WP4 Methods

Deliverable D 4.3.4

Summary of used complex methodology and process description on hydraulic 1D and 2D, CBA, ESS, ecological assessment and stakeholder analysis as input of D 4.4.2 and therefore of output 5.1.

WP	**WP4: Flood prevention pilots**
Activity	Activity 4.3
Deliverable	D 4.3.4 Summary of used complex methodology and process description on hydraulic 1D and 2D, CBA, ESS, ecological assessment and stakeholder analysis as input of D 4.4.2 and therefore of output 5.1.
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Involved partners	All partners from countries with pre-selected pilot areas, CUEI, WWF HU, TUM
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1. Summary

Deliverable D 4.3.4 summarizes the various complex methodologies used within Work Package 4 (WP4) of the Danube Floodplain Project to evaluate floodplain restoration measures. This included the following tasks:

- One-dimensional hydraulic models' chain along the Danube and its tributaries
- Two-Dimensional Hydrodynamic Modeling in five pilot areas
- Stakeholder engagement
- Habitat modeling in five pilot areas
- Ecosystem services mapping and assessment in five pilot areas
- Cost-benefit analysis of restoration measures in five pilot areas

The one-dimensional (1D) modeling investigations at the Danube and three tributaries (Morava, Tisza, and Sava) were conducted in Deliverable D 4.1.2 to investigate the trans-regional effect of flood mitigation due to floodplain restoration. For this, a model chain approach was applied, where project partners (PPs) simulated in a river section the current state (CS), i.e. including all active floodplains, and the restoration scenario (RS), i.e. activating the potential floodplains (PFP) delineated in Activity 3.1. This was implemented for different hydrological scenarios or actual flood events. The results of the simulated flood peak reduction (ΔQ) and the translation of the flood wave (temporal displacement of the peak, Δt) were analyzed quantitatively and compared for each hydrological event for both scenarios.

In all other deliverables of WP4, we investigated three restoration scenarios in five pilot areas (Begecka Jama, Bistret, Krka, Middle Tisza, and Morava). The scenarios are a current state scenario (CS) and two different restoration scenarios (RS1 – realistic and RS2 – optimistic). The restoration measures included e.g. dike relocation to reactivate floodplains, land use change and topographical variations in the river bed, and floodplain expansion (e.g. by reactivating old oxbows).

In Deliverable D 4.1.1, we assessed the response of floodplain restoration measures to different flood events. Local and national partners applied two-dimensional (2D) hydrodynamic models to investigate the hydraulic efficiency of restoration measures for all restoration scenarios for three hydrological events (HQ2-5, HQ10-30, and HQ100) in each pilot area. For the results' assessment, we used spatial results of the maximum water depth and flow velocity of each scenario. Furthermore, we analyzed the results of the simulated streamflow time series at the downstream model border, in particular looking at the reduction of the flood peak discharge and the translation of the flood wave (time shift of maximum discharge).

In Deliverable 4.2.3, a meso-scale habitat modeling was conducted, whose general aim was to evaluate whether the floodplain restoration scenarios are capable of improving typical floodplain habitats. Such prediction was made based on environmental co-variables, derived from the previously modeled hydraulic parameters (e.g., water depth, flow velocity, etc.). A semi-automated approach was chosen for deriving potential habitat types. Then, a set of (fuzzy) rules was used to describe the different habitats.

The restoration measures affect a wide range of stakeholders. Therefore, in Activity 4.2, a stakeholder workshop was held in each pilot area to map the kind and intensity of the use of ecosystem services

(ESS). During the workshops, stakeholders discussed the project, the planned measures in the pilot areas, and the expected outputs of the project. As a result of the stakeholder meetings, the most relevant ESS were recognized by the stakeholders in the pilot areas (results in Deliverable D 4.2.1). A further method for mapping the provisioning and regulating ESS of pilot areas was estimating the capacities to provide ESS by using land use /land cover data in MAES typology and CORINE. By jointly classifying all provisioning and regulating ESS, areas with a particularly high/low provision of ESS (so-called hotspots/cold spots) could be identified (results in Deliverable D 4.2.2).

In Deliverables D 4.3.1 and 4.3.2, results and methods of the extended cost-benefit analysis (CBA) are presented. To extend this decisional method, our work used ESS maps from the previous deliverables and focused on six ESS, i.e. flood mitigation, carbon storage, greenhouse gases sequestration, cultivated goods provisioning, nutrients retention, and nature-based recreation. For this, we applied the methodologies suggested in the Toolkit for Ecosystem Service Site-Based Assessment (TESSA) complemented with alternative approaches (e.g., questionnaires on social media). The methodology allowed a profitability analysis of the restoration measures.

2. Introduction

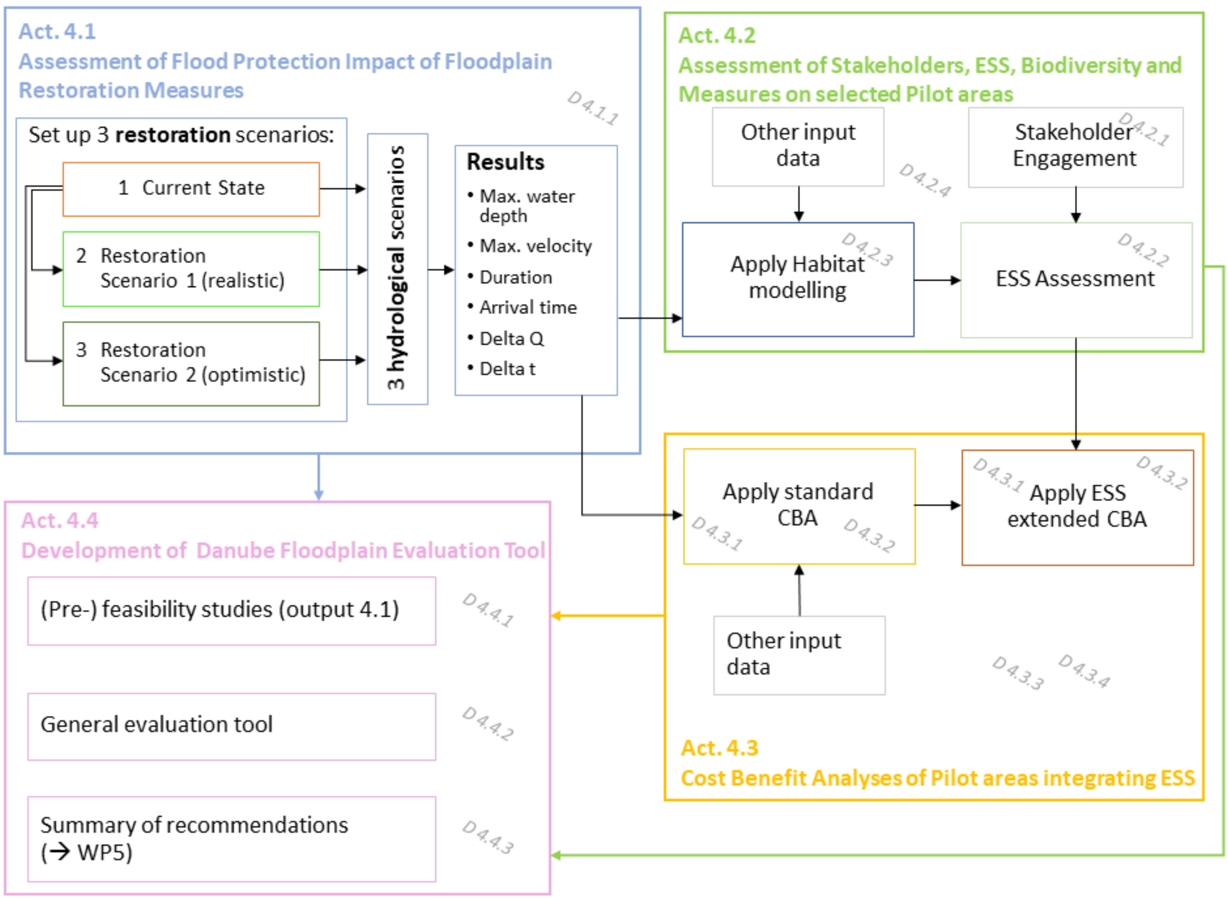

Figure 1. Flow chart of the tasks in WP4 in the pilot areas including activities and deliverables

Figure 1 shows the framework, in which this deliverable is included, namely work package 4 (WP4) of the Danube Floodplain Project. In deliverable D 4.1.1 (flood prevention measures tested in pilot areas) (Danube Floodplain, 2020a), the effect of floodplain restoration measures in different flood events was assessed. The national partners applied hydrodynamic two-dimensional models in five pre-selected pilot areas to investigate the hydraulic efficiency of restoration measures. Spatial results of the applied hydrodynamic models in raster format of the maximum water depth and flow velocity of each scenario are available for each pilot area showing different effects depending on the restoration measures and maximum discharge of the simulated flood event. These results are an important input for the ecosystem services and the flood risk assessments. The planned measures in the pre-selected pilot areas affect a wide range of stakeholders including landowners and residents. Therefore, stakeholders were informed from the beginning about the intentions of the project and were partly involved in the development of the measures. This process, which included stakeholder workshops in the pilot areas, is described in deliverable D 4.2.1 (Danube Floodplain, 2019c), where the fundamental knowledge of the stakeholders is recorded and was later used to evaluate the ecological, economic, and cultural values of the pilot areas with the aid of the ecosystem services approach. The ecosystem services were mapped for deliverable D 4.2.2 (Danube Floodplain, 2020c), which provided information about nature's regulatory services like nutrient retention, the supply of natural products like water, and also about the cultural uses within an area, including the stakeholders' point of view. Both reports about the stakeholder analysis, their interests and benefits from the floodplains (Danube Floodplain, 2019c), and the report about the ecosystem services mapping (Danube Floodplain, 2020c) created the basis for further analysis of ecosystem services and provided useful input data for a more specific and monetary-based assessment of the floodplain restoration measures in Activity 4.3. This lead to deliverable D 4.3.1 (Danube Floodplain, 2021a), which includes the results in an extended cost-benefit analysis (CBA), estimated following the methodology described in D 4.3.2 (Danube Floodplain, 2021b). An additional deliverable of Activity 4.3 is the current one (D 4.3.4), which aims at summarizing the whole methodology of WP4.

3. Methodology of the One-Dimensional Models' Chain

Adapted from Danube Floodplain (2020b)

As one of the most transboundary rivers in the world, the Danube river crosses ten different countries and its drainage area comprises 19 countries (Sommerwerk et al., 2010). Therefore, it is crucial to assess any changes along the river not only on a national level but considering all potentially affected countries to prevent adverse upstream and downstream consequences (Timmerman et al., 2011). Within the Danube Floodplain Project, a continuous one-dimensional (1D) hydrodynamic model chain was created from Neu-Ulm (Germany) to Calarasi (Romania) to assess the transboundary effect of restoration measures on the peak discharge and the wave translation during a flood event in the Danube River Basin (DRB). The continuous model along the Danube not only allows assessing local effects but also enables assessing transnational and potential superposition of effects. For the implementation of the model chain, each country along the Danube River created an individual 1D hydrodynamic model, respectively. To connect the individual models, the output of the previous upstream model was used as an input for the downstream model. Different hydrological scenarios were simulated in two scenarios for each model: first, representing a current state scenario, i.e. with all currently active floodplains; second, including potential additional floodplains (Table 1) identified in Activity 3.1 (Danube Floodplain, 2019a). Additionally, the effects of restoring floodplains along the tributaries Morava, Tisza, and Sava were evaluated (Table 2).

3.1 Active and Potential Floodplains

In Activity 3.1 of the Danube Floodplain project (Danube Floodplain, 2019a), the project partners, responsible for different DRB countries, determined existing floodplains (active floodplains, AFPs) in their national reaches along the Danube and tributaries. They also recognized – together with other national authorities – potentially restorable areas along the rivers, which were then delineated and defined as potential floodplains (PFPs) (Table 1, Table 2, and Figure 2). In the transboundary Danube stretches, the partners of the interested countries delineated neighboring PFPs together.

Restoration scenarios of potential floodplains were mainly generated (in the models) by dike relocations. This resulted, in some cases, in the reactivation of historical floodplains. Moreover, although some PFPs are currently controlled polders, in the project's framework they were assumed to be uncontrolled polders, i.e. they are modeled so that they are flooded when the river exceeds the riverbank. Furthermore, land use change was implemented in the potential floodplain areas (e.g. from crops to pasture or riparian forest), which required changes of the roughness coefficients of the area in the models. Finally, some PFPs are extensions of existing active floodplains. Figure 2 shows the location of the potential floodplains determined within the project and included in the investigated restoration scenario.

*Table 1. Delineated potential floodplains along the Danube and gauges, where the 1D model results are handed over to the next downstream partner (highlighted with an asterisk *)*

Country	DFGIS_ID	Location	River km	PFP size [ha]
DANUBE				
DE	Neu-Ulm Bad Held*		2587	-
	DE_DU_PFP01	Oberelchingen - Lech	2491	16698
	DE_DU_PFP02	Lech - Neuburg	2478	3736
	DE_DU_PFP03	Grossmehring	2451	493
	DE_DU_PFP04	Katzau	2437	309
	DE_DU_PFP05	Geisling / Gmuend	2337	2503
	Englhartszell*		2201	-
AT	AT_DU_PFP01	Tullnerfeld	1938	16066
	AT_DU_PFP02	Nationalpark Donau-Auen	1880	12139
	Thebnerstrassl*		1879	-
SK	Cunovo*		1851	-
HU	HU_SK_DU_PFP01	Szigetköz	1797	15711
	HU_DU_PFP06	Paks	1521	2214
	HU_DU_PFP07	Veránka-sziget	1463	16172
	HR_HU_DU_PFP01	Béda-Karapnacsa	1426	5471
	Bezdan*		1426	-
RS	RS_DU_PFP01	Siga - Kazuk	1409	6059
	RS_DU_PFP02	Vajska	1362	5988
	RS_DU_PFP03	Kamariste	1324	10072
	Drencova*		1016	-
RO/ BG	DU_PFP_BG01	Slivata	753	2024
	DU_PFP_RO01-BG02	Bistret-Dolni Tibar	698	18477
	DU_PFP_RO02-BG03	Dabuleni-Potelu-Corabia-Zagrajden	634	14306
	DE_PFP_BG04	Belene	576	5448
	RO_DU_PFP03	Suhaia-Zimnicea	554	6478
	DE_PFP_BG05	Vardim	537	1839
	Calarasi*		375	-

A standardized evaluation of the individual floodplains was performed with the floodplain evaluation matrix (FEM) approach (Activity 3.2) (Danube Floodplain, 2019b) by using several hydrological, hydraulic, ecological, and socio-economic parameters.

In the 1D model chain of Activity 4.1, the same predefined floodplains were investigated, however not separately, but in a continuous simulation along the whole river for one flood event. This means that we did not evaluate an HQ_{100} peak runoff upstream of each floodplain (like in the FEM evaluation), but we used a long-distance approach, with continuous varying flood magnitudes along the rivers. The corresponding information about the floodplains is specified in Table 1.

