and Morava River and develop in the depressions of the historic floodplain terrain.

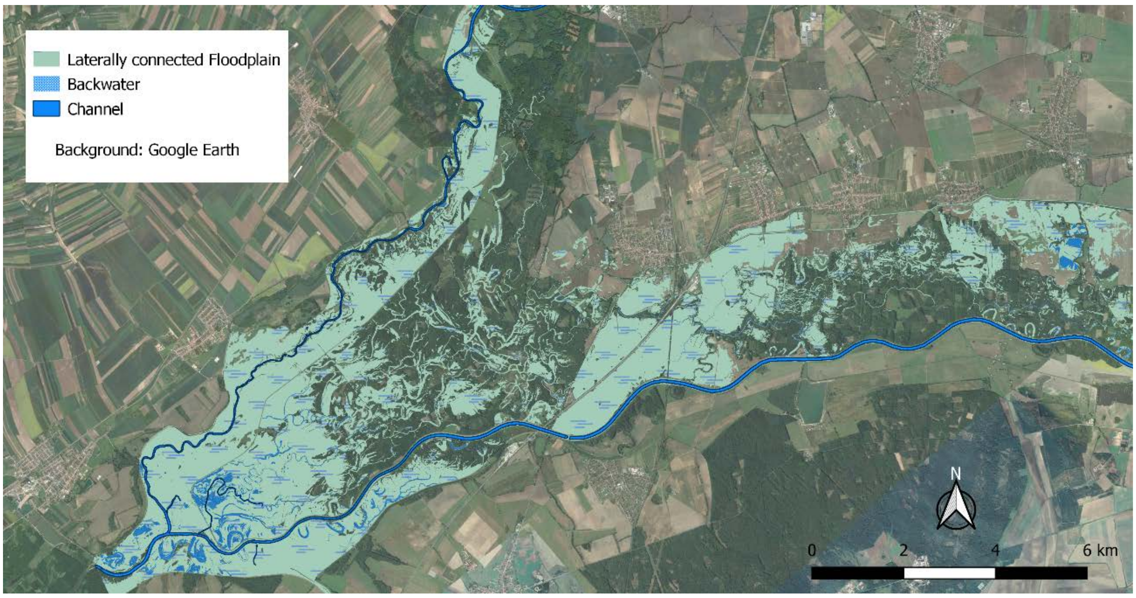


Figure 20: Meso-habitats of the Morava pilot areas in the current state

These backwaters provide habitat for amphibians like *Bombina bombina* and also stagnophilic fish species like *Misgurnus fossilis.* The limitations of connectivity reduces the habitat suitability for fish species migrating between main channel and backwater systems.

In the realistic restoration scenario, dyke relocation is intended to re-connect oxbows and parts of the floodplain to channel. Figure 21 shows an example of the effect of dyke relocation on the formation of backwaters.