*Table 2. Delineated potential floodplains along the tributaries Morava, Tisza, and Sava. The gauges where the 1D model results are handed over upstream of the confluence with the Danube River are highlighted with an asterisk *.*

Country	DFGIS_ID	Location	River km	PFP size [ha]
MORAVA				
SK	SK_M_PFP01	Hodonín	96	745
	SK_M_PFP02	Tvrdonice	90	412
	SK_M_PFP03	Kostice	85	271
	SK_M_PFP04	Brodské	80	290
	SK_M_PFP05	Kuty	72	1484
	Devínska Nová Ves*		8	-
TISZA				
HU	HU_T_PFP01	Tisza-Túr köz	724	2089
	HU_T_PFP02	Inerhát	492	3945
	HU_T_PFP03	Dél-Borsod	445	3107
	HU_T_PFP04	Hanyi-Jászság	388	3618
	HU_T_PFP05	Közép-Tisza	337	3997
	HU_T_PFP06	Szolnok-Tiszaug	270	9140
	HU_T_PFP07	Tiszaug-Csongrád	255	5759
	Tiszasziget*		167	-
RS	Titel*		9	-
SAVA				
RS	RS_S_PFP01	Bosutske šume	8521	187
	Beograd*		1	-

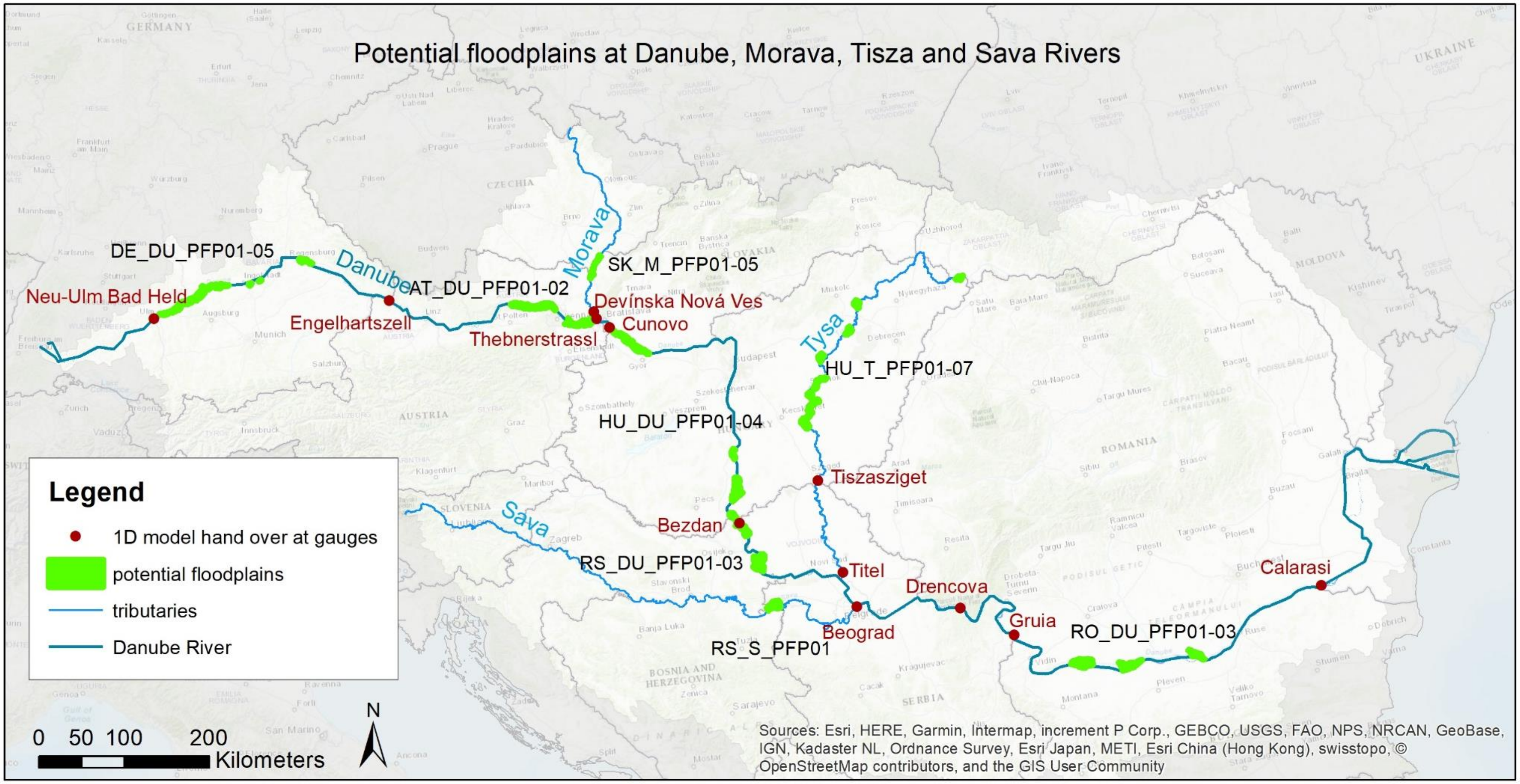

Figure 2. Location of the potential floodplains of Danube, Morava, Tisza (Tysa), and Sava Rivers in the Danube basin

3.2 Development of the 1D Hydrodynamic Model Chain

All countries developed two 1D hydrodynamic models for their respective parts of the Danube River. The current state (CS) model includes all active floodplains and was calibrated with data from local authorities. The second model represents a restoration state (RS) and was developed based on the calibrated CS model. In the RS model, the determined additional potential floodplains were included. Table 3 shows the details of the models created by the project partners. For the Austrian stretch, an already existing 2D model was applied. It also has to be mentioned that the section between the Iron Gate I and Iron Gate II was not considered within this project. The hydraulic conditions differ significantly before and after the structures and thus do not require a connection of the Serbian Danube section and the Romanian Danube section. To create one continuous model, the output hydrograph of the upstream model was used as input for the next downstream model.

Similarly, a CS model and an RS model were created for the investigated tributaries (Table 4). The Tisza tributary model was implemented by two countries (Hungary and Serbia). As no potential floodplains were determined in Serbia, the results from the Hungarian partner were transferred downstream in one model, i.e. CS and RS models match.

Table 3. Applied 1D hydrodynamic model, corresponding responsible project partners (PP), and extents of the models

River	Country	Responsible PP	1D section	from	to	1D/2D model
Danube	DE	TUM / BAFG	D_01_DE	Neu-Ulm	Engelhartszell	SOBEK 1D
	AT	BOKU	D_02_AT	Engelhartszell	Thebnerstrassl	Hydro_AS-2D
	SK	VUVH	D_03_SK	Thebnerstrassl	Cunovo	1D HEC RAS
	HU	EDUVIZIG	D_04_HU	Cunovo	Bezdan	1D HEC RAS
	RS	JCI	D_05_RS	Bezdan	Drencova	1D HEC RAS
	RO	JCI / NARW	D_06_RO	Drencova	Gruia	Iron Gates section: was not modeled
	RO	NARW	D_07_RO	Gruia	Calarasi	1D HEC RAS

Table 4. Applied 1D hydrodynamic model, corresponding responsible project partners (PP), and extents of the 1D model delineation at the tributaries Morava, Tisza, and Sava

River	Country	Responsible PP	1D section	from	to	1D model
Morava	CZ/SK	MRBA/VUVH	M_01	Hodonin	Devínska Nová Ves	1D HEC RAS
Tisza	HU	KOTIVIZIG	T_01_HU	Tiszabecs	Tiszasziget	1D HEC RAS
	RS	JCI	T_02_RS	Tiszasziget	Titel	1D HEC RAS
Sava	HR/RS	JCI	S_01	HR border	Beograd	1D HEC RAS

To assess the effects of additional floodplains on the peak reduction (ΔQ[1]) and the temporal displacement (Δt[2]) of the flood wave, several simulations were compared. Along the Danube model chain, nine simulations were compared (three hydrological scenarios applied to the CS and the RS models). For each of the three tributaries, six simulations were performed (three different hydrological scenarios applied to the CS and the RS model).

Figure 3 shows an example of the modeling section analyses. In the CS model, existing active floodplains were included in the 1D model, while in the RS 1D model, the potential floodplains were additionally implemented. At the downstream border of the modeled section, the output hydrographs of the CS and RS were compared for each flood event. The difference in maximum runoff (ΔQ) and the difference in time (Δt) between the two hydrographs downstream of each potential floodplain were analyzed. Additionally, model output hydrographs of the current and the restored state at the downstream model border were compared.

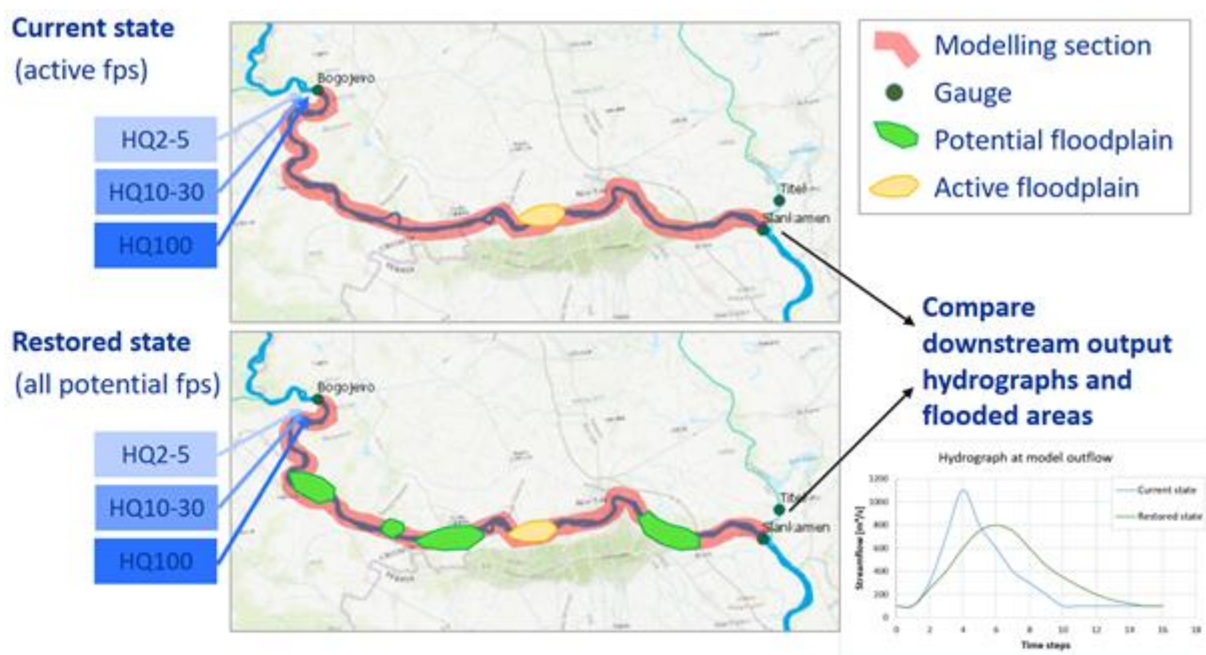

Figure 3. Example of the current state and restored state 1D models in the sections with input and output analysis

[1] ΔQ: difference of the maximum runoff (Q_{max}) values between the modeled restoration scenario and current state scenario, either in m^3/s or in % change, compared to the current state.
[2] Δt: difference of the peak time between of the restoration scenario and the current state scenario in hours.

3.3 Application of Different Hydrological Scenarios to the CS and RS Model

3.3.1 Tributaries Morava, Sava and Tisza

For tributary models (Morava, Sava, and Tisza), gauging data for different flood magnitudes (HQ_{2-5}, HQ_{10-30} and ca. HQ_{100}) were chosen by the national partners. The three HQs represent three different flood magnitudes (and corresponding return periods) and thus three different hydrological scenarios: a low, medium, and high flood event, respectively. The input for these hydrological scenarios was derived from past real events at the tributaries. In some cases, the observed flood waves are up- or down-scaled to generate the appropriate return period. The necessary input data for the model start and all lateral tributaries were obtained from national hydrological authorities.

All different flood events were simulated with existing 1D models in the three tributaries Morava, Tisza, and Sava, and for the CS and RS model. The Morava and the Sava models were run by a single partner from the start to the confluence with the Danube. At the Tisza, the Hungarian section was simulated by the KOTIVIZIG partners, while the lower reach on Serbian territory was investigated by JCI. However, there are no potential floodplains on the Serbian stretch, so the two generated hydrographs (CS and RS) were forwarded downstream in one Serbian CS model to the confluence with the Danube.

3.3.2 Simulations of Past Real Flood Events at the Danube River

The goal of the activity was to analyze a trans-regional effect of floodplain restoration at the Danube River and to investigate the propagation of possible floodplain restoration effects downstream. Therefore, it was decided to commonly examine the three past flood events of 2006 (Figure 4), 2010 (Figure 5), and 2013 (Figure 6) with data of the respective gauges in the DRB (Table 5). For the gauge Mohács (HU), the nearby station Bezdan (RS) is visualized due to data availability. The three selected events have different magnitudes (HQ of flood peaks) in each Danube section, ranging from HQ_2 to larger than HQ_{100} events. The timeframe of the events was set so that the flood wave could reach Calarasi and then the peak could also decline, as follows:

- 2006: from 08.03.2006 to 04.06.2006;
- 2010: from 13.05.2010 to 04.08.2010;
- 2013: from 13.05.2013 to 20.07.2013.

To achieve a continuous model chain, the most upstream partner, Germany, obtained measured hydrographs of the Danube from the upstream model border gauging station, Neu-Ulm Bad Held, for the identified, required time-series length. With the provided time series, the simulations were run and transferred step by step to each downstream partner. The national partners provided time series of measured tributary streamflow data as lateral input for their national reaches when necessary.

As shown in the example of Figure 2, two model variations were simulated (CS and RS). The resulting discharge time series of the current state (active floodplains) and the restored state (potential floodplains) were then compared. The most upstream partner (Germany) handed over both model results (current and restoration state) time series for each event to the next partner (Austria) who used it as input.

The tributaries' inflow runoff for each modeling stretch was derived from observed data at their respective gauges. After simulating the three events for both scenarios, the results were handed over to the next downstream partner in the chain. The results were analyzed as described in Section 3.2.

Table 5. Hydrological data availability of the three Danube flood events 2006, 2010, and 2013 from national partners

	Gauge	River km	Peak time	Peak [m³/s]	~HQ peak	No. of upstream gauges	Temporal resolution
2006							
DE	Passau-Ilzstadt	2225	29.03.2006	4820	HQ2-5	21	15 min
AT	Thebnerstrassl	1879	31.03.2006	7728	HQ10		15 min
SK	Devín	1880	31.03.2006	8024	HQ10	1	1 h
HU	Mohács	1447	07.04.2006	8050	HQ50	15	1 h
RS	Smederevo	1116	16.04.2006	14800	HQ100	4	1 d
RO	Calarasi-Chiciu	375	24.04.2006	16210	>HQ100	9	1 h
2010							
DE	Passau-Ilzstadt	2225	03.06.2010	4850	HQ2-5	21	15 min
AT	Thebnerstrassl	1879	05.06.2010	7944	HQ10		15 min
SK	Devín	1880	05.06.2010	8071	HQ10	1	1 h
HU	Mohács	1447	10.06.2010	7500	HQ20	15	1 h
RS	Smederevo	1116	29.06.2010	12700	HQ10-20	4	1 d
RO	Calarasi-Chiciu	375	07.07.2010	14620	>HQ20	9	1 h
2013							
DE	Passau-Ilzstadt	2225	03.06.2013	10000	>HQ100	21	15 min
AT	Thebnerstrassl	1879	06.06.2013	10640	HQ50-100		15 min
SK	Devín	1880	07.06.2013	10572	HQ100	1	1 h
HU	Mohács	1447	11.06.2013	8300	HQ50-100	15	1 h
RS	Smederevo	1116	17.-18.6.2013	10500	HQ2-5	4	1 d
RO	Calarasi-Chiciu	375	22.06.2013	10840	HQ2	9	1 h

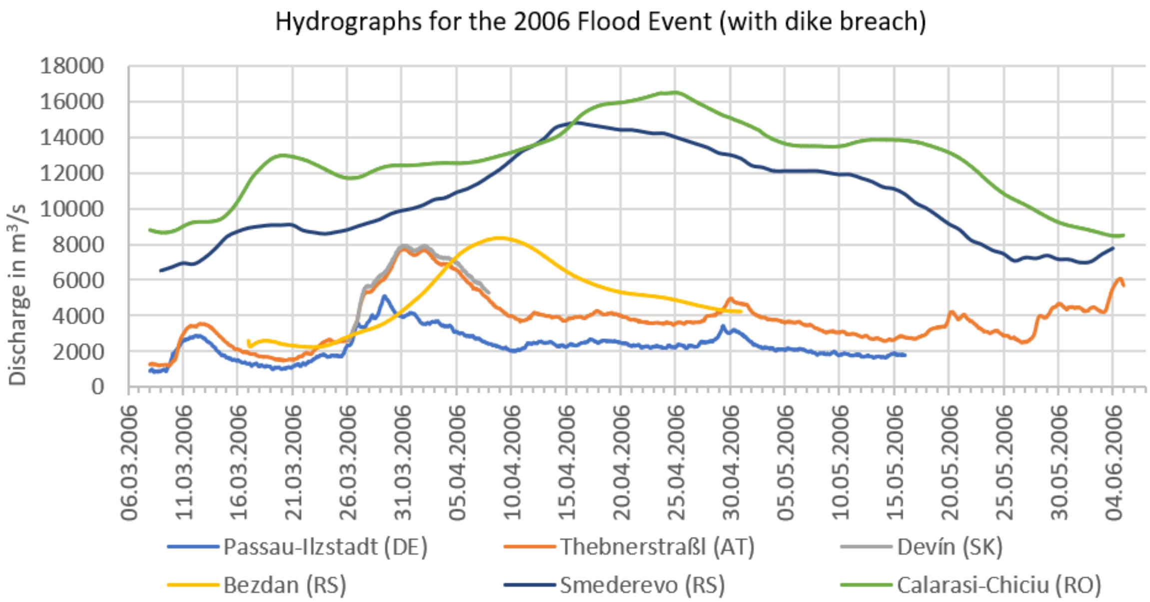

Figure 4. Development of the flood discharge (hydrographs) from Passau-Ilzstadt gauge to the most downstream gauge (Calarasi Chiciu) during the 2006 flood event (measured gauge data). The data for the gauge Smederevo was retrieved from http://www.hidmet.gov.rs/latin/hidrologija/povrsinske_godisnjaci.php (Hydrology Year Books of the Republic Hydrometeorological Service of Serbia).

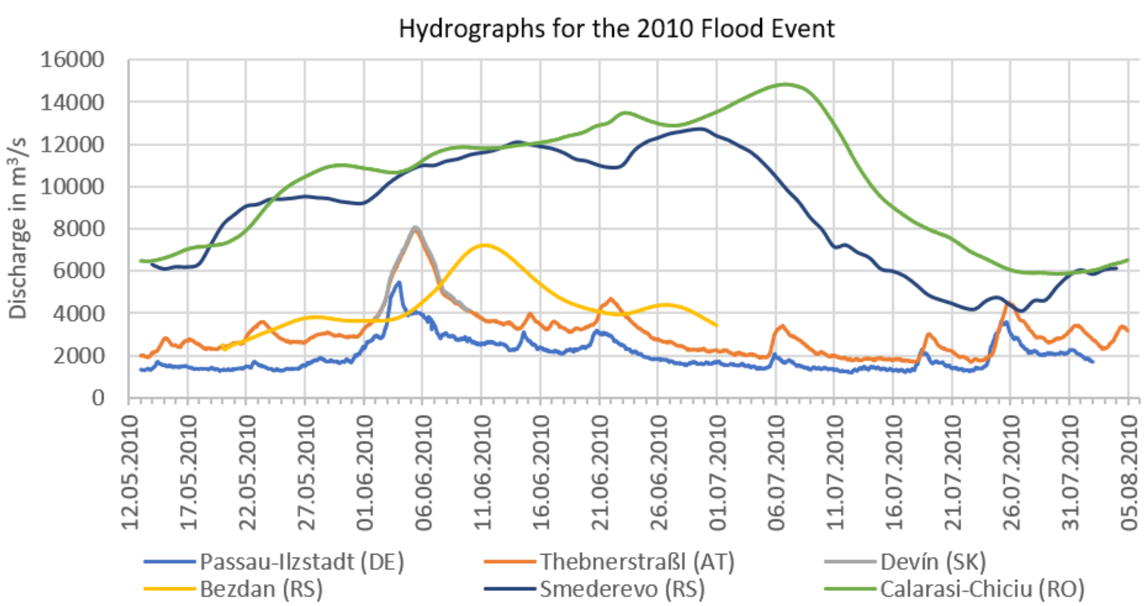

Figure 5. Development of the flood discharge (hydrographs) from Passau-Ilzstadt gauge to the most downstream gauge (Calarasi Chiciu) during the 2010 flood event (measured gauge data). The data for the gauge Smederevo was retrieved from http://www.hidmet.gov.rs/latin/hidrologija/povrsinske_godisnjaci.php (Hydrology Year Books of the Republic Hydrometeorological Service of Serbia).

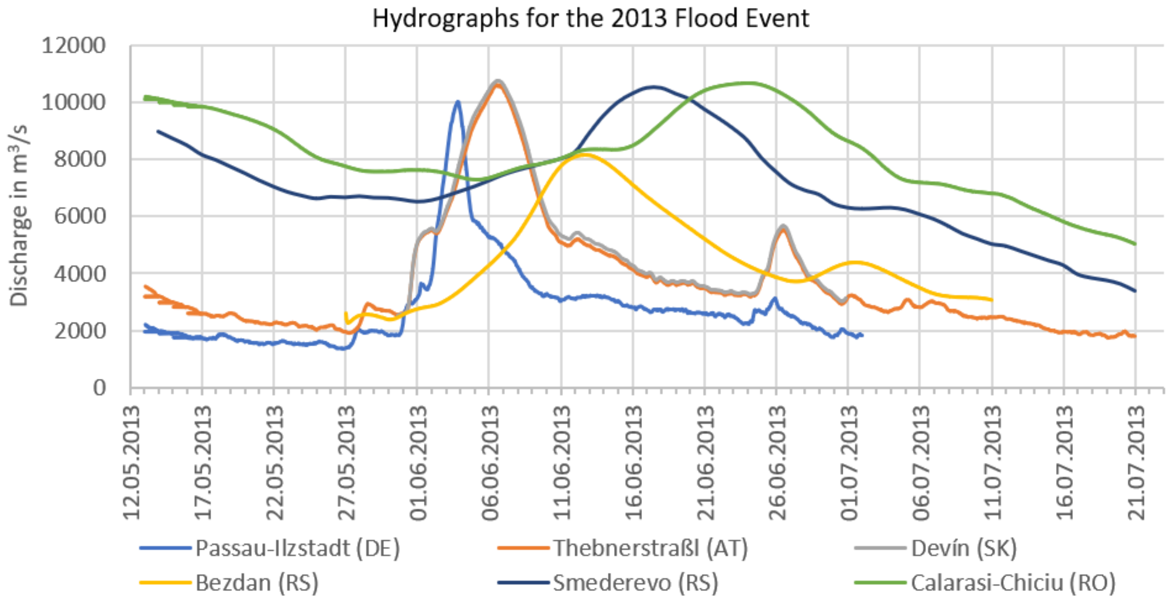

Figure 6. Development of the flood discharge (hydrographs) from Passau-Ilzstadt gauge to the most downstream gauge (Calarasi Chiciu) during the 2013 flood event (measured gauge data). The data for the gauge Smederevo was retrieved from http://www.hidmet.gov.rs/latin/hidrologija/povrsinske_godisnjaci.php (Hydrology Year Books of the Republic Hydrometeorological Service of Serbia).

4. Methodology of the Two-Dimensional Hydrodynamic Modeling

Adapted from Danube Floodplain (2020a)

Within the framework of deliverable D 4.1.1, a two-dimensional (2D) hydraulic model was set up for the current state scenario and both restoration scenarios for all pilot areas. Despite the high data requirements and the high demand for computational power, hydraulic modeling is a widely applied tool to achieve spatially detailed representations of river-floodplain interactions (Stone et al., 2017). To assess the effects of floodplain restoration measures on the flood hazard, hydraulic 2D-models are well suited. The project partners along the DRB (Table 6) were responsible for the creation of the 2D models for each pilot area. First, the current state model was set up, calibrated, and validated with input data requested from local authorities (Table 6). After calibrating and validating the current state model, the measures of both restoration scenarios were implemented. This was done e.g., by adjusting the digital elevation model (DEM), the channel geometries, and the roughness coefficients of the models according to the planned measures. For each model, unsteady flow simulations for three hydrological scenarios (HQ_{2-5}, HQ_{10-30}, and HQ_{100}) were performed. The results obtained from the model runs were then evaluated regarding several hydraulic components (water depth, flow velocity, flooded area, peak discharge, stored volume, temporal displacement of the flood wave). These parameters were used to assess the impact of the restoration scenarios of the flood hazard. The complete methodology and results description can be found in the deliverable's report of the Danube Floodplain project (Danube Floodplain, 2020a).

4.1 Modeling Procedure

The modeling in the pilot areas was conducted as follows. First, the project partners (PPs) requested necessary data (DEM, ground survey data, land use data to derive roughness criteria, hydrological data) to other national authorities to set up the current state (CS) 2D model. Based on the obtained data, the CS model was calibrated and validated in an adequate spatial resolution. In the next step, all project partners defined the floodplain restoration measures and differentiated them into two restoration scenarios (RS) in cooperation with the identified local stakeholders (from work package 2) and other national partners (additional details can be found in Section 4.2). Following the agreed scenarios, the responsible partners modified the CS 2D model to set up the two restoration scenario models accordingly. The PPs performed unsteady simulation runs for all setup models with the three hydrological scenarios (Section 4.3). The results were consistently visualized and analyzed regarding the above-mentioned hydraulic components (water depth, flow velocity, flooded area, peak discharge, stored volume, and temporal displacement of the flood wave). A short overview of the properties of the 2D models set up in the five pilot areas is represented in Table 6.

Table 6. 2D model properties in all pilot areas

	Begecka Jama	Bistret	Krka	Middle Tisza	Morava
Model details					
Responsible PP	JCI	NARW	IZVO-R ltd. (External partner of DRSV)	KÖTIVIZIG	VUVH
2D model type and version	HEC-RAS 5.0.7	HEC-RAS 5.0.7	MIKE FLOOD v. 2012	HEC-RAS 5.0.7	HEC-RAS 5.0.7
2D model size (km^2)	10.13	176.98	85.56	49.51	147.37
Length river section (km)	6.4	27.5	21.23	68	34.86
Spatial resolution	1x1m	5x5m	1x1m	1x1m	2x2m
Temporal resolution	1 hour	1 hour	1 hour	1 hour	1 hour
Number of nodes	CS 30855 RS1 31412 RS2 31997	CS - 115135 RS1 - 151914 RS2 - 230968	380266	CS 165057 RS1 170182 RS2 170182	1448241
Nodes per km^2	CS 2656 RS1 2701 RS2 2751	CS - 2265 RS1 - 1826 RS2 – 1026	4444	CS 1597 RS1 1602 RS2 1602	10000
Input data					
DEM (source and year)	LiDAR Survey (2019)	5 x 5m (2007-2008)	LiDAR (2015)	Survey (2018)	2x2m (2010)
Cross-sections (year)	Not available	Cross-section and bathymetry 2007-2017	Cross sections and bathymetry (2019)	Survey (2018)	Not available
Roughness coefficients	Manning (Average from aerial photo for entire area = 0.6)	Manning per land use class	Manning (calibrated)	Manning (Hungarian standard)	Manning per land use class
Boundary conditions	Stage-discharge curves, Hydrographs obtained from 1D modeling	Downstream-normal depth, rating curves Upstream – discharge hydrographs	Stage-discharge curves, hydrographs	Stage-discharge curves, hydrographs	Stage-discharge curves, hydrographs
Considered inflow from tributaries	Not available	Not available	Radulja River	Zagyva River	Dyje River Myjava River
Calibration					
Parameter	Water level	Water level	Water level	Water level	Peak discharge
Flood event	2006	2006	2010	2013 (including old dykes)	2010

4.2 Restoration Scenarios in the Pilot Areas

Each pilot area PP in cooperation with national authorities as well as the identified stakeholders developed the two restoration scenarios, specific for each pilot area. The planned restoration measures were discussed with relevant stakeholders on a stakeholder workshop in each of the pilot areas, including various domains like fishery, agriculture, shipping, municipal authorities, nature protection, residents, etc. The results of these stakeholder meetings are summarized in deliverable D 4.2.1 (Danube Floodplain, 2019c).

In Table 7, a summary of all restoration measures in the pilot areas for both scenarios is given. Different kinds of restoration measures, e.g. in-stream measures which change the roughness and the shape of the riverbed, alterations in the floodplain size (through e.g. dike relocation), as well as morphological and/or land cover changes in the floodplain were determined. The main purpose of the restoration measures is to re-establish natural floodplain conditions and to achieve a win-win situation for both, the environment and flood protection.

After an agreement on the explicit restoration measures in each scenario with the stakeholders, the project partners set up the three 2D models for the pilot areas:

1. **Current State (CS)**
   The first model represents the current state of the area (CS). It is set up based on a recent high-resolution DEM and up-to-date ground survey data. It is the base model for the restoration scenarios models.
2. **Realistic restoration scenario 1 (RS1)**
   In the second 2D model (realistic restoration scenario 1; RS1) all planned measures are implemented, e.g. dike relocation, modification of land cover, and river geometry.
3. **Optimistic restoration scenario 2 (RS2)**
   Furthermore, an optimistic scenario model (optimistic restoration scenario 2; RS2) is developed which includes more extensive measures. With this approach, the maximum capacity of flood protection obtained by restoration measures in the pilot areas without consideration of real limitations is shown.

To quantify the effects of the two restoration scenarios, the simulation results of both were compared with the current state scenario.

Table 7. Restoration measures determined and implemented for RS1 and RS2 for the five pilot areas (RS1 = realistic implementation scenario; RS2 = optimistic implementation scenario)

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 the 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/oxbows	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 riparian 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 the 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		

4.3 Hydrological Scenarios

To assess the changes of the effects of floodplain restoration to flood events, it was decided to apply at least three hydrological scenarios to the CS, RS1, and RS2 models. All investigated scenarios were analyzed with a non-steady input hydrograph, to determine the differences in the flood peak discharge, the flood wave translation, and several spatial hydraulic components. In previous studies of floodplain assessment, mostly steady-state simulations were applied, which are less demanding in terms of computational performance but do not reveal the important procedure of water expansion and retreat during a flood event (Stone et al., 2017).

A frequent flood event (HQ_{2-5}), a medium flood event (HQ_{10-30}), and a 100-year flood event (HQ_{100}) were simulated by the project partners in their pilot area models. The input data for these events were mainly taken from observed past events in the pilot areas at nearby gauging stations or up- or downscaled hydrographs of these events to fit the selected HQ values. National hydrological authorities provided the data. The combination of the hydrological scenarios with the three restoration scenarios gives a total of nine scenarios simulated for each pilot area.

The transient time series were added as an input to the model in hourly time steps at the upper model boundary in the main channel. Major tributaries were considered and implemented with a steady runoff value or unsteady observed runoff time series where data was available. The lateral inflow of small magnitude was added punctually at several locations.

For more information regarding the results of the 2D modeling of the pilot areas, please refer to Deliverable D 4.1.1 (Danube Floodplain, 2020a).

5. Methodology of the Stakeholder Engagement

Adapted from Danube Floodplain (2019c)

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).

Prospective flood protection and restoration measures are to be implemented to result in win-win situations. This means that the measures not only should improve flood protection but also benefit nature. Among others, one aim of the project was to test and evaluate the potential win-win situations in the five pilot areas.

The planned measures affect a wide range of stakeholders, including landowners and residents. Therefore, their interest in the project was particularly high and it was important to get these stakeholders enthusiastic about the measures. In addition, 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.

5.1 Stakeholder Engagement to Assess Ecosystem Services

Ecosystem services can be determined in many ways. There are many software for evaluating ecosystem services, such as InVEST by the Natural Capital Project (2020), ARIES by Villa et al. (2014), TESSA by Peh et al. (2013), RESI by Podschun et al. (2018), etc. Another method is the enquiring of stakeholders, which can be done in different ways. Questionnaires or choice experiments can be used to assess the ecosystem services. It is also possible to ask residents about which ecosystem services are used in the study area or to hold the survey in the form of discussion rounds.

A stakeholder workshop was held in each of the five pilot areas to assess the kind and intensity of the use of ecosystem services. Four of the five workshops followed immediately after the National kick-off press event, during which the project and the planned measures were presented. Only in the pilot area Bistret (Romania), the National kick-off event was held two months before the workshop.

5.2 Identification of Stakeholders

The assessment of ecosystem services with the help of stakeholders needs a detailed analysis regarding which interest groups are suitable for the stakeholder workshops. To identify stakeholders, the following questions were considered:

- Who can be affected by the planned measures?
- Who is active in the pilot area or is familiar with the pilot area?
- Who benefits from the pilot area?
- Who has knowledge of the ecological situation of the pilot area?

Among stakeholders, we could find, for example, 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, the experience from the "River Ecosystem Service Index (RESI)" Project was used (Podschun et al., 2018). Within this project, a list of 25 relevant ecosystem services of German rivers and floodplains was generated along with the identification of relevant stakeholders associated with these services. The identified stakeholders were finally assigned to seven target groups:

1. Local public authority
2. Regional public authority
3. National public authority
4. Sectoral agency
5. Interest groups including NGOs
6. Higher education and research
7. International organization
8. General public

This classification (excluding the "General public" group), was also used to identify stakeholders for the National Kick-off event (whose report is found in deliverable D 2.1.1, Danube Floodplain, 2018).

5.3 Discussion of Stakeholder Engagement Method

During the workshops, stakeholders had time to discuss the project, the planned measures in the pilot areas, and the expected outputs of the project. The assessment of ecosystem services allowed stakeholders to engage with topics outside of their interest fields. For example, representatives from the different water authorities also dealt with the forestry use of the riparian forests bordering the river or with the cultural offerings of the region.

The workshops enabled everyone to expand their knowledge of the pilot area and their understanding of different uses. The acquired knowledge and understanding of other sectors can help in the later planning and implementation of flood protection and restoration measures. Nevertheless, not only authorities benefitted from the event. The community representatives were also able to discuss their concerns with those involved in the project and who will later implement the measures. This, in turn, is of great interest to the project planners. The participants of the workshops 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.