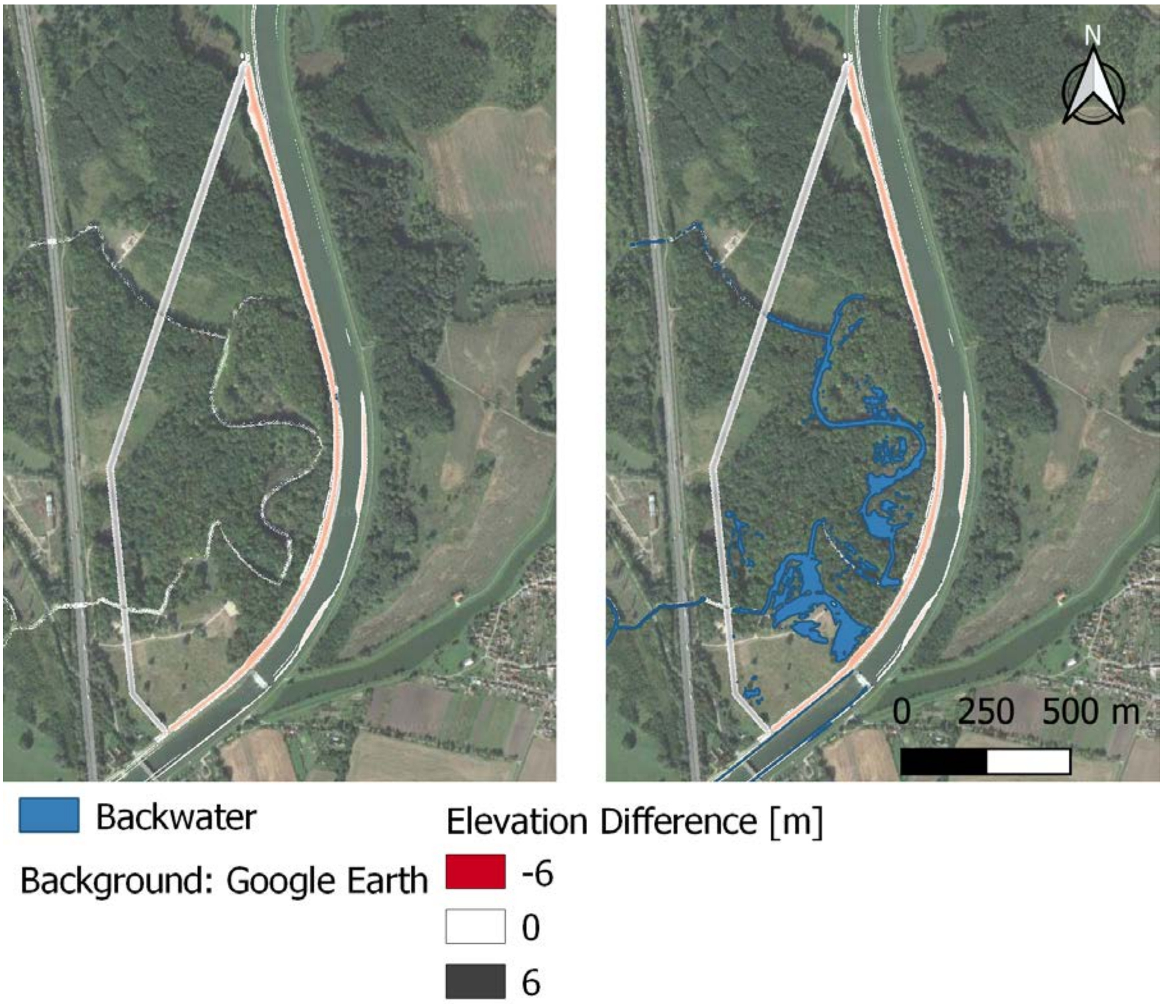


Figure 21: Example of oxbow reconnection by dyke re-location. Left side is the current state, right side the realistic restoration scenario. The elevation difference shows the intended dyke relocation

Such reconnection of oxbows creates valuable habitat for fish species migrating between channel and backwater such as *Gymnocephalus spp.* Within the realistic scenario, all in all 7 dyke relocations are planned increasing the number of connected oxbows and thus backwater area. While most of dyke relocations seem to have the expected effect of oxbow re-connection, there are also oxbows where the connectivity is not fully restored by dyke relocation alone. Here, further measures like a deepening of the oxbow might be necessary. The effect of dyke relocation on the increase of connected floodplain area and on the development of further backwaters like e.g. ponds is still unclear due to the complex terrain. Here, further calibration and validation work is required to give reliable results.

In the optimistic restoration scenario, changes in the channel planform are intended. This is a particularity compared to all other restoration scenarios where the focus has entirely been on the modification of lateral connectivity by means of dyke relocation or establishment of connection didges. It is intended to re-establish meanders in the channelized river especially in the river section close to the confluence with the Thaya River (Fig. 22). The planned meanders increase the area belonging to the channel habitat from 256 ha in the current state to 283 ha in the optimistic state. In addition, the flow velocity during an HQ2.5 flood event is reduced from above 1 m/s to approximately 0.7-1 m/s. This increases the habitat suitability for lowland river fish species like *Gobio albipinnatus* which depend on moderate flow conditions.