Overall, the approach of discussing and assessing ecosystem services with stakeholders before and after the implementation of measures is not only of great interest and benefit to the stakeholders themselves but also a good means of mediating between different sectors. By involving as many stakeholders as possible, restoration measures can be evaluated from a wide range of perspectives. This allows to identify and address issues that might not have even been recognized in advance.

6. Methodology of the Habitat Modeling

Adapted from Danube Floodplain (2020d)

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. Different options were available to establish this linkage.

As riparian ecosystems depend on the hydrological connectivity between channel and floodplain, the habitat modeling work depends on external hydraulic modeling results which were provided by the project partners of the pilot areas (Danube Floodplain, 2020a). For the habitat modeling, frequent flood events are the most relevant, thus the HQ2-5 scenario was chosen for this purpose. Flow velocity and water depth were available for all pilot areas. In addition, in four out of five pilot areas, arrival time was also provided and has proven to be a suitable indicator of connectivity to the main river channel, as this is a crucial parameter for riparian vegetation development.

In the context of eco-hydraulics, there are different spatial scales relevant for habitat modeling, following conceptual developments from hydro-morphology (Zavadil and Stewardson, 2013). These conceptual frameworks emphasize the role of multiscale analysis, ranging from the entire catchment, over river segments, to single geomorphological or hydraulic units. However, since the pilot areas (with a small spatial extent) were the focus of the Danube Floodplain Project, the focus was set to smaller spatial scales on the level of hydraulic/geomorphological units. Within eco-hydraulics, these spatial scales are often referred to as meso-scale and microscale (Newson and Newson, 2000; Zavadil and Stewardson, 2013). Thus, deliverable D 4.2.3 (Danube Floodplain, 2020d) focused on the level of habitats and did not dive into detailed species assessment. A schematic representation of the methodology followed for habitat modeling can be seen in Figure 7.

At the meso-scale, the focus was set on the identification of patches of typical floodplain habitats, as defined in Table 8. Floodplain ecology is driven by the connectivity between the channel and the floodplain. Specifically, four types of connectivity can be distinguished: longitudinal, i.e. in the upstream-downstream direction, lateral, i.e. via surface flow between the channel and the floodplain, vertical via groundwater, and temporal, considering the flow regime of a river (Amoros & Bornette, 2002; Naiman et al., 2005). Within the Danube Floodplain Project, we considered only lateral floodplain connectivity, due to the nature of the hydraulic models and the hydrological scenarios used in Activity 4.1. This gave only a partial picture, as the vertical connectivity via the groundwater was not considered (Amoros & Bornette, 2002).

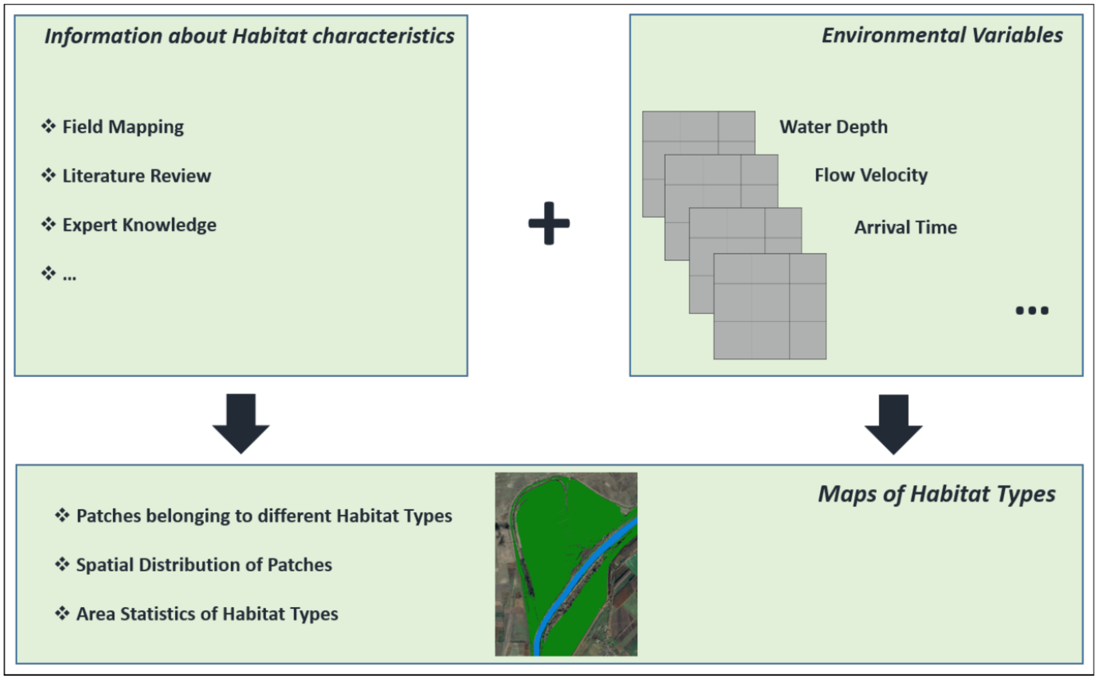

Figure 7. Principle of habitat modeling at the meso-scale

Table 8 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 8. 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[3]	Patches at the interface of channel and floodplain with low slope and high flood duration during minor flood events (HQ2-5)

[3] Not applicable in Danube Floodplain project

7. Methodology of the Ecosystem Services Approach

Adapted from Danube Floodplain (2020c)

7.1 Introduction to the Concept of Ecosystem Services

The basic idea behind the ecosystem service (ESS) approach is understanding the connection between humans and nature. Human kind and nature mutually influence each other. Human activities have a direct or indirect impact on nature. Conversely, natural events affect society and its well-being. Thus, ESS are the way to describe direct or indirect economic, material, health, or psychological benefit to people. The ESS approach aims to show the benefits and value of ecosystems to society and to improve the conditions for sustainable management of nature and ecosystems. With the help of the ESS approach, trade-offs between different sectoral uses can be identified. ESS can help mediate between science and society or between different stakeholders. In addition, they are a good tool to estimate and present the impact of management measures on the ecosystem, but also on other benefits.

The term "ecosystem service" was defined and distinguished in the three different groups, according to the CICES classification by Haines-Young and Potschin (2017) into regulating services, provisioning services, and cultural services. Climate regulation, extreme water regulation, and the maintaining of the lifecycle are regulating services. Provisioning services provide people with products of nature such as food, drinking water, and raw materials. Services that have symbolic, cultural, aesthetic, or intellectual value and create a sense of well-being are considered cultural services, e.g. recreation or sports in the landscape. The Millennium Ecosystem Assessment (Alcamo, 2003) and the UK National Ecosystem Assessment (UK NEA) by Morris and Camino (2011) also defined a fourth group, i.e. the supporting services. The supporting services are defined as "ecosystem services that are necessary for the production of all other ecosystem services, such as primary production, production of oxygen, and soil formation" (Alcamo, 2003). These are not taken into account in the Danube Floodplain Project, because these supporting services represent processes, whose products are used and not actual services.

7.2 Assessment of Ecosystem Services in the in the Pilot Areas by Using Land Cover/Land Use Data

The restoration measures had not yet been exactly determined at the time of the workshops. Additionally, the stakeholder workshops did not determine the current provision of all ESS, but only the intensity of use of the identified ones. Therefore, a further method for mapping the provisioning and regulating ESS of pilot areas was developed following the method of Burkhard et al. (2009), who estimated the capacities to provide ESS by using CORINE land cover data in a study case in Germany. In the Danube Floodplain project, ESS were assessed based on land cover/land use data from Copernicus (European Environment Agency, 2012) and additional CORINE land cover data (European Environment Agency, 2018) with the help of responsible project partners of the pilot areas (and some external experts not related to the project). The Copernicus land use/land cover data is available in different resolutions (MAES typology). The more detailed the ecosystem classification, the higher the MAES level (level 1 to level 4). In the Begecka Jama pilot area, the MAES level 3 was used for legal reasons; in all other pilot areas, the more detailed ecosystem classification MAES level 4 could be used. However, the Serbian Project Partner revised the Copernicus land cover/land use data level 3, to add details to it. The intensity of the provision of the ESS in the pilot areas was indicated by values between 0 and 5 (see Table 9).

Table 9. Scale for the intensity of provided and used ecosystem services of pilot areas

Class	**0**	**1**	**2**	**3**	**4**	**5**
Intensity	Missing	Very low	Low	Medium	High	Very high

Table 10 gives an overview of all considered ESS and their definitions. By jointly classifying all provisioning and regulating ESS, areas with a particularly high provision of ESS (so-called hotspots) and also areas with a very low provision of ecosystem services (so-called cold spots) could be identified.

Table 10. All ecosystem services (ESS) and their definitions that are considered in Activity 4.2 of the Danube Floodplain Project

ESS class	**ESS**	**Definition**
Provisioning ESS	agricultural product	All plant foods produced by agricultural cultivation
	wood	Wood for heating or creating wood products (furniture, roof trusses)
	animal product	Meat, cold cuts, milk, butter, wool, etc.
	game meat	Game meat obtained by hunting and offered for sale, like goose, duck, deer, boar, etc.
	honey	Honey and other products from the beehive
	fish	Fish or fish products offered for sale, produced by professional fishing or aquaculture
	water	Water for drinking or irrigation from surface water bodies or groundwater bodies
Regulating ESS	local climate regulation	The ability of forests and water bodies to influence local temperatures by evaporation or storing of heat under tree crowns or in water bodies. In the summer months, the air is cooled by evaporation, in autumn and spring the heat is stored and slowly released into the environment.
	air purification	The ability of plants to purify air by assimilation of particulates or harmful gases.
	low water regulation	The ability of rivers and floodplains to reduce the risk of a river drying out due to the inflow from aquifers in floodplains or by stabilizing the river water level through the roughness of the river.
	flood retention	The ability of rivers and floodplains to retain or flatten flood waves. The retention volume is used by overflow/flooding.
	nutrient retention	The ability of floodplains to store nutrients (N, P, C) by uptake into stationary biomass, by deposition as sediments, or to decimate nutrients by microbial degradation or respiration (in case of C)
	noise regulation	Availability of forests with undergrowth to reduce noise by the refraction of acoustic noise

ESS class	ESS	Definition
	provision of habitats	Availability of habitats in typical functional and structural quality, which may be used by typical biotic communities of rivers and floodplains, which may then partially be used by humans.
Cultural ESS	recreational activity	All activities that take place in the area and lead to recreation or are carried out as a hobby, such as hiking, cycling, jogging, photography, mushroom picking, bird watching, hunting, etc.
	water-related activity	All activities that are carried out in or on water bodies and are done as a hobby or for recreation, like swimming, canoeing, stand-up paddling, sport fishing, etc.
	tourism	Special places that are visited by tourists or activities that are done by tourists, for example, hunting or fishing tourism, ports for cruise ships, hotels, summer cottages, thermal baths, historical places, etc.
	education	All activities that lead to further education for oneself or others, for example, scientific research, cultural heritage, archaeological sites, information events, etc.

For this purpose, the values of all ESS were divided into five classes according to Table 11. This classification was also applied for all provisioning ESS and all regulating ESS separately. For the classification of the intensity of the provisioning ESS, only the real occurring provisioning ESS of each pilot area were considered. This means that only the sum of the intensity of the occurring ESS was used for the classification.

Table 11. Scale for the intensity of provisioning and regulating ESS together

Class	**1**	**2**	**3**	**4**	**5**
Intensity	Missing to very low	Low	Medium	High	Very high

Different factors were used to identify and evaluate the individual ecosystem services of the provisioning ESS class, discussed with the respective project partner of the pilot areas. The ESS agricultural products were identified employing land cover/land use classes indicating the cultivation of crops, vegetables, fruit trees, berries, or wine. Different grasslands and forest types were used to define the ESS animal products. The localization of the ESS game meat differs from one pilot area to another. In some pilot areas, ducks and geese were hunted. In this case, water bodies were used in addition to forest and grassland areas. Depending on the study area, different habitat types are important for the production of honey. In Hungary (pilot area Middle Tisza), honey from forests is very common. However, the provision of the ESS honey was mainly assigned to grassland habitats. Water bodies indicate the ESS fish provisioning. Water bodies, which only serve as spawning habitats (due to their temporary connection with the river) but are nevertheless essential for fish production, were also considered. It was also assumed that rivers and lakes can be used for water supply (as drinking water or for irrigation).

The intensity of provisioning ecosystem services can be derived directly from the land cover/land use classes. For the individual adaptation to the conditions of the individual pilot areas, the respective project partners were involved on-site. The intensity of regulating ecosystem services cannot be derived directly from the land cover/land use classes. Other abiotic and biotic factors as well as the structure of the land cover/land use play a role here. Therefore, a literature review was first conducted to obtain indications of which other factors are responsible for the intensity of individual regulating ecosystem services; then, the approach of Burkhard et al. (2009) was adapted; third, it was discussed with experts from the project consortium as well as experts independent of the project; finally, the intensity of ESS provision of individual land cover/land use classes was estimated. The decisive factor for estimating the ESS local climate regulation of different land cover/land use types was the evaporation function. The air purification ESS was estimated according to the research of Vieira et al. (2018). According to this study, the air purification of natural structured forests with tree-, shrub-, and herb-layers is higher in comparison to managed grasslands. The important factors for assessing the ESS low water regulation were groundwater recharge and evaporation rate. The higher the groundwater recharge and the lower the evaporation, the higher the low water regulation. However, roughness caused by macrophytes also plays a role in the water. To assess the ESS flood retention, special attention was paid to the level of roughness of a land cover/land use type and, in the case of water bodies, to the absorption capacity of increased runoff. The results of the RESI project (Podschun et al., 2018) were taken into account when assessing nutrient retention in different land use classes. According to these results, nutrient retention is higher in natural floodplain-type habitats than in heavily fertilized or sealed areas. The density and width of tree and shrub cover of a land cover/land use type are decisive for noise regulation. A naturally structured forest can best reduce noise, but lines of trees and shrubs also have a noise-reducing effect.

When assigning the value of the ESS provision of habitats to a habitat type, it was considered to which extent the habitat type is typical of riparian zones and to which extent the habitat type is close to nature. Accordingly, the highest value (5) was assigned to floodplain typical habitats, such as riparian forests and water bodies connected to the river. A medium value (3) was given to land cover/land use types that occur naturally both in and outside the floodplains and are close to nature (e.g. near-natural forests). The lowest value (0) was given to habitats that are of artificial origin and do not occur naturally in the floodplain area (e.g. sealed areas or buildings).

For the pilot area Bistret, a deviation from the method used in the other pilot areas was needed to calculate the scenarios. As there was no data on the location of the measures and no spatial delineation, the flood depth from the 2D-hydrodynamic modeling was used to delimit the areas affected by the dike relocations. The ESS of each single land cover/land use type were then either upgraded or downgraded, depending on whether the ESS benefit or arise weakened by the increased flooding. For example, it was assumed that the ESS *agricultural product* would be reduced by frequent floods. The ESS received a malus of -1, and instead, it was assumed that the agricultural land could be converted into grassland. Thus, ESS such as animal products, game meat, or local climate regulation received a bonus of +1.

An example of the intensity of ESS according to each land cover/land use type can be seen in the case of the Begecka Jama pilot area in Table 12.

Table 12. Example of the estimated intensity of the potential ESS of each land cover/land use type MAES code 3 for the pilot area Begecka Jama, as a result of work done by project-related and not related experts.

land cover/ land use type	**MAES 3**	**Provisioning ESS**					**Regulating ESS**						
		wood	animal product	honey	water	fish	air purification	local climate regulation	low water regulation	flood retention	noise regulation	nutrient retention	provision of habitats
Urban fabric	111	0	0	0	0	0	0	0	0	0	0	0	0
Industrial, commercial and military units	112	0	0	3	0	0	1	2	3	0	1	0	1
Natural and semi-natural broadleaved forest	311	5	1	3	0	0	5	5	1	4	5	5	5
Transitional woodland and shrub	341	4	2	2	0	0	2	4	2	1	3	3	3
Managed grassland	410	1	5	3	0	0	2	4	2	3	2	3	2
Natural grassland without trees and shrubs	421	1	5	5	0	0	2	4	2	3	2	5	3
Beaches and dunes	621	0	0	0	0	0	0	1	5	3	0	1	1
Interconnected running watercourses	911	0	0	0	5	5	0	5	4	5	0	5	5
Separated water bodies belonging to the river system	912	0	0	0	3	3	0	5	2	5	0	5	5
Highly modified natural water courses and canals	913	0	0	0	2	3	0	5	2	5	0	5	4
Natural water bodies	921	0	0	0	5	5	0	5	5	5	0	5	4

8. Methodology of the Extended Cost-Benefit Analysis

Adapted from Danube Floodplain (2019c), Danube Floodplain (2021b), and Perosa et al. (2021b)

Floodplain restoration projects are sometimes difficult to finance. Therefore, the Danube Floodplain Project aims to show the profitability of these measures, since floodplain restoration can help for flood risk reduction, but can also bring other ecosystem services (Guida et al., 2015). Therefore, an extended cost-benefit analysis is used to estimate ecosystem services of floodplains and show their additional value, leading to integrated planning and improved regional policy making, which was called for by scientists (Petz et al., 2012). Moreover, the huge economic losses due to floods at the Danube River Basin level, e.g. 2 billion Euros in 2010 and 2.3 billion Euros in 2013, (ICPDR, 2015) lead to considering the inclusion of ESS in monetized form.

8.1 Input Data for Extended Cost-Benefit Analysis

For the ESS assessment, required as input data for the extended cost-benefit analysis, a consistent quantity of input data is necessary. The statistics deal with the parameters that affect ESS, such as agricultural production, the population density, or emission factors of different greenhouse gases, as well as stakeholder interests.

As a result of the stakeholder meetings, Table 13 reports the ESS that were recognized by the stakeholders in the study areas (Danube Floodplain, 2019c). A summary of the corresponding potential TESSA methods used for each ESS sub-group in this paper can be seen in the last column.

A set of important input data is given by the shapefiles of ESS maps, the result of the stakeholder meetings, and ecosystem services analysis described in Chapter 7 ("Methodology of the Ecosystem Services Approach").

In addition, we divided the study areas into the following habitat types:

- Grass-dominated
- Tree-dominated
- Crop-dominated (no rice)
- Crop-dominated (rice)
- Wetland-dominated

These corresponding maps can also be seen in the Annexes of the deliverable D 4.3.2 (Danube Floodplain, 2021b).

When lack of data characterized the area of study, publicly available data were used for each country or the corresponding NUTS2 areas 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.

Table 13. Summary of the ecosystem services (ESS) identified by stakeholders and the corresponding potential methodology to estimate ESS within the TESSA framework (Danube Floodplain, 2020c).

ESS group	ESS sub-group	Begecka Jama	Bistret	Krka	Middle Tisza	Morava	ESS estimate method
	Greenhouse gases sequestration	✓		✓	✓	✓	Tier 1 of IPCC[1]
	Flood retention	✓		✓		✓	Not available in TESSA
	Flood protection	✓	✓	✓	✓	✓	Hydrodynamic modeling and damage functions (Huizinga et al., 2017)
	Water quality: Nutrients retention	✓		✓			Statistical analysis of nutrients in DRB
	Local climate regulation	✓	✓	✓	✓	✓	Not available in TESSA
	Noise regulation					✓	Not available in TESSA
Provisioning of cultivated goods	Crops		✓	✓	✓	✓	Mixture of TESSA and publicly available information
	Livestock and bees	✓	✓	✓	✓	✓	
	Aquaculture		✓	✓		✓	
Provisioning of harvested wild goods	Wood	✓	✓	✓	✓	✓	Available in TESSA, neglected due to high data requirement
	Fish	✓	✓	✓			
	Game meat		✓	✓	✓		
Nature-based recreation and tourism	Recreational ESS	✓		✓	✓	✓	Online questionnaires and individual travel cost method (adapted from TESSA)
	Tourism	✓	✓	✓	✓	✓	
	Education	✓		✓	✓	✓	
Habitat provisioning	Terrestrial habitats	✓	✓	✓	✓	✓	Not available in TESSA
	Spawning areas	✓	✓	✓	✓	✓	

8.2 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). According to Feuillette et al. (2016), the lack of information in CBA on interactions in the ecological system leads to limited and biased results, due to the high complexity of ecosystems; CBA requires therefore specific methods to express environmental services in monetized benefits. As a consequence, according to ICPDR (2015), the economic/extended CBA is the more appropriate method for evaluating public policies than a simple financial CBA, since government interventions are often related to the provision of public goods and ecosystem services, which have an impact on society as a whole. In the case of environmental policy measures, an extended CBA will often be called for, but the external environmental effects often do not correspond to any market prices.

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 alternative strategies of potential restoration areas. The costs and benefits addressed in an economic CBA may include indirect and non-priced external effects (ICPDR, 2015), such as environmental effects. If such externalities are included in the analysis in monetary terms, we refer, according to Brouwer and Sheremet (2017), to a "social CBA". One of the main challenges of the proposed work is to translate the ESS into quantitative values so that they can be compared with standard costs and benefits of the floodplain restoration measure, and therefore considered in the decisional process.

CBA of river restoration projects are rare and a reason for this is the relative scarcity and difficulty of data acquisition related to the costs of restoration activities (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, also in terms of implemented restoration measure. 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). The extended CBA process is graphically conceptualized in Figure 8.

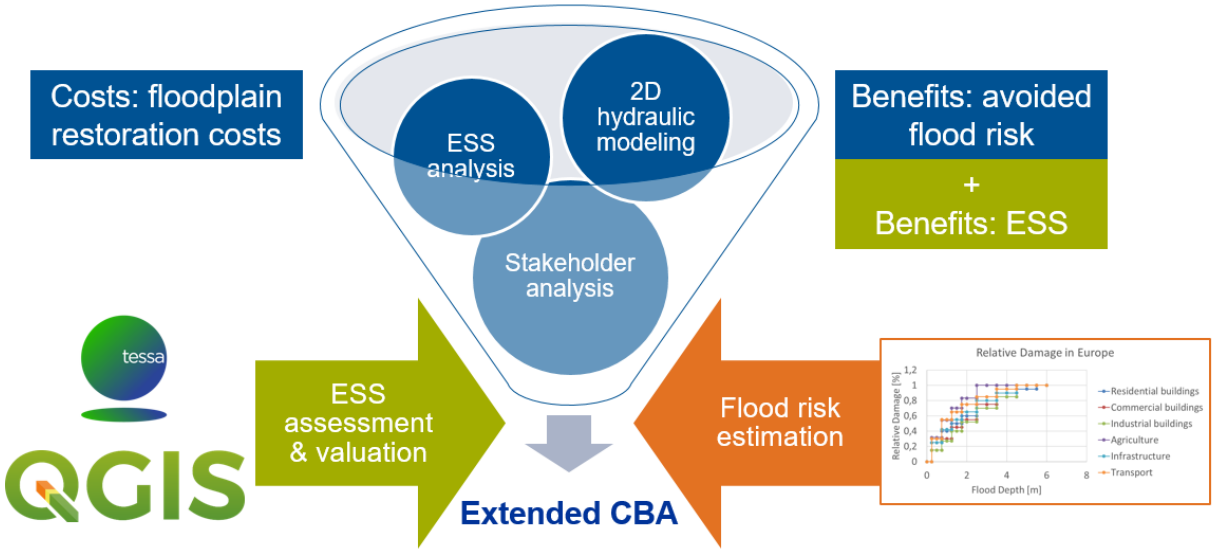

Figure 8. Workflow of the extended cost -benefit analysis for floodplain restoration measures in the Danube Floodplain project.

Before analyzing the benefits and costs of the restoration measures, these have to be discounted, to be made comparable with each other, assuming the discounting parameters presented in Table 14. The discount rate was chosen based on the literature: Monge et al. (2018) used various discount rates ranging from 1 to 5% for estimating payments for forest ecosystem services; Dittrich et al. (2019) applied a rate of 3.5% up to year 30 (Dittrich et al., 2019) for a cost-benefit analysis of afforestation related to flood-risk nature-based solutions; Jeuland and Pattanayak (2012) took an average of 4.5% discount rate (social) for assessing the implications of cookstoves in health, forest and climate impacts (Jeuland and Pattanayak, 2012). The European Commission recommends that for the social discount rate 5% is used for major projects in Cohesion countries and 3% for the other Member States (Sartori, 2015). However, Terrado et al. (2016) used also lower discount rates (2% and 3%) to assess the sensitivity of the results to this parameter. In general, there is a lack of consensus on the discount rate to use in ecosystem services valuation studies (Hein et al., 2016).

Table 14. Parameters used for the cost-benefit analysis

Parameters for discounting
r = 0.04
N = 50

These parameters are used in the following equation (1), to derive the multiplication factor used to estimate the present value (PV) of the costs and benefits, based on annual values, for a discount rate *r* and a project life of *N* years.

$$Annuity\ to\ present\ = \frac{((1+r)^N)-1}{r*((1+r)^N)} \qquad (1)$$

The discounted values were then used in this project to estimate the benefits-costs difference and the benefits-costs-ratio. The benefits-costs difference (BC-difference) is the simple subtraction of the costs PV from the benefits PV of the restoration measures. A positive BC-difference represents a profitable project for the selected timeframe. The benefits-costs-ratio (BCR) is a common parameter used in CBA analysis to evaluate its results. It consists of the following equation (2). A BCR higher than one corresponds to a profitable project.

$$BCR\ = \frac{PV\ of\ Benefit\ Expected\ from\ the\ Project}{PV\ of\ the\ Cost\ of\ the\ Project} \qquad (2)$$

8.3 Ecosystem Services Assessment with TESSA

The TESSA Toolkit (Peh et al., 2013) was used as theoretical background for the ESS estimation and evaluation. To make the estimation faster, the assessment steps were reproduced in a python code for QGIS3. The workflow followed can be seen in Figure 9.

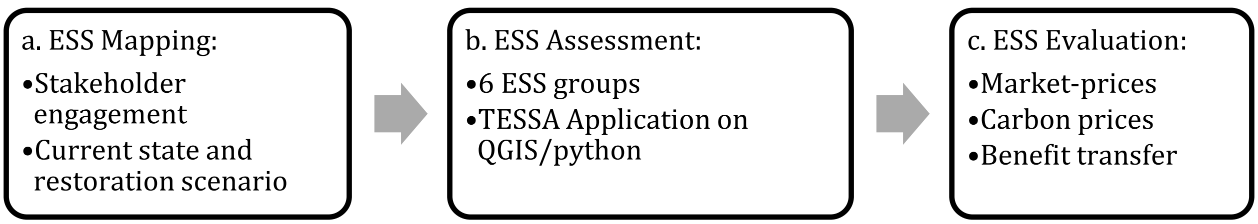

Figure 9. Workflow of the ecosystem services assessment with TESSA (Peh et al., 2013)

In general, to estimate the value of ESS, four categories of approaches exist (Grizzetti et al., 2016):

- cost-based: e.g. replacement costs;
- revealed preferences: e.g. travel costs;
- stated preferences: e.g. willingness to pay;
- benefit-transfer, e.g. meta-analytic value transfer functions.

A detailed description of these methods can be seen in deliverable D 4.3.2 (Danube Floodplain, 2021b).

The practical tool used to implement TESSA is written in python and can be run from QGIS3. It consists of three packages (up to now), divided according to the division of the methodologies implemented in the TESSA Toolkit and to ESS types. The code can be run from QGIS3 (QGIS.org, 2020) and, together with illustrative input data, is available on GitHub (GitHub, 2020). Each section is described in the next chapters. The sections can be run independently and each of them corresponds to different files of functions (included in the library of the code).

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 protection, global climate regulation, cultivated goods, nutrients retention, nature-based recreation). Then, the total sum of the ESS values was calculated by summing the singular ESS groups for each scenario. This was used for the subsequent inclusion of the additional benefits of the restoration measures in the extended cost-benefit analysis.

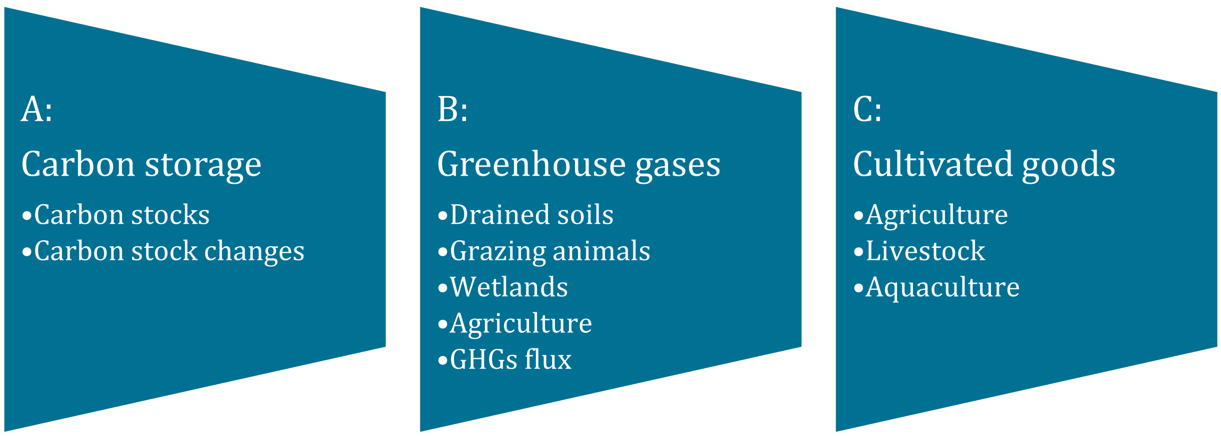

Figure 10. Sections of the python code available in GitHub (GitHub, 2020) written to estimate ecosystem services according to TESSA (Peh et al., 2013).

8.4 Flood Mitigation

The flood mitigation ESS was estimated through flood risk estimation. The water depth maps for each pilot area resulted from the 2D hydrodynamic modeling of the three return period groups of high probability (2 to 5 years), medium probability (10 to 20 years), and low probability (100 years), produced and analyzed under Activity 4.1 (Danube Floodplain, 2020a) for both current state and restoration scenarios. For the estimation of the flood-caused damages, we applied to all scenarios the Joint Research Centre (JRC) damage functions (Huizinga et al., 2017) shown in Figure 11 to estimate the flood-caused damage in the pilot areas. As Table 15 shows, the flood damage functions are applied to six land use types, which were derived for the pilot areas from the CORINE land use land cover dataset (EEA, 2019) as shown in Table 17. Finally, we applied the trapezoidal method for flood risk (expected annual damage) estimation (Olsen et al., 2015).

Table 15. Land use types included in the JRC damage functions (Huizinga et al., 2017)

JRC land use types
Residential buildings
Industrial or commercial buildings
Agriculture
Infrastructure
Transport
Other

Finally, we applied the trapezoidal method for flood risk (expected annual damage, EAD) estimation (Olsen et al., 2015), as shown in the following function:

$$EAD = \frac{1}{2}\sum_{i=1}^{n}\left[\left(\frac{1}{T_i} - \frac{1}{T_{i+1}}\right)(D_i + D_{i+1})\right] + \frac{D_n}{T_n}, \qquad (3)$$

where $n = 3$ is the number of return periods, T is the return period in years (shown in detail for each study area in Table 16, together with their corresponding lower and upper uncertainty boundaries), and D is the corresponding damage.

Table 16. Return periods T used for the flood risk estimation with corresponding lower and upper uncertainty boundaries, with a number of return periods of n = 3.