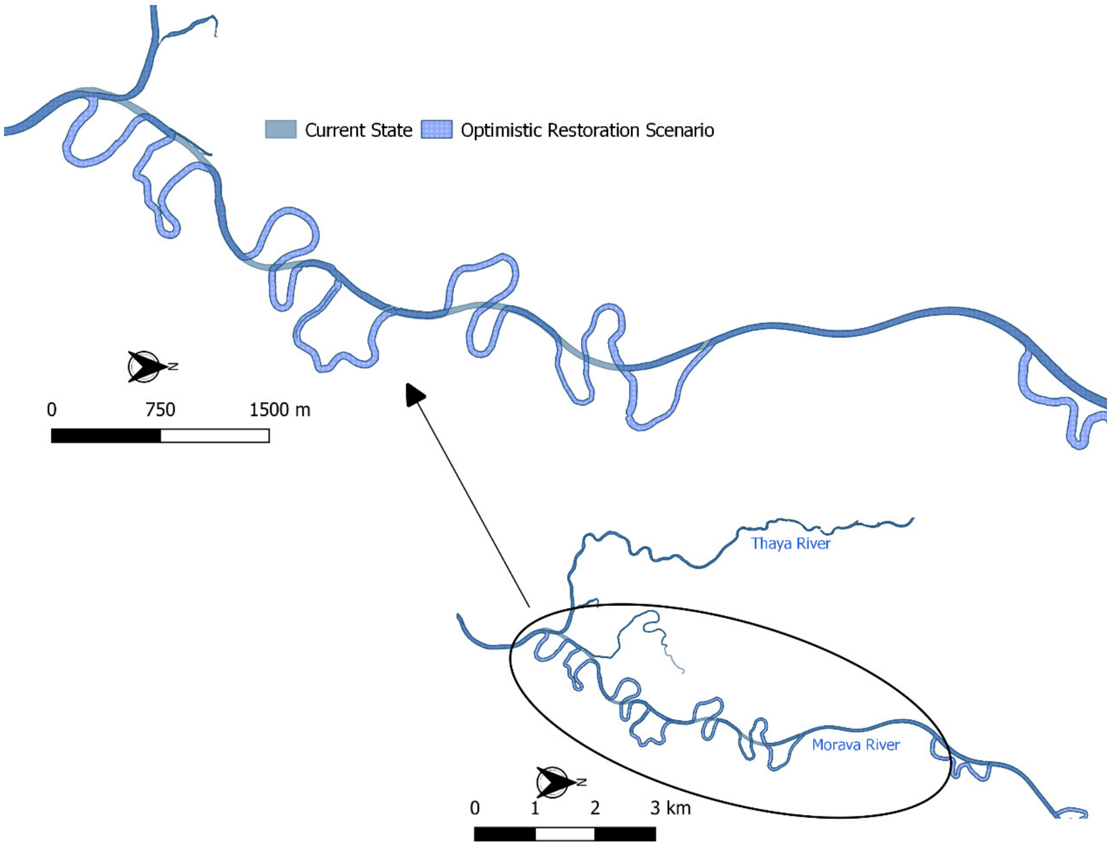


Figure 22: Channel planform modification in the optimistic restoration state by re-introduction of meanders

Due to the changes in flow conditions and the general modification of the river structure also the area of backwater habitats is significantly increased by this restoration measure. These backwaters partly are predicted in the form of connected oxbows but also as stagnant ponds forming in depressions on the floodplain. These pond-like backwaters are highly relevant habitats for amphibians having only a minor benefit from oxbows being re-connected to the channel. In an overall evaluation, the restoration by restoring the original river planform and removing barriers of lateral connectivity allows to re-establish natural dynamics of the river system. These dynamics will form a small-scale mosaic of habitat patches as it becomes already obvious from the meso-scale habitat model. Due to the complexity of the floodplain topography of the Morava area and the complex hydrological reaction of this terrain further, more detailed investigation is recommended for a final evaluation.

5. Conclusion

Biodiversity of floodplain habitats is extremely complex and driven by a variety of factors, biotic as well as abiotic. In the context of the Danube Floodplain application form, biodiversity is understood as the ability of a floodplain to provide typical floodplain habitats for a range of species and species communities. This habitat provision is mainly driven by hydrological dynamics arising from the connectivity between channel and floodplain. Reducing this connectivity is the major threat of floodplain ecosystems in the Danube Basin. Consequently, the majority of restoration scenarios elaborated within the Danube Floodplain project focus on increasing the lateral connectivity. The approaches to achieve this are nevertheless quite different. Most common measure is the relocation of dykes, but also the creation of connection channels or even the modification of channel planform have been suggested. It has become obvious that the focus is in general on aquatic habitats like oxbows or connected backwaters being relevant (spawning) habitats for different fish species. Developing typical habitats for amphibians, also typical floodplain species, has been less in focus. This species group depends on pond-like backwaters ideally only vertically connected to the river. The development of typical floodplain vegetation is fostered by providing the hydrological conditions suitable for establishment and development. Increasing the lateral connectivity of floodplains and thus increasing the hydrological dynamic is likely to improve the situation for riparian vegetation. However, only in the Middle Tisza pilot area, an active management of vegetation is considered.

Generalizing the results from the different pilot areas leads to the statement that floodplain habitats and thus biodiversity in the sense of the application form of the Danube Floodplain project will benefit from increasing the lateral connectivity as intended by the majority of restoration scenarios. However, it needs to be considered that floodplain ecosystems are highly complex and react to a range of factors which cannot be considered here. For instance vertical connectivity via groundwater plays a major role for vegetation development but also for the formation of ponds being habitats for amphibians. While the assessment on the meso-scale shows the general tendency for the development of habitats, the microscale gives insights on the level of species or specific communities. However, this requires in-depth knowledge of the specific setting which cannot be obtained without extensive field work. While this is beyond the scope (and the possibilities) of the Danube Floodplain project, such analysis can give more detailed insights in the ecological consequences of restoration measures on the species level and allows a prioritization of measures for specific target species.

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