	Begecka Jama	**Bistret**	**Krka**	**Morava**
T_1 - High probability	3.5 yr ± 1.5 yr	2 yr ± 1 yr	3.5 yr ± 1.5 yr	5 yr ± 1.5 yr
T_2 - Medium probability	15 yr ± 5 yr	10 yr ± 2 yr	10 yr ± 2 yr	30 yr ± 5 yr
T_3 - Low probability	100 yr ± 5 yr	100 yr ± 5 yr	100 yr ± 5 yr	100 yr ± 5 yr

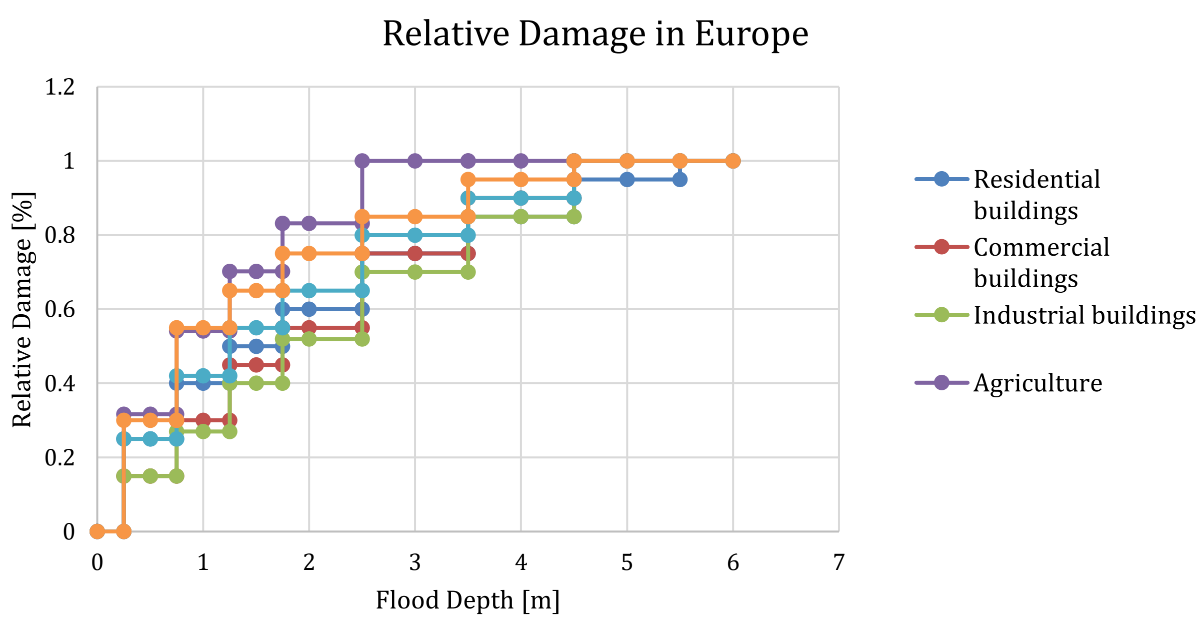

Figure 11. Damage curves used to estimate flood risk in the pilot areas (Huizinga et al., 2017)

Table 17. Land use translation from CORINE to JRC

CLC18 code	CLC18 description	JRC code	JRC description
111	Continuous urban fabric	110	Residential buildings
112	Discontinuous urban fabric	110	Residential buildings
121	Industrial or commercial units	121	Industrial or commercial buildings
122	Road and rail networks and associated land	122	Transport
123	Port areas	120	Infrastructure
124	Airports	120	Infrastructure
131	Mineral extraction sites	130	Infrastructure
132	Dump sites	130	Infrastructure
133	Construction sites	133	Industrial or commercial buildings
141	Green urban areas	140	Infrastructure
142	Sport and leisure facilities	140	Infrastructure
211	Non-irrigated arable land	200	Agriculture
212	Permanently irrigated land	200	Agriculture
213	Rice fields	200	Agriculture
221	Vineyards	200	Agriculture
222	Fruit trees and berry plantations	200	Agriculture
223	Olive groves	200	Agriculture
231	Pastures	200	Agriculture
241	Annual crops associated with permanent crops	200	Agriculture
242	Complex cultivation patterns	200	Agriculture
243	Land principally occupied by agriculture with significant areas of natural vegetation	200	Agriculture
244	Agro-forestry areas	200	Agriculture
311	Broad-leaved forest	0	Other
312	Coniferous forest	0	Other
313	Mixed forest	0	Other
321	Natural grasslands	0	Other
322	Moors and heathland	0	Other
323	Sclerophyllous vegetation	0	Other
324	Transitional woodland-shrub	0	Other
331	Beaches dunes sands	0	Other
332	Bare rocks	0	Other
333	Sparsely vegetated areas	0	Other
334	Burnt areas	0	Other
335	Glaciers and perpetual snow	0	Other
411	Inland marshes	0	Other
412	Peat bogs	0	Other
421	Salt marshes	0	Other
422	Salines	0	Other
423	Intertidal flats	0	Other
511	Water courses	0	Other
512	Water bodies	0	Other
521	Coastal lagoons	0	Other
522	Estuaries	0	Other
523	Sea and ocean	0	Other
999	NODATA	0	Other

8.5 Global Climate Regulation: Carbon Storage

In the context of the TESSA toolkit, the ecosystem service of "global climate regulation" refers to the exchange of carbon dioxide and other greenhouse gases between the atmosphere and the plants, the animals, and soil within ecosystems. In the Danube Floodplain Project, the tasks of the global climate regulation ESS were divided into two blocks: the "Carbon storage" package and the "Greenhouse gases" package.

The carbon stocks estimation is done following the Tier 1 methodology of the IPPC reports (IPCC, 2006) by separating the biomass stocking into four parts: the above-ground biomass (AGB), the below-ground biomass (BGB), the litter biomass (LB), and the dead wood biomass (DWB). For each part, the carbon stock estimates are read from the IPPC tables (IPCC, 2006). For some land uses and habitats, the IPCC reports did not provide the default factors for biomass calculation; therefore, the estimates of carbon dioxide flux (CO_2), methane flux (CH_4), and nitrous oxide flux (N_2O) of various habitat types were found in the estimates done by ANDERSON-TEIXEIRA and DeLUCIA (2011). The tables used for the specific cases are described in Table 18. Additionally, spatial data provided by the FAO and ITPS (2018) was used to estimate the organic carbon stored in soils.

Table 18. Tables used to extract the carbon stocks estimates according to the different biomass types and the habitat types

Biomass source	Habitat/Land use	Data sources
AGB	Tree-dominated	IPCC 2006 Guidelines - table 4.7 (IPCC, 2006)
AGB	Grass-dominated, Wetland-dominated	Values of GHGs flux for various habitats (ANDERSON-TEIXEIRA and DeLUCIA, 2011)
BGB	Tree-dominated	IPCC 2006 Guidelines - table 4.4 (IPCC, 2006)
BGB	Grass-dominated	IPCC 2006 Guidelines - table 6.1 (IPCC, 2006)
BGB	Wetland-dominated	Values of GHGs flux for various habitats (ANDERSON-TEIXEIRA and DeLUCIA, 2011)
LB	Tree-dominated	IPCC 2006 Guidelines - table 2.2 (IPCC, 2006)
LB	Grass-dominated, Wetland-dominated	Values of GHGs flux for various habitats (ANDERSON-TEIXEIRA and DeLUCIA, 2011)
DWB	Tree-dominated, Grass-dominated, Wetland-dominated	Values of GHGs flux for various habitats (ANDERSON-TEIXEIRA and DeLUCIA, 2011)

After extracting all carbon stocks estimates, the above-ground and below-ground carbon stocks were calculated in tons by multiplying them times the corresponding habitat area and by applying the following conversion factors:

- 0.5 for tree-dominated, forest plantations, woody savannas, perennial crop-dominated habitats, and urban parks;
- 0.47 for grass-dominated habitats, inland wetlands, and urban lawn.

Similarly, the litter and dead wood carbon stocks were calculated by multiplying the carbon stocks estimates by the areas of the shapefile of habitats types and by using a conversion factor of 0.5 for litter and a conversion factor of 0.4 for dead wood. For the soil organic carbon, due to the lack of data availability, the estimate was extracted from the GLOSIS - GSOCmap (v1.5.0), a global soil organic carbon map (GSOCmap) created by FAO and ITPS (2018).

By summing up the carbon stocks and the soil carbon stocks, the total carbon stocks of the status quo are calculated in tons. Note that the carbon stocks are a static calculation of the status quo of the carbon stored in the pilot area. Per se, they do not have a role in the extended CBA, unless a change in the habitat types would take place in the planned restoration scenarios.

8.6 Global Climate Regulation: Greenhouse Gases Flux

8.6.1. Carbon stock increment (in tree-dominated areas)

In this estimation, it was assumed that the change of carbon stocks takes place in the tree-dominated area only. To calculate the growth of carbon stocks, the growing rates of planted trees (Mean Annual Increment, MAI, expressed in m^3/ha/yr) were taken from the Planted Forests Database (PFDB) (FAO, 2003). After obtaining the MAI, the Carbon Fraction (CF) to dry matter of wood was read (in tons carbon/tons dry matter) from table 4.3 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2014). Required are also the biomass conversion and expansion factors (BCEF_R), expressed in tons of biomass removal (m^3 of biomass removals)-1 [tons/m^3] and extracted from table 4.5 of the IPCC report (IPCC, 2014). They are default values for conversion of wood and fuelwood removals in merchantable volume to total above-ground biomass removals. The BCEF_R is chosen based on the forests' growing stock level in m^3/ha/year, estimated by the Global Forest Resources Assessment (FRA) (FAO, 2016). Finally, the increment of the carbon stock in tree-dominated areas was calculated in tons C/year by following the formula (4).

Annual growing stock [m^3 dry matter/ha/year]	X	BCEF_R [ton dry matter / m^3 dry matter]	X	CF [ton C/ton dry matter]	X	Area [ha]	(4)

8.6.2. Carbon stock losses (in tree-dominated areas)

The carbon losses due to disturbances in the pilot area according to the suggestions of the TESSA Toolkit (Peh et al., 2013) was based on IPCC's default Tier 1 methods (IPCC, 2014). The procedure assumes that the change of carbon stock takes place in the tree-dominated area only. Disturbances can come from wood removals, fuelwood collection and charcoal removals, or other disturbances (e.g. illnesses, fires, etc.).

The procedure follows the same concept of the carbon stock increment, but in this case, instead of considering the growing rate, we consider the removals. These were derived in the estimation from different sources. The "Forestry Production and Trade" section of the FAOSTAT database (FAO, 2019) provides data on the national level on annual roundwood removals, annual fuelwood removals, and annual charcoal removals [m^3/year]. The data are then scaled from the country values to the pilot area. The reference year was 2017.

Other disturbances (such as illnesses and fires) can only be estimated; this requires that the user provides the entries on the size of the area affected by disturbances, the biomass in tons dry mass/hectare that is removed by the disturbance in the above-ground biomass area, which is affected by the disturbance, and the fraction of hectares in respect to the hectares of the area of disturbance in the pilot area that is affected by the disturbance itself.

The total carbon stock losses were then calculated as the sum of the carbon losses due to the three disturbances types wood removal, fuelwood and charcoal removal, and losses due to other disturbances.

8.6.3. Net carbon sequestration

Based on the previous sections, the net carbon sequestration is calculated for the existing scenario (whether it is the current state scenario or any other restoration scenario), as shown in equation (5).

Annual Net Carbon Sequestration of Pilot Area [ton C/yr]	=	Annual Gross Carbon Sequestration of Pilot Area [ton C/yr]	-	Annual Carbon Loss (Total) [ton C/yr]	(5)

8.6.4. Greenhouse Gases Emission and Sequestration

The procedure for estimating the quantity of greenhouse gases (GHGs) sequestered from the atmosphere in the floodplain areas follows the steps suggested by the second part of the section on "global climate regulation" ESS in the TESSA Toolkit (Peh et al., 2013).

The following IPCC tables were used to extract coefficients for the GHGs flux estimation:

- Tier 1 CO_2 emission/removal factors for drained organic soils in all land-use categories (IPCC, 2014)
- Tier 1 CH_4 emission/removal factors for drained organic soils (EFCH4_land) in all land-use categories (IPCC, 2014)
- Default CH_4 emission factors for drainage ditches (IPCC, 2014)
- Default emission factors for CH_4 from rewetted organic soils (all values in kg CH_4-C ha-1 yr-1) (IPCC, 2014)
- Enteric fermentation emission factors for Tier 1 method (IPCC, 2006)
- Tier 1 enteric fermentation emission factors for Cattle (IPCC, 2006)
- CH_4 measured emissions for flooded land (IPCC, 2006)

Moreover, look-up tables from other sources were used:

- Table from Eurostat with the heads of domestic animals in the NUTS 2 regions (Eurostat, 2020a)
- Table from FAOSTAT with the emissions of different GHGs from agricultural practices (FAO, 2019)
- CH_4 emission factors of wild grazers following the methodology suggested in the TESSA Toolkit (M11, Table B) (Peh et al., 2013)
- CH_4 emission factors of natural wetlands following the methodology suggested in the TESSA Toolkit (M11, Table A) (Peh et al., 2013)

Additionally, spatial information about wetlands categories was used, as suggested in TESSA (Peh et al., 2013)

8.6.4.1. CO_2 emissions from drained soils

In the case of drained soils, input data used for CO_2 emissions are those found in Table 2.1 of Chapter 2 of IPCC (2014), which gives the appropriate default emissions factors as the annual flux of carbon as CO_2 from on-site oxidation or sequestration (expressed in tons CO_2 ha-1 y-1). Fundamental for this section is also the information on the percentage of habitat land that was drained in the past and has not been rewetted, for the following tree-dominated, grass-dominated, and crops-dominated habitats. According to the different types of land use, the emission factors are extracted from Table 2.1 and the emissions of CO_2 are calculated by multiplying the emission factor times the area of the land use, with a result expressed in tons CO_2/yr.

8.6.4.2. CH_4 Emissions from grazing animals

To estimate the emissions of CH_4 due to the presence of grazing animals in the pilot area, the procedure is divided into two sections: one for the domestic animals, and one for the wild grazers. In this case, also a reliable estimate of the number of domestic animals present and/or a population estimate for wild grazers is necessary. Therefore, the Eurostat database on was used to extract the information on the heads of domestic animals counted per hectare (Eurostat, 2020a) in the NUTS2 regions (Eurostat, 2019). Otherwise, the information was provided by the pilot area owners. Besides that, the estimation of emitted CH_4 from domestic grazers requires Tables 10.10 and 10.11 of Chapter 10 of the IPPC reports (FAO, 2006), which present the information on the emission factors in [kgCH_4/head/yr]. By knowing the number of grazers' heads, it is possible to calculate the emissions of CH_4 in one hectare per year [tons CH_4/ha/yr] due to domestic grazers, by multiplying that value times the emission factor corresponding to the grazer type and adjusting the units of measure.

The same procedure used for the domestic grazers was used for the wild grazers. The emission factors for this section are not provided by the IPPC reports but are found in the TESSA Toolkit (Peh et al., 2013). To provide a reliable value of wild grazers heads present in the pilot area each year, the estimates were provided by local partners and were not extracted from publicly available statistics.

Finally, the emissions from both kinds of grazers were summed up into one value to express the total emissions of CH_4 per year caused by the presence of grazers in the pilot area. The estimate of CH_4 emissions from grazers was then assumed to be present only on the grass-dominated sections of the pilot areas.

8.6.4.3. CH_4 emissions from wetlands

Important to estimate the CH_4 emissions from wetlands is to know the type of wetland that characterizes the pilot area. For this, the optimal way to import this information into the tool is by creating a shapefile of the wetlands divided according to their different categories. The shapefile should include:

- Habitat Class: in this case, it will always be a wetland dominated habitat or a rice field;
- The wetland category:
  - Natural inland;
  - Managed drained;
  - Managed not drained;
- Specified characteristics of the category:
  - Position of the water table for the natural inland wetlands:
    - Distance to water table more than 20 cm;
    - Distance to water table less than 20 cm;
  - For the managed drained wetlands, whether they have been:
    - Rewetted;
    - Not rewetted;
  - For the managed not drained wetlands, whether the wetland is:
    - Flooded;
    - Used for wastewater treatment;
- The presence of shunts in the wetland (only where the water table > 20 cm).

The estimation of emitted CH_4 from natural wetlands requires the table of the emission factors taken from the TESSA Toolkit (Peh et al., 2013), which presents the information on the emission factors in [kgCH_4/head/yr]. For the other wetland types, Tables 2.3 and 3.3 from the IPCC reports (IPCC, 2014) are used to get the emission factors of “Drained not rewetted” and “Drained and rewetted” wetlands respectively. For “Managed not drained wetlands”, only the case of flooded wetlands was used so far. This requires the IPCC table 3.A.2 from the IPCC Report’s Volume 4’s “Appendix 3: CH_4 Emissions from Flooded Land: Basis for Future Methodological Development” (IPCC, 2006).

8.6.4.4. N_2O emissions from agriculture

An excursion from the TESSA’s methodology was done for the estimation of the N_2O, due to the complexity of the tasks and to the high requirements of data. The alternative to the TESSA-suggested methods was the use of FAO estimated data that were found on the FAOSTAT data portal (FAO, 2019). The FAO dataset requires the following information to extract the emissions information:

- Desired year for the statistics, now set at "2017" by default;

- Source of the N_2O emissions, here set as "Agriculture total";
- The country in which the pilot area is located.

This requires the information on the agricultural land area which was extracted from the CORINE 2018 (EEA, 2019) with code 2 of the first detail level. The raster was then used to extract the area size of croplands in the corresponding country of the pilot area. The emissions for the whole country per year [tons N_2O/yr] were then scaled to the pilot area assuming that the crop-dominated and the grass-dominated areas are emitting N_2O (the total agriculture emissions come from the use of fertilizers and from the grazing animals that are located in the grass-dominated areas). For all other habitat types, it was assumed that no N_2O emissions are produced.

8.6.4.5. CO_2 equivalent and overall GHG flux

For each separate habitat at the site, we put together all annual greenhouse gas fluxes and express them in a single figure. This required the following steps.

First, the carbon sequestration from trees was considered. Since each atom of carbon sequestered represents one molecule of CO_2 removed from the atmosphere, we expressed the net carbon sequestration (tons C y-1) and in terms of CO_2 (tons CO_2y-1) by multiplying the values by $\frac{44}{12}$. This is because the molecular weights of C and O are 12 and 16 respectively.

In a second step, the estimations of emissions and sequestrations were converted to carbon dioxide equivalents, so that they could be added together to calculate the overall greenhouse gas flux. In the case of the Danube Floodplain Project, no climate-carbon feedbacks were considered, being the GWP_{100} for methane: 28, for nitrous oxide 265, and for carbon dioxide 1.

Third, all values were summed over the area from which the emissions are estimated, to get a singular value that can be used for the extended CBA.

8.7 Monetary Value of Carbon Storage and GHGs Flux

We calculated the corresponding monetary value of the stored carbon and the GHGs flux by multiplying the estimated CO_2 equivalents times the values of the CO_2 emissions taxation systems documented in the report of the World Bank (World Bank, 2020b). The Slovenian Carbon tax rounded up to the nearest integer is 19 USD^{2020} per metric tons of carbon dioxide equivalent (tCO2e) (World Bank, 2020b) as well as the European Union (EU) Emissions Trading System (ETS) for the year 2020 (World Bank, 2020a). In the previous years, the EU ETS values were 16 USD^{2020} per tCO2e in 2018 and 25 USD^{2020} per tCO2e in 2019 (World Bank, 2020a). Since the overarching framework of the international carbon market remains unclear and decisions for future prices in the EU are postponed to 2021 (World Bank, 2020b), we used the values from 2018 and 2019 to estimate error calculations of the values of stored carbon and GHGs flux services.

8.8 Cultivated Goods

The estimation of cultivated goods ESS was divided into three parts, based on the most important (and possible to estimate) provided goods: agricultural, livestock, and aquaculture goods. In the analysis, we tried to follow the TESSA guidelines (Peh et al., 2013) as much as possible, according to the data availability.

8.8.1. Input data

The necessary input data for agriculture and livestock ESS provisioning come from FAOSTAT tables:

- for agriculture: national market prices of primary crop products;
- for livestock: number of livestock heads at the national level, the quantity of livestock primary products at the national level, national market prices of primary livestock products.

The necessary input data for aquaculture ESS provisioning come from Eurostat tables:

- quantity of aquaculture primary products at the NUTS2 level;
- market prices of primary aquaculture products at the NUTS2 level.

Fundamental for the estimations was also the use of spatial data from EarthStat (Monfreda et al., 2008) raster files of the harvested areas, one file for each indicated most important crops, and of the yield, one file for each indicated most important crops.

8.8.2. Agricultural products

The basic knowledge of the crop types present in the pilot area was provided by the local authorities. The spatial extension of the agricultural production areas was given instead by the stakeholder ESS maps on cultivated goods. From the list of crop types, we used two maps per crop type published by EarthStat (Monfreda et al., 2008):

1. A raster map of the harvested hectares [ha/pixel];
2. A raster map of the yield [tons/ha].

The EarthStat maps were created by combining national, state, and county-level census statistics with a global data set of croplands on a 5 by 5 minutes (~10 km by 10 km) latitude/longitude grid. The resulting datasets depict circa the year 2000 of 175 distinct crops of the world (Monfreda et al., 2008). The two maps were then used to extract the average value of harvested hectares and of yielded crop per each entry of the stakeholders' ESS shapefile with a recognized ESS = “agricultural product” for all crop types. With this information, it was then possible to calculate the total yield of each listed crop type for the selected areas in tons per year.

The ESS value of crop production was then estimated with the market-based valuation methodology of market prices. The necessary data are found in the “Trade - Crops and livestock products” section of the FAOSTAT database (FAO, 2019), which provides the producer prices per unit [USD/ton]. We extracted the data from the uploaded FAOSTAT table and calculated the total earnings of crop cultivation in the pilot area by multiplying the market prices times the production for each crop type.

In case the product did not show a price in the FAOSTAT tables for the specific country, we took an average of the prices of the other Danube countries for the years 2016 to 2018.

8.8.3. Livestock products

The basic knowledge of the livestock species present in the pilot area should be provided by the user. The spatial extension of the "animal" production areas is given instead by the stakeholder ESS map on cultivated goods. Due to the missing data from the local stakeholders, this section uses as input data the national data from the FAOSTAT database (FAO, 2019) that are then scaled according to the size of the area recognized by the stakeholders (in the stakeholder ESS map).

The tables used from FAOSTAT provide:

- livestock quantity [Number of stock's heads];
- primary production according to livestock type and product [ton];
- market prices of primary livestock products [USD/ton].

The ESS value of livestock products is estimated with the market-based valuation methodology of market prices. The necessary data are found in the "Trade - Crops and livestock products" section of the FAOSTAT database (FAO, 2019), which provides the producer prices per unit [USD/ton]. In case, the product does not show a price in the FAOSTAT tables for the specific country, the code makes an average of the prices of the other Danube countries for all provided years (2016 to 2018).

8.8.4. Aquaculture

The basic knowledge on the fish species cultivated in aquaculture in the pilot area should be provided by the pilot area owners. The spatial extension of the fish production areas was given by the stakeholder ESS map on cultivated goods. Due to the missing data from the local stakeholders, this estimation used as input data, the national data from the Eurostat database (Eurostat, 2020b) that were then scaled according to the size of the area recognized by the ESS map. The Eurostat tables provide information on the fish production in tons liveweight produced per year and on the revenue of the fish production in each European country in Euros (from the first transaction) per year.

8.8.5. Uncertainty estimation of cultivated goods

To estimate the results' uncertainty boundaries, we used the minimum and maximum national statistics values of primary production (for livestock goods), producer prices (for agricultural goods), or both (for aquaculture goods) in the periods 2014 to 2018 (for agricultural and livestock goods) or 2008 to 2017 (for aquaculture goods).

8.9 Nutrients Retention

Although some steps overlap with the guidelines, the estimation of the nutrients retention by the floodplains did not follow TESSA because we did not have access to measured data of water quality upstream and downstream of the studied floodplain areas. Instead, we analyzed the data from the DanubeGIS (ICPDR, 2020) of total nitrogen (TN) measurements at the Danube and its tributaries and combined them with our knowledge on the presence of active floodplains in the DRB (Danube Transnational Programme, 2020). We analyzed comparable measurements (5 days of buffer) between upstream and downstream of the floodplains and obtained an average value of TN retention of floodplains as 1.51 mg N/l and of $1.69 \cdot 10^{-4}$ mg N/l/ha (Figure 12).

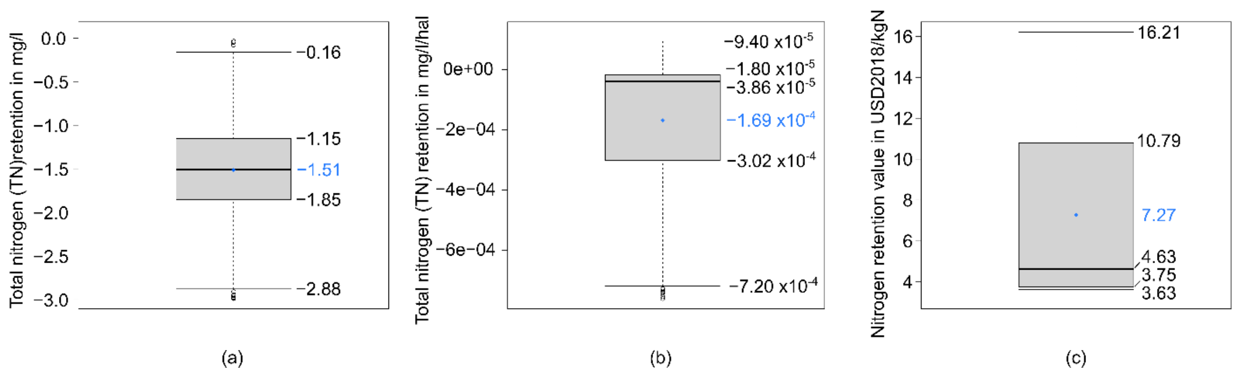

Figure 12. Boxplots of the variables used to estimate the retention of nutrients from the floodplains (blue points and values indicate the average value): (a)-(b) total nitrogen (TN) retention in the Danube (representation without outliers) in terms of measured retained concentrations (in mg/l) downstream from upstream of Danube active floodplains (a) and in terms of measured retained concentrations per unit area of the active floodplains (in mg/l/ha) (b); (c) value of the nutrients retention ecosystem service according to the database set up by Perosa et al. (2021a) on the values of Danube floodplains' ecosystem services (in USD^{2018}/kg N). Adapted from Perosa et al. (2021b).

To understand the TN retention of the whole floodplain, i.e. to scale the value in mg N/l/ha to a total value of retained kg TN, we needed the volume of water filtered by the floodplain per year. Therefore, we took the floodplains' activated volume that we simulated for extreme flood events (HQ2 to HQ5, HQ10 to HQ20, and HQ100) and calculated the expected annual retention volume (EARV) with the trapezoid method, as shown in the following function:

$$EARV = \frac{1}{2}\sum_{i=1}^{n}\left[\left(\frac{1}{T_i} - \frac{1}{T_{i+1}}\right)(RV_i + RV_{i+1})\right] + \frac{RV_n}{RV_n}, \qquad (6)$$

where $n = 3$ is the number of return periods, T is the return period in years, and RV is the corresponding retention volume. The specific values of T (together with their corresponding lower and upper uncertainty boundaries) and RV for each study area can be found in Table 16 and Table 19 respectively. The estimation is valid under the assumption that the volume that is additionally retained by the restored floodplain in comparison to the CS scenario is also the volume that is additionally filtered by the floodplain.

Table 19. Retention volumes RV associated to a number of return periods (T) of $n = 3$. The RV values were used for the retention volume estimation of the current state (CS) and restoration scenario (RS) of all three study areas.

	Begecka Jama			Bistret			Krka			Morava		
	RV_1	RV_2	RV_3	RV_1	RV_2	RV_3	RV_1	RV_2	RV_3	RV_1	RV_2	RV_3
CS [m³]	4.19×10⁷	5.54×10⁷	6.07×10⁷	3.02×10⁸	3.53×10⁸	3.96×10⁸	1.43×10⁷	1.87×10⁷	2.67×10⁷	7.40×10⁷	7.87×10⁷	8.61×10⁷
RS1 [m³]	4.21×10⁷	5.55×10⁷	6.08×10⁷	3.02×10⁸	3.71×10⁸	5.21×10⁸	1.44×10⁷	1.88×10⁷	2.66×10⁷	5.86×10⁷	6.50×10⁷	7.40×10⁷
RS2 [m³]	4.50×10⁷	5.82×10⁷	6.36×10⁷	5.87×10⁸	8.06×10⁸	9.88×10⁸	1.42×10⁷	1.88×10⁷	2.65×10⁷	7.26×10⁷	8.04×10⁷	9.13×10⁷

To attribute a monetary value to the TN retention of the floodplain, we applied the benefit transfer (BT) method by using the database of floodplains' ESS values in the DRB and its intersecting countries Perosa et al. (2021a). We used only the values expressed in USD^{2018}/kg N and applied their average of 7.27 USD^{2018}/kg N (Figure 12) to the estimated annual quantity of retained TN for each study area. To estimate the corresponding errors, we applied the values 3.75 USD^{2018}/kg N and 10.79 USD^{2018}/kg N, being these the first and third quartiles of the benefit transfer values respectively.

8.10 Nature-Based Recreation

Following TESSA's guidelines, the individual travel cost method (ITCM) was applied to assess the nature-based recreation (e.g. exercising, experiencing nature, etc.) provided by the floodplain areas and their restoration. As a response to the COVID-19 pandemic and its consequent travel restrictions (Süddeutsche Zeitung, 2020), this method was based on interviews that were conducted online through LimeSurvey (LimeSurvey GmbH) from 7th August 2020 to 1st September 2020 for the pilot areas Begecka Jama, Krka, and Morava, and from 5th November 2020 to 31st December 2020 for the Bistret pilot area. We used Facebook events (Facebook Inc., 2020a) and Instagram (Facebook Inc., 2020b) posts (with hashtags related to the pilot areas) to advertise the survey (in locations with a radius of 20 km around Begecka Jama, 20 km around Kostanjevica na Krki, 40 km around Lanzhot for Morava, and 40 km around Bistret). To retrieve data on the restoration scenarios, the interviews included a section in which the respondents described their potential reaction to the hypothetical floodplain restorations. A template of the interviews can be found in the annexes of deliverable D 4.3.2 (Danube Floodplain, 2021b). The ITCM requires as input data the count of the visits of an individual to a site in a year, the corresponding travel cost (TC) to the site (sum of the cost to get to the site with fuel prices for each country from the European Commission (IEA, 2020) and additional expenses), and can include other characteristics (e.g. age, education level, etc.). As described for example in Hanauer and Reid (2017) or Borzykowski et al. (2017), each respondent was represented by applying the function of equation (7):

$$number\ of\ visits\ per\ year = \alpha + \beta \times TC + \gamma \times age \quad (7)$$

where α is the intercept, and β and γ are the coefficients estimates. Based on the fitted Poisson model, the consumer surplus per visit was calculated as the negative inverse of the constant (-1/β) of the TC variable. Multiplying the consumer surplus by the total number of visits gave a total consumer surplus for the site. To estimate the results' uncertainty boundaries, we propagated the lower and upper boundaries derived from the standard error of the β coefficients. The total number of visits was retrieved from additional e-mail conducted interviews (Nisavic, 08/18/2020; Krhin, 08/17/2020; Bártek, 08/19/2020; Motyčková, 08/17/2020) and personal communication with local authorities (Čechová, 08/25/2020).

8.11 Value of the ESS by Benefit Transfer

When no data is available to implement the substitution costs method, the ESS valuation can be implemented by benefit-transfer, more specifically through a meta-analytical process. The input data used for this method is stored in the ESS values database, whose input data are represented per country in Figure 13. The description of this methodology is found in Perosa et al. (2021a), as well as the benefit-transfer functions produced to quickly estimate provisioning, regulating, and cultural ESS in the DRB.

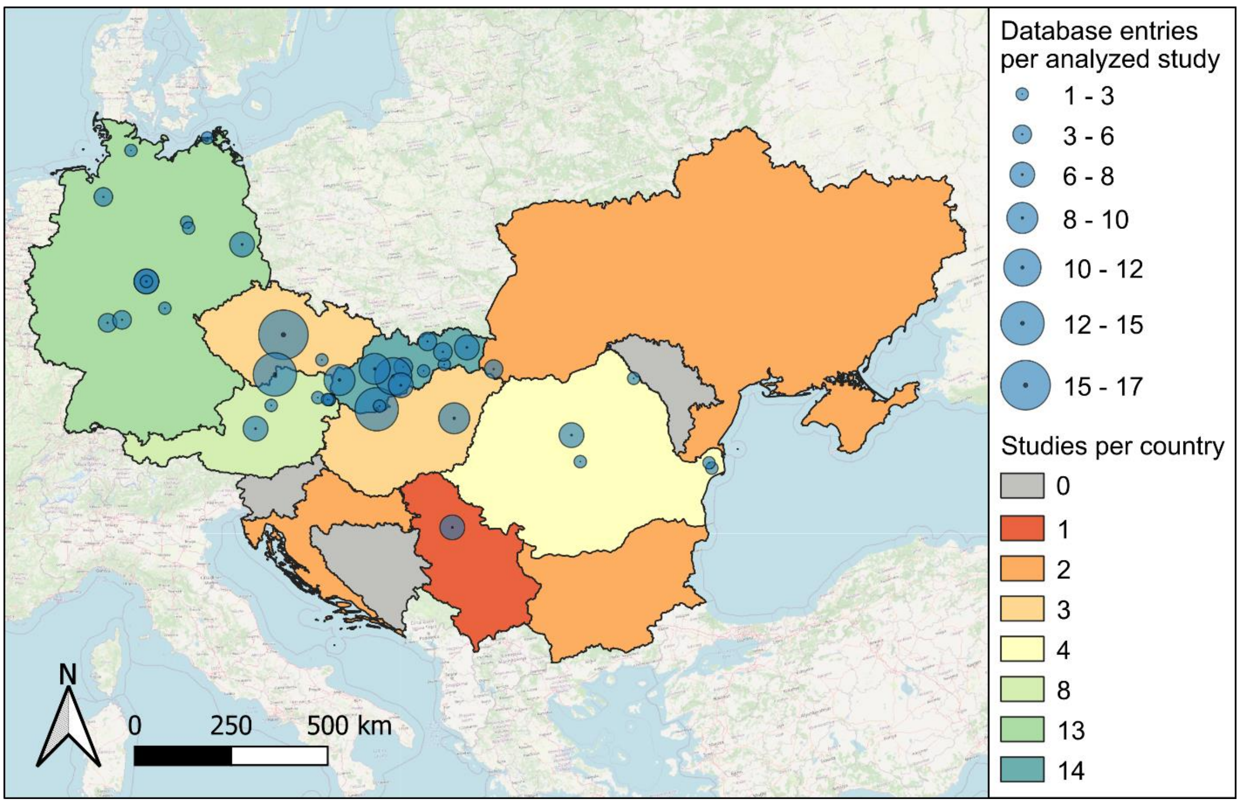

Figure 13. ESS values database and corresponding number of entries per country. Results from Perosa et al. (2021a).

9. Conclusions

This deliverable is a summarizing work of the methodologies used in work package 4 (WP4) of the Danube Floodplain Project, titled “Flood prevention pilots”.

In Activity 4.1, flood prevention measures were tested through two-dimensional hydrodynamic modeling in the project’s pilot areas, by applying different hydrological scenarios (HQ_2 to HQ_5, HQ_{10} to HQ_{30}, and HQ_{100}) to a current state and different restoration scenarios (RS1 and RS2). In this way, we could investigate the hydraulic efficiency of the restoration measures. These results are an important input for the ecosystem services, the ecological, and the flood risk assessments.

Stakeholders’ engagement was part of Activity 4.2. Stakeholders participated in workshops in the pilot areas, during which fundamental knowledge was collected through open discussions and ecosystem services mapping. Ecosystem services mapping was later on enriched with a land use/land cover approach. Another theme of Activity 4.2 is habitat modeling, which was implemented on the meso-scale through a method based on environmental co-variables, such as water depth and flow velocity, to evaluate the floodplains’ lateral connectivity performance.

In Activity 4.3, a monetary-based assessment of the floodplain restoration measures was implemented. This consists in applying the TESSA’s recommendations for the assessment of six ecosystem services types: flood mitigation, carbon storage, greenhouse gases sequestration, cultivated goods provisioning, nutrients retention, and nature-based recreation. Their monetary evaluation made it possible to include the mentioned services in an extended cost-benefit analysis, for profitability analysis of the restoration measures.

A side task of Activity 4.1 was also the one-dimensional hydrodynamic model chain, created from Neu-Ulm (Germany) to Calarasi (Romania) to assess the transboundary effect of restoration measures on the peak discharge and the wave translation during a flood event. For this, all countries along the Danube River created individual models, which were connected by using the output of the upstream model as input for the downstream model. Also in this case, different hydrological scenarios were simulated for a current state (only active floodplains) and a restoration scenario (including potential floodplains identified in Activity 3.1). The same process was implemented for the tributaries Morava, Tisza, and Sava.

The results and discussions of the presented methodologies can be found in deliverables D 4.1.1 (Danube Floodplain, 2020a) and D 4.1.2 (Danube Floodplain, 2020b) for Activity 4.1, in deliverables D 4.2.1 (Danube Floodplain, 2019c) and D 4.2.2 (Danube Floodplain, 2020c) for ecosystem services mapping, in deliverable D 4.2.3 for habitat modeling (Danube Floodplain, 2020d), and in deliverable D 4.3.1 for the extended cost-benefit analysis (Danube Floodplain, 2021a).

References

Alcamo J. Ecosystems and human well-being: A framework for assessment. Washington, DC: Island; 2003.

ANDERSON-TEIXEIRA KJ, DeLUCIA EH. The greenhouse gas value of ecosystems. Global Change Biology 2011;17(1):425–38.

Bártek V. Questions on the Nature-Based Recreation around the Morava River. E-mail, 08/19/2020.

Baveye PC, Baveye J, Gowdy J. Monetary valuation of ecosystem services: It matters to get the timeline right. Ecological Economics 2013;95:231–5.

Borzykowski N, Baranzini A, Maradan D. A travel cost assessment of the demand for recreation in Swiss forests. Rev Agric Food Environ Stud 2017;98(3):149–71.

Brouwer R, Sheremet O. The economic value of river restoration. Water Resources and Economics 2017;17:1–8.

Burkhard B, Kroll F, Müller F, Windhorst W. Landscapes' capacities to provide ecosystem services - A concept for land-cover based assessments. LO 2009;15:1–22.

Čechová A. Characteristics of the Morava pilot area. E-mail, 08/25/2020.

Chaudhary S, McGregor A, Houston D, Chettri N. The evolution of ecosystem services: A time series and discourse-centered analysis. Environmental Science & Policy 2015;54:25–34.

Danube Floodplain. D 2.1.1: Communications and Stakeholder Engagement Strategy; 2018.

Danube Floodplain. D 3.1.3. Danube Floodplain inventory for active and potentially restorable floodplains; 2019a.

Danube Floodplain. D 3.2.3. Priority list with potential preservation and restoration areas (based on FEM); 2019b.

Danube Floodplain. D 4.2.1. Report about the stakeholder analysis, their interests and their benefits from the floodplains in the pilot areas resulting from the workshops; 2019c.

Danube Floodplain. D 4.1.1. Report on the technical realization scenarios taken into consideration for modelling, the implementation in a 2D model and assessment of the impact; 2020a.

Danube Floodplain. D 4.1.2. Technical document concerning the homogenization of different models, as well as the basin wide assessment of the strategy measures' impact and efficiency as input for D 4.3.4 and D 4.3.2; 2020b.

Danube Floodplain. D 4.2.2. Report, database and maps of ESS analysis of the pilot areas including a list, description, assessment, and ranking concerning the demands and supplies; 2020c.

Danube Floodplain. 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 4.4.1 and part of output 4.1; 2020d.

Danube Floodplain. D 4.3.1. Report on assessment results of the CBA applied to the pre-selected pilot areas including ESS, stakeholders and biodiversity as input for 4.4.1 and therefore part of the feasibility studies in output 4.1; 2021a.

Danube Floodplain. D 4.3.2. Method documentation describing the implementation of ESS and biodiversity to traditional CBA as input for D 4.3.4 and therefore of output 5.1; 2021b.

Danube Transnational Programme. Interreg Danube Floodplain: Reducing the flood risk through floodplain restoration along the Danube River and tributaries, 2020. http://www.interreg-danube.eu/approved-projects/danube-floodplain/outputs?page=1 (accessed 2020).

Dittrich R, Ball T, Wreford A, Moran D, Spray CJ. A cost-benefit analysis of afforestation as a climate change adaptation measure to reduce flood risk. J Flood Risk Management 2019;12(4).

EEA. Corine Land Cover (CLC) 2018, 2019. https://land.copernicus.eu/pan-european/corine-land-cover/clc2018?tab=metadata.

European Commission. Eurostat, 2020. https://ec.europa.eu/eurostat/home? (accessed 2020).

European Environment Agency. Riparian Zones Land Cover/ Land Use, 2012 (accessed 2020). https://land.copernicus.eu/local/riparian-zones/land-cover-land-use-lclu-image.

European Environment Agency. CORINE Land Cover. GeoTIFF, 2018 (accessed 2020). https://land.copernicus.eu/pan-european/corine-land-cover/clc2018.

Eurostat. NUTS 2016: European Union; 2019.

Eurostat. Main livestock indicators by NUTS 2 regions: Eurostat Statistical Database; 2020a ef_lsk_main.

Eurostat. Production from aquaculture excluding hatcheries and nurseries (from 2008 onwards): Eurostat Statistical Database; 2020b fish_aq2a.

Facebook Inc. Facebook, 2020a. https://www.facebook.com (accessed 2020).

Facebook Inc. Instagram, 2020b. https://www.instagram.com/ (accessed 2020).

FAO. Planted forests database (PFDB): Structure and Contents. Rome: Forest Resources Development Service, Forest Resources Division, FAO; 2003. Planted Forests and Trees Working Papers 25.

FAO. Global Forest Resources Assessment 2005: Progress towards sustainable forest management. Rome: Food and Agriculture Organization of the United Nations; 2006.

FAO. Global Forest Resources Assessment 2015: How are the world's forests changing?; 2016.

FAO. FAOSTAT: Statistical Database. Rome: FAO; 2019.

FAO and ITPS. Global Soil Organic Carbon Map (GSOCmap): Technical Report. Rome: FAO and ITPS; 2018.

Feuillette S, Levrel H, Boeuf B, Blanquart S, Gorin O, Monaco G et al. The use of cost–benefit analysis in environmental policies: Some issues raised by the Water Framework Directive implementation in France. Environmental Science & Policy 2016;57:79–85.

GitHub. TESSA4QGIS, 2020. https://github.com/FPerosa/TESSA4QGIS (accessed 2021).

Grizzetti B, Lanzanova D, Liquete C, Reynaud A, Cardoso AC. Assessing water ecosystem services for water resource management. Environmental Science & Policy 2016;61:194–203.

Guida RJ, Swanson TL, Remo JWF, Kiss T. Strategic floodplain reconnection for the Lower Tisza River, Hungary: Opportunities for flood-height reduction and floodplain-wetland reconnection. Journal of Hydrology 2015;521:274–85.

Guisan A, Zimmermann NE. Predictive habitat distribution models in ecology. Ecological Modelling 2000;135(2-3):147–86.

Haines-Young R, Potschin MB. Common International Classification of Ecosystem Services (CICES) V5.1and Guidance on the Application of the Revised Structure; 2017.

Hanauer MM, Reid J. Valuing urban open space using the travel-cost method and the implications of measurement error. Journal of environmental management 2017;198(Pt 2):50–65.
Hein L, van Koppen CSA, van Ierland EC, Leidekker J. Temporal scales, ecosystem dynamics, stakeholders and the valuation of ecosystems services. Ecosystem Services 2016;21:109–19.
Huizinga J, Moel Hd, Szewczyk W. Global flood depth-damage functions: Methodology and the database with guidelines: Joint Research Centre (JRC); 2017.
ICPDR. Flood Risk Management Plan for the Danube River Basin District. Vienna, Austria: ICPDR; 2015.
ICPDR. Danube River Basin Water Quality Database, 2020 (accessed 2019). http://www.icpdr.org/wq-db/.
IEA. Fuel Consumption of Cars and Vans – Analysis, 2020. https://library.wmo.int/doc_num.php?explnum_id=7332 (accessed 2020).
IPCC, editor. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Hayama, Japan: Institute for Global Environmental Strategies; 2006.
IPCC, editor. 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands. Switzerland: IPCC; 2014.
Jeuland MA, Pattanayak SK. Benefits and costs of improved cookstoves: assessing the implications of variability in health, forest and climate impacts. PloS one 2012;7(2):e30338.
Krhin M. Questions on the Nature-Based Recreation around the Krka River. E-mail, 08/17/2020.
LimeSurvey GmbH. LimeSurvey: An Open Source survey tool. Hamburg, Germany: Limesurvey GmbH.
Logar I, Brouwer R, Paillex A. Do the societal benefits of river restoration outweigh their costs? A cost-benefit analysis. Journal of environmental management 2019;232:1075–85.
Maddock I, Harby A, Kemp P, Wood P. Ecohydraulics: An Introduction. In: Maddock I, Harby A, Kemp P, Wood P, editors. Ecohydraulics. Chichester, UK: John Wiley & Sons, Ltd; 2013. p. 1–6.
Monfreda C, Ramankutty N, Foley JA. Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000. Global Biogeochem. Cycles 2008;22(1):n/a-n/a.
Monge JJ, Daigneault AJ, Dowling LJ, Harrison DR, Awatere S, Ausseil A-G. Implications of future climatic uncertainty on payments for forest ecosystem services: The case of the East Coast of New Zealand. Ecosystem Services 2018;33:199–212.
Morris J, Camino M. Economic assessment of freshwater, wetland and floodplain (FWF) ecosystem services: MK45 2QP: UK National Ecosystem Assessment (UK NEA) 2011 (accessed July 12, 2020). http://uknea.unep-wcmc.org/LinkClick.aspx?fileticket=lVLEq%2BxAI%2BQ%3D&tabid.
Motyčková K. Questions on the Nature-Based Recreation around the Morava River. E-mail, 08/17/2020.
Naiman RJ, Décamps H, McClain ME. Riparia: Elsevier; 2005.
Natural Capital Project. InVEST, 2020. https://naturalcapitalproject.stanford.edu/software/invest (accessed 2020).
Newson MD, Newson CL. Geomorphology, ecology and river channel habitat: mesoscale approaches to basin-scale challenges. Progress in Physical Geography: Earth and Environment 2000;24(2):195–217.

Nisavic J. Nature Park Begecka Jama. E-mail, 08/18/2020.
Olsen A, Zhou Q, Linde J, Arnbjerg-Nielsen K. Comparing Methods of Calculating Expected Annual Damage in Urban Pluvial Flood Risk Assessments. Water 2015;7(12):255–70.
Peh KS-H, Balmford A, Bradbury RB, Brown C, Butchart SHM, Hughes FMR et al. TESSA: A toolkit for rapid assessment of ecosystem services at sites of biodiversity conservation importance. Ecosystem Services 2013;5:51–7.
Perosa F, Fanger S, Zingraff-Hamed A, Disse M. A Meta-Analysis of the Value of Ecosystem Services of Floodplains for the Danube River Basin. Science of the Total Environment 2021a:146062.
Perosa F, Gelhaus M, Zwirglmaier V, Arias-Rodriguez LF, Zingraff-Hamed A, Cyffka B et al. Integrated Valuation of Nature-Based Solutions Using TESSA: Three Floodplain Restoration Studies in the Danube Catchment. Sustainability 2021b;13(3):1482.
Petz K, Minca EL, Werners SE, Leemans R. Managing the current and future supply of ecosystem services in the Hungarian and Romanian Tisza River Basin. Reg Environ Change 2012;12(4):689–700.
Podschun SA, Albert C, Costea G, Damm C, Dehnhardt A, Fischer C et al. RESI - Anwendungshandbuch: Ökosystemleistungen von Flüssen und Auen erfassen und bewerten; 2018. Berichte des IGB Heft 31/2018.
QGIS.org. QGIS Geographic Information System: Open Source Geospatial Foundation Project; 2020.
Sartori D. Guide to cost-benefit analysis of investment projects: Economic appraisal tool for cohesion policy 2014 - 2020. 2014th ed. Luxembourg: Publ. Office of the Europ. Union; 2015.
Schägner JP, Brander L, Maes J, Hartje V. Mapping ecosystem services' values: Current practice and future prospects. Ecosystem Services 2013;4:33–46.
Sommerwerk N, Bloesch J, Paunović M, Baumgartner C, Venohr M, Schneider-Jacoby M et al. Managing the world's most international river: the Danube River Basin. Mar. Freshwater Res. 2010;61(7):736.
Stone MC, Byrne CF, Morrison RR. Evaluating the impacts of hydrologic and geomorphic alterations on floodplain connectivity. Ecohydrol. 2017;10(5):e1833.
Süddeutsche Zeitung. Massive Ausgangsbeschränkungen für ganz Bayern ab Samstag, 2020 Mar 20 (accessed September 02, 2020). https://www.sueddeutsche.de/gesundheit/gesundheit-muenchen-massive-ausgangsbeschraenkungen-fuer-ganz-bayern-ab-samstag-dpa.urn-newsml-dpa-com-20090101-200320-99-404727.
Terrado M, Momblanch A, Bardina M, Boithias L, Munné A, Sabater S et al. Integrating ecosystem services in river basin management plans. J Appl Ecol 2016;53(3):865–75.
Timmerman JG, Koeppel S, Bernardini F, Buntsma JJ. Adaptation to Climate Change: Challenges for Transboundary Water Management. In: Leal Filho W, editor. The Economic, Social and Political Elements of Climate Change. Berlin, Heidelberg: Springer Berlin Heidelberg; 2011. p. 523–541.
Vieira J, Matos P, Mexia T, Silva P, Lopes N, Freitas C et al. Green spaces are not all the same for the provision of air purification and climate regulation services: The case of urban parks. Environmental research 2018;160:306–13.
Villa F, Bagstad KJ, Voigt B, Johnson GW, Portela R, Honzák M et al. A methodology for adaptable and robust ecosystem services assessment. PloS one 2014;9(3):e91001.

World Bank. Carbon Pricing Dashboard: Up-to-date overview of carbon pricing initiatives, 2020a. https://carbonpricingdashboard.worldbank.org/map_data (accessed September 08, 2020).
World Bank. State and Trends of Carbon Pricing 2020: (May). Washington, DC; 2020b.
Zavadil E, Stewardson M. The Role of Geomorphology and Hydrology in Determining Spatial-Scale Units for Ecohydraulics. In: Maddock I, Harby A, Kemp P, Wood P, editors. Ecohydraulics. Chichester, UK: John Wiley & Sons, Ltd; 2013. p. 125–142